Title of Document: ALTERNATE LOWER EXTREMITY RESISTANCE TRAINING TO INCREASE STABILITY IN YOUNG AND ELDERLY ADULTS

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Abstract

The prevalence of falls in the elderly population and the high susceptibility of the elderly to resulting injuries constitute a major health, wellness, and financial problem in the United States. Studies have shown that through resistance training, the elderly can improve their muscular strength and their balance. In this study, we compared the effects of two different types of resistance training, whole-leg and individual-joint, on the muscle strength and balance capabilities of both college-aged and elderly participants. Using a matched-pair, random assignment design, we collected and analyzed data from participants using a motion analysis system, force plate, and leg press machine. We tested participants at regular intervals over the course of their six-week training programs. We hope that our results and conclusions will help pave the way for future research so that the elderly can experience a lower rate of falls and a better quality of life.

ALTERNATE LOWER EXTREMITY RESISTANCE TRAINING TO INCREASE

STABILITY IN YOUNG AND ELDERLY ADULTS

By

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Chapter 1. Introduction

1.1   Occurrence and Consequence of Elderly Imbalance

Physical degeneration due to aging often results in frailty. As one ages, muscular atrophy and skeletal deterioration causes weakness, which leads to injuries from falls. These injuries rank among the most significant reasons for geriatric hospitalization (American Geriatric Society, et al., 2001). Injuries from falls can be very serious, resulting in hip and femur fractures, and often lead to death (Keene, et al., 1993). Even the Healthy People 2020 initiative proposes to reduce the rate of emergency department visits due to elderly falls through physical therapy in hopes that therapy will improve balance and strength (Department of Health and Human Services, 2010). To achieve these ends, this study explores new uses of current physical therapy technology to better improve balance and decrease the incidence of injury from falls.

1.2   Current Approaches to Attenuate the Effects of Aging

Prior research has shown that physical training through specific exercises can strengthen muscles around joints, thereby greatly decreasing the possibility of malfunction and instability (Pijnappels, et al., 2008). In Pijnappels et al.'s study, focus was put into increasing muscle mass in order to increase muscle strength. They were able to show a correlation between increased strength and balance. Participants performed knee extensions, leg presses, and calf raises for the sole purpose of building muscle. Many physical therapists use these techniques to help patients improve their balance after recovering from a wide range of injuries. One study in 2000 researched the effect of intense strength training on stroke patients. After one year, patients significantly increased muscle strength, which led to improved balance (Weiss et al, 2000). Strength training is also a common technique used to rehabilitate patients after receiving ACL

(anterior cruciate ligament) reconstruction surgery. Physical therapists recommend performing repeated leg presses to increase leg strength to heal more quickly (Biggs, et al., 2009).

Strength training is not only used to treat injuries, but physical therapists use strength training as a preventative measure for elderly patients to decrease the risk of falls. Preventative strength training is supported by studies that suggest that exercises developed to strengthen muscles help the elderly community improve balance. One study showed that after 6 weeks of strength training, 87% of subjects that originally fell no longer fall during training. Additionally, 90% of subjects that had an injury six months prior to the trial did not sustain any injuries in the six months following the trial (Means, et al, 2005). Another study attempted to increase muscle strength with negative work. Both negative and positive work led to increased muscle size, but negative work led to a greater increase in strength and balance scored according to the Berg balance scale (LaStayo, et al., 2003). The Berg balance scale is developed by Katherine Berg in 1989 to clinically measure balance based on fourteen different actions including standing in different positions, sitting down, standing up, turning, and other movements (Berg, et al, 2009). This scale is trusted and used in many studies to quantify subjects' balance.

Other researchers have looked at combining strength training with other modes of exercise to see if there is a greater improvement on balance. In one study, aerobic exercise in conjunction with typical strength training led to a greater increase in strength, balance, and mobility (Sauvage, et al., 1992). In another study, training was enhanced with specific balance exercises such as walking and moving from a sitting to a standing position. When compared to subjects who only performed strength training exercises, those who performed enhanced balance training had a greater improvement in stability, walking speed, and confidence (Steadman, et al., 2003).

1.3 The Problem: Whole-leg Training Increases Strength but Decreases Neural Versatility

The study of various muscular systems, including that of the hand, has shown that muscular systems often exhibit interdependency, the firing of multiple analogous muscles in a motor system from a motor impulse directed to one muscle. Other studies take this concept one step further and show that separate training of individual joints results in greater muscular control and minimizes interdependency (Shim, et al, 2008).

Stability depends greatly on the ability to correct the error of moving one's center of mass beyond one's base of stability. In terms of the leg joints (hip, knee, and ankle), often the fastest and most efficient way of correcting an error made by one joint is the movement of the two non-malfunctioning joints in the opposite orientation from the error. As such, whole-leg exercises, while increases strength, also reinforces interdependency. Therefore, the two non-malfunctioning joints would also fire in the direction of the error, increasing the chances of falling instead of stabilizing balance. Conversely, minimization of interdependency through individual-joint exercises would allow other joints to fire independently of the erroneous joint and compensate for the error instead of amplifying it.

1.4 Objectives

Based on these concepts, several specific objectives are addressed in this study. First, it is important to verify that strength training does in fact increase balance with increased muscle mass. Afterwards, the focus can shift to comparing the increases of balance from whole-leg training (WLT) and individual-joint training (IJT).

1.5   Outline of the Study

1.5.1 Match-paired WLT and IJT Participants

Two subject groups were recruited for this study. Subjects between the ages of 18-24 from the University of Maryland, College Park campus were recruited as our young adult (college) subjects. Geriatric subjects aged 62 and older from the College Park, Maryland area were recruited for the study to represent the elderly population. The subjects were match-paired for BMI and age into two experimental groups: the whole-leg training (WLT) group and the individual-joint training (IJT) group. The WLT group trained solely with the leg press exercise so strength training of the entire leg was performed at once. The IJT group trained with back extension, knee extension, and ankle plantarflexion exercises so as to focus on each of the three joints individually. All subjects performed their assigned exercises under the guidance of a trainer three times a week for six weeks.

1.5.2 Testing for Standing Sway, Perturbation Recovery, and Strength

All subjects were tested four times total over the course of the trial – before any training took place, to get a baseline of performance, and then every two weeks to track the progress of balance improvement. Three tests were performed during each testing session. First, a quiet standing (stabilometry) test was performed in which the subject stood in place while their movements were recorded in order to determine the location of the center of mass (COM) and center of pressure (COP). Next, a lower extremity perturbation test was used to observe the subjects' recovery ability after their COM was pushed perturbed. Finally, increased strength was tracked by recording the subjects' repetition maximum (1-RepMax). This was recorded by observing the maximum amount of weight the subject was able to press with a leg press machine.

Following training and testing, the data was analyzed to observe the change in strength and balance variable for both the WLT and IJT groups. The muscular strength and improvement of balance variables between the two groups were compared.

1.6 General Hypothesis

Based on previous studies, we hypothesize that individual joint training will improve balance more than whole leg training. We also hypothesize that both individual joint training and whole leg training will increase muscular strength, and other variables that contribute to the ability to balance, but that individual joint training will increase motor synergy, and therefore decrease interdependency more than whole-leg training.

1.7 Contributions to the Research Field

Currently, the majority of physical therapy programs focus more on whole-leg exercises, so research validating the greater benefit of individual-joint exercises and the development of an interventional therapy program using such exercises would be of great interest to the geriatric population and other populations prone to falling. In addition to having interventional value, preemptive individual-joint training would allow for prevention of muscular and neural degeneration and, thus, lack of balance. Since individual-joint training focuses on increasing muscular independence through neural adaptation as well as increasing muscular strength, young and old would benefit from its application.

Chapter 2. Literature Review

2.1 Introduction

There is a plethora of geriatric research regarding unintentional falls and their subsequent detrimental effects on the quality of life of the elderly population. Many studies have examined the effectiveness of preventative measures in preventing falls in the geriatric population. However, most of the research have simply studied the effects of a single type of neuromuscular exercises and have failed to develop a routine that specifically targets the muscles involved in preventing falls. This study is an attempt to establish research regarding the effectiveness of particular set of strength training exercises used in fall prevention programs.

Analysis of established research in the field will identify the geriatric population as a particularly vulnerable group and will pinpoint the research problems that underpin this study. An extensive review of the biomechanical and neuromuscular principles behind each of the training and testing routines employed in this study will be provided. Next, a review of literature that discusses the principles behind this study's methodology for data collection and analysis will be presented. A section regarding the predicted outcomes and related principles in biomechanics will follow. Finally, the literature will review the selection of the two target age groups of study and how they relate to one other as well as any background reasoning regarding subject selection.

2.2 Vulnerability of the Geriatric Population

After the age of 60, the incidence of falls and the severity of resulting injuries both rise steadily. Of senior citizens aged 65 and older who live independently and are generally healthy, 35% to 40% fall annually. This rate increases for those aged 75 and older (Rubenstein et al., 2002). Seniors aged 65 and older who do not live independently but rather live in nursing homes or hospitals have an incident rate of falls that is about three times higher than that of their

independent-living counterparts. Injury rates are considerably higher as well; 10%-25% of falls in these institutions result in fractures, lacerations, and other serious injuries (American Geriatric Society, 2001).

Unintentional injuries are the fifth leading cause of death in older adults, and falls are the cause of about two-thirds of the deaths resulting from unintentional injuries. Research shows that 75% of deaths due to falls in the United States occur in the 13% of the population age 65 and over (Josephson et al., 1991). Even though many elderly people do not die from falls, the resulting injuries they suffer decrease their standard of living and can require them to make significant changes in their lifestyles. Falls account for over 80% of injury-related admissions to hospitals of people older than 65 years (Kannus et al., 2005). According to the study published in 2001 by American Geriatric Society (AGS), British Geriatric Society and the American Academy of Orthopaedic Surgeons Panel on Falls Prevention, of those who participated in the study, 5% of the elderly adults who fell sustained fractures while 5-10% of those who fell suffered major injuries that required medical attention. The study also concluded that recurrent falls usually resulted in admission of previously independent elderly persons to long-term care programs (Annals of Long Term Care., 2001). This is a particularly threatening statistic because while more than 30% of independently living elderly and more than half of institutionalized elderly fall annually, about half of those who fall do so repeatedly (Kannus et al., 2005).

On this note, it is important to recognize that the high incidence of falls in the elderly is not the specific problem at hand. Young children and athletes actually have an even higher incidence rate of falls than the elderly. It is the high susceptibility to injury of the elderly in addition to the high rate of falls that sustains the true issue. The elderly are more vulnerable to injury than other age groups as many elderly people suffer from comorbid diseases. Also, all

elderly people experience age-related physiological decline, such as slower reflexes. These factors combine to make even the most minor fall potentially debilitating (Bezon et al., 1999).

There are even more factors that render the elderly more vulnerable to falls and resulting injuries. The elderly are at high risk of falls because they experience increased cognitive dysfunction as they age. A vast amount of research has associated falls with even mild cognitive dysfunction. Cognitive function requires a mastery of executive function—higher-order cognitive processes that control and integrate other cognitive abilities. As adults age, they increasingly experience impaired central executive functioning. Therefore, the elderly naturally become more susceptible to falls and fall-related injuries (Liu-Ambrose, 2008).

Two major factors are necessary for a person to effectively maintain balance: the ability to manage a changing base of support and center of mass (COM) and the ability to adjust quickly disequilibrium (Ferber et al., 2002). Unfortunately, the elderly are less able to maintain their balance and are therefore more vulnerable to falls because many significant physical and neurological changes they experience as they age impair these abilities. For instance, the elderly suffer a significant decrease in muscle strength and power due to muscular and tendinous degeneration and adverse neurological changes (Macaluso & De Vito, 2003).

Senile sarcopenia, loss of muscle mass from aging, is one of the main causes of loss of muscle strength and power. Older adults have muscles that are about 20% smaller than those of young adults. This is most probably because of reduced size and number of muscle fibers as well as alterations in the internal arrangement of these fibers that occur as adults age. Elderly adults have shorter muscle fibers than young adults do by 10% - 16%. As for muscle strength, the force per unit area of muscle, referred to as specific tension, is also lower for the elderly than for young adults both at single fiber and whole muscle levels. Loss of muscle strength depletes the

elderly of the strength they need in order to regain balance when they begin to fall (Pijanpells et al., 2008).

Tendons undergo detrimental changes with age as well. As adults age, the stiffness of their tendons are reduced. This result in greater elongation of tendon and a reduction of the force the tendons can exert. In addition, reduced tendon stiffness leads to a slower rate of moment generation and slower afferent feedback on muscle length changes. Therefore, reduced stiffness of tendons slows down the reaction time of the elderly as they begin to fall and inhibits the ability of the elderly to carry out the rapid muscle movements necessary for regaining balance quickly enough to prevent the fall. (Pijanpells et al., 2008).

Detrimental neurological changes include decreasing activity of agonist muscles, the muscles that contract to cause a specific motion, and increasing activity of antagonist muscles, the muscles that relax as the agonist muscles contract to allow the same specific motion (Pijnappels et al., 2008). Additionally, as people age, the number of motor neurons in the spinal cord declines, resulting in a loss of motor units and a rearrangement of others to a higher innervation ratio, resulting in less independent control of muscle groups (Enoka ,1997).

All of these findings combined show that muscular degeneration as well as the tendinous degeneration that the elderly experience both contribute to weakness and slower reaction times— crucial factors that lead to restricted ability to recover from loss of balance. These physiological weaknesses coupled with the detrimental impact of changes in neural mechanisms make it harder for the elderly to coordinate the many different muscle actions required for balance recovery in the short period of time between when they first loose balance and when they hit the ground (Pijnappels et al., 2008).

2.3 Fundamental Principles of Balance and Falling

Balancing is a complex process that involves coordination of multiple sensory, motor, and biomechanical components. Balance involves the communication between the sensory system and the biomechanical responses of the muscles. This study focuses on just the biochemical responses because they are more easily manipulated and strengthened than those of the sensory system. Balance is critically dependent on the motions of the ankle, knee, and hip joints, which are in turn controlled by the ankle, thigh, and lower trunk muscles (Nashner & Peters, 1990). While the traditional view of motor control is strictly top down, with the nervous system controlling the movements, new theories of motor control divide the control evenly into three separate areas instead— the brain, the muscles, and the environment (Turvey & Fonseca, 2009). Among these three areas, the muscles are the easiest to manipulate. Also, many believe that any commands issued by the brain are limited by the potentials of the musculature; if the physical body is incapable of performing an action, the action will fail when the brain issues the command. Assuming that the physical body is the limitation that can be most effectively manipulated, we focused our research on training and strengthening the body in order to improve balance.

The ability to effectively maintain balance depends on two major factors: 1) the ability to manage a changing base of support and center of gravity, as well as 2) the ability to adjust quickly to changes in the equilibrium (Ferber et al., 2002). Simply speaking, maintaining balance involves keeping the center of gravity (COG) steady over a base of support. Typically speaking, the base of support is defined as the area outlined between the area of contact of feet and flat surface (Nashner & Peters, 1990). A person's base of support can be approximated by measuring a person's limits of spontaneous sway, or the amount of sway he or she presents when standing

upright in an undisturbed fashion. When a person moves such that the COG moves outside the perimeter of the base of support, he or she experiences a perturbation in balance and must recover using a series of rapid muscle movements.

As one falls, one's natural response is to take a rapid step or a series of steps forward in an effort to recover one's balance and stabilize the center of gravity (Luchies et al., 1994; McIlroy & Maki, 1996; Hsiao & Robinovitch, 1998). The act of balance recovery by stepping (BRBS) can be divided into three phases: step initiation, swing, and contact (Hsiao & Robinovitch, 1999). During each phase, the biomechanical aspects of the body's motion work to prevent or recover from a perturbation of balance. It makes sense, then, that improvement of functions in any of the three phases can lead to an increased ability to recover balance. This study is based on the principle that by improving the strength of the lower extremities through resistance training, people can grow quicker and more able to react during each of the three BRBS phases and can thereby diminish their threat of succumbing to falls and suffering subsequent injuries.

It is important to carefully examine the falling process in order to understand what is required to regain one's balance and exactly why the elderly have such difficulty in doing so. When a person trips, his body is propelled forward usually as a result of a kinematic constraint imposed by an obstacle. Gravity further accelerates this propulsion forward. In order for the person to successfully regain his balance, he must complete the appropriate muscle actions to stop the forward movement. As the person falls, he inevitably positions one leg ahead of the other to regain his balance; this leg is called the recovery leg. In order to stop the fall, he must position the recovery leg correctly through signals sent by the brain to the recovery leg. The proper placement of the recovery leg is anterior to the body center of mass. With such a

placement, the recovery leg generates enough momentum to counteract the body's forward movement during the trip. Secondly, supporting leg plays an essential role in balance recovery as it must provide the adequate push-off force to give the recovery leg enough time and clearance to reach the position necessary to prevent the fall. The support leg can only accomplish this by generating the necessary joint movements in a timely fashion (Pijnappels et al., 2008). As previously stated, the elderly undergo significant physiological and neurological decline that makes completing these movements quickly very difficult.

For the support limb to create an effective push-off force, the body must complete a number of specific rapid muscle responses, including a large ankle plantar flexion, a knee flexion, and a hip abduction. The knee flexion and hip extension are opposite movements to those that are required in a normal gait cycle. As such, completing these movements require very fast reduction of force in hip flexors and knee extensors and a rapid increase of force in the opposite movements. This rapid reversal of the direction of the hip and knee moments is very difficult for the elderly due to their elongated reaction time. Furthermore, the ankle extensor movement must increase force to levels required for maximal vertical jumping. Therefore, even though falls occur during or after placement of the recovery leg, most of the process of balance recovery occurs during the push-off force of the support limb. Through its processes during a fall, the support leg reduces angular momentum so that the recovery leg has less to accomplish in terms of countering the forward-moving force. Additionally, as previously mentioned, if the support leg can carry out its processes quickly, the recovery leg has more time to reach the correct position and can effectively reduce the remaining angular momentum before a person falls. While young adults can usually complete these processes quickly and efficiently, older adults

have trouble doing so due to the muscular, tendon, and neurological degeneration they experience in the aging process (Pijnappels et al., 2008).

2.4 Neuronal Adaptations to Strength Training

While this study focuses on physical training to increase subjects' muscle strength and their ability to maintain balance, various motor control theories have purported that any changes in musculature are inevitably also accompanied by neurological adaptations. Previous studies have concluded that while after three to five weeks of isotonic strength training, hypertrophy (or the increase in muscle mass) was the greatest contributor to strength, it was the neural adjustments resulting from the strength training that became the major contributor to strength in the long run (Moritani & deVries, 1979). Similarly, research has shown that older adults exhibited a 40-300% strength increase over 8 to 12 weeks of strength training while only 10-15% of the increase was attributable to muscle increase (Enoka, 1997).

Three main pieces of evidence support the theory that neural mechanisms play a major role in adaptations during physical activity. First, strength increases in the first few weeks of training prior to a significant increase in muscle mass. The cross-sectional areas of muscle fibers, which would increase with an increase in muscle mass, do not exhibit significant increase until eight weeks into a training program (Enoka, 1997). Second, the effect of "cross-education," in which an untrained limb will exhibit signs of strength increase when its opposite limb is trained, is also evidence of the role neural adjustment in increasing strength (Farthing et al., 2007). Third, increases in muscle strength are task specific. For example, in 1997, Enoka found that isotonic muscle strength increased after 12 weeks of isotonic training, while isometric strength of the same muscles showed no significant increase. While a number of studies point to the role of

neuromuscular adaptation in strength increase, the precise mechanism by which these adaptations occur remains unknown.

2.5 Criteria for Subject Selection

This study compares the impacts of two different types of strength training on two age groups: young adults and the elderly. In addition to simply looking at improvements for each training regimen, we also investigated whether each protocol's results were age-dependent. Research shows that rates of falling and serious fall-related injuries vary with age among adult populations (Schultz et al., 1997). As such, this study was designed to examine age-related differences in balance improvement as a result of strength training. Previous studies indicate that the geriatric population experiences an overall decrease in mobility linked with declines in lower extremity strength (Brown et al., 1995; Duncan et al., 1993; Gehlsen et al., 1990). Using this information in conjunction with other research, a working hypothesis was formed. This study tested the hypothesis that young adults, because of their inherent higher lower extremity strength, would improve less from training routines than elderly subjects would. Since the elderly subjects start off at a lower baseline of strength, their room for improvement is markedly higher than that of the younger subjects. In addition, since most balance problems occur as a symptom of old age, the geriatric population would benefit more from the training exercises.

The use of college-aged students as a comparison group with the elderly has been previously established as a common practice in the geriatric field. Wojcik et al. in 2001 recruited subjects from the university community to compare with elder subjects living independently in the community. In the Wojcik study, the average ages of each group were 25 years and 72 years;; following Wojcik's procedure, this study hoped to recruit young adults aged 18-25 and elderly

subjects 60-80. Due to the difference in the perturbation device used between this study and the Alexander study, this study lowered the age limit for geriatric subjects for their benefit.

Aside from considering age during subject selection, gender was a primary consideration at the beginning. Studies have found that gender does not appear to affect the ability to recover from a fall in young adults, and the result is mixed in the geriatric population (Thelen et al., 1997; Wojcik et al.; 1999, Grabiner et al., 2005). Based upon the ambiguous results of previous studies, this study disregards gender as a variable when measuring and comparing the improvements in balance recovery.

2.6 Principles Behind the Training Routines

While there are two "modes" of falling, forward and backwards, this study focuses on studying the mechanisms of the forward fall, or slip. As mentioned above, the most common response to a slip forward, for both the young and the elderly, is to perform a single step or a series of steps to regain balance. To that end, specific muscles used in balance recovery were researched thoroughly in order to develop training routines that would strengthen the muscles needed to regain balance.

In this study, training processes targeted the hip, knee, and ankle muscles due to their prominent role in balance recovery and fall prevention (Nashner & Peters, 1990). Previous research has suggested that dorsiflexion strength, or the ability to flex one's feet, is one of the discriminating characteristics between fallers and non-fallers (Whipple et al., 1987). A more recent study also provided showed that there is a connection between the isokinetic dorsiflexion strength and the maximum lean angle from which the subjects could recover; in other words, the stronger one's ankles, the better one could recover from an induced fall (Grabiner et al., 2005).

The Star Excursion Balance Test (SEBT) is a clinical test of dynamic postural control in which an individual balances on one leg while reaching the other in each of eight different directions (Norris & Trudelle-Jackson 2011). Using electromyography (EMG) it is possible to determine which muscles are most active during the reach phases. A threshold of muscle activity that is 40% to 60% of maximal voluntary isometric contraction (MVIC) has been previously suggested as necessary to elicit a strengthening stimulus. Muscle activity of less than 25% maximal effort, however, may indicate that the muscle is functioning to maintain stability (Anderson et al., 2006). Norris and Trudelle-Jackson examined muscle activity of the vastus medialis oblique, vastus lateralis, medial hamstring, biceps femoris, anterior tibialis, and gastrocnemius in 10 healthy subjects during the performance of all 8 directions of the SEBT. They reported that muscle activity for all but the gastrocnemius is direction dependent. They also determined that the muscles that are most responsible for postural control during the SEBT were the gluteus maximus (GMax), gluteus medius (GMed), and vastus medialius (VM).

EMG activity of the GMax was consistent across most reach directions (between 21% and 29%) but reached a maximum in the anterior direction (Norris & Trudelle-Jackson, 2011). They also reported VM amplitudes from 69% to 77% MVIC and similar to findings for the GMax, they were fairly consistent across all the reach directions maxing in the anterior direction. GMed muscle activity in the study ranged from 22% to 49% MVIC when measured in the anterior direction. This all suggests that the greatest muscle activation comes when reaching and extending forward. In order to train the muscles to achieve the greatest strength gains, the exercises must mimic this motion.

Strengthening the muscles significantly contributes to balance recovery capabilities. The elderly are only slightly slower at activating muscles following a perturbation than the young are

(Woollacott et al., 1988; Peterka & Black, 1990). The difference in response between the elderly and the college age students can be mostly attributed to the difference in muscle strength between the two populations. Further research studies have also shown that older adults have significantly lower cross-correlations of activity amplitudes between synergistic muscles and antagonistic muscles than the young adults (Manchester et al., 1989; Woollacott et al., 1993). Additionally, research has shown that older adults around 70 years old show a 20-40% decrease in strength as well as a decrease in the ability to generate joint torques (Doherty et al., 1993; Thelen et al., 1996). Based upon a significant amount of previous research, this study is focusing on improving the muscle strength of the elderly subjects in an effort to improve their balance maintenance skills.

2.7 Predicted Outcomes

Muscular interdependency is a phenomenon that has been exhibited in many motor systems throughout the body, most notably in the fingers of the hand. This phenomenon is also known as the "enslaving phenomenon" (Slobounov et al., 2002). Muscular interdependency occurs when a muscle group contracts when a neighboring or analogous muscle group contracts, such as the involuntary bending of the middle or pinky finger when the ring finger is bent, despite conscious effort being put to keep them straight (Shim et al., 2008).

Muscular interdependency, like any other neurological pathways, can be adjusted through resistance training. For example, resistance training of one finger while the others are restrained causes a decrease in the interdependency between the fingers of the hand (Shim et al., 2008). Similarly, training can initiate adaptations to reduce the coactivation of agonist and antagonist muscles by focusing motor command to the appropriate muscles (Duchateau et al., 2006). In other words, training adjusts the neural pathway to decrease the coactivation of agonist and

antagonist muscles, increasing the strength of the agonist muscle in performing the specific movement.

Since both types of training protocols in this study, the individual joint and the whole leg, are based upon resistance training principles, it was predicted that both the young and elderly subjects would experience an increase in strength. While the two resistance training routines used in this study are both types of strength training, the individual joint protocol is more focused on developing the neural pathways of each individual joint than the whole leg protocol is. Therefore, considering the principles of neural adaptation and muscular interdependency, it was predicted that training each individual joint and its neural pathway would have a synergistic effect such that the subjects undergoing the individual joint protocol would increase their strength and balance capabilities more than those undergoing the whole leg protocol would. This prediction was based upon similar results observed in a 2008 study on the motor system of the hand. In this study, three protocols – simultaneous finger training, individual finger training and individual finger training with other fingers retrained – were presented to subjects and the results indicated that individual finger training reduced finger interdependency the most (Shim et al., 2008).

As stated in section 2.5 of this chapter, it was also predicted that the elderly would show a more marked improvement over the course of the training due to their strength being inherently lower than the college students'; furthermore, it was hypothesized that due to the age of onset of balance problems, the geriatric population would benefit more from the strength exercises than the college students. One proposed explanation of the balance problems facing the geriatric population is the idea that the problems in the geriatric population could be due to a combination of small deficiencies in a large number of motor-related functions (Horak et al., 1989; Hsiao &

Robinovitch, 1999). The deficiencies in motor-related functions affect balance recovery for the elderly. There is overwhelming evidence that there are significant differences in recovery style between young and elderly adults. In a 2008 review article examining a variety of studies, it was concluded that even though the very basic biomechanical parameters are unaffected by the difference in recovery style between young and elderly adults, the underlying complex neuromuscular capacities could be greatly influenced by the differences (Hsiao-Wecksler, 2008). Based upon these principles, it was further predicted that the individual-joint protocol in this study, which addresses several motor-related neurological networks separately, would be the most beneficial for the elderly population.

2.8 Summary

The purpose of this study is to analyze two different types of resistance training, individual joint and whole leg, to see whether training each individual joint involved in fall prevention would be more effective than training the entire lower extremity. Differences between the elderly population and college-aged population in response to the two types of training exercises are also explored. The biomechanical and neurological aspects of maintaining and improving balance are complex. Each factor is further influenced by age and the physical condition of the subject.

Literature review has revealed that extensive research has been completed regarding the biomechanical aspects of fall prevention. Researchers have identified the major target joints involved in falls and fall prevention. Furthermore, ample research has firmly established the link between neural adaptations and strength training. In related areas of motor control, evidence suggests that muscle interdependency and muscle independency can be utilized to strengthen the motor unit's response to certain triggers. Based upon these studies, this research aims to identify

a protocol that is best suited to help the geriatric population improve their ability to maintain balance. This research is also an investigation into whether the effects of individual joint training are age-specific or if the findings can apply to people of all ages.

Chapter 3. Methodology

3.1 Experimental Procedures

Prior to testing, the subjects were screened for sedentary lifestyles and for the absence of confounding disorders. Once subjects were selected for the study, they were match-paired by similar BMI, and then split into the two training groups. Subjects in both the whole-leg training and single-joint training groups attended the first testing session before any training has taken place, the result of which will serve as the subjects' baseline data of standing stability, recovery ability, and lower extremity strength for each individual subject using a stabilometry (quiet standing) test, perturbation, and strength test, respectively. All subsequent testing sessions followed the same protocol. The same experimental procedure was used for both college-aged subjects and elderly subjects.

After initial testing, all subjects were oriented with the training equipments specific to their respective group and were required to demonstrate proper understanding of equipment operation before performing repetition maximums (1-RepMax) for each exercise. To obtain the 1-RepMax, the trainer asked the subject to perform one repetition of the exercise at moderate resistance, and then slowly increase resistance until the subject could not perform one repetition. The increases in resistance are diminished as the trainer honed in on the subjects' 1-RepMax. After determining the subjects' 1-RepMax, the trainer determined what weight to train the subject. All subjects were trained throughout the study using 75% of this initial 1-RepMax (Shim, J.K., personal communication, October 13, 2009).

Participants were given four testing sessions; before the first training session (baseline determination session), after two weeks of training, after four weeks of training, and the final

session that took place after six weeks of training. This was determined to be adequate for the team to get enough data while leveraging the schedules of the testers, trainers, and subjects, while finding opportunities to use the School of Public Health Kinesiology Lab. If a subject missed a training session, which happened on only a few occasions, their testing session was rescheduled so that four data points would still be collected. Before each testing session, the subject was outfitted with reflective sensors for the VICON[TM] T160/40/20 motion analysis infrared camera system to detect their movement. This was performed by one tester or trainer while the other tester calibrated the infrared camera system.

A subjects' level of standing stability is one indicator of good balance via muscle steadiness in maintaining an upright posture, which was quantified using the quiet standing test. This test identified each subjects' center of mass (COM) and the variability in the COM during their natural stance. Subjects were asked to stand still for 3 intervals of 15 seconds each on a piezoelectric force plate (Kistler Instrument Corporation) with their feet on the force place at a comfortable shoulder width apart and their arms relaxed at their sides (Geuze, 2003). The subject had no knowledge of when the data recording occurred for each of the three intervals to diminish the subject-expectancy effect. This standing-sway test was done with the subject in the center of the eight peripheral Vicon cameras, which collected data on the participants' motion in three-dimensional space. Simultaneously, the force plate collected data on the subjects' force shifts in the medial-lateral, anterior-posterior, and vertical planes. The force plate also recorded the subjects' center of pressure (COP) during quiet stance.

The most important indicator of good balance and muscle synergy in the subjects is their agility: the ability to move and change position of the body quickly and effectively while under control to recover from a center of balance displacement. This was quantified using the

perturbation test, which uses the force plate, the Vicon system, and a perturbation device. The perturbation device used will be explained in more detail in the next section, but for now, the perturbation device is composed of a weighted volleyball, tethered to a support stand. The testers release the ball after pulling it to a certain height to allow the ball to follow a pendulum-like movement and knock participants off balance.

The ground reaction forces were monitored by the force plate in the same manner as in the stabilometry test. The VICON system was set up around the perturbation device and the subject to track joint movement. After explaining to the subjects how the perturbation device functions, subjects were asked to attempt to recover from their perturbation and restore balance, while standing on the force plate with their arms at their sides. They were told to react naturally to the perturbation. Rarely did the subjects lose their center of balance to the degree that they took a step to recover; most subjects did not step at all. This was due to the carefully measured weight of the perturbation device during its design and construction. Before beginning the test trials, subjects performed a practice test in which they were warned when the ball would be released, so that they were familiarized with the functionality of the device before any data was collected. The participants experienced three perturbations, which occurred at random interval lengths.

After conducting all the perturbation tests, the tester removed the reflective markers from the subjects, and then prepared them for the strength test. The strength test was used to measure lower extremity output to show that the training is improving the subjects' lower extremity strength. To prove an increase in the subjects' lower extremity strength, the data from this test must show that the subjects' one 1-RepMax is increasing. Using a Kesier^{TM} pneumatic leg press machine (the same used in the training) we were able to measure the subjects' leg power output.

As the subject sat in the seat of the leg press machine, the tester would then slide the seat of the machine so that the subjects' knees were as close to their chest as possible while still being comfortable. The college-aged subjects tend to be able to move closer to the extension plate than the elderly, due to a decrease in flexibility among the elderly subject group.

Once the subject found their ideal distance from the extension plate that was the optimal level of comfort and extendable distance, the tester helped them find the right spot on the extension plate to put their feet. The participants placed their feet so that the tip of their feet was two-thirds of the length from the bottom of the pedal. They were then instructed to push the pedals outward with both feet, while extending the ankle at the end of the push (Coffey et al., 2006). The tester then made sure that the subjects were not locking their knees at the full extension for safety concerns. Participants started at a lower weight and increased the weight after each repetition of each leg extension. The weight increase is decreased as the tester hones in on the subjects' initial or improved 1-RepMax. Once the subject failed to complete an extension, the tester would record the previous weight of the subjects' successful extension. Subjects were allowed to take short breaks and try again if they desired.

When the strength test was concluded, subjects were then compensated for their participation in the test, and the team prepared the system again for the next subject coming to test that day.

3.2 Equipment

For the testing procedure, four pieces of equipment were used to collect our data; the piezoelectric force plate, the Vicon motion capture system, and the pneumatic leg extension machine were provided by the University of Maryland's Kinesiology Lab in the School of Public

Health, while final piece of equipment, the perturbation device, was designed and built by the team.

The first piece of equipment used was the quartz piezoelectric force plate manufactured by the Kistler Instrument Corporation to measure the ground reaction forces (GRFs) produced by the subjects under testing conditions (Kistler, 2009). GRFs include force, acceleration, and pressure parameters (Kistler, 2009). Griffiths (2006) suggests that the plate can be used for stability analysis and measurements of force, power, and work output among our subjects. For the evaluation, normal force experienced by the subjects was measured, or the force in the perpendicular direction with respect to the ground surface. This device detected subjects' center of pressure in the standing-sway test, which allowed for the data analysis to determine if there was an improvement in subjects' standing maintenance of their center of pressure as a result of the training. This device was used in conjunction with the Vicon system.

The VICON[TM] T160/40/20 motion analysis infrared camera system allowed for the measurement of captured motion in three-dimensional space. This device was used to conduct both the standing-sway and perturbation testing in three-dimensional spatial analysis. Before the first subject began their testing, the laboratory floor was marked for the locations where the eight cameras would be placed. This was done to ensure that the camera positioning throughout the experiment remained constant. The cameras were assembled around the piezoelectric force plate in a fashion that allowed for maximum coverage of all the reflective markers. Before each testing session, team would assemble the VICON camera system on tripods, connected them to the mainframe computer, and calibrate them. Calibration of the VICON system was performed by waving five-marker T-shaped reflective wand around the center the systems' field of vision. This

ensured that each camera was properly recording subject motion information using the largest field of vision.

While the system was being calibrated, another team member outfitted the subject with the 34 reflective markers (see appendix?) on the subject so they can be identified by the VICON infrared camera system. To further ensure consistent data collection, subjects were told before each testing session to come wearing tighter fitting clothing and sneakers that allowed all reflective markers to be observable by the system. Otherwise, loose shorts or baggy shirts were pinned tighter so that all 34 reflective markers were consistently in the same locations on each subjects' respective bodies. The following chart details the precise locations the markers were placed on the subjects. An extra reflective marker was placed on the top of the perturbation volleyball so the motion of ball would be picked up by the VICON system.

Table 1. **Marker Placement**. A detailed list of the location and marker count for each body part.

Body Part	Location(s)	Total Marker Count
Feet	Point of Sneaker, tip of interior ankle, tip of exterior ankle, back of heel	8
Leg	Tip of interior knee, tip of exterior knee	4
Trunk	Sternum, distal ends of clavicals, anterior and posterior hip markers, right shoulder blade	8
Arm	Middle knuckle distal ends of ulnar and radial bones. lateral and medial elbow joints	10
Head	Tip of head (on a helmet piece) and C7 vertebrae	2

The three-dimensional motion measurements data from the eight infrared cameras was synchronized with the data retrieved from the force plate to allow statistical performance of

multidimensional analysis (VICON, 2009). The accompanying VICON software enabled record keeping of the data collected from the VICON system. According to Griffiths (2006), digitizing software detects these reflections in the film at every frame, calculates the center of each marker, and records the point coordinates within each frame in sequential order in the form of a table or graph. Griffiths (2006) suggests that displacement, velocity, acceleration, angular displacement, angular velocity, and angular acceleration at each joint can be computed from the data.

The third piece of equipment: the perturbation device also used in conjunction with the force plate and VICON system was marked with reflective marker to synchronize data capturing. The perturbation device, custom designed by the team (see appendix), was made from PVC piping, and uses soft rope to dangle a partially-deflated volleyball that has been filled with three pounds of sand to give it weight. The PVC was spray-painted black to eliminate its reflective coating. During the initial design and prototype development of the perturbation device, the three pound weight of the volleyball was derived from trial and error among members of the team to determine the optimal weight for maximum perturbation and minimal discomfort of the subject.

To find the ideal weight, sand was poured into a hole cut in the exterior bladder of the volleyball, which fit in between the partially-deflated inner bladder and the exterior bladder. When the weight of the volleyball was below five pounds, it was determined to not have enough force to displace the subject. When the ball was tested above five pounds, the displacement threw off the subjects' off balance too much, while potentially being uncomfortable for the subject, especially the elderly participants. The perturbation device was built so that the height of the ball was adjustable to ensure that the ball's point of contact on the subject remained constant, the upper part of the back. The top of the volleyball weight is equipped with a reflective marker so that the pendular motion of the device is captured on the VICON system.

The fourth and last piece of equipment used during testing was the Kesier^{TM} pneumatic leg press machine, used to conduct the strength test. The unit of weight that this machine used was pounds per square inch. This device is also used by the trainers for the whole-leg training regiment during the training sessions. This device used for measuring the improvements in strength from their baseline during the six week training period through improvements in the subjects' 1-RepMax. It was used in conjunction with Bertec Corporation force plate to convert the weight units from pounds-per-square inch to newtons, so training could be conducted and normalized with other force-based leg press machines. This was done by having a member of the team exert force on the machine from 50 psi to 600 psi at every 50 psi. The psi readings were correlated to the force readings from the Bertec force plate, and a linear regression was calculated to find the conversion factor (Figure 1).

PSI to Force Conversion

$$y = 1.8293x - 16.458$$
$$R^2 = 0.99851$$

Legend:
- sqrt(sum(avgxyz))
- Linear (sqrt(sum(avgxyz)))

Y-axis: Force (N)
X-axis: Pressure (PSI)
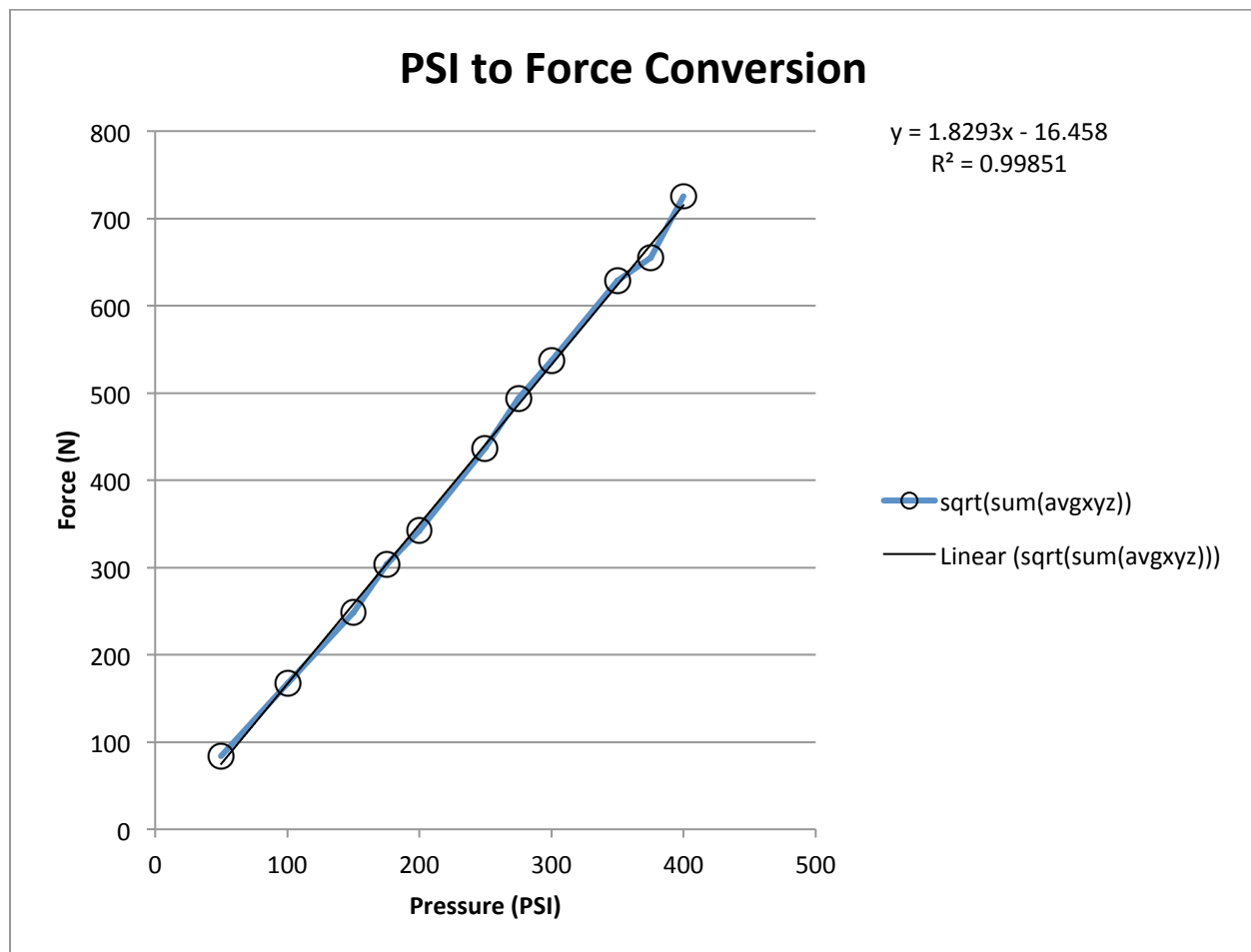
Fig 1. **PSI to Force Conversion Plot**. We plotted a relationship of pressure (PSI) against Force (Newtons) in order to convert between the data outputted by the leg press machine in the SPH gym and the leg press machine in Ritchie Coliseum.

3.3 Subjects

In order to implement a matched-subject random assignment design, the subjects were distributed evenly into two groups matched for BMI. Due to the insufficiency of similar studies that would set a precedent for an appropriate sample size along with budgetary, retention, and temporal constraints, the sample size for the project was 18 (n=18), divided between the four subject groups, the college aged individual joint training group and whole leg training group, and

elderly individual and whole leg training groups. Of the 18 subjects 10 were in the college age groups while 8 were in elderly groups. Dr. Jae K. Shim suggested that the minimal sample size should include 8 subjects per group (n = 32) (Shim, J.K., personal communication, October 6, 2009) in order to have any statistical power.

The age range for the younger group was 18-24 years. A key point to a subject's eligibility was that they must have been sedentary at the start of the study, meaning they did not engage in regular exercise, especially progressive resistance training (i.e. weight lifting) or intercollegiate athletics. Significant extraneous exercise has the possibility to confound data by introducing neural and muscular changes not induced by the experimental training. An increase in the cross-section area of the muscle can also contribute to an increase in strength, which is a qualitative measure of the change in muscle stature (Reeves, Narici, & Maganaris, 2004). The International Physical Activity Questionnaire (IPAQ) short form was used to quantify the activity level of the subjects. IPAQ is available to the public at the IPAQ Research Committee website (Persch, Ugrinowitsch, Pereira, & Rodacki, 2009). The subjects were asked to answer a series of short questions and the responses scored according to the accompanying rubric in the IPAQ manual (IPAQ Research Committee, 2005). Both the IPAQ manual and scoring rubric are available online in various formats and languages at http://www.ipaq.ki.se. The short form IPAQ can be found in Appendix H. Additionally, since the project tested neurological responses to muscular training, the subjects must have been free of any disorders that could impair neurological or skeletal-muscular activity, as individuals affected by neurological or musculoskeletal disorders may respond to training and testing modules differently than healthy subjects (Hale, Miller, Barach, Skinner, & Gray, 2009).

Whenever a study is done with human subjects, there are confounding variables that

cannot be absolutely controlled for. For example, it was not possible to monitor subject intake of nutritional supplements, recreational drugs, or alcohol. Nutritional supplements can increase muscle mass and energy level and drugs of any kind will affect subjects' physiological responses to training and testing, all of which would skew the gathered data. For the elderly subjects, it was critical for the researchers to carefully screen their medications, as some medications have adverse side effects on balance and neurological responses. However, there is no feasible and ethical method to limit subject intake of nutritional supplements or consumption of alcohol, recreational, or medical drugs. The effects of these potentially confounding variables were minimized through screening the initial pool of subjects to eliminate those who self-report drug and alcohol abuse; however, lack of subject honesty could confound results. It is also possible that some subjects may have falsely reported their information due to the monetary incentive; but to counter this possible confounding variable, the specific parameters of subject requirement were not advertised. Instead, only the most basic requirements such as age, gender, and being a member of University of Maryland, College Park community were included on advertisements. To maintain subject confidentiality, each candidate was assigned a subject number prior to the screening process and any volunteered information was only associated with the subject number and used solely for screening and matching purposes. The researchers followed strict confidentiality guidelines and keep all data gathered throughout the experiment private.

The college-aged subjects who participated were students recruited from the University of Maryland, College Park campus between the ages of 18 and 24. To recruit this age group, advertisements were posted around the University of Maryland campus, in classrooms and in dorms. Permission was obtained from the University administration before such postings were erected. A sample of the flier advertisements used throughout the campus can be seen in

Appendix B. Special attention was paid toward students residing on North Campus due to the close proximity of the North Campus high-rise residence halls to the testing and training center located in the School of Public Health building. Additionally, most of the students interested in participating in the study happened to live on North Campus and were interested in participating in the study primarily because of the convenient location. Residents of North Campus tend to be freshmen and sophomores with the exception of resident assistants, so this study primarily caught the attention of young adults in the 18-21 age range.

Listserv advertisements were also used to inform students of the opportunity to participate in this study. A sample of the message sent out over university department and college listservs can be found in Appendix C and L. Listservs are essential for advertising because they aggregate information regarding opportunities on campus and send them to all students in particular colleges, living-learning programs, or student groups. Therefore, the listservs helped to advertise this study to the entire student population rather than just freshmen and sophomores. Prospective subjects filled out surveys regarding their physical characteristics, living habits, and health conditions. Students who were regularly involved in rigorous sports or had a regular leg weight-training routine at the time the research was conducted were not allowed to participate in the study. This decision was made in order to ensure that the results obtained were definitively results of the training program and not results of any activities outside of the study, Based on these surveys, subjects were carefully selected and placed into matched pairs on the basis of similar BMI. The subjects in the matched pairs were then randomly divided, one into the whole-leg training group and one into the individual-joint training group.

In order to recruit elderly subjects, contacts were established with long-term care facilities and retirement communities within a twenty-mile radius around College Park.

Additionally, the alumni center's database of contact information for graduates who fall within the 62-80 year age-range was utilized. Advertisements were also posted among establishments in College Park that are frequented by independent-living elderly adults—such as grocery stores, restaurants, and churches. Regardless of these efforts, the elderly subjects who participated in this study were primarily relatives of group members and young adult subjects or friends of other subjects in the study. One of the reasons for this is that many elderly people who responded to advertisements that fell within the target age range were far more active than average elderly people. Just like protocols for the young adults who applied to participate in the program, prospective elderly subjects were not accepted into the program if they regularly engaged in lower body weight training. As such, word of mouth from past subjects was essential for securing sedentary elderly subjects who viewed the idea of a six-week weight-training program as somewhat daunting. Additionally, recruiting elderly subjects related to other subjects or researchers helped with preventing many elderly subjects from dropping out before the end of the program. This was crucial for this study because there were so few training periods that the regular dropout rate usually experienced when working with elderly subjects would have brought the project to a standstill.

Subject retention with college students was difficult as well. Students may drop out due to a myriad of reasons including the added stress of schoolwork which can makes participating in a training program three times each week a burdensome time commitment. As many physical training experiments experience problems with subject retention when working with subjects of all ages, proper subject compensation was essential. Based on previous studies, approximately 50% of all subjects who start a self-monitored exercise program will drop out; although members of the research team will monitor the exercise-training program, the project still relied heavily on

the subjects' continuous voluntary participation (Dishman, 1991). Each young adult subject received $50 and each elderly subject received $100. These amounts were paid in a tiered distribution. Each subject received compensation on each of the four testing days, in increasing increments. For example, each elderly subject earned $10 at the initial test, $20 at the second test, $30 at the third test, and $40 at the final test. Additionally, all subjects who completed the program were entered into a raffle for an iPad 2. Subjects who did not complete all six weeks of training were not included in the raffle. In another effort to maximize subject retention, subjects were allowed to miss one training session every two weeks of training if it was necessary. Meanwhile, each subject, whether elderly or college aged, was assigned to one trainer for the duration of the program. Therefore, because the trainers established strong relationships with the subjects, the subjects were more likely to stay committed to the program.

3.4 Training Protocol

Each training session began with a series of stretching exercises in preparation for the weight training. Each exercise required the subject to complete 10 repetitions at 70% of the one repetition maximum in 3 sets. This load to repetition ratio has been determined to be the most effective in increasing muscle strength (Kawamori & Haff, 2004). The subjects received up to two minutes of rest between each set of repetitions of the same exercise and five minutes of rest between sets of different exercises. Although this training plan totals three exercises for subjects engaging in individual-joint training and only one exercise for subjects participating in whole-leg training the different trainings are indeed equal and comparable because each joint is receiving as much training in the individual-joint training sessions as the whole-leg is receiving in whole-leg training sessions (Shim personal interview, November 17, 2009).

3.4.1 Individual Joint Training

At every training session the subject will perform the prescribed exercises under the supervision of a researcher. This training protocol can be found in Appendix Q.   In order to prevent any biases and difference in training styles the researcher individually trained and supervised the subject for the duration of the trial. Individual-joint training sessions were comprised of three different exercises: leg extension exercises that target the knees, hip extension exercises that target the hips, and ankle plantarflexion exercises.

The leg extension isolates the knee joint as the knee is extended to push a plate loaded lever upwards. Subjects sit on the lever leg extension machine with their backs supported by the seat of the machine and their shins resting against the padded lever from below. During each repetition of the exercise, the subjects slowly extend their knees, lifting the lever as they straighten their legs. After fully extending their legs, the subjects will pause for a moment and then slowly bend their knees again, bringing the lever back to its original position. Griffing (2009) clarified that for safety and stability during the exercise, subjects should take care to keep their back supported against the seat and grip the handles on each side of the machine. Sitting upright in the machine also ensures that the subject completes the exercise correctly and successfully using the target muscles.

The target muscles of the knee extension are a large group of muscles known as the quadriceps. This muscle group is comprised of four muscles, the vastus lateralis, vastus medialis, vastus intermedius, and the rectus femoris (Saladin, 2007). Diagrams of the quadriceps can be found in appendix X. All four muscles insert into the tibial tuberosity of the tibia via the patella, where the quadriceps tendon becomes the patellar ligament, which then attaches to the tibia. The

vastus lateralis, vastus medialis, and vastus intermedius originate from the femur while the rectus femoris originates from the iliac crest of the pelvis. All four contract concentrically to extend the knee and straighten the leg. During eccentric contraction, the knee is flexed and the leg is bent (Saladin, 2007).

The standing hip extension isolates the hip joint as the leg is down and back to swing a plate loaded lever. The subjects stand on the platform with lever fulcrum at height of hip articulation, facing to one side placing the hollow of knee against the padded swing arm. During each repetition of the exercise, the subjects slowly extend their leg pushing downward and backwards against the lever until they reach a point where they can no longer extend the hip further. The hip is then flexed and the leg is then returned to the starting position (Griffing, 2009). When performing the exercise, participants must not swing the leg back and forth as this generates momentum and decreases the amount of work needed to move the weight. Excessive movement and speed can also lead to injuries and strain of the muscle.

The target muscles of the hip extension are the gluteus maximus, gluteus medius, adductor magnus, semitendinosus, semimembraneosus, and biceps femoris (long head) (Saladin, 2007). The primary movers that also contribute heavily to balance are the gluteus maximus and the gluteus medius. When the gluteus maximus takes its fixed point from the pelvis, it extends the femur and brings the bent thigh into a line with the body during concentric contraction and flexes the hip to raise the leg when eccentrically contracting. The gluteus medius adducts the thigh when the leg is straightened (Saladin, 2007).

The ankle plantarflexion exercise isolates the ankle as the toes are pointed (plantarflexion) with a weight attached to the heel. During this exercise, the subjects will have a bar strapped to

the bottoms of their feet. A weight hung from the end of the bar behind the ankle. Subjects placed one knee on a raised surface with their foot out behind them. From that position, they pointed their toes so that they pointed behind them, paused, then relaxed and dorsiflexed to complete one repetition (Griffing, 2009). Many subjects needed additional stabilization as the ankle is often not strong enough to stabilize itself while flexing. Stabilization was provided when needed but did not assist the subject in lifting the weight.

The target muscles of the ankle plantarflexion exercise are the gastrocnemius, soleus, plantaris, peroneus longus, peroneus brevis, posterior tibialis, flexor digitorium longus, and flexor hallucis longus. The gastrocnemius and the soleus are the largest of these muscles and are the primary targets (Saladin, 2007). The gastrocnemius is located with the soleus in the posterior compartment of the leg. The lateral head originates from the lateral condyle of the femur, while the medial head originates from the medial condyle of the femur. Its other end forms a common tendon with the soleus muscle; this tendon is known as the caalcaneal tendon or achilles tendon and inserts onto the posterior surface of the calcaneus, or heel bone. The gastrocnemius and soleus contract concentrically to plantarflex the ankle and contract eccentrically to dorsiflex the joint (Saladin, 2007).

3.4.2 Whole Leg Training

Just like the individual joint regimen the subjects in whole leg training performed their training under the supervision of the same researcher throughout the training process. Instead of isolated each joint; the hip, knee, and ankle joints were are trained in one motion on the leg press.

The leg press is performed by on a machine in which the subjects sit on the seat and place their feet against the plate. The subjects then push the plate by extending their legs to their full

length and pointing their toes without locking their knees (Yessis, 2002). The muscles used include the gluteus maximus, quadriceps, hamstrings, adductor magnus, soleus, and gastrocnemius (Saladin, 2007). While the leg extends the muscles excluding the hamstrings contract concentrically and contract eccentrically while the leg is bent back into the starting position.

The hamstrings are a flexor muscle group located on the back of the thigh. They are antagonistic to the quadriceps and oppose their muscle movements. During leg extension they contract eccentrically and concentrically contract during the flexion of the leg. The three muscles that comprise the hamstring are the semitendinosus, semimembranosus, biceps femoris long & short head all flex the knee, while all but the short head of biceps femoris extend the hip as well (Saladin, 2007).

The training procedure for the whole leg subjects is identical to that of the individual joints except for the exercises they complete. Any differences in the results of the subjects would be because of the different models of muscle activation that arise from the different regimens. Individual joint training is designed to enhance and emphasize the ability of the joints to operate independently of each other while whole leg training strengthens the co-activation and synergy that arises when muscle groups are activated together.

3.5 Statistical Analysis

3.5.1 Summary

Based on our methodology, Team BALANCE collected three types of data. Strength was quantified from output by the leg press machine. Using the VICON system and the connected force plate, Team BALANCE is able to map the movement of each subject's body segment. And

the changes in force displacement in either the anterior-posterior direction or the up-down direction.

3.5.2 One Repetition Maximum as Measurement of Strength

During each of the testing sessions, all subjects pressed on a leg press machine. The subject incrementally increases the psi, a measure of pressure, against which they are pushing. By recording the highest psi at which they can comfortably extend their legs, we have a measurement of their relative strength. The number is known as the One Repetition Maximum (1-RepMax), or the maximum amount of force the subject can generate in one repetition of leg extension. The 1-RepMax generated at each subject's first testing session right before training serves as the baseline to which their improvement is normalized against. Furthermore, as we outlined in the previous sections on training methodology, that same 1-RepMax value is also used to determine the strength at which the trainers train the subjects.

At each subsequent testing session every two weeks, the subjects were asked to repeat the leg press exercise and the psi value recorded. Each testing session's psi value is then normalized to the one measured in the first testing session at 0 weeks and the overall percent increase plotted. The range for percent increase ranges from 0-100% and a negative value would indicate a decrease in strength. Since each subject had a different level of strength when they entered into the study, team BALANCE decided to eliminate that confounding variable by normalization to the baseline 1-RepMax. Furthermore, team BALANCE performed a double normalization. Not only was the 1-RepMax data from the second and third testing session normalized to the baseline 1-RepMax, but we also normalized the value to each subject's body weight (kg). The double-

normalization eliminates sex and initial body weight as confounding variables and compares only the percent increase in strength throughout time for each of the subject groups.

3.5.3 Data Cleaning and Recovery

As we will discuss in Chapter 5 of the thesis, our collected data suffered from a variety of limitations. The original design of the testing protocol called for four testing sessions, at 0, 2, 4, and 6 weeks of training. Due to incomplete marker detection, Team BALANCE decided to discard the VICON data for several subjects for their final testing session. By disregarding their data, the subject pool for the last testing session shrunk to a point where no significant data analysis was possible. As a result, Team BALANCE decided to look only at the first 4 weeks of training, which corresponded to the first three testing sessions.

The VICON system is an extremely sensitive instrument that picks up slight reflections. Under ideal conditions, the markers are placed as closely to the subject's skin as possible and the subject should wear clothing that is both tight and non-reflective. However, some subjects felt uncomfortable with the idea of tight or short clothing. As a direct result of their clothing choice, some of the markers became blocked during a few seconds during the testing session. In order to analyze the data, Team BALANCE "recovered" data for those markers by approximating their position using a connected marker and previous data. For example, if the marker on the inner ankle was missing, we would use the marker data from the outer ankle marker as well as the pattern found in other testing sessions to estimate roughly where the missing marker is located during the interval. If the data set is too damaged to recover with sufficient levels of confidence, the entire data set is discarded.

3.5.4 Impact Time

The impact time served as a reference time point for quantifying each subject's reaction to the perturbation. In the MATLAB scripts, the impact time is delineated by the variable "bhit", which alludes to the process of determining the impact time. By plotting the anterior-posterior and vertical positions of the ball, we were able to determine the impact time or impact frame from the time output at which the change of the ball's position during the downward swing diminishes significantly. We then record the "bhit" value for future use. Before any data is generated from the ball marker, the ball's positional output ran through a low-pass filter to filter out noisy signals.

3.5.5 Force Displacement After Impact

The six ground reaction forces were recorded on the Kistler piezoelectric force plate during the perturbation trials. Several steps were taken to process the force plate data. First, the force plate data was re-saved in a comma-separated values (CSV) format after deleting numerous columns of repeated data that hindered processing CSV files in MATLAB. Second, similar to the ball marker, the force plate data were also put through a low-pass filter set at the same frequency as the VICON data for the ball. Next, the data from the force plate ran through a low-pass filter and a variable, "tstamp" was added to the output .mat file to give results with respect to time in an easily understood manner. To analyze the displacement of force throughout the perturbation period, each subject's force data in all three orientations, medial-lateral (Fx), anterior-posterior (Fy), and up-down (vertical, Fz), were normalized to the weight measured from the force in vertical direction. The weight is determined as the average of the Fz data for the one second before "bhit". Thus, all subsequent analysis of force plate data are of the ratio of

the force measured (N) to the body weight (N) from the Fz data. For instance, if a subject is perfectly still and standing with all force in the vertical direction, the ratio of measured force to body weight would be 1.

3.5.6 Covariance During Subject Force Displacement

Covariance of each subject is determined from the VICON data of the reflective body markers. The center of mass (COM) of the subject is first determined, using the subjects body mass (kg) and calculations as presented in Appendix AK (male and female subjects have slightly different scripts for calculating COM; however, only the script for male subjects are shown). After finding the COM, the COM is also put through a low-pass filter. The covariance is calculated from the "function COV" of the Appendix AK, by taking the difference between the positional variance and COM variance and dividing the difference by the positional variance. The covariance was calculated for movement in all three orientations.

3.4.7 Two-Way Repeated Measures ANOVA

A 2-way repeated measures ANOVA was done for our data as it allows for two independent variables with repeated measures given the weeks of training. The age group, college-aged and elderly, served as one independent variable, and the training type, individual joint or whole leg training served as the second independent variable. The within group factor was the repeated measure of all variables given the training progression.

Chapter 4: Results

4.1 Summary

The strength data from the 1-RepMax test, the delta force (DF) in both the anterior-posterior (AP) direction and vertical direction, the center of pressure (COP) range in AP and medial-lateral (ML) directions, as well as the delta variance (DV) data in all three axes quantifying muscle synergy are reported here. Due to large variability in the data sets and small sample size, nothing conclusive is drawn. Inconclusive result may also indicate that there is no difference between the two strength training regimens, whole-leg training and individual joint training. Statistical analysis using a two-way repeated measures ANOVA reveals some statistically significant ($p < 0.05$) differences between certain subject groups that bear further investigation. However, most of the comparisons returned a non-significant result.

4.2. Strength represented by 1-RepMax
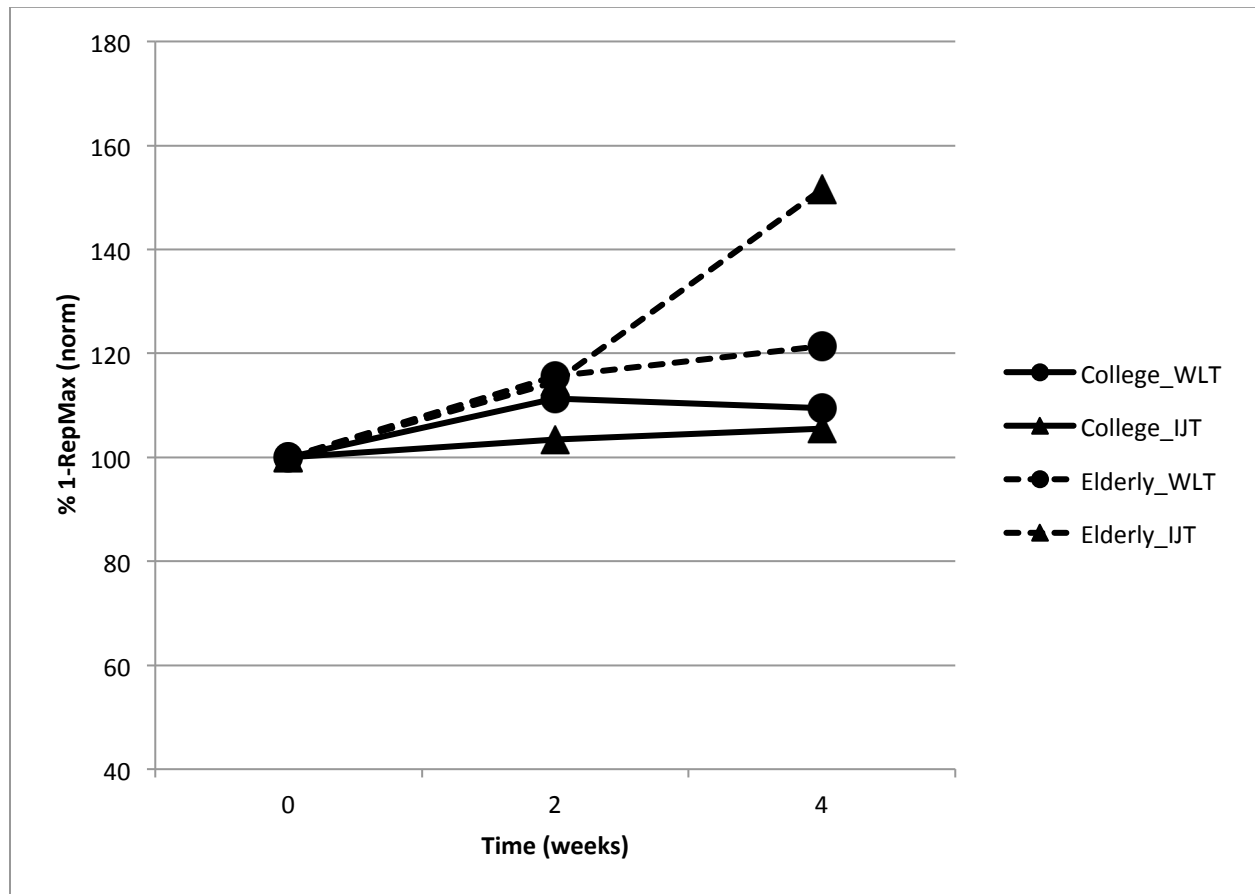
Fig 2. Average Percent Increase of Strength. The average percent of 1-RepMax for each subject group, normalized to initial baseline level 1-RepMax values, shows a general trend of increase.

Since all subjects started their strength training at 75% of their baseline 1-RepMax, or their 1-RepMax result prior to training, and the baseline 1-RepMax was different for each individual, all the 1-RepMax data was normalized to each individual's baseline 1-RepMax. By looking at the percent increase of strength throughout the duration of the training program (Fig 2), we hoped to identify which training provided the greatest increase in terms of lower body

strength for the subjects, and whether the age of the subjects affected the degree of 1-RepMax change.

Without taking into account the standard deviation, we see that the average 1-RepMax increased for all subject groups. By the end of four weeks into the training program, college students using the whole leg training protocol experienced a 9.5% increase in strength, and the individual joint training protocol, a 5.5% increase in strength. On the other hand, we saw a greater strength increase for the elderly subjects who were in the IJT group, a 51.6% increase versus a 21.4% increase for the WLT group.

However, the large variance for individual participant's result within each group resulted in large standard deviations. The variability in our data rendered many graphical differences between the subject groups to be non-significant. From the two-way repeated measures ANOVA (2x-RM-ANOVA), we did see a close to significant interaction of subject age ($p=.053$), and also a significant interaction between training period and age ($p=.033$).

4.3 Delta Force in Anterior-Posterior and Vertical Direction

Ground reaction forces (GRF) were recorded during the perturbation trials. The ground reaction forces in the vertical direction and in the AP direction were analyzed for the maximum range of force change during recovery stage of perturbation. Because all participants have different weights but were perturbed with the same three pound mass, their force recordings were normalized to each of their body weights. Figure 3 shows an example of force recording during the perturbation trials with ball impacting on the participant at 1 second. The two arrows point to the maximum shift in GRF in the anterior and posterior direction normalized to subject's body weight. Standard deviations from three perturbation trials are indicated by the thinner red lines

above and below the thicker red line, which is the average GRF in AP direction. The delta force (DF) is represented by the difference between the two arrows. We expected the DF to decrease with training and more so for IJT group and for the elderly group.
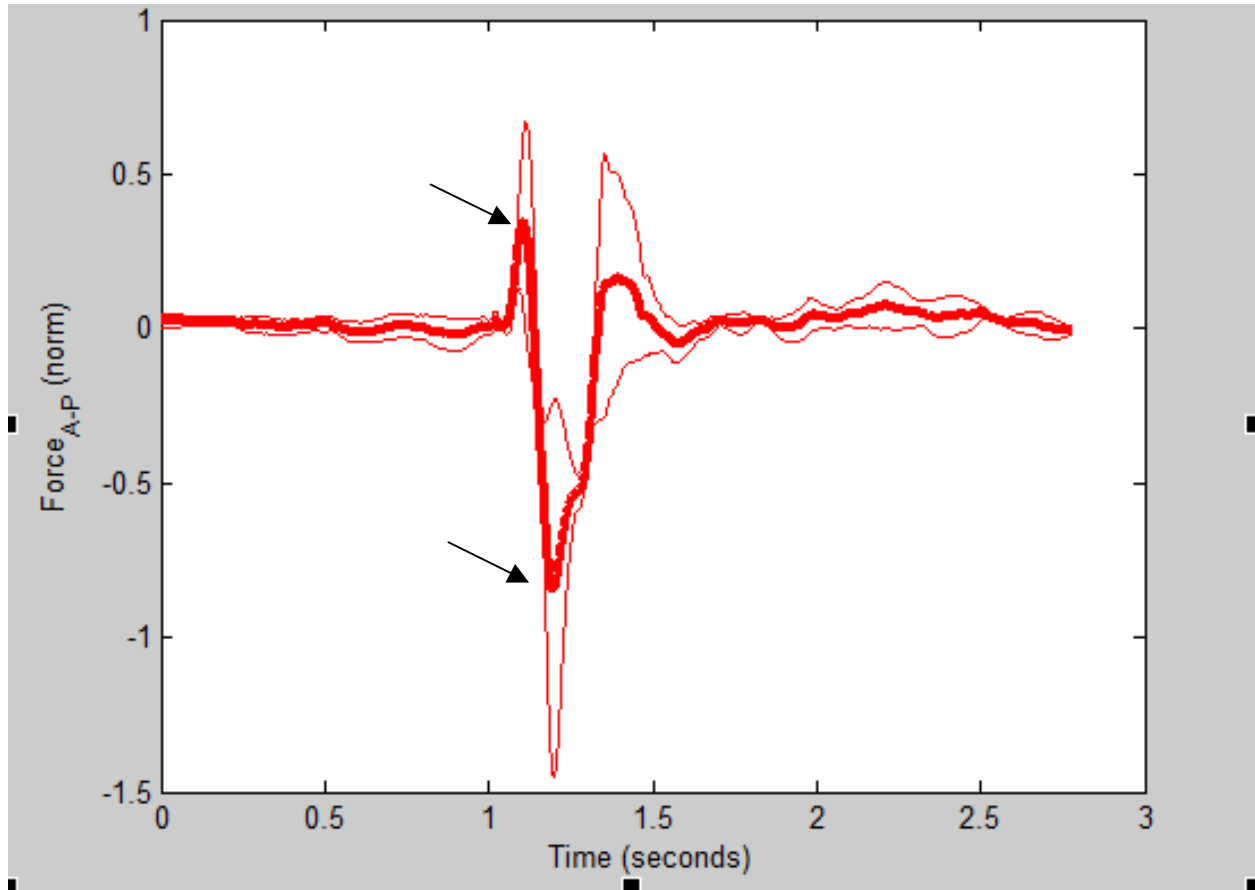
Fig 3. Normalized Ground Reaction Force in Anterior-Posterior Shift. The shift in the AP GRF in response to a perturbation applied at 1 second. The difference in displacement in the anterior direction indicated by the top arrow to the displacement in the posterior direction as indicated by the lower arrow represents DF.

Figure 4 summarizes the results from the DF result for each group with respect to training period and no significance can be derived from the 2x-RM-ANOVA for effect of age, training

regimen, or training period. College IJT group showed a significant decrease in DF, this is most likely attributed to a large decrease in the GRF shift in the anterior direction for this group.
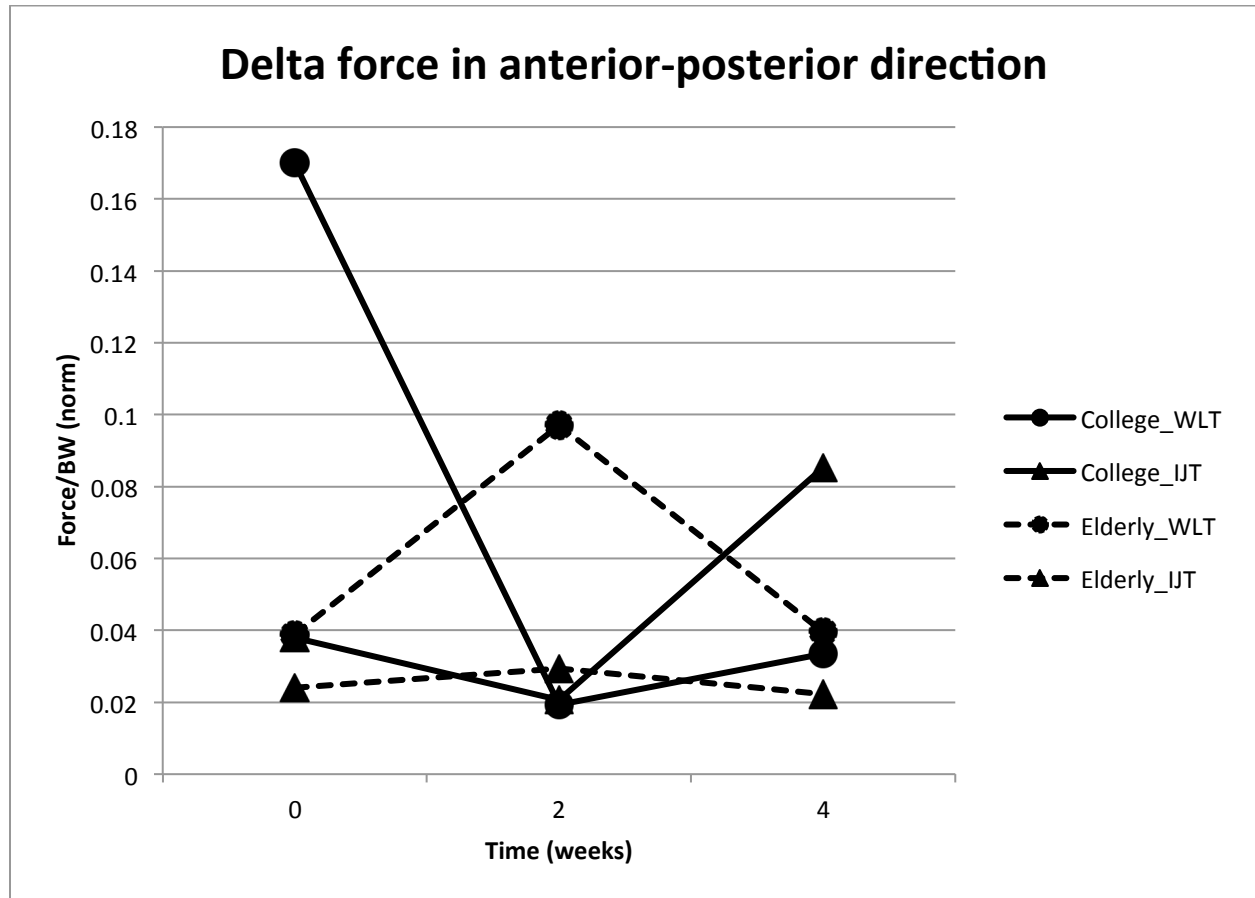
Fig 4. Delta Force in the Anterior-Posterior Direction. Delta force, distance between the arrows in fig 3, are the individual values in this Figure.
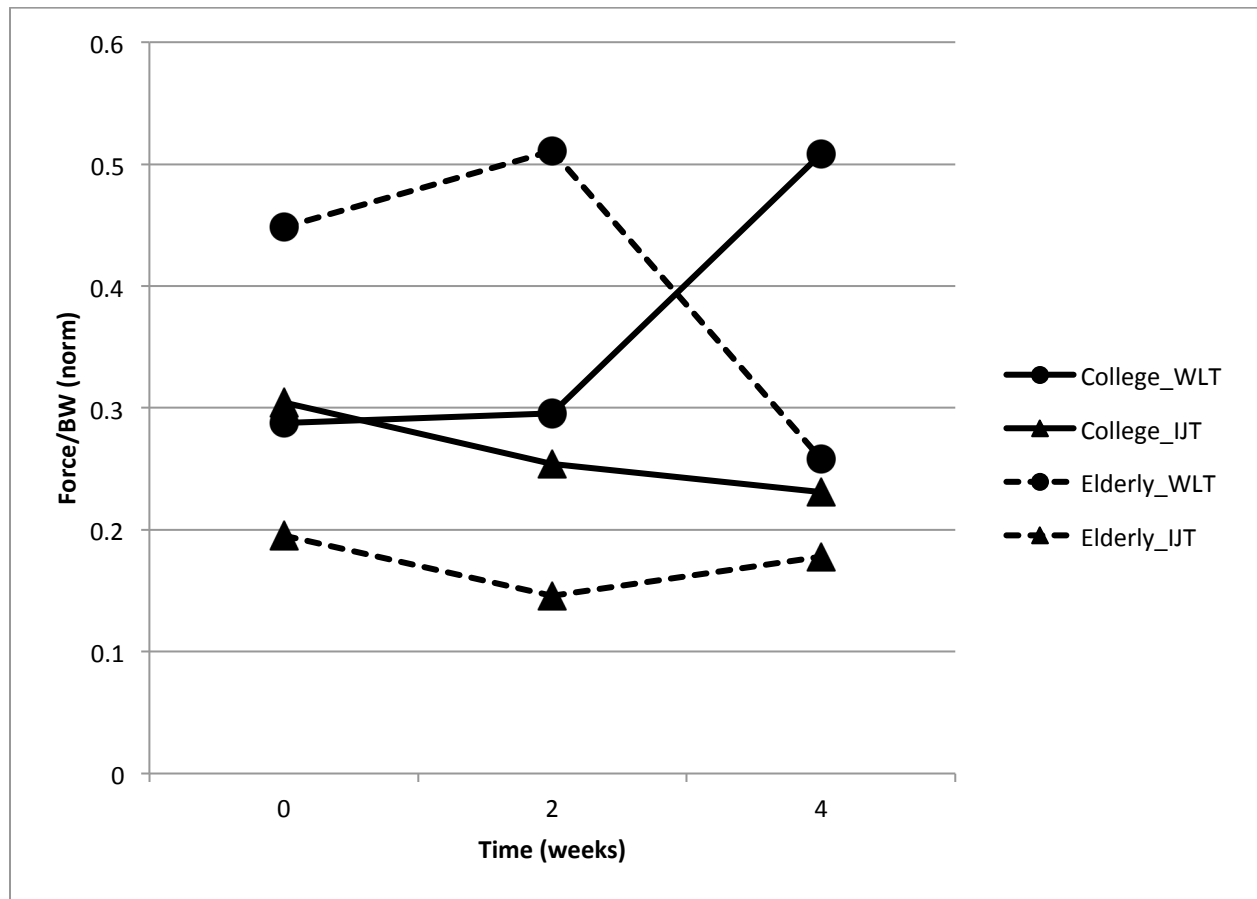
Fig 5. Delta Force in the Vertical Direction. The graph shows the shift in GRF in vertical direction for all subject groups across the entire study process.

The GRF in the vertical direction was also analyzed using DF. Again, the raw recordings were normalized to participants' body weights. Although we see a trend in decrease for three subject groups, the college IJT, elderly WLT, and elderly IJT groups, no statistical significance is derived from the repeated measures ANOVA as individual differences within each groups is too large.

4.4 Center of Pressure in Anterior Posterior and Medial Lateral Direction
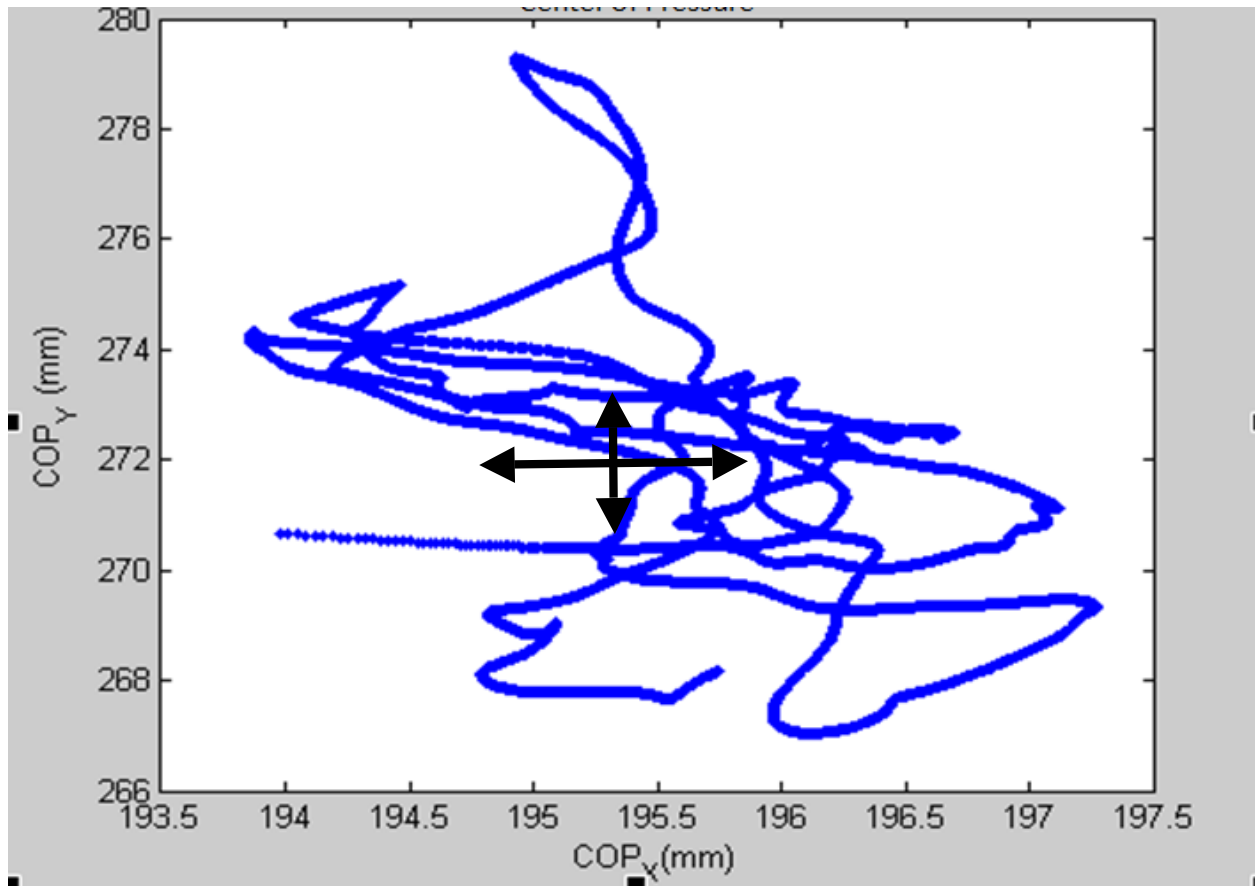
Fig. 6. Center of Pressure in Medial Lateral and Anterior Posterior Direction. During quiet standing, center of pressure data in ML and AP position were recorded and analyzed for the range of the middle 50% of the data.

Center of pressure recordings from the Kistler piezoelectric force plate were recorded during the quiet standing phase of the testing session. Participants stood naturally for 15 seconds and the beginning 10 seconds of the recording were included in the results. Raw data was analyzed; no normalization procedure was applied. Figure 6 shows the tracing of the COP and using a boxplot function in Matlab, we quantified the middle 50% of the COP in ML and AP, as represented by the horizontal and vertical arrows, respectively.
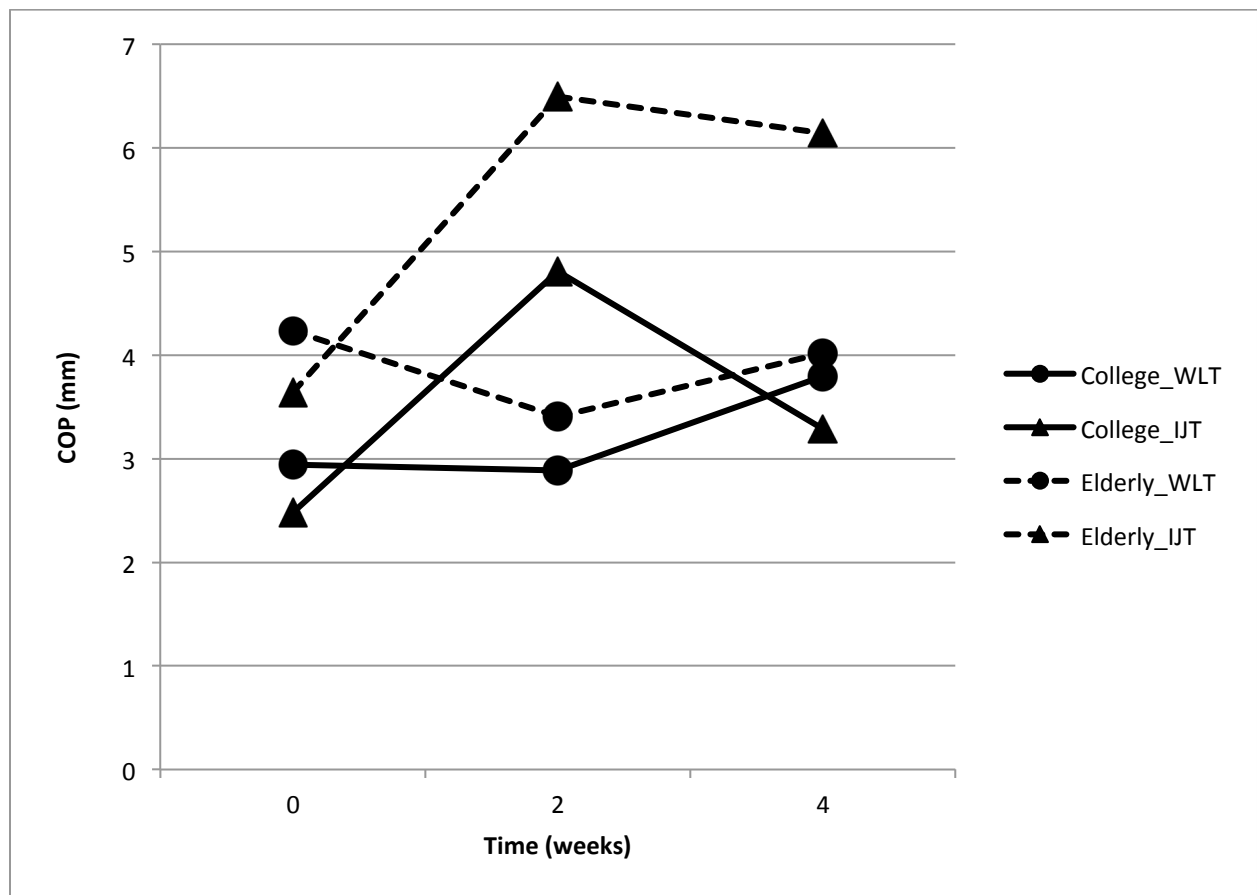
Fig 7.   Middle 50 Percent of Center of Pressure Reading in the Anterior-Posterior Direction. The effect of age, training, and training period on the COP measurement in AP axis during quiet standing.

From the 2x-RM-ANOVA, we again did not see any significant effect of different age groups, training regiments, or duration of training on the range of the COP in AP direction (Figure 7). The COP range in both directions is expected to decrease with training and training period, and more so for the elderly groups; however, we did not even see a trend in decreasing COP, except for a slight decrease for the elderly WLT group. Despite a large standard deviation and lack of statistical significance, the elderly WLT group had higher COP range than college WLT group, and the elderly IJT group had higher COP range than the college IJT group. This is

what we expected to see, more sway during the quiet standing for elderly subjects than for college-aged subjects. The COP result in ML direction as presented in Figure 8 also lacked significance. There seemed to be a dual interaction of independent variables, age and training type, with *p* value of 0.021, which was not hypothesized. And the only group with a trend in decreasing COP range was college WLT group. The standard deviation range for the first value of college WLT group overlapped with the much smaller standard deviation values from subsequent test; thus, a difference in middle 50% COP range for this group cannot be concluded.

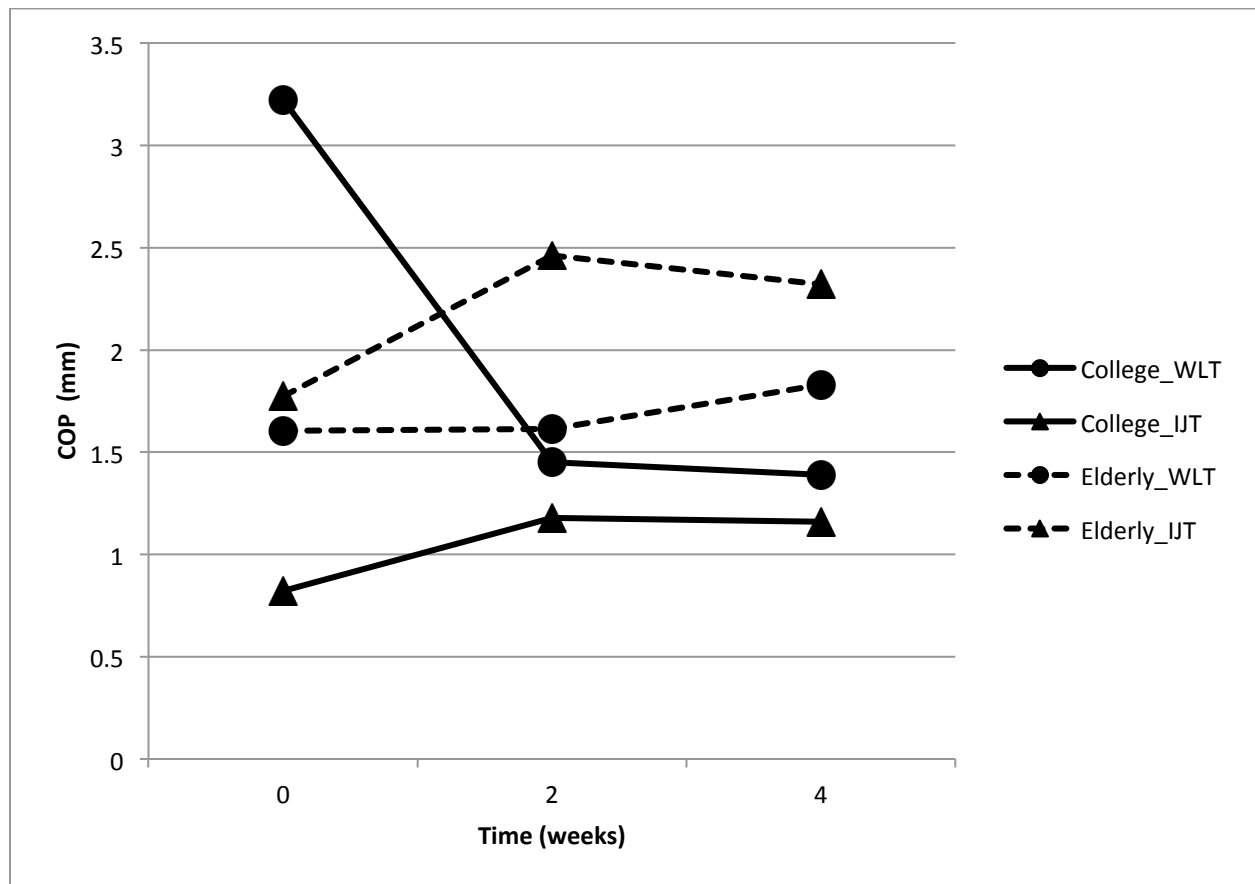**Fig 8. Middle 50 Percent Center of Pressure Range in Medial Lateral Axis.** The effect of age, training, and training period on the COP measurement in ML axis during quiet standing.

4.5 Delta Variance Analysis in All Three Axes

Proper maintenance of balance requires a combination of strength and synergy, the latter of which was quantitatively measured using delta variance (DV). The DV is calculated from positional variances of the markers (PosV) and the whole-body center of mass variance (WBCOMV) as seen in Equation 1. Positive values of DV indicate a greater index of synergy. On the other hand, negative DV values translate to a poor index of synergy. Because greater DV suggest greater degree of independent joint movements; the greater the DV, the greater the muscular control. The DV was calculated using MATLAB and quantified using 2-way Repeated Measures ANOVA.

$$DV(arbitrary\ unit) = \frac{PosV - WBCOMV}{PosV}$$ (Equation 1)

The DV values prior to analysis were normalized to the values calculated from the first testing session before any training took place. All analyzed and graphed data represent to percent DV of the first DV result. The average DV for each group in the ML axis seemed to increase for all groups except for the elderly IJT group. This is the expected result; yet, despite this promising trend, the result could be confounded by large individual variance within each subject group. We also hypothesized the DV would increase more for both elderly groups than the college age groups; however, the average group DV shows just the opposite (Figure 9).
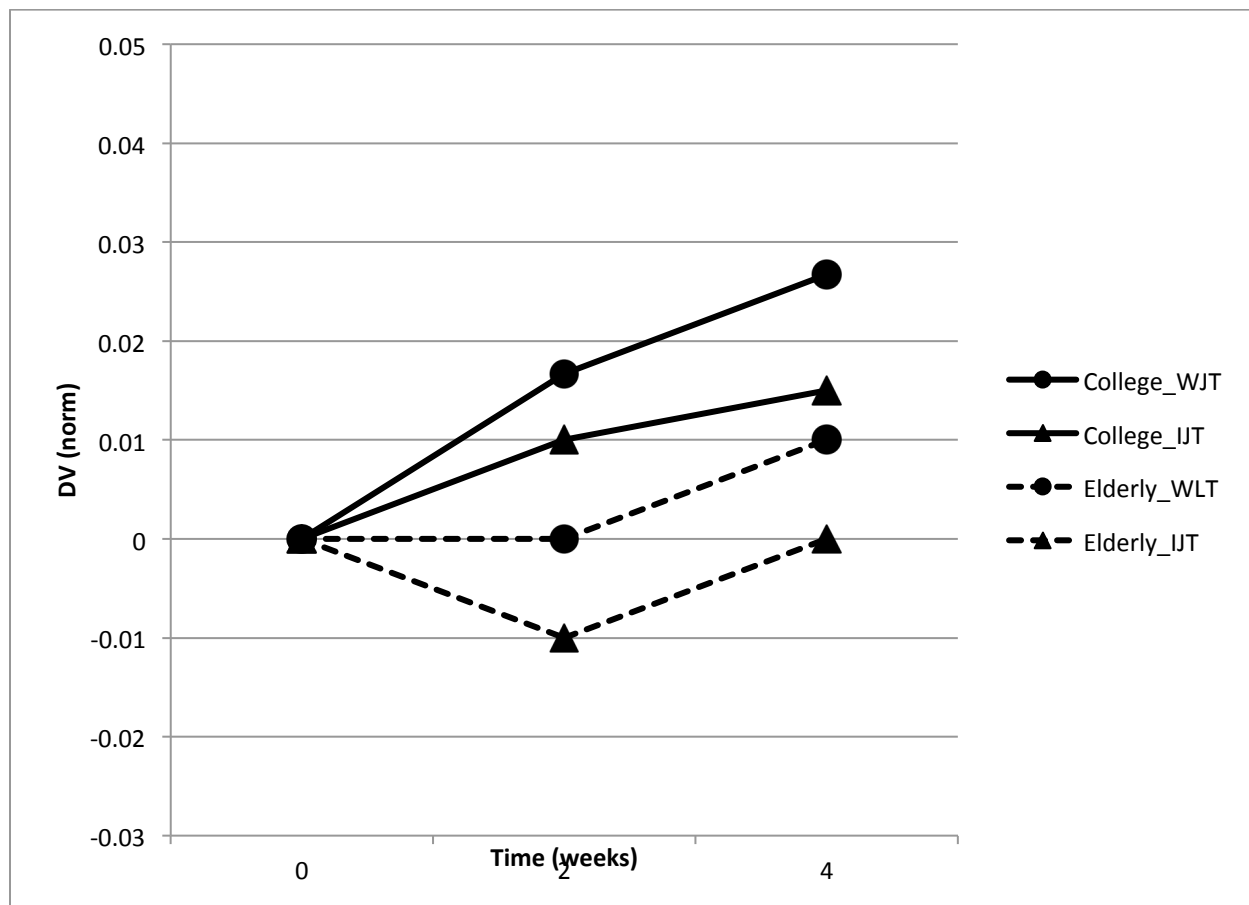
Fig 9. **Average Delta Variance in Medial Lateral Axis**. Average DV of each age-exercise group in the ML direction after zero, two, and four weeks of training.

Percent DV with respect to training, age, and training duration was also analyzed in the AP axis and the vertical axis (Figure 10 & Figure 11). No significance resulted and also no general trend is seen in the graphical representations of the results.

Fig 10. **Average Delta Variance in Anterior Posterior Direction**. Average DV of all subjects within each age-exercise group in the AP direction after zero, two, and four weeks of training.
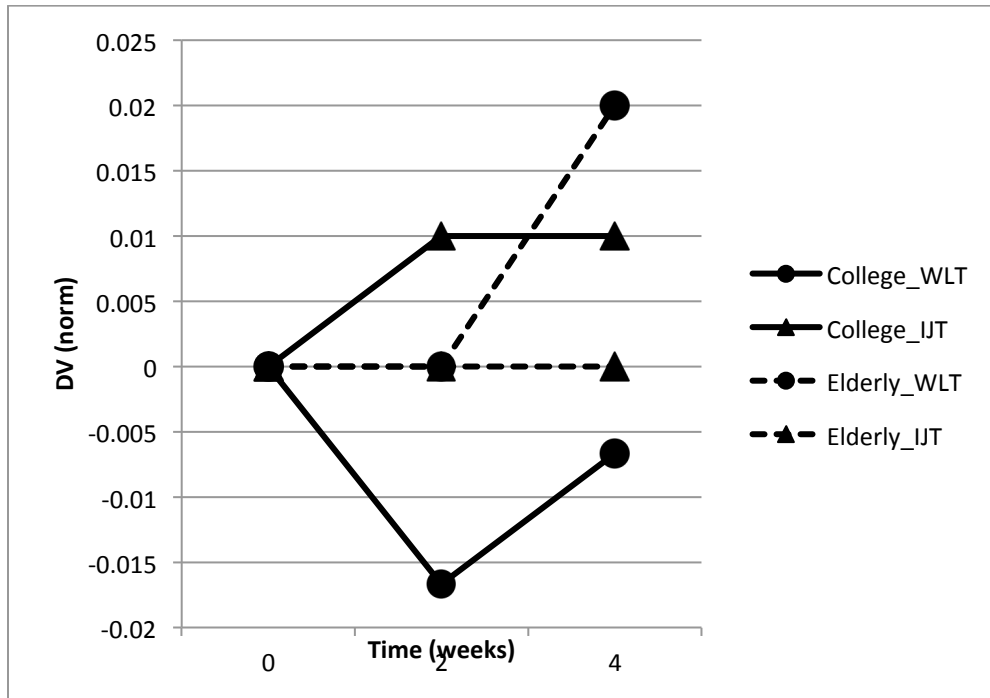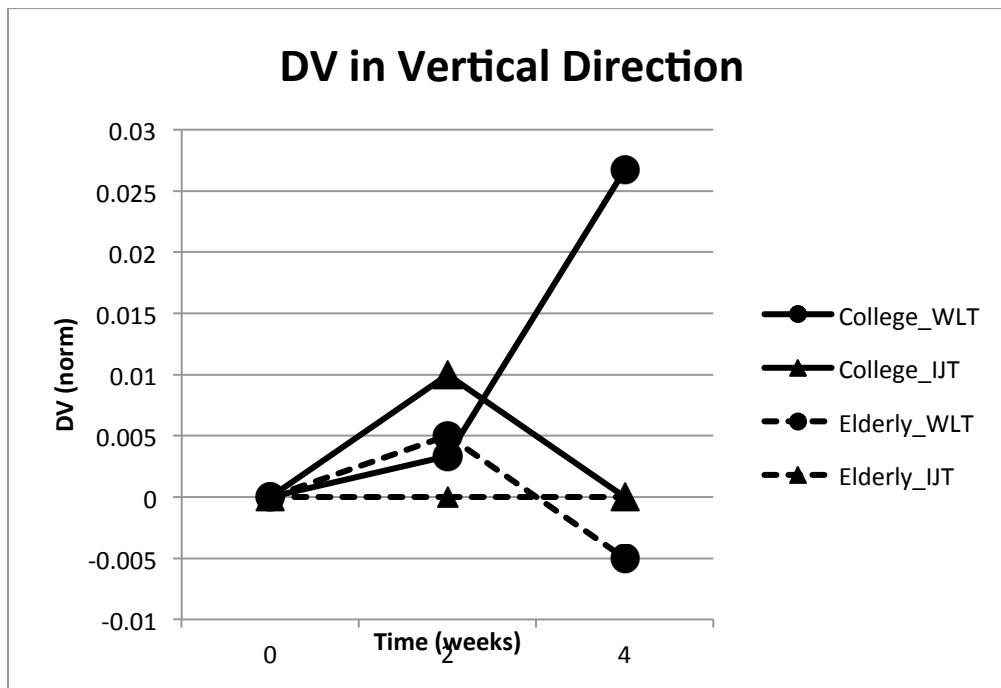

Fig. 11   Average Delta Variance in Vertical Direction. Average DV of all subjects within each age-exercise group in the vertical direction after zero, two, and four weeks of training.

Chapter 5. Discussion

5.1 Conclusions

The study had three questions it was seeking to answer: whether strength training increased strength, if the elderly would show a greater improvement overall, and if participants under the individual joint group would have better balance. From the data, the only hypothesis that is conclusively supported is that strength training does indeed improve strength regardless of age. For the other two hypothesis, data analysis returned inconclusive and non-significant results.

The increase in strength observed in all subject groups supports the initial hypothesis that strength training would increase strength regardless of age. However, interestingly, the increase in strength is statistically non-significant between groups of different training type. The increase in strength is contributed to the fact that both individual joint and whole leg training protocols are standard strength training protocols. Strength training protocols, by definition, should increase the strength of participants. In the first three to five weeks of training, participants usually report an increase in mass, or hypertrophy, which is correlated with an increase in the participants' strength output (Moritami & deVries, 1997). A limitation of the current study design is the failure to take into account changes in muscle mass. The focal point of the study was measuring changes in center of pressure and no attempt was made at recording changes of musculature. Due to the limitation, the current study cannot confirm the correlation between an increase in strength and an increase in muscle mass. Similar studies, however, have confirmed that training at 80% of participants 1-RepMax was sufficient to increase subject strength (Kryger & Anderson, 2007). Other studies have reported similar results, lending credence to the significance the study observes between strength training and participant strength increase.

While the 1-RepMax numbers, normalized to each subject's initial 1-RepMax, shows an improvement in each participant's strength, there is no overall statistically significant difference between the two training protocols. However, at both the two-weeks and four-weeks testing session, elderly subjects in the whole leg training protocol showed a more significant increase in their average 1-RepMax values than their counterparts in other training protocols. The significance two-weeks and four-weeks during the training protocol somewhat supports the hypothesis that whole leg training protocol would produce a greater increase in strength than individual joint training protocol. The results were more obvious in the elderly participants due to our second hypothesis. Research indicates that human muscle strength is greatest between the ages of 20-30 years and starts declining steadily after the age of 65 years (Marly et al., 2006). Since the elderly had a lower baseline when at the start of the study, they were able to improve more and achieve a statistically significant improvement faster. The decrease in muscle strength is largely due a decrease in the strength of the muscle fibers, which can be improved by strength training. For young adults, who are at the peak of their strength, there really is little improvement that can happen even with strength training. Combining Marly et al.'s research and the findings by Moritami and deVries could explain why the elderly subjects were able to experience a significant increase in their strength output after four weeks of training.

While the 1-RepMax numbers yielded somewhat significant results in terms of comparing between the different age groups, statistical analysis failed to produce conclusive results in terms of a comparison between individual joint training and whole leg training for improving synergy. Analysis with SPSS software running a 2-way ANOVA analysis failed to detect significant differences between the results of the two training protocols. Most, if not all, of the lack of statistical significance can be contributed to the large standard deviation in the data.

The large standard deviation results largely from the small sample size and various limitations in data collection. However, it is worth noting that synergy, force displacement, and strength all contribute to balance. Previous studies have shown that increase in strength correlates with increased balance (Holviala et. al. 2006). Since all three factors contribute to the increase in balancing abilities, we can conclude with limited confidence that an increase in strength could lead to an increase in balance in balance for all subjects, regardless of what training protocol they followed.

5.2 Limitations

There were numerous limitations and challenges over the course of the program's three-year timeline that has restricted the scope and depth of the original intended research. Of the original 11-member team, 5 had left over the course of the experiment. There were three dropouts and two early graduates. The decrease in manpower forced several redistributions of responsibilities and caused inefficiency during adjustment periods. It also increased the scheduling problem.

With trainers and testers dropping out or graduating, it became much more difficult to match subjects' schedules to the remaining trainers' and testers'. In addition to matching the team's schedules with the participants', scheduling had to fit the lab and equipment availability. Problems that arose with scheduling coordination resulted in missed training and testing sessions, which further resulted in problematic data. Since matching schedules were often difficult to maintain, certain subjects may have had testing and training sessions that were close together. For example, a scheduling difficulty resulted in training sessions that come within 24 hours before the testing session, despite the team's best efforts to separate testing sessions and training

sessions by a day. This may have had a negative impact on the validity of the data, as the subject might not have had enough time to rest so that they would have maximum performance.

Due to the delegation of responsibility amongst members of the team, such as trainer or tester, not all members' interaction with the subjects was equal. This resulted in subjects having no rapport with members of the team during the testing sessions, since testers were not actively training subjects throughout the week. In some situations, this lack of initial rapport made it uncomfortable for the subject, who was being outfitted with reflectors for the VICON system. This too may have had a negative impact on the data, especially since this occurred in the first testing session.

The expensive equipment needed to conduct the experiment proved to be a limiting factor for several reasons. Being an undergraduate research group, little priority was given to the team for borrowing the VICON camera system, which was being shared with several other graduate research groups. In addition, in the second semester of the experiment, the force plate malfunctioned. It caused a semester setback when the force plate needed to be fixed – which prevented training or testing for an duration of five months. Due to the complexity of the equipment being used and lack of appropriate training in using the equipment, the team was forced to in many situations adapt to a trial-and-error learning scenario in many situations during data collection, which lead to problematic, incomplete, or even missing data. As the team improved with their ability to utilize the complicated equipment, the validity of the data increased. This one semester setback combined with incomplete data became especially burdensome when it was time for data analysis. As deadlines drew closer, the pressure to work with limited data put the team under a lot of strain, and forced the team to adjust the intended scope of the project.

The many adjustments to the scope of the project over its duration proved to be a potential limitation for several reasons. Initially, Team Balance was created in order to find a solution for a practical issue; determining whether whole-leg or individual-joint training would improve elderly balance to reduce or prevent falling, and to pursue new information; how joint synergy could be used to improve balance in general. The scope of our hypothesis was set to incorporate both goals, which later proved to be a poor decision as Team Balance lacked the resources to find a significant answer to both. To accomplish the broad research objectives, the two training methods were used in each of the two subject groups. The student population would act as the control for the whole-leg and individual joint training for the elderly population for understanding the joint synergy.

Funding for the project was another limitation. Team Balance applied for grants to fund the experiment, and failed to receive any; which left the team to make do with the modest stipend from the Gemstone program and personal contributions. With more money, it would have been possible to potentially hire more qualified trainers, and potentially hire someone with statistics and data analysis experience. With more help, it would have been definitely possible to train more people, which would have allowed the team to increase its subject size in each of the four subject pools and thus, increase the significance of the results. Without the grant money, scope of the project should have been narrowed. This would have allowed for an increased focus for a specific subject group, for instance, recruitment, training and testing only elderly participants, which would have given the narrower results a much greater impact.

It was very difficult to recruit more qualified subjects to train, despite the fact that a lot of effort went to participant recruitment. There are many potential reasons for this – the lack of funding meant that the team could not afford to pay participants the standard research subject

rate of $10 an hour, while expecting that subjects come all the way to the School of Public Health for an average of three hours a week for six weeks. Although there was a high response to the advertisements, most of those subjects failed the IPAQ screening procedures the team had in place. It was very rare to find a sedentary subject that wanted to "get paid to work out", as most of the applicants who applied to be subjects were not qualified to participate because they were athletic, or were already working out and not comfortable with stopping for the duration of the experiment.

Even some of the qualified subjects ended up having suspicious results due to potential leniency of the subject qualification guidelines. For example, several subjects ended up being more athletic than they first indicated when they completed the screening survey; which could have negatively impacted the quality of the data collected. These subject qualification guidelines themselves ended up becoming a limiting factor as well. For instance, a subject have fulfilled all qualifications for an acceptable elderly subject, except his age was a year too low as defined by the parameters sent to the IRB at the inception of the project. This occured at a stage when the subject was needed to fill a hole created by the discarding of the data from a subject who was later discovered to have not qualified for the program.

Not only the lack of data, but the lack of experience with data processing also complicated data analysis. A lot of manual labor was necessary to transform the data collected from the VICON system and force plate into usable data. Despite having equal volume of data for all subject groups, a larger subject pool for each group would have definitely improved the significance of the data, and more experience and more man power in data processing would have sped up the analysis process.

Finally, the lack of control over certain subject participation requirements proved to be a limiting factor, and a potential degradation of the quality of data collected. When subjects have been approved to be trained and tested, they were asked to suspend their gym or athletic activities for the duration of the six week experiment in an attempt to prevent confounding variables. However, there is no proof that subjects truly committed and abstained from outside exercise as it is impossible to monitor the subjects outside the testing or training area. Additionally, during the testing sessions when the testers asked subjects to perform the strength test, there is no way to force the subject to continue increasing their new one repetition maximum. A subject may have stopped attempting to increase their maximum weight before they hit their bodies' maximum force output capacity, which might understate the strength improvement data.

5.3 Future Directions

The results of the study have applications that go beyond fall prevention in the elderly; balance and postural control are critical components of a wide range of activities. In order to make stronger conclusions that could be broadly generalized there are certain improvements and modifications that we would implement on our project if we could repeat it with more resources (Figure 12).

As previously mentioned, the number of participants, recruited and retained during the course of our study, impacted the statistical power of the analysis. Based upon previous studies in the kinesiology field, the study was designed with at least 40 subjects (n= 40) in mind. The number would ideally allow for the creation of a control group in addition to the four experimental groups (i.e. Elderly Whole Leg, Elderly Individual Joint, College Whole Leg and

College Individual Joint). The ideal study design would also include match pairing based on gender to eliminate gender as a confounding variable. Previous studies have shown that men are able to generate more peak force than women (Schulz et al., 2012). The discrepancy was shown to exist in young adults, ages 20-35 and the elderly, ages 65 and older. Since these age ranges are very similar to the groups we used it can be assumed that the pattern would hold true for our data. Blocking between sexes will allow us to control for this variance as well as make it possible to quantify the degree that strength varies and observe sex effects on strength and balance gains (Figure 13).

Creating a control group is not vital to our project because with our methodology each subject's pretest serves as a baseline and a control. However, having a control group is always a beneficial method because it can expose otherwise unseen and unexpected confounding variables. Under the revised methodology the control group would consist of eight individuals, two young adult males, two elderly males, two young adult females, and two elderly females. These participants would be evaluated for strength and balance throughout an equal time period as the experimental groups but not undergo a physical training regimen. They would be recruited using the same requirements as our other subject, meaning they would be sedentary, however they would remain sedentary for the entirety of the training.

It has been shown in our thesis that training has a positive effect on patient strength. However, general strength can be a measure of both muscle strength, and proper neural enervation of the musculature. Moreover, the musculature is comprised of numerous different types of muscles that are all required in overall limb and body function. In the context of rehabilitation, future works would benefit from differentiating i) muscle vs. neuronal conditioning and ii) individual joint vs. whole limb recovery.

An excellent methodology to differentiate between these variables is electromyography (EMG). In general, EMG monitors the electrical potential generated by muscle cells during muscle contractions. Muscle contraction normally generates a characteristic profile in which the electrical potential, or action potential, increases only after neuronal stimulation, and during muscle contraction; whereas electrical potential is nearly non-existent prior or after neuronal stimulation. Therefore, comparing our patients' EMG profiles to identify abnormalities can be a potent additional tool for analysis. For example, patients with an abnormally high electric potential prior to muscle contraction that is alleviated after training would suggest improvement of neuronal function. Whereas, patients with improved action potential during testing may suggest that training improved musculature. Additionally, EMG analysis of discrete portions of the limb, compared to the overall limb, could discern if improvements are specific for individual joints or whole limb. This can be assessed in two ways with EMG: dermal (e.g. skin) or intramuscular. In dermal EMG dermal patches are applied to the patients skin and electrical potentials are monitored. Because the monitoring is indirectly done through skin, specific muscle action potentials cannot be ascertained. However, as the patch is easily applied topically, it does not need to be performed by a health professional. Alternatively, an intramuscular measurement is done with an electric conducting needle that penetrates into the musculature. This has the advantage of measuring specific muscles, and is ideal in discerning the individual joint or whole limb effect of training. However, the analysis must be performed by a trained nurse or technician, and can be sometimes painful. Participants could reject it and therefore limit the enrollment in the study. Overall, EMG analysis, whether dermal or intramuscular, is an attractive methodology that could be additionally employed in future studies. Ideally, given the

resources and patient participation we would favor intramuscular; however, future work with similar resources would most likely employ dermal EMG assays (Figure 14).

Since we are interested in understanding the mechanisms behind the deviating character of the positive and negative swaying pre-trained and post-trained subjects, analyzing on levels besides those in the methodology would be beneficial for future directions. Looking at human joint angles, and analyzing on inverted pendulum are two ways identified, which could offer a more in-depth analysis.

The human body can be modeled as a single-link inverted pendulum (Kowalczyk et al. 2012.) An inverted pendulum is a pendulum, in which its mass is above its pivot point. (Figure 15) To further explain, in contrast to an inverted pendulum, a standard pendulum is defined by being stable when it is hung downwards. Since, an inverted pendulum is characterized by its instability, balance is essential for it to remain upright. To balance an inverted pendulum, torque and pivot are applied as a system, which feedback on each other. For example, if a human wants to remain in an upright position it must discern and correct themselves with the angle adjustments necessary to do so. When a person's knee's lock for example, they will be set-off balance since they will not have a complete feedback system. This explains why it would be a good idea to include such a basis for analysis in future directions.

To measure data in an inverted pendulum basis, dynamic stability is assessed by quantifying the margin of stability (MS), which is derived from subtracting the extrapolated center of mass, from the base of the support. Horizontal velocity of the center of mass, its vertical project in the anterior-posterior direction and the vibration analysis of this type of pendulum determine the center of mass, which is extrapolated (Hohne et al., 2011.) The MS is

used to compare to base line, a control group, and to quantify changes in balance. A higher MS, for example would mean an increase in balance.

As previously noted, another way to compare the effect, which training had on a subjects balance and sway is to measure joint-angles. This can be done with a mark-system, like that described in the methodology section, where the participant defines each joint in a system with a marker read by a data collection device such as a VICON Motion Capture. Measures need to be collected at baseline and analyzed on inclination angles. The smaller the angles in perturbation, the better the balance. Although between the ankle, hip, and knee joints there will be somewhat of a netting effect, since these joints act as a system.

Ideally in the future we would like to see an adaption of our project to be done in elderly or retirement homes as rehabilitation for those who have broken their hip or have other common aging-related injuries. Injuries such as broken-hips affect balance in a number of ways. Patients are at a higher risk of falling after hip fracture especially as age becomes more advanced. Moreover, the physical limitations of arthritis of the healed hips are what cause the declination in functionality (Pils. K et al. 2011). This decline in functionality is what places a patient at a higher risk of falling.

Furthermore, when bone and muscle heal from a break or other problem, they deviate from what the neurological processes had been trained to work with, making processes such as balance even harder. It has to be re-learned, through physical therapy protocols such as the one proposed and tested in our experiment. Moreover, often the healed appendages do not function as well or as quickly when trying to prevent or halt a fall, as if the body had not suffered such a

complication. Implementing our protocols as a rehabilitation method would be the most socially beneficial.

Another way we can test rehabilitation is in people with balance degenerative diseases. Since balance has both neurological and muscular components in future experiments we could have people with neurological diseases and people with muscular diseases complete our protocols for a comparison similar to ours which compared young adults versus elderly adults in the model described in our methodology. This could help quantify how much of the training is neurological and how much is muscular, especially when compared to our baseline and control group proposed above. Moreover this would allow us to make recommendations for which type of patient our rehabilitation protocols would be most effective and for which type of diseases there would be limitations. There might be some afflictions that do not benefit as much as others from balance or strength training. Likewise, there might be a point were there are diminishing returns training patients whom could be harmed going through protocols such as these.

One study found that elderly persons with diabetes had a decreased sense of balance, and a slower reflex (Morrison et al., 2010). The decreased sense of balance and a slower reflex all result in a higher risk for falling in elderly participants. The same study showed an improvement in the same elderly patients after a training protocol similar to our study. The balance of these subjects improved after a training, similar to ours, which leads to a conclusion that our protocol could serve as a mediating factor for patients with diabetes.

In addition, we could maintain records of our subjects and their reported feelings as they go along in training and maintaining a course of action, which allows for additional data collection to see how, after the training is over their balance and strength is changed compared to

their feelings describing the change. Elderly adults in other papers report feelings of fearfulness of falling, a decreased sense of independence, pain or a reduced value of life after a fall or thinking about a fall (Freiberger et al., 2012). These feeling often times do not go away even after training protocols such as ours are followed. The reasons behind this are something, which could be researched further. The psychological analysis of what would make an elderly person feel safer, and more independent during and after training would add depth to our results. (Figure 16). In Figure 16, a potential simple survey could be employed to measure a subject's feelings during the progress of the protocols. A protocol, which would give an added sense of security, would also make protocols like ours more readily accepted into common practice. A data collection methodology for surveys given on scaled levels of comfort, and providing an open ended response could give future researchers an insight into protocols, such as these. Feedback, which focuses on a subjects comfort would be the type that would give researchers the most readily implementable protocols since comfort would facilitate the acceptance of such protocols.

Studies have reported improvement in physical performance for geriatric participants with training that is focused on strength, balance and endurance for a two-year period. One of the limitations the current study suffered from was the short duration of training time – participants and trainers were unable to maintain a long-term relationship. Furthermore, the study could not personalize training protocols for each individual participant within the limited time span. Being able to maintain a relationship with our subjects would allow us to follow-up with them after the training has finished, and to compare extrapolations of results to actual results over time. From these measures we could also further modify our methodology.

Finally, another future extension of our experiment could be based off the fact that our project was focused on increasing balance through increasing strength. Since there are many

different ways to strength train (i.e. training for power versus training for endurance), another future study could see if there is a certain training routine that was the most optimal for increasing balance through varying load and repetition ratios. We could even look to add a training protocol for quickness in reflex training, since the faster a person can correct a deviation in sway, the less likely they will fall.
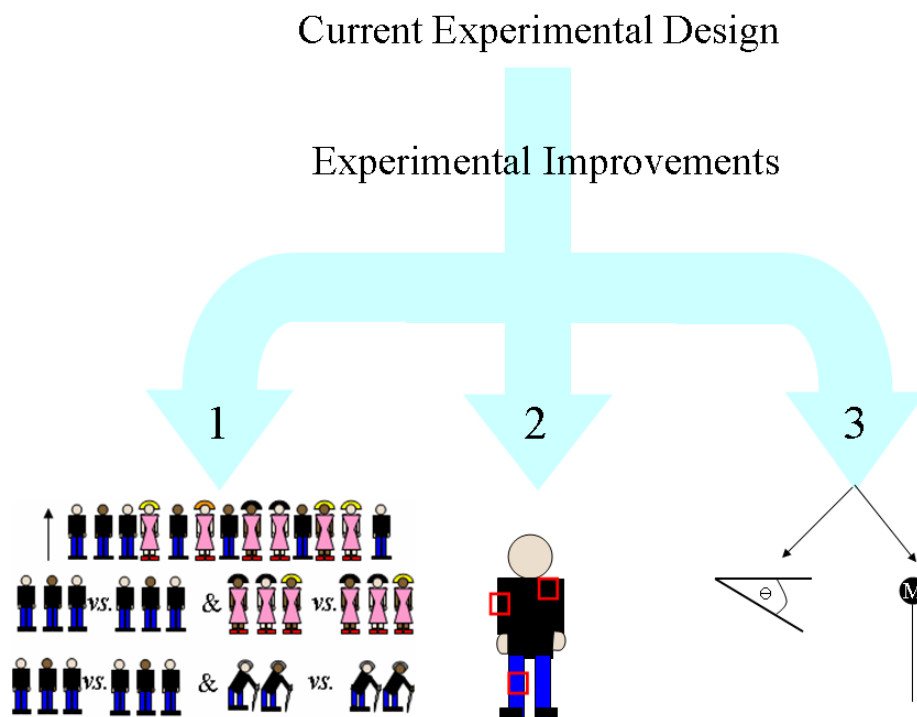
Fig 12. **Improvement for experimental design**. Future works can incorporate several changes to our current design that will enhance data collection and analysis. 1) *First arrow*: Number of participants can be increased (n≥ 40) and non-trained controls incorporated, as well as grouping by gender and age. 2) *Second arrow:* Electromyography (EMG) examination of specific muscle-areas (boxed in red) can delineate neurological and musculature effects of the training regimen. 3) *Third arrow*: (left, theta) joint angle and (right, mass [M]) inverted pendulum can be used in addition during data analysis to further elucidate the effects of training on limb motion and balance, respectively.
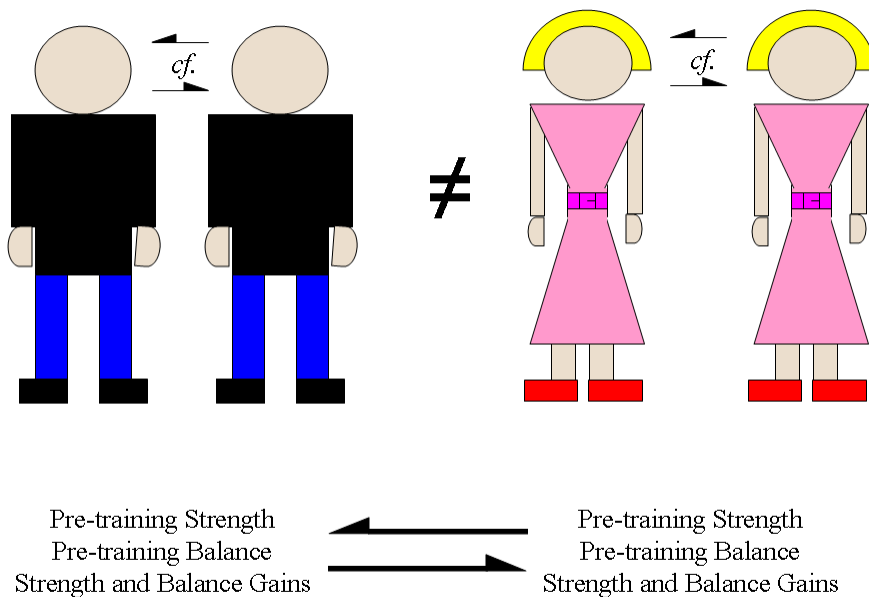
Fig 13. **Controlling for gender can enhance data analysis**. Initially, participants in each gender are compared to one another (*cf.*) and the pre-training strength, balance, and post-training gains are analyzed. Blocking segments of participants by gender will allow for us to determine if there are sex-specific differences in the pre-training strength, balance and post-training gains. These values can then be compared to the other gender.
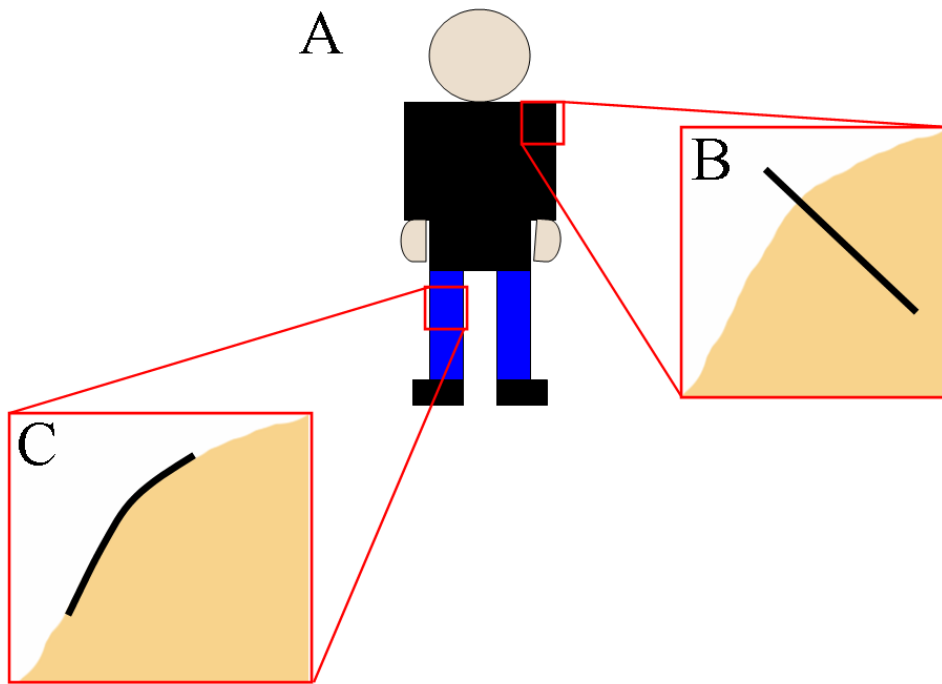
Fig 14. **Electromygraphy (EMG) assesses neuronal and musculature enervation**. A) A participant is subjected to specific tissue examination (red boxes) using the EMG methodology. B) EMG analysis using subdural needle insertion. A needle (black bar) is inserted into the musculature to assess the electrical potential generated by muscle cells during testing. This method is specific to the surrounding musculature, but is invasive. C) EMG analysis using supradural patches. A patch (black bar) is placed upon the skin to assess the electrical potential generated by muscle cells during testing. This method is less specific, generalizing the electrical potential for a larger number of muscle cells; however, the technique is not invasive.
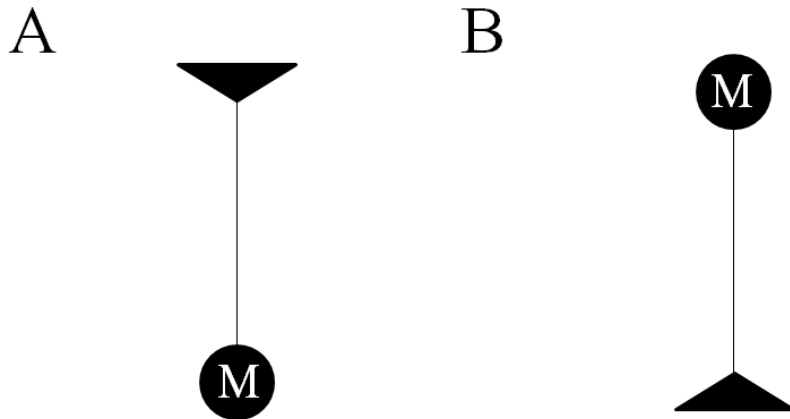
Fig 15. **Comparison of standard and inverted pendulums**. A) Standard pendulum B) inverted pendulum. An amount of mass (M) is at rest when a standard pendulum is hung upside down. An amount of mass (M) in an inverted pendulum requires a system to maintain it in the position above the pivot point (where the line meets the triangle).

1-2-3-4-5-6-7-8-9-10

Rate the level of fear from falling by circling an above number. One being the maximum amount of fear possible and 10 being the maximum level of safety.

Please respond below with any comments regarding comfort or feeling:_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Fig 16. **Sample psychological survey to measure fear of falling in subjects**. Above patients can circle a number and below they have an option to free-respond in open format with comments.

Appendices

Appendix A: *IRB Application and Addendums*

UNIVERSITY OF MARYLAND, COLLEGE PARK

Institutional Review Board

Initial Application for Research Involving Human Subjects

Name of Principal Investigator (PI) or Project Faculty Advisor *(NOT a student or fellow)*	Dr. Jae Kun Shim	**Tel. No**	(301) 405 2492
Name of Co-Investigator (Co-PI)	N/A	**Tel. N**	N/A
E-Mail Address of PI	jkshim@umd.edu	**E-Mail Address of**	N/A

Name and address of contact to receive   Dr. Jae Kun Shim

Name of Student Investigator   Emily Green   **Tel.**   (484) 947-3427

E-Mail Address of Student Investigator   egreen15@umd.edu

Check here if this is a student master's thesis ☐ or a dissertation research project ☐

Department or Unit Administering the   **Department of Kinesiology**

Project Title   Alternate lower extremity resistance training to increase stability in young adults.

Funding Agency:

ORAA Proposal ID Number:

Names of any additional Federal agencies providing funds or other support for this research project:

_____

Target Population: The study population will include (Check all that apply):

☐	pregnant women	☐	neonates
☐	minors/children	☐	prisoners ☐ individuals with mental disabilities
☐	human fetuses	■	students ☐ individuals with physical disabilities

Exempt or Nonexempt (Optional): You may recommend your research for exemption or nonexemption by checking the appropriate box below. For exempt recommendation, list the numbers for the exempt category(s) that apply. Refer to pages 6-7 of this document

If exempt, briefly describe the reason(s) for exemption.

Date	**Signature of Principal Investigator or Faculty Advisor**

Date	**Signature of Co-Principal Investigator**

Date	**Signature of Student Investigator**

Date	**REQUIRED** Departmental Signature
	Name ,

Title of Project

Alternate lower extremity resistance training to increase stability in adults.

1. Abstract

The purpose of this research is to examine whether resistance training of the hip, knee, and ankles joints independently improves the ability to recover balance more effectively than resistance training of these three joints simultaneously. Both types of training improve balance recovery through increase of muscular strength, but training each joint individually should lessen muscular interdependency among joints, which may further improve balance recovery. Additionally, this study seeks to further understand how resistance training can adjust muscle control by the central nervous system. Subjects will be directed and supervised by a trainer on a one-on-one basis during training. Subjects will be secured by a harness or provided a plinth for support as well as supervised by at least one researcher during testing. All data collected will be confidential to the extent permitted by law, and subjects' names will not be associated with said data.

2. Subject Selection

a. Undergraduate or graduate students from 18 to 24 years of age will be recruited for the study through advertisement on fliers (Appendix A, J, and K) and through various university

listservs (Appendix C) at the University of Maryland, College Park. Subjects who express their interest through phone or email will receive the replies in Appendices E1 and E2, respectively.

b.　　　Subjects must not be participating in personal resistance training or any competitive athletics, and they must not have any disorder, injury, or medication that impairs neuromuscular function.

c.　　　This study seeks to examine and compare the efficacies of two different types of lower extremity training to improve balance; physical activity that would improve balance outside of the experimental training would lead to deceptively increased improvement. Any factor that impairs neuromuscular function would similarly decrease apparent improvement.

d.　　　We hope to recruit a total of 16 subjects.

3. Procedures

Potential subjects will be screened before recruitment for neuromuscular disorders, medications, and use of alcohol and other drugs with a survey (Appendix G). They will also be screened for active participation in athletic activity or resistance training (Appendix H). After recruitment, subjects will be match-paired for height, weight, gender, and general fitness. The pairs will be split up, one subject from each pair per training group. Subjects will train three times a week for six weeks. Training will take approximately 30 minutes per session. Researchers will be extensively trained in use of the exercise equipment and will supervise the subjects' training on a one trainer per subject basis. Trainers will follow the standardized script with minimal deviation (Appendix E). The whole leg training (WLT) group will train using the leg press exercise, and the individual joint training (IJT) group will train using the leg extension, ankle plantarflexion, and back extension exercises. The weight used in the resistance training will be 70% of the subject's repetition maximum (RM). The preliminary testing session will determine each subject's initial parameters, including RM. Each testing session has three portions. Subjects will be asked to press as hard as possible on the pedal of a Kin-Con dynamometer to measure their maximum muscular strength (RM). The subjects will then be asked to stand still on a piezoelectric force plate to quantify the subject's ability to maintain a stable upright position. The last test measures the subjects' ability to recover balance. The subject will again be asked to stand on the piezoelectric force plate. They will be told to relax and expect a light perturbation in the area of their lower back. They will then be lightly perturbed with a mass of 2 kilograms moving at up to 2.4 meters per second. The force plate will record their reaction to this slight perturbation. Tests will be administered after weeks two, four, and six of training.

4. Risks and Benefits

Subjects may experience muscle soreness after resistance training and testing. Any risk of physical injury during testing is addressed by the application of a harness to catch subjects or the presence of a plinth for subjects to catch themselves if they do lose their balance. Any physical injury during training is prevented by the constant presence and instruction of a trained member of the research group. The subjects will gain greater lower extremity muscular strength from the

training. Theoretically, subjects will also gain an improved ability to regain balance.

5. Confidentiality

Confidentiality of individual test results is assured, as each subject will be assigned a file number to be used on all forms and data files. Subjects' test results are shared with that subject only. At no time will subjects' names be used for identification outside the study such as in conference presentations and research papers. All documents that can be used to identify subjects, including consent forms, will be kept in a lockable cabinet in the office of the principal investigator. Only the principal and other investigators of this study will have access to the cabinet.

6. Information and Consent Forms

A consent form will be used for participation in the study (Appendix N). All participants will receive a copy of the consent form for their records. During each testing session, one of the investigators will verbally explain the experimental procedures, benefits, and risks of the testing. The investigator will also explain that participation is voluntary and subjects may refuse to participate in or withdraw from the study at anytime without penalty.

7. Conflict of Interest

There is no potential conflict of interest.

8. HIPAA

We are not using protected health information or "PHI".

9. Research Outside of U.S.

All experiments will be conducted in the U.S. at the University of Maryland, College Park campus.

10. Research involving prisoners

Not applicable.

Want to Get in Shape?

Participate in Team BALANCE's research studying kinesiology protocols for balance and be compensated to work-out your legs 3 times a week for 30 minutes for just 6 weeks located in School of Public Health at UMD!

Eligible candidates are sedentary and are aged 18-24 without physical or neurological impairments affecting balance.

Marla Benedek

(410) 302-2841 or

BalanceUmd@gmail.com

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(410) 302-2841 or

BalanceUmd@gmail.com

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(410) 302-2841 or

BalanceUmd@gmail.com

Marla Benedek

Appendix C

Listserv Advertisement

RESEARCH PARTICIPANTS NEEDED

Gemstone Team BALANCE is currently recruiting for a research study located in the School of Public Health at UMD that needs participants like you! If you choose to participate in our study, you can be compensated up to $50 and entered into a raffle for a prize worth approximately $500 to work out for 30 minutes three times a week for six weeks! Testing will be conducted before the first week of training and after weeks 2, 4, and 6. Research will improve understanding of how different exercises can improve balance.

If you are interesting or have any questions, please email Balanceumd@gmail.com or call Marla Benedek at (410) 302-2841 for more information.

Appendix D

INFORMED CONSENT FORM

Project Title	*Alternate lower extremity resistance training to increase stability.*
Statement of Age	*I state that I am at least 18 and not more than 24 years of age and wish to participate in a program of research being conducted by Jae Kun Shim, PhD and Gemstone Team BALANCE in the Department of Kinesiology at the University of Maryland, College Park.*
Purpose of Study	*The purpose of this research is to examine how resistance training of the hip, knee, and ankles joints independently improves the ability to recover balance compared to resistance training of these three joints simultaneously.*
Procedures	*We will be asking you to train three times a week for approximately half an hour each time, doing lower extremity exercises such as leg press, leg extension, back extension, and ankle plantarflexion (toe points). We will also ask you to press down on a pedal with your foot while seated, to stand still for 20 seconds, and to recover from a perturbation (padded 2kg ball hitting you lightly) while you stand on a force plate. Your position will be recorded as a stick Figure with a network of cameras. Testing sessions are once before training and again after weeks 2, 4, and 6 of training. We will compensate you for your participation in this study with $10 at the first testing session, $20 at the second testing session, $30 at the third session, and $40 at the final session for a total of $100.*
Confidentiality	*All information collected in this study is confidential to the extent permitted by law. We will be grouping the data that you provide with data that others provide for reporting and presentation. Your name will not be used. All data will be stored in a lockable file cabinet that only the principal investigator and his collaborators will have access to.*
Risks	*You may experience the discomfort of muscle soreness following*

	training and testing. You may also experience slight discomfort from the light perturbation (described in the Procedures section) and subsequent slight loss of balance.
Benefits, freedom to withdraw, & Ability to Ask Questions	*There are no direct benefits to you. You are free to ask questions or withdraw from participation at any time without penalty.*
Contact Information of Investigator	*Jae Kun Shim, PhD (e-mail: jkshim@umd.edu)* *Emily Green, Undergraduate Student(email: egreen15@umd.edu)* *2136 HHP Bldg., The Department of Kinesiology* *University of Maryland, College Park, MD 20742*
Contact Information of Institutional Review Board	*If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; e-mail: irb@deans.umd.edu; telephone: 301-405-4212*
Is any medical treatment available if I am injured?	*The University of Maryland does not provide any medical, hospitalization or other insurance for participants in this research study, nor will the University of Maryland provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.*

NAME

SIGNATURE _____

DATE _____

Appendix E

Training Scripts

Stretching

How are you doing today? First, before we get start the training, we need to stretch our muscles to help prevent injury. This should only take a few minutes, and I'll be doing the stretches with you. First, let's take a seat and put our right legs out. Grab your right foot with your right hand, lean forward, and hold as I count to 20. Now switch to your left leg out and hold as I count to 20. Stick both legs out, lean forward, grab as far down your leg as possible, and hold for 20. Now, bring your feet together and pull them in towards yourself. Lean forward, press your elbows down on your knees, and hold for 20. Now, let's stand back up. Grab the toe of your right foot with your left hand behind your back and pull upward for 20. Lastly, switch to left foot with right hand and hold for 20. That will be all the stretching we will be doing today. Thank you for following along. Now we can move on to the training part of this session.

Whole Leg

This exercise is the leg press. You must sit on this chair and bring your legs to your chest. Take care not to hit the plate in front of you. I need you to place your feet up on the plate, placing each foot about one quarter of the way on each side of the plate. Then, you must extend your legs, but make sure not to fully lock out your knees. Then, slowly bring your legs back into your chest. That was one repetition; but you are going to do 10 repetitions in each set. You are going to complete 3 sets and in between sets, you will have 2 minutes to rest.

Individual joint:

Hip *extension:* This exercise is the hip extension. You have to lay on the bench with knees legs over pads and align your hips with the lever fulcrum. Grasp the handles at each side. During the exercise, make sure you keep your abdominal muscles tight and your knees relaxed. Now under control, extend hips and knees pushing the bar down until legs are straight. Now return to original position by flexing hips and knees. That's one repetition; you're going to do 10 repetitions in each set. You are going to complete 3 sets and in between sets you will have 2 minutes to rest.

Leg curl: This exercise is the leg curl. First lie on your stomach on the machine and place your ankles under the padded arm. During the exercise, make sure to keep your hips flush against the bench, your abdominal muscles tight and a natural arch in your back. Now under control, curl the weight up to a 90° angle so your lower leg is pointing straight up. Stop there making sure your

hips don't come up, and then under control, lower the weight back down until your leg is straight again. That is one repetition and you will be doing 3 sets of 10 repetitions.

Ankle isolation: This exercise is the ankle isolation. First sit on this bench with your legs hanging down and I'm going to strap the isolator to your feet. All you have to do is under control point your toes so your ankles are fully extended. Then reverse the motion until your feet are parallel to the floor again. That is one repetition and you will be doing 3 sets of 10 repetitions.

Appendix F

1. Phone:

Hi *(insert name here)* you've contacted us saying that you might be interested in taking part of our research study. I'm going to explain it to you and then I'll answer any questions that you have. First, a little bit about us, we are a Gemstone team called Team BALANCE and we're studying how weight training can affect or improve someone's balance. The way it will work, if you chose to take part, is you would have to come and do a pre-screening first. This would be a short simple questionnaire to make sure that you qualify for the study. If you are selected then we will have you come back for your first test, this is where we'll establish your starting point. After this test we'll work with you and your schedule to match you up with a trainer who you'll meet with 3 times a week for training sessions that should last about 30-45 minutes. Every 2 weeks you'll be tested again to measure your progress. The program is six weeks long with four tests including the first one. You'll get paid after each test, $5 at the initial test, $10 at the second test, $15 at the third test, and $20 at the final test, at which point you will also earn one entry into the raffle for a prize worth approximately $500. One thing you have to be aware of is that you can't be participating in any weight training outside the program for the duration of the study, if you do cardiovascular activities such as running or swimming you can continue those. Any questions? If you don't have any right now, you can always reach us by email (balanceumd@gmail.com) or this number (410) 302-2841.

2. Email:

Hi *(insert name here),*

You've contacted us saying that you might be interested in taking part of our research study. We are Team BALANCE and we're studying how weight training can affect or improve someone's balance as the focus of our Gemstone project.

If you chose to take part, you would first have to come and do a pre-screening. This would be a short simple questionnaire to make sure that you qualify for the study. If you are selected then you will come back for your first test in order to establish your starting point. After this test we will work with you and your schedule to match you up with a trainer who you'll meet with 3 times a week for training sessions that should last about 30-45 minutes. Every 2 weeks you will be tested again to measure your progress. The program is six weeks long with four tests, including the first one. You'll get paid after each test, $5 at the initial test, $10 at the second test, $15 at the third test, and $20 at the final test, at which point you will also earn one entry into the raffle for a prize worth approximately $500. One thing we need to point out is that you cannot be participating in any weight training outside the program for the duration of the study. However, if you do cardiovascular activities, such as running or swimming, you can continue those.

Feel free to email us back if you have any questions or call us at 410-302-2841.

Appendix G

All of the information on this form will remain strictly confidential to the extent permitted by law.

Date_____   Email _____

Height_____ Weight_____ Gender M / F (please circle)

Do you have any history of neurological disorders? If so, which ones?

Do you have any history of asthma or breathing disorders? If so, please explain.

Do you have any history of muscular disorders? If so, please explain.

Do you have any history of skeletal problems? If so, please explain.

Do you currently take any medications which would impair balance, affect alertness, or neurological functioning? If so, please explain.

Do you smoke or chew tobacco products?

Do you drink alcoholic beverages? If so, how often?

Do you take narcotics, recreational drugs, or barbiturates?

What times are you most available during the week, please be detailed:

What times are you most available during the weekend, please be detailed.

Appendix H

INTERNATIONAL PHYSICAL ACTIVITY

QUESTIONNAIRES

This is the final SHORT LAST 7 DAYS SELF-ADMINISTERED version of IPAQ from the 2000/01 Reliability and Validity Study. Completed May 2001.

IPAQ: SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken in 12 countries (14 sites) across 6 continents during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages. IPAQ is suitable for use in regional, national and international monitoring and surveillance systems and for use in research projects and public health program planning and evaluation. International collaboration on IPAQ is on-going and an international prevalence study is under development.

Using IPAQ

Worldwide use of the IPAQ instruments for monitoring and research purposes is encouraged. It is strongly recommended, to ensure data quality and comparability and to facilitate the development of an international database on health-related physical activity, that

•   no changes be made to the order or wording of the questions as this will affect the

psychometric properties of the instruments,
- if additional questions on physical activity are needed they should follow the IPAQ items,
- translations are undertaken using the prescribed back translation methods (see website)
- new translated versions of IPAQ be made available to others via the web site to avoid duplication of effort and different versions in the same language,
- a copy of IPAQ data from representative samples at national, state or regional level be provided to the IPAQ data storage center for future collaborative use (with permission) by those who contribute.

More Information

Two scientific publications presenting the methods and the pooled results from the IPAQ reliability and validity study are due out in 2002. More detailed information on the IPAQ process, the research methods used in the development of the IPAQ instruments, the use of IPAQ, the published papers and abstracts and the on-going international collaboration is available on the IPAQ web-site. **www.ipaq.ki.se**

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

IPAQ: SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS

NOTE: EXAMPLES OF ACTIVITIES MAY BE REPLACED BY CULTURALLY RELEVANT EXAMPLES WITH THE SAME METS VALUES (SEE AINSWORTH *ET AL*., 2000).

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that you do as part of your everyday life. The questions are about the time you spent being physically active in the last 7 days. They include questions about activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Your answers are important.

Please answer each question even if you do not consider yourself to be an active person. THANK YOU FOR PARTICIPATING.

In answering the following questions,

"vigorous" physical activities refer to activities that take hard physical effort and make you breathe much harder that normal.

"moderate" activities refer to activities that take moderate physical effort and make you breathe somewhat harder that normal.

1a. During the last 7 days, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling,?

Think about *only* those physical activities that you did for at least 10 minutes at a time.

_____ **days per week** !   **or**   **none**

1b. How much time in total did you usually spend on one of those days doing vigorous physical activities*?*

_____ **hours** _____ **minutes**

2a. Again, think *only* about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week** !   **or**   **none**

2b. How much time in total did you usually

spend on one of those days doing

moderate physical activities*?*

_____ **hours** _____ **minutes**

3a. During the last 7 days, on how many days did you **walk** for at least 10 minutes at a

time? This includes walking at work and at home, walking to travel from place to place,

and any other walking that you did solely for recreation, sport, exercise or leisure.

_____ **days per week** !   **or**   none

3b. How much time in total did you usually

spend walking on one of those days*?*

_____ hours _____ minutes

The last question is about the time you spent sitting on weekdays while at work, at home, while doing course work and during leisure time. This includes time spent sitting at a desk, visiting friends, reading traveling on a bus or sitting or lying down to watch television.

4. During the last 7 days, how much time in total did you usually spend *sitting* on a

week day?

_____ hours _____ minutes

This is the end of questionnaire, thank you for participating.

Appendix I

Institutional Review Board Application

Initial Application Approval

To:	Principal Investigator, Dr. Jae Kun Shim, Kinesiology Student, Emily Green, Kinesiology
From:	James M. Hagberg
	IRB Co-Chair
	University of Maryland College Park
Re:	IRB Protocol: 10-0466 - Alternative lower extremity resistance training to increase stability in young adults
Approval Date:	September 02, 2010
Expiration Date:	September 02, 2011
Application:	Initial
Review Path:	Expedited

The University of Maryland, College Park Institutional Review Board (IRB) Office approved your Initial IRBApplication. This transaction was approved in accordance with the University's IRB policies and procedures and 45 CFR 46, the Federal Policy for the Protection of Human Subjects. Please reference the above-cited IRB Protocol number in any future communications with our office regarding this research.

Recruitment/Consent: For research requiring written informed consent, the IRB-approved and stamped informed consent document will be sent via mail. The IRB approval expiration date has been stamped on the informed consent document. Please note that research participants must sign a stamped version of the informed consent form and receive a copy.

Continuing Review: If you intend to continue to collect data from human subjects or to analyze private, identifiable data collected from human subjects, beyond the expiration date of this protocol, you must submit a Renewal Application to the IRB Office 45 days prior to the expiration date. If IRB Approval of your protocol expires, all human subject research activities

including enrollment of new subjects, data collection and analysis of identifiable, private information must cease until the Renewal Application is approved. If work on the human subject portion of your project is complete and you wish to close the protocol, please submit a Closure Report toirb@umd.edu.

Modifications: Any changes to the approved protocol must be approved by the IRB before the change is implemented, except when a change is necessary to eliminate an apparent immediate hazard to the subjects. If you would like to modify an approved protocol, please submit an Addendum request to the IRB Office.

Unanticipated Problems Involving Risks: You must promptly report any unanticipated problems involving risks to subjects or others to the IRB Manager at 301-405-0678 or jsmith@umresearch.umd.edu

Additional Information: Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns. Email: irb@umd.edu

The UMCP IRB is organized and operated according to guidelines of the United States Office for Human Research Protections and the United States Code of Federal Regulations and operates under Federal Wide Assurance No. FWA00005856.

UNIVERSITY OF MARYLAND COLLEGE PARK

Institutional Review Board

Addendum Application

Protocol Number	10-0466
Protocol Title	Alternate lower extremity resistance training to increase stability in adults.
Risk Classification

(check one) | ■ Greater than Minimal Risk
☐ Minimal Risk |

Principal Investigator	Dr. Jae K. Shim	Email Address	jkshim@umd.edu
Address for Approval Letter	Dr. Jae Kun Shim

0110F School of Public Health Building
University of Maryland, College Park, MD 20742-2611 | Telephone Number | (301) 405 2492 |

Student/Co-Investigators	Emily Green	Email Address	egreen15@umd.edu
Telephone Number	(484) 947-3427		

To ensure an accurate and streamlined review of your Addendum Application, please provide the following information:

1) State what is being proposed and where in the protocol and/or consent what was changed.

Subject Selection: We hope to recruit 16 elderly adults, aged 62-80, from around College Park, Maryland, in addition to the currently approved 16 college-aged subjects. The elderly subjects will be recruited through a flyer (Appendix H), craigslist and newspaper advertisement (Appendix I), student referrals (Appendix J), and announcements at interested elderly communities (Appendix K).

Procedures: The subject screening survey has been revised to include height, weight, and gender to facilitate the match-pairing process; all information remains strictly confidential (Appendix F). All screening documents will be given and collected in person in a confidential environment. Alcohol consumption must not exceed an average of 0.12 standard drinks (0.6 fl. oz.) per kilogram of body mass per week for male participants and 0.06 per kilogram per week for female participants. Additionally, clearance will be obtained in writing from the medical doctors for participation in this study for all subjects aged 62-80 before enrollment in the study.

Information and Consent Forms: A consent form has been added for subjects aged 62-80 (Appendix L).

2) Provide the rationale/justification for the change.

Physical degeneration due to aging often results in frailty, causing injuries from falls to rank among the most significant reasons for geriatric hospitalization (American Geriatric Society, et. al., 2001). Additionally, the Healthy People 2020 initiative proposes to reduce the rate of emergency department visits due to elderly falls through physical therapy to improve balance and strength (Department of Health and Human Services, 2010).

American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. (2001). Guideline for the prevention of falls in older persons. *Journal of the American Geriatrics Society*. *49*(5), 664-672.

Pijnappels, M., Reeves, N.D., Maganaris, C.N., van Dieen, J.H. Tripping without falling; lower limb strength, a limitation for balance recovery and a target for training in the elderly. *Journal of Electromygraphy and Kinesiology*, *18*(2), 188-196.

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3) State what impact the change has on risks to participants. Please state the number of currently enrolled participants and if the change in risk will require re-consent. If the changes will not require re-consent, please state why.

Due to the inherently increased frailty due to aging, the change will increase the risk of discomfort associated with resistance training and testing: muscle soreness, discomfort from the perturbation, and discomfort from the subsequent slight loss of balance. Also, as there are currently no participants enrolled in our experiment, there will not be an issue with re-consent.

4) State whether the change has an impact on the scientific integrity of the study, (i.e. decreases, increases, no impact).

The change should have no impact on the scientific integrity of the study.

5) List the documents included with the application that have been modified (consent forms, flyers, data collection forms, surveys). State what has been changed in each modified document.

Appendix F, H-L: see below

Want to Get in Shape?

Participate in Team BALANCE's research studying kinesiology protocols for balance and be compensated to work-out your legs 3 times a week for 30 minutes for 6 weeks located in School of Public Health at UMD! There will also be 4 30-minute testing sessions: once before training and again after every two weeks.

Eligible candidates are sedentary and are aged 62-80 without physical or neurological impairments affecting balance.

Emily Green

(484)–947-3427 or BalanceUmd@gmail.com

Emily Green

(484)–947-3427 or BalanceUmd@gmail.com

Emily Green

(484)–947-3427 or BalanceUmd@gmail.com

Emily Green

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Emily Green

Appendix K

Want to Exercise?

Participate in Team BALANCE's research studying kinesiology protocols for balance and be compensated to work-out your legs three times a week for 30 minutes for six weeks in School of Public Health at UMD! There will also be four 30-minute testing sessions: once before training and again after every two weeks.

Eligible candidates must be sedentary and aged 62-80, without physical or neurological impairments affecting balance.

If you are interested, please contact Emily Green at (484) 947-3427 or email us at BalanceUmd@gmail.com

Appendix L

RESEARCH PARTICIPANTS NEEDED

Gemstone Team BALANCE is currently recruiting for a research study, located in the School of

Public Health at UMD, College Park, that needs help finding participants age 62-80 years old!

They can be compensated up to $100 to work out for 30 minutes three times a week for six weeks! Testing will be conducted before the first week of training and after weeks 2, 4, and 6. Research will improve understanding of how different exercises can improve balance.

If you are interested or have any questions, please email Balanceumd@gmail.com or call Emily Green at (484) 947 3427 for more information.

Appendix M

Email contact to elderly subjects

Attention, those want to exercise! If you are between the ages of 62-80 and have no neurological, muscular or skeletal disorders, team balance wants you! We are a research team located in University of Maryland's School of Public Health. We are examining how two types of physical training help increase balance. We hope to learn more about how to improve balance and strength to prevent future falls. We would like to train you 3 times per week for 30 minutes each for 6 weeks. There will also be 4 30-minute testing sessions: once before training and again after every two weeks. You will be compensated for your participation with $10 for signing up, then $20, $30, and $40 at the end of weeks 2, 4, and 6, respectively. If you are interested please contact Emily Green at (484) 947-3427 or email us at BalanceUmd@gmail.com. Again, the phone number is 484-947-3427 or email us at BalanceUmd@gmail.com Thank you!

Appendix N

INFORMED CONSENT FORM

Project Title	*Alternate lower extremity resistance training to increase stability.*
Statement of Age	*I state that I am at least 62 and not more than 80 years of age and wish to participate in a program of research being conducted by Jae Kun Shim, PhD and Gemstone Team BALANCE in the Department of Kinesiology at the University of Maryland, College Park.*
Purpose of Study	*The purpose of this research is to examine how resistance training of the hip, knee, and ankles joints independently improves the ability to recover balance compared to resistance training of these three joints simultaneously.*
Procedures	*We will be asking you to train three times a week for approximately half an hour each time, doing lower extremity exercises such as leg press, leg extension, back extension, and ankle plantarflexion (toe points). We will also ask you to press down on a pedal with your foot while seated, to stand still for 20 seconds, and to recover from a perturbation (padded 2kg ball hitting you lightly) while you stand on a force plate. Your position will be recorded as a stick Figure with a network of cameras. Testing sessions are once before training and again after weeks 2, 4, and 6 of training. We will compensate you for your participation in this study with $10 at the first testing session, $20 at the second testing session, $30 at the third session, and $40 at the final session for a total of $100.*
Confidentiality	*All information collected in this study is confidential to the extent permitted by law. We will be grouping the data that you provide with data that others provide for reporting and presentation. Your name will not be used. All data will be stored in a lockable file cabinet that only the principal investigator and his collaborators will have access to.*
Risks	*You may experience the discomfort of muscle soreness following training and testing. You may also experience slight discomfort from the light perturbation (described in the Procedures section)*

	and subsequent slight loss of balance.
Benefits, freedom to withdraw, & Ability to Ask Questions	*There are no direct benefits to you. You are free to ask questions or withdraw from participation at any time without penalty.*
Contact Information of Investigator	*Jae Kun Shim, PhD (e-mail: jkshim@umd.edu)* *Emily Green, Undergraduate Student(email: egreen15@umd.edu)* *2136 HHP Bldg., The Department of Kinesiology* *University of Maryland, College Park, MD 20742*
Contact Information of Institutional Review Board	*If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; e-mail: irb@deans.umd.edu; telephone: 301-405-4212*
Is any medical treatment available if I am injured?	*The University of Maryland does not provide any medical, hospitalization or other insurance for participants in this research study, nor will the University of Maryland provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.*

NAME

SIGNATURE

DATE

Appendix O

Addendum Application Approval

To: Principal   Investigator,   Dr.   Jae   Kun   Shim,   Kinesiology
             Student, Emily Green, Kinesiology

From: James   M.   Hagberg
             IRB Co-Chair
             University of Maryland College Park

Re: IRB Protocol: 10-0466 - Alternative lower extremity resistance training to
             increase stability in young adults

Approval
Date: March 07, 2011

Expiration
Date: September 02, 2011

Application: Addendum

Review Path: Fullboard

The University of Maryland, College Park Institutional Review Board (IRB) Office approved
your Addendum IRB Application. This transaction was approved in accordance with the
University's IRBpolicies and procedures and 45 CFR 46, the Federal Policy for the Protection of
Human Subjects. Please reference the above-cited IRB Protocol number in any future
communications with our office regarding this research.

Recruitment/Consent: For research requiring written informed consent, the IRB-approved and
stamped informed consent document will be sent via mail. The IRB approval expiration date has
been stamped on the informed consent document. Please note that research participants must sign
a stamped version of the informed consent form and receive a copy.

Continuing Review: If you intend to continue to collect data from human subjects or to analyze
private, identifiable data collected from human subjects, beyond the expiration date of this
protocol, you must submit a Renewal Application to the IRB Office 45 days prior to the
expiration date. If IRBApproval of your protocol expires, all human subject research activities
including enrollment of new subjects, data collection and analysis of identifiable, private
information must cease until the Renewal Application is approved. If work on the human subject

portion of your project is complete and you wish to close the protocol, please submit a Closure Report to irb@umd.edu.

Modifications: Any changes to the approved protocol must be approved by the IRB before the change is implemented, except when a change is necessary to eliminate an apparent immediate hazard to the subjects. If you would like to modify an approved protocol, please submit an Addendum request to the IRB Office.

Unanticipated Problems Involving Risks: You must promptly report any unanticipated problems involving risks to subjects or others to the IRB Manager at 301-405-0678 orjsmith@umresearch.umd.edu

Additional Information: Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns. Email: irb@umd.edu

The UMCP IRB is organized and operated according to guidelines of the United States Office for Human Research Protections and the United States Code of Federal Regulations and operates under Federal Wide Assurance No. FWA00005856.

Appendix P
Stretching Checklist
-Ensure that all subjects perform these stretches before each testing session.

Ankle Rotation
Ankle Stretch
Lunge Stretch
Hands on the knees and rotate "bring it around town"
Hands on knee Knee extension and retraction
Leg behind the back, grab with opposite hand
Touch your toes
Touch ankle standing up
Wrist flex
Arm rotation
Elephant arms
Elbow over head
10 jumping jacks

Appendix Q

Individual Joint Training
Individual-joint training sessions will be comprised of three different exercises: leg extension exercises that target the knees, back extension exercises that target the hips, and ankle plantarflexion exercises.

<u>Leg Extension</u>

During the leg extension exercise, participants will sit on the lever leg extension machine with their backs supported by the seat of the machine and their shins resting against the padded lever from below. During each repetition of the exercise, the participants will slowly extend their knees, lifting the lever as they straighten their legs. After fully extending their legs, the participants will pause for a moment and then slowly bend their knees again, bringing the lever back to its original position.
Griffing (2009a) clarifies that for safety and stability during the exercise, participants should take care to keep their back supported against the seat and grip the handles on each side of the machine. Sitting upright in the machine also ensures that the participant completes the exercise correctly and successfully using the target muscles.

<u>Back Extension</u>

It begins the same way as the leg extension exercises: the participants sit in a machine with their backs against the padded lever. However, in this exercise, the participants' feet are supported on an immovable platform and their hips rest against the back of the seat of the machine. From this position, the participants will lean backwards, extending their spines into an arch-shape, pause for a moment, and then return to the original position, completing one repetition. While this exercise is referred to as a "back extension" and does primarily target the back, we are interested in the muscles required for stabilization during this exercise. As Griffing (2009b) clarifies, the exercise does not only work the back but also the muscles used to complete the repetitions, namely the quadriceps, gluteus maximus, adductor magnus, and hamstrings, and hips.

<u>Ankle Isolation</u>

We plan to use the specific exercise suggested by Griffin (2009c): ankle plantarflexion for the gastrocnemius and the soleus muscles. During this exercise, the participants will have a bar strapped to the bottoms of their feet. A weight will hang from the end of the bar behind the

ankle. Participants will sit on a raised surface, their feet not touching the ground. From that position, they will stretch out their legs, rotate their feet downward and point their toes toward the ground, pause, then bring their feet back up to the original level position to complete one repetition.

Rotate the order of the exercises so that the fatigue inherent in the resistance training will temper the effect of each exercise equally. This measure will also serve to break up the routine and encourage active participation from the subjects.

In a regular individual-joint training session, the participants will begin by stretching with their trainer in preparation for the weight training. The trainer will then instruct the participants in the first exercise—for example, plantar flexion. Each participant will complete ten repetitions at 75% of the maximum amount of weight he or she can lift—in other words, the one repetition maximum. There will be two minutes of rest between each set of repetitions of the same exercise and five minutes of rest between sets of different exercises. Each of the three training exercises for the training session will follow this format. Although this training plan totals three exercises for participants engaging in individual-joint training and only one exercise for participants participating in whole-leg training, our mentor, Dr. Shim, has assured us that the different trainings are indeed equal and comparable because each joint is receiving as much training in the individual-joint training sessions as the whole-leg is receiving in whole-leg training sessions (personal interview, November 17, 2009).

Appendix R
Training (Whole-leg)

The whole-leg exercise we are using is the leg press. The leg press uses all three joints, the hip, the knee, and the ankle, to produce force to push a weight away and upwards. The exercise is performed on a machine in which the subjects lay on the pad and place their feet against the plate which is on a track with a 45° elevation. The subjects then push the plate by extending their legs to their full length without locking their knees (Yessis, 2002). The muscles used include the Gluteus Maximus, Quadriceps, Hamstrings, Adductor Magnus, Soleus, and Gastrocnemius. During the pushing the subjects' muscles are contracting concentrically and during the recover they are resisting the weight as well so the muscles contract eccentrically (Griffing, 2009c). Each participant in the whole-leg group would complete 3 sets of 10 repetitions each training session at 75% of their one rep max. High amount of repetitions with low weight train muscles to be able to contract repeatedly for long periods of time, building endurance; while a low number of repetitions with a larger amount of weight increases muscle size much more increasing strength significantly (Milner, 2008). We are using 75% of the one rep max because this is the perfect amount of weight with the repetitions used to build both strength and endurance.

Appendix S
Safety Precautions

General

-Dynamic stretching before the work out, static stretching afterward
-Always follow the stretching protocols before starting any weight training
-Demonstrate proper training procedure to the subject before they start
-Proper footwear, sneakers or some sort of flat-footed shoes
-Thorough scan of all equipment to make sure all parts intact, especially check to see if all pins are in place
-Follow a proper weight progression, don't unnecessarily add weight
-Controlled motion of the lift throughout all phases
-Make sure no known knee or leg issues exist that could predispose test subject to injury
-Monitor all techniques to ensure a full range of motion is achieved

Whole Leg

-Never hyperextend the knees
-Starting position should have knees roughly 90% extended
-Eccentric movement should be at a controlled tempo that would allow subject to pause under control at the bottom of the movement

Leg Extension

-Hold on to the handrails
-Movement is completed by the full extension of the knee (lock out the knees)
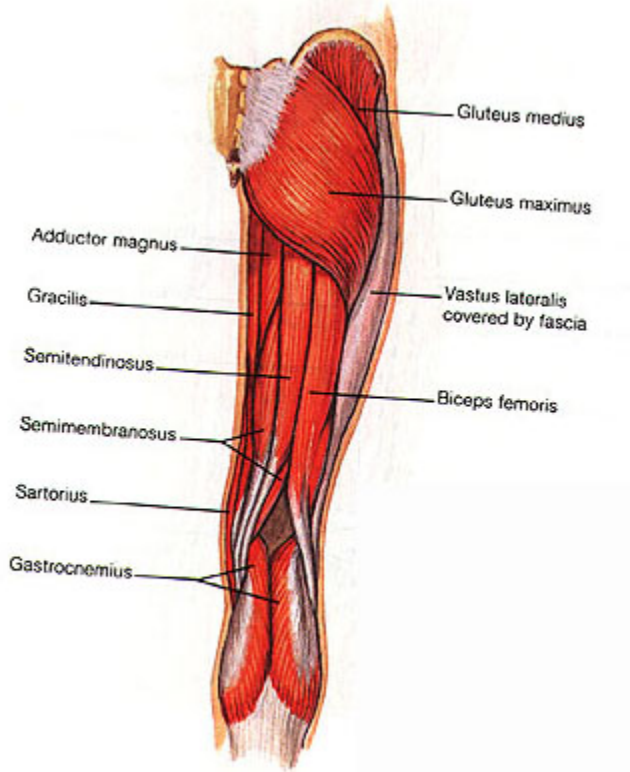-Make sure hips remain anchored to avoid thrusting

Leg Curl

-Hold the handrails
-Maintain balance on the stomach rest
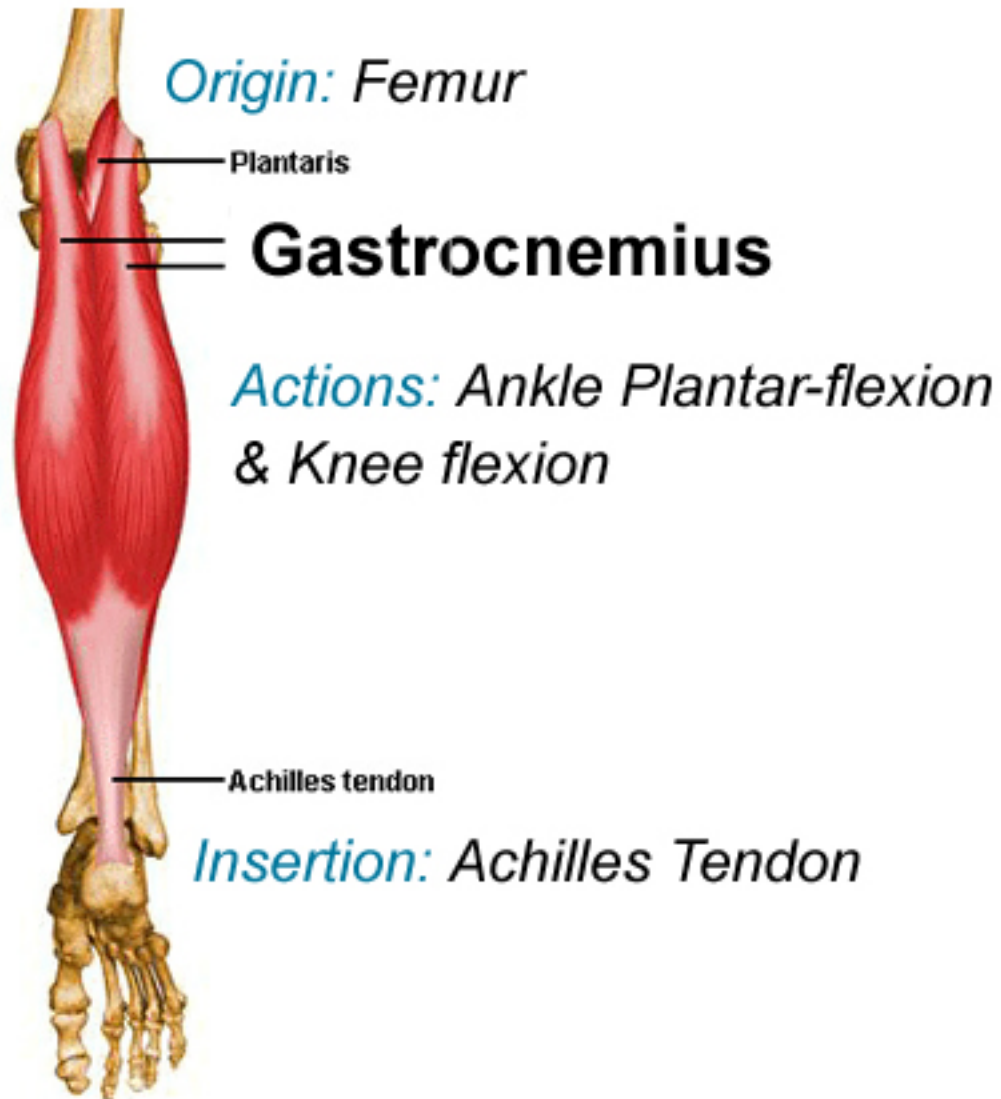-Make sure hips remain anchor to avoid thrusting of the buttocks

Ankle Isolation:

-Controlled dorsi/plantar flexion to ensure a full range of motion
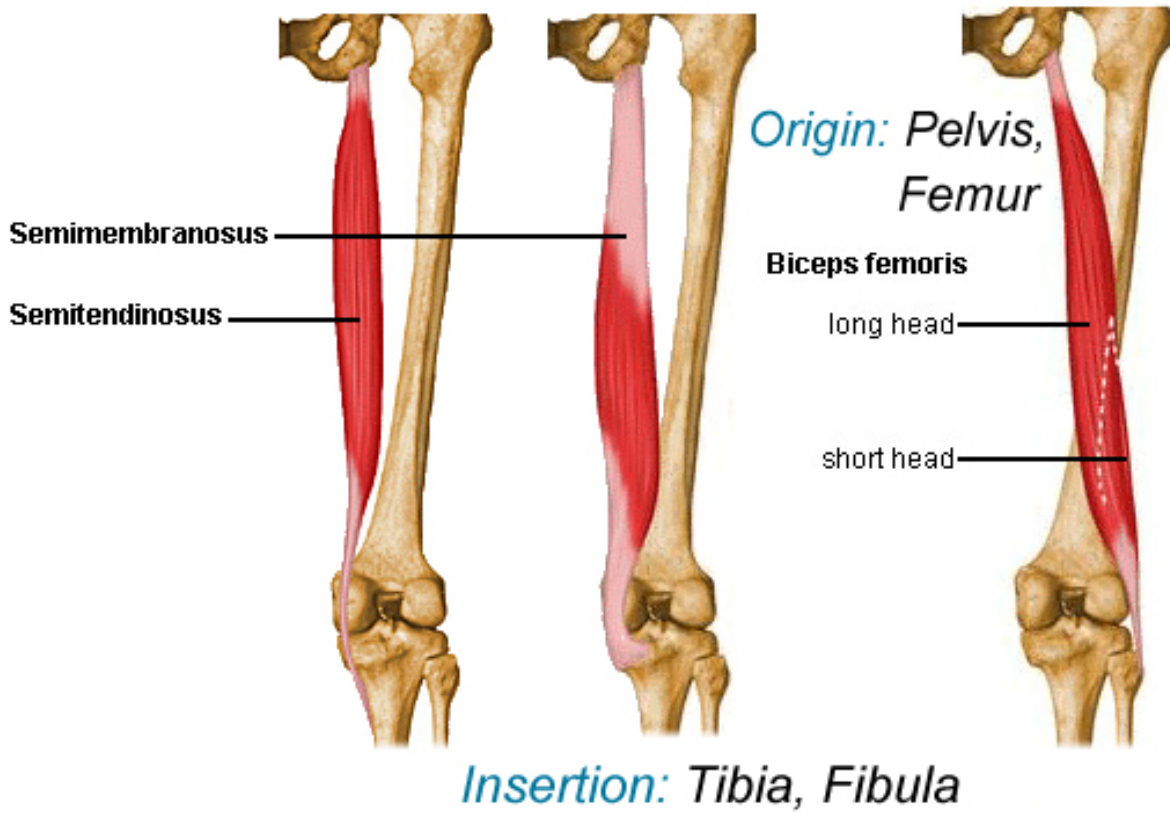-Make sure the weights are properly strapped on

Appendix T

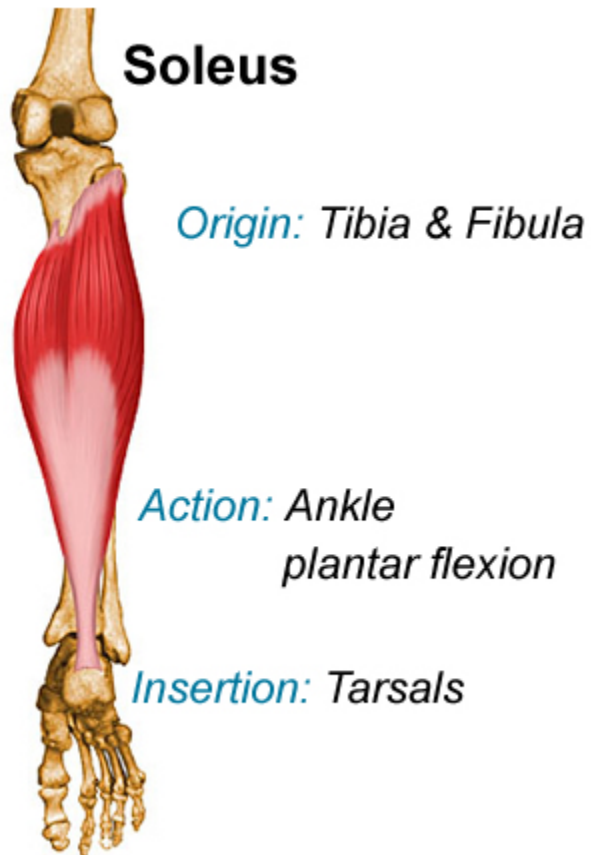http://www.physioweb.org/muscular/muscle_names.html

Origin: Femur

Plantaris

Gastrocnemius

Actions: Ankle Plantar-flexion & Knee flexion

Achilles tendon

Insertion: Achilles Tendon

http://www.thansworld.com/ONLINEanatomy_1/pages/section5/oi_gastro.htm

Hamstrings

Semimembranosus

Semitendinosus

Origin: Pelvis, Femur

Biceps femoris

long head

short head

Insertion: Tibia, Fibula

Actions: Knee flexion, Hip extension

http://www.thansworld.com/ONLINEanatomy_1/pages/section5/oi_hamstrings.htm

Appendix W

Appendix X

Quadriceps

Superficial **Deep**

Origin: Pelvis & Femur

Vastus lateralis

Vastus lateralis

Rectus femoris

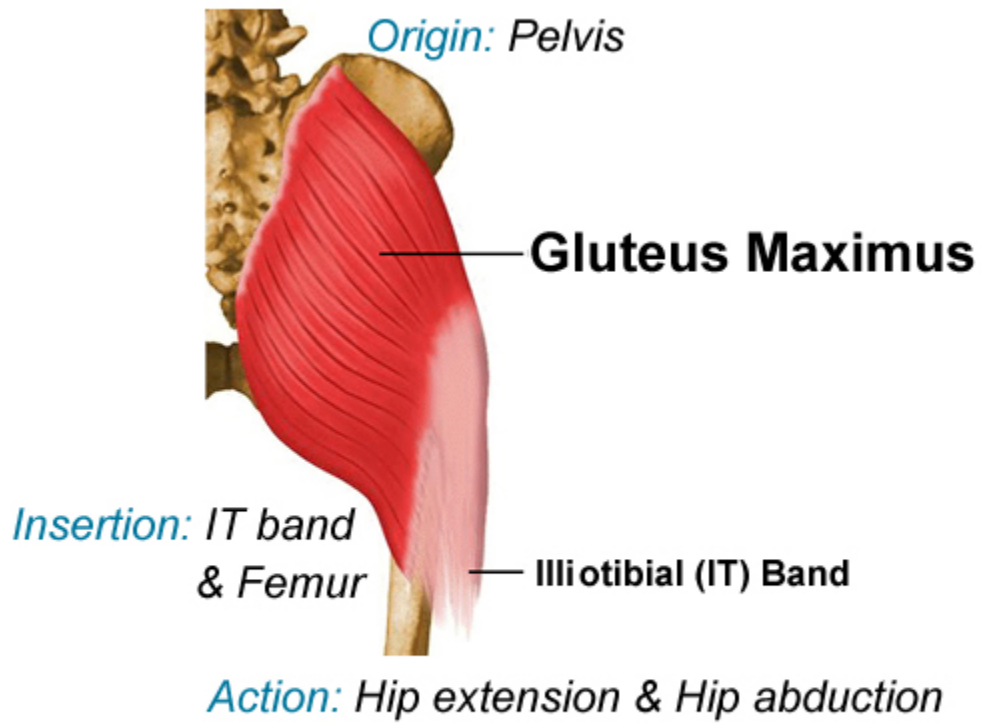Vastus intermedius

Vastus medialis

Vastus medialis

Insertion: Tibia (via patella)
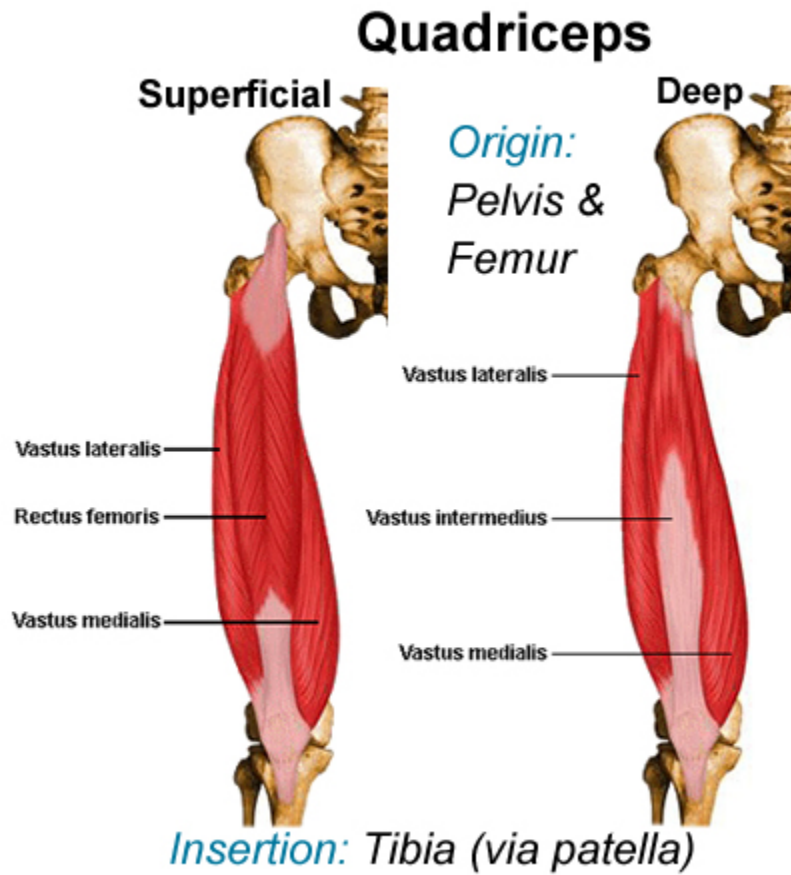
Actions: Knee extension, Hip flexion

http://www.thansworld.com/ONLINEanatomy_1/images/section5/oi_quadriceps.jpg

Appendix Y

Origin: Pelvis

Gluteus Maximus

Insertion: IT band & Femur

Illiotibial (IT) Band

Action: Hip extension & Hip abduction

http://www.thansworld.com/ONLINEanatomy_1/images/section5/oi_gluteus.jpg

Appendix Z

Origin: Pelvis

— **Gluteus Medius**

Action: Hip extension
Hip abduction

Insertion: Femur
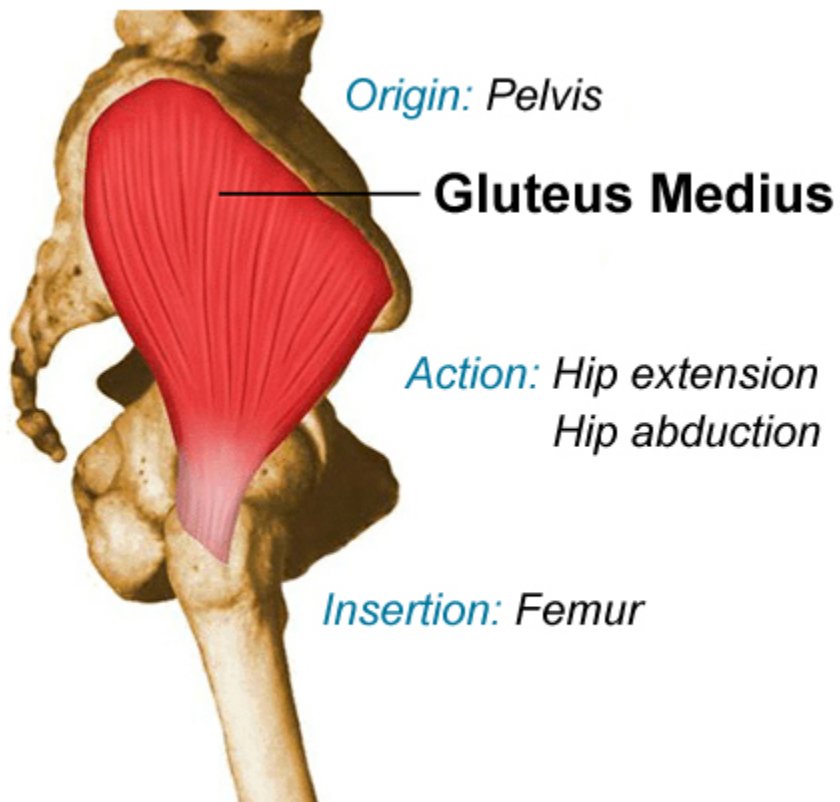
http://www.thansworld.com/ONLINEanatomy_1/images/section5/oi_gluteus_medius.jpg

Appendix AA

http://www.performbetter.com/wcsstore/MFACatalogAssetStore/images/catalog/4975PS.jpg

Appendix AB

Appendix AC

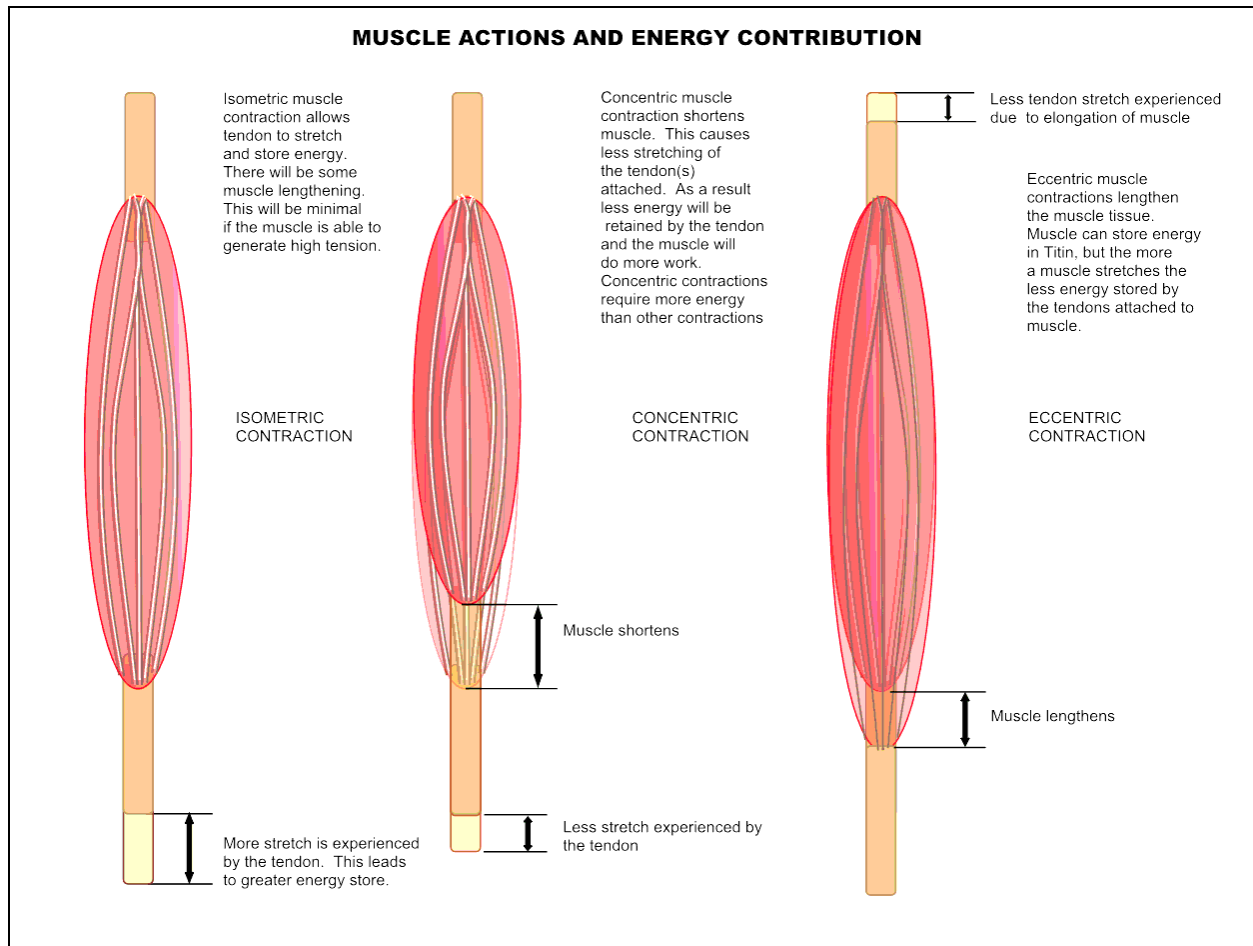**Appendix AD**

http://www.pfcfitnessequipment.com/uploads/private/rVR%204865_2396_mid.jpg

Appendix AE

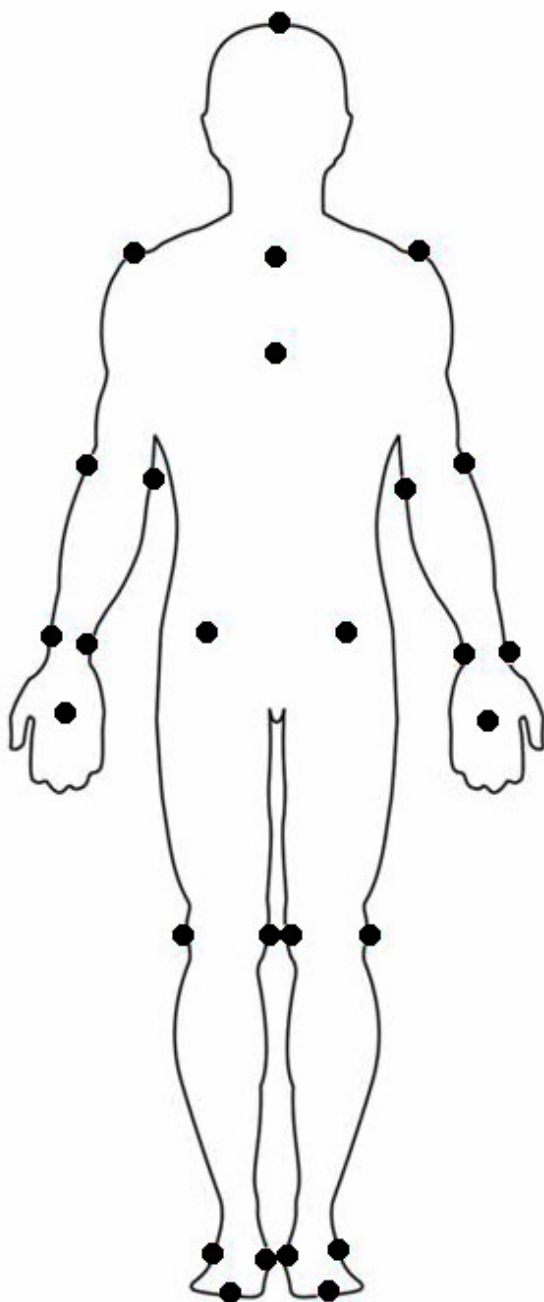http://fitnessanddefense.com/wp-content/uploads/2011/04/leg-extension-exercise.jpg
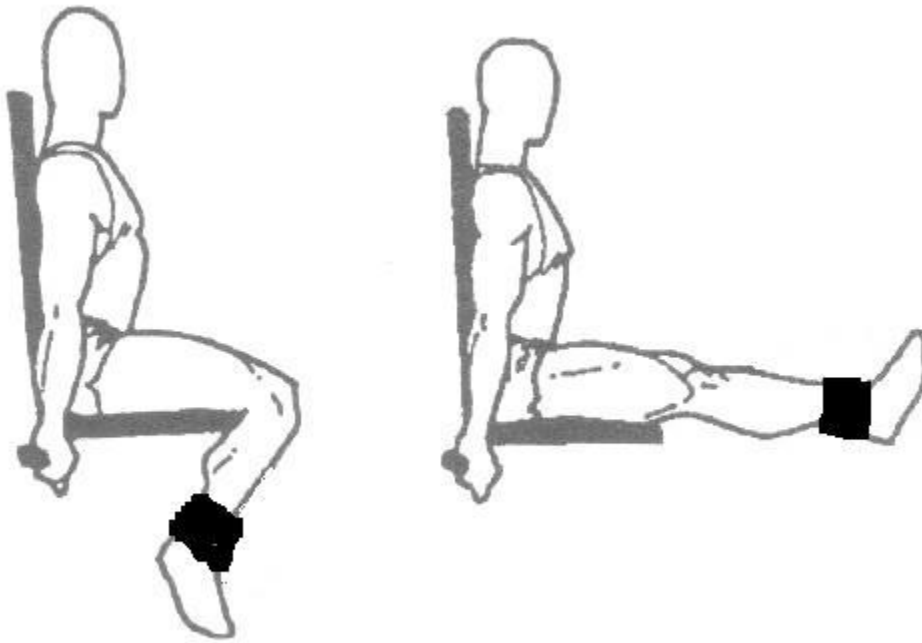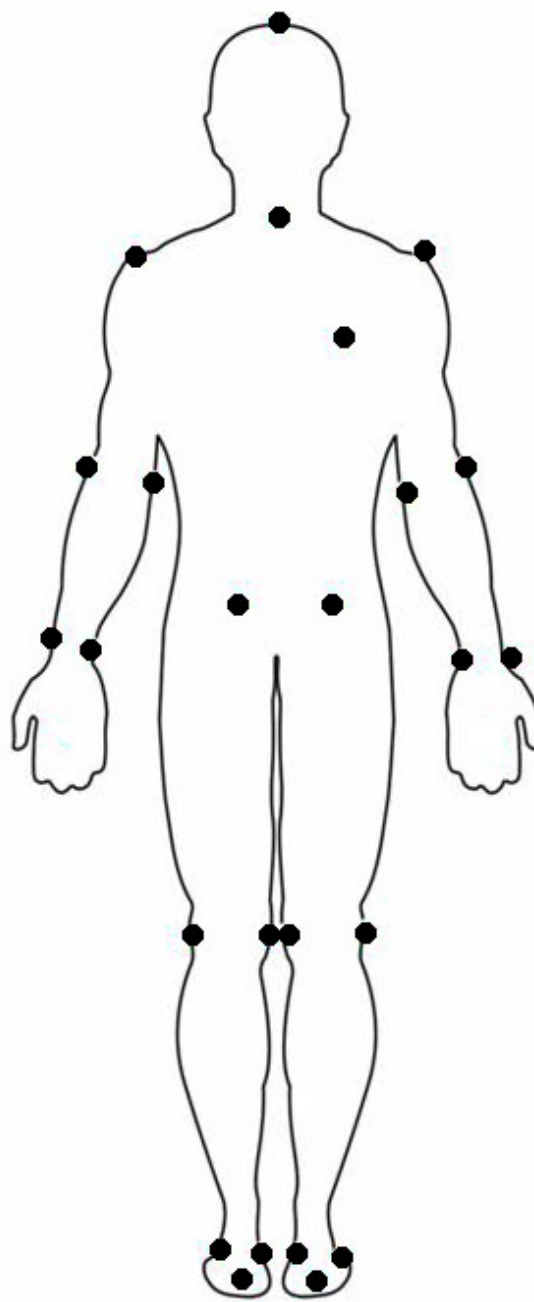
Appendix AF

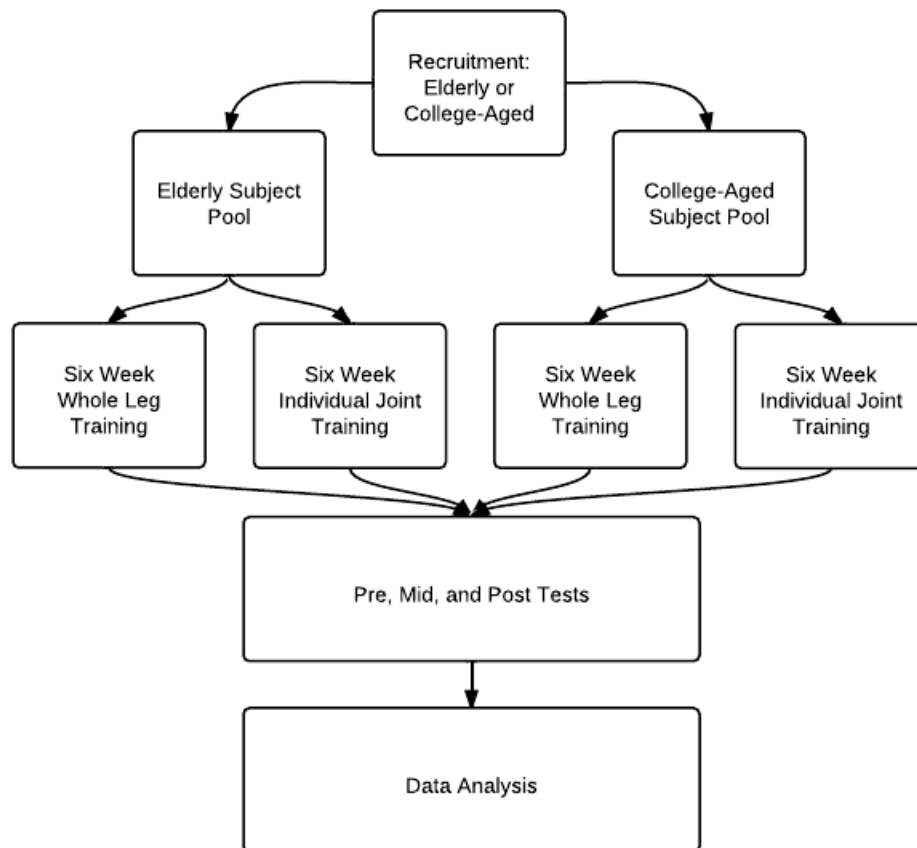http://maximum-maximorum.com/wp-content/uploads/2010/06/Muscle_Actions.gif
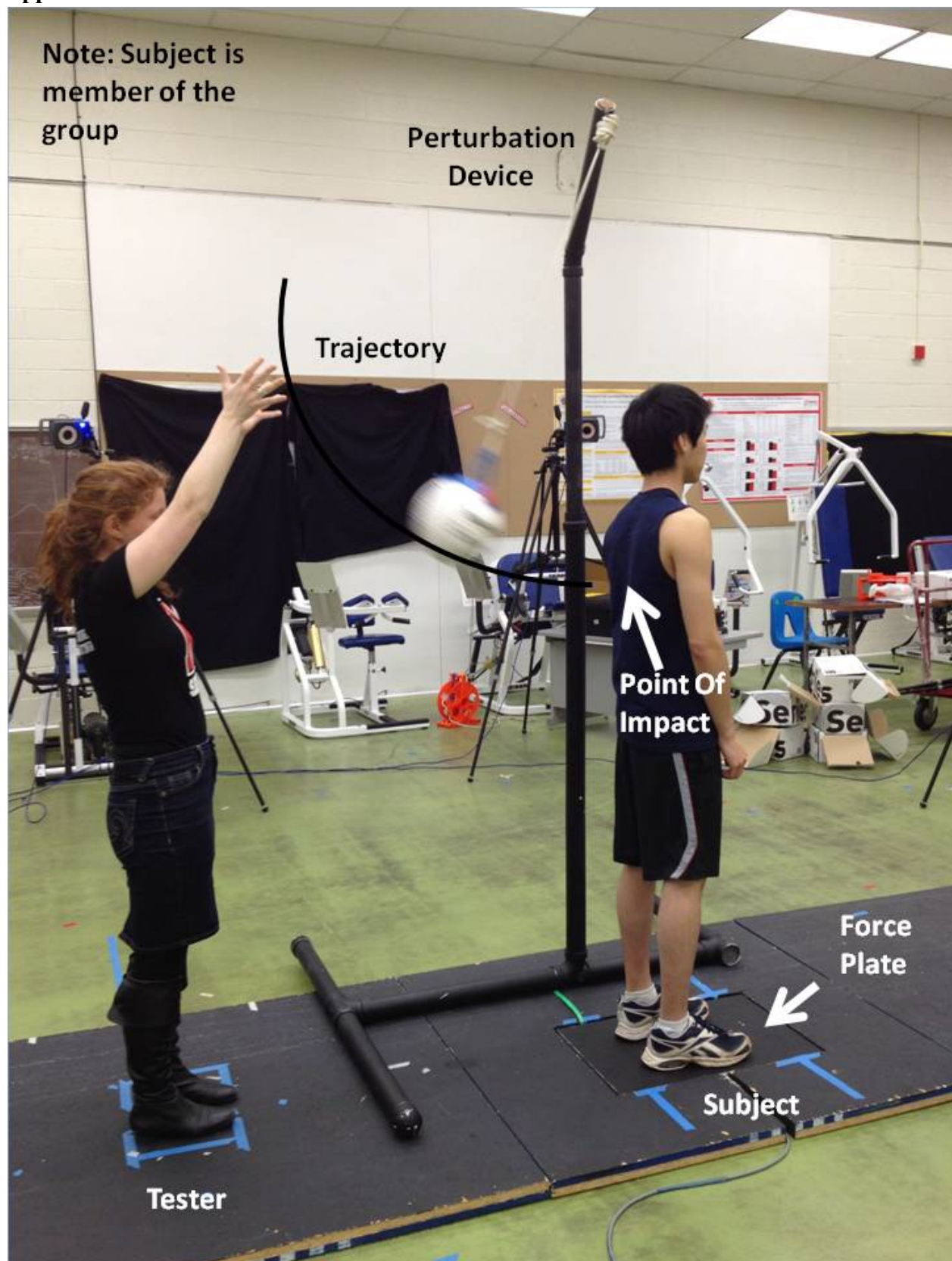
Appendix AG

Appendix AH

Appendix AK

```
% equations for Male adult. by Minjoo Kim Oct. 2010
% References ; de Leva, 1996a & 1996b.
% Function: Calculate whole body center of mass; saves the WBcom variable.

function D = COMAM_KNES670(data)
BM = 66 ; % insert body mass (Kg) for each subject


based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered\';
[filename, pathname]=uigetfile('*.csv', 'Pick a data file', ...
    [based]);

[pathstr, name, ext]=fileparts(filename);
data=dlmread([pathname filename], ',', 6,1);%(3,6)

% HEAD
VERT  = data(:,2:4);
C7    = data(:,5:7);
CLAV  = data(:,8:10); % notch
% Upper Extremity
lACRO = data(:,11:13);
lELB  = data(:,14:16);
lELBm = data(:,17:19);
lWRIa = data(:,20:22); % radial
lWRIb = data(:,23:25); % ulna
lMET3 = data(:,26:28); % 3rd finger
rACRO = data(:,29:31);
rELB  = data(:,32:34);
rELBm = data(:,35:37);
rWRIa = data(:,38:40);
rWRIb = data(:,41:43);
rMET3 = data(:,44:46);
% Lower Extremity
lKNE  = data(:,59:61);
lKNEm = data(:,62:64);
lANK  = data(:,65:67);
lANKm = data(:,68:70);
lHEEL = data(:,71:73);
lTOE  = data(:,74:76);
rKNE  = data(:,77:79);
rKNEm = data(:,80:82);
rANK  = data(:,83:85);
rANKm = data(:,86:88);
rHEEL = data(:,89:91);
rTOE  = data(:,92:94);
%Trunk
lASIS = data(:,47:49);
rASIS = data(:,50:52);
lPSIS = data(:,53:55);
rPSIS = data(:,56:58);

%%% Define joint centers
```

```matlab
% Neck
NECK = (C7 + CLAV)/2
lSJCz = lACRO(:,3) - (lACRO(:,3)-lELB(:,3))*0.1429;
lSJCx = lACRO(:,1);
lSJCy = lACRO(:,2);
lSJC = [lSJCx lSJCy lSJCz];
rSJCz = rACRO(:,3) - (rACRO(:,3)-rELB(:,3))*0.1429;
rSJCx = rACRO(:,1);
rSJCy = rACRO(:,2);
rSJC = [rSJCx rSJCy rSJCz];
lEJC = (lELB + lELBm)/2;
rEJC = (rELB + rELBm)/2;
lWJC = (lWRIa + lWRIb)/2;
rWJC = (rWRIa + rWRIb)/2;
lKJC = (lKNE + lKNEm)/2;
rKJC = (rKNE + rKNEm)/2;
lAJC = (lANK + lANKm)/2;
rAJC = (rANK + rANKm)/2;
PW = mean(abs(lASIS(:,1) - rASIS(:,1)));
PD = mean(abs(lASIS(:,2)-lPSIS(:,2))+abs(rASIS(:,2)-rPSIS(:,2)))/2;
lHJC = [0.14*PW+lASIS(:,1),-0.37*PD+lASIS(:,2),-0.79*PW+lASIS(:,3)];
rHJC = [-0.14*PW+rASIS(:,1),-0.37*PD+rASIS(:,2),-0.79*PW+rASIS(:,3)];
MIDH = (lHJC+rHJC)/2;

%%% COM of each segment for FEMALE
HEADcom  = CalCOM1(VERT,NECK,0.5976,0.0694,BM);
lUARMcom = CalCOM1(lSJC,lEJC,0.5772,0.0271,BM);
rUARMcom = CalCOM1(rSJC,rEJC,0.5772,0.0271,BM);
lFARMcom = CalCOM1(lEJC,lWJC,0.4574,0.0162,BM);
rFARMcom = CalCOM1(rEJC,rWJC,0.4574,0.0162,BM);
lHANDcom = CalCOM1(lWJC,lMET3,0.7900,0.0061,BM);
rHANDcom = CalCOM1(rWJC,rMET3,0.7900,0.0061,BM);
lSHNKcom = CalCOM1(lKJC,lAJC,0.4459,0.0433,BM);
rSHNKcom = CalCOM1(rKJC,rAJC,0.4459,0.0433,BM);
lFOOTcom = CalCOM1(lHEEL,lTOE,0.4415,0.0137,BM);
rFOOTcom = CalCOM1(rHEEL,rTOE,0.4415,0.0137,BM);
lTHIGcom = CalCOM1(lHJC,lKJC,0.4095,0.1416,BM);
rTHIGcom = CalCOM1(rHJC,rKJC,0.4095,0.1416,BM);
TRUNKcom = CalCOM1(C7, MIDH,0.4486,0.4346,BM);
%%% Whole Body COM

 WBcom                                                                        =
(HEADcom+lUARMcom+rUARMcom+lFARMcom+rFARMcom+lHANDcom+rHANDcom+lSHNKcom+rSHNK
com+lFOOTcom+rFOOTcom+lTHIGcom+rTHIGcom+TRUNKcom)/BM;


 datastr.WBcom =WBcom;
 datastr.HEADcom=HEADcom;
 datastr.lUARMcom=lUARMcom;
 datastr.rUARMcom=rUARMcom;
 datastr.lFARMcom=lFARMcom;
 datastr.rFARMcom=rFARMcom;
 datastr.lHANDcom=lHANDcom;
 datastr.rHANDcom=rHANDcom;
```

```
datastr.lSHNKcom=lSHNKcom;
datastr.rSHNKcom=rSHNKcom;
datastr.lFOOTcom=lFOOTcom;
datastr.rFOOTcom=rFOOTcom;
datastr.lTHIGcom=lTHIGcom;
datastr.rTHIGcom=rTHIGcom;
datastr.TRUNKcom=TRUNKcom;
datastr.BM=BM;

save([based, name], 'datastr');
```

```
function butterworth
%lowpass filter set

based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered\'; [filename, pathname]=uigetfile('*.mat', 'Pick a
data file', [based]);

load([pathname, filename], 'datastr');

fc=10
fs=370 %100, 370


WBcom=datastr.WBcom;
    HEADcom=datastr.HEADcom;
    lUARMcom=datastr.lUARMcom;
    rUARMcom=datastr.rUARMcom;
    lFARMcom=datastr.lFARMcom;
    rFARMcom=datastr.rFARMcom;
    lHANDcom=datastr.lHANDcom;
    rHANDcom=datastr.rHANDcom;
    lSHNKcom=datastr.lSHNKcom;
    rSHNKcom=datastr.rSHNKcom;
    lFOOTcom=datastr.lFOOTcom;
    rFOOTcom=datastr.rFOOTcom;
    lTHIGcom=datastr.lTHIGcom;
    rTHIGcom=datastr.rTHIGcom;
    TRUNKcom=datastr.TRUNKcom;

    totaltime=size(WBcom)


[b a]=butter(2,2*fc/fs, 'low');
WBcom1(:,:)=filtfilt(b,a,WBcom(:,:));
HEADcom1(:,:)=filtfilt(b,a,HEADcom(:,:));
lUARMcom1(:,:)=filtfilt(b,a,lUARMcom(:,:));
rUARMcom1(:,:)=filtfilt(b,a,rUARMcom(:,:));
lFARMcom1(:,:)=filtfilt(b,a,lFARMcom(:,:));
rFARMcom1(:,:)=filtfilt(b,a,rFARMcom(:,:));
lHANDcom1(:,:)=filtfilt(b,a,lHANDcom(:,:));
rHANDcom1(:,:)=filtfilt(b,a,rHANDcom(:,:));
lSHNKcom1(:,:)=filtfilt(b,a,lSHNKcom(:,:));
```

```matlab
rSHNKcom1(:,:)=filtfilt(b,a,rSHNKcom(:,:));
lFOOTcom1(:,:)=filtfilt(b,a,lFOOTcom(:,:));
rFOOTcom1(:,:)=filtfilt(b,a,rFOOTcom(:,:));
lTHIGcom1(:,:)=filtfilt(b,a,lTHIGcom(:,:));
rTHIGcom1(:,:)=filtfilt(b,a,rTHIGcom(:,:));
TRUNKcom1(:,:)=filtfilt(b,a,TRUNKcom(:,:));

datastr1.WBcom1=WBcom1;
datastr1.HEADcom1=HEADcom1;
datastr1.lUARMcom1=lUARMcom1;
datastr1.rUARMcom1=rUARMcom1;
datastr1.lFARMcom1=lFARMcom1;
datastr1.rFARMcom1=rFARMcom1;
datastr1.lHANDcom1=lHANDcom1;
datastr1.rHANDcom1=rHANDcom1;
datastr1.lSHNKcom1=lSHNKcom1;
datastr1.rSHNKcom1=rSHNKcom1;
datastr1.lFOOTcom1=lFOOTcom1;
datastr1.rFOOTcom1=rFOOTcom1;
datastr1.lTHIGcom1=lTHIGcom1;
datastr1.rTHIGcom1=rTHIGcom1;
datastr1.TRUNKcom1=TRUNKcom1;


save( [based,filename] ,'-append', 'datastr1')
```

```matlab
function butterworth_ball
%%% smooths the ball's trajectory

clc;
based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered\'  [filename, pathname]=uigetfile('*.csv', 'Pick a data file', ...
    [based]);


[pathstr, name, ext]=fileparts(filename)
data=dlmread([pathname filename], ',', 6,1);


ball=data(:,95:97); %2:4 If ball apex, and base only, 95:97
fc=10;
fs=370; %370Hz or 100Hz

[b a]=butter(2, 2*fc/fs, 'low');
ball1(:,:)=filtfilt(b,a,ball(:,:));
datastr2.ball1=ball1;

filename
save( [based,name],'-append','datastr2')
```

```matlab
function timechange
%creates time stamps for every frame and saves in force plate matfile in a
%variable called 'tstamp'.
```

```matlab
clc;
based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered/';

[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);

%%for creating converted timestamp for FP data
% load([pathname, filename], 'Forcexyz1');
% tf=size(Forcexyz1(:,1)) %total number of frames
% at=tf/1110 %actual time in seconds 1110 if recording at 370Hz,(1200 if recording at 100Hz)
% tpf=at/tf %time per frame


%%for creating converted timestamp for vicon data
% % [filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);
load([pathname, filename], 'datastr2');
ball1=datastr2.ball1;
tf=size(ball1(:,1))
at=tf/370; %370, or 100
tpf=at/tf


for ii=1:tf
    n=ii;
tstamp(ii,1)=tpf*(n-1);


end
save([based, filename],'-append', 'tstamp')
```

```matlab
function secondbutterworth
%low pass filter for force plate data

 based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered/';
 [filename, pathname]=uigetfile('*.csv', 'Pick a data file', ...
   [based]);

[pathstr, name, ext]=fileparts(filename)
Force=dlmread([pathname filename],',',3,1);

fc = 10; % cut off frequency is 10*3 Hz
fs = 1110 % sampling rate (Hz), 3*370, 12*100 (Hz)
% later trials use 100 Hz
[B,A] = butter(2,2*fc/fs, 'low');
Forcexyz1(:,:)=filtfilt(B,A,Force(:,:));

 save([based, name],'Forcexyz1');
```

```matlab
function realBW_fs_bhit
%calculates BW, saves frequency, and ball hit frame
```

```matlab
clc;
    based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered/';


datafiles=dir(fullfile(based,'*FP.mat'))
size(datafiles)
for i=1:size(datafiles,1)
    datafiles(i).name
    load([based, datafiles(i).name],'Forcexyz1')

    realBW=abs((sum(Forcexyz1(1:1000,9)))/(1000))
    fs=input(sprintf('input frequency of data set:'));
    bhit=input(sprintf('input ball hit frame: '));

    save([based,datafiles(i).name], '-append', 'realBW','fs', 'bhit')

end
```

```matlab
    function averageFxyz
    %%calculates average for forces for each subject in each test
    %%session.(within subject)
    %%calculate the standard dev and plots average and stdev


    clc;clf
    based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered/';

%%
    [filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);
    load([pathname, filename], 'Forcexyz1', 'tstamp', 'bhit', 'fs', 'realBW');
  [pathstr, name, ext]=fileparts(filename)

  k1=3;      %time in second after ball hit
  k2=k1;
  k3=k1;

  t1=tstamp;
  bhit1=bhit
  fs1=fs;
  realBW1=realBW;

  if fs1==370
  freqscale1=3; %freq scale 3 or 12
  elseif fs1==100
     freqscale1=12;
  end

  startf1=freqscale1*(bhit1-fs1); %start frame
```

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```matlab
endf1=freqscale1*(bhit1+k1*fs1); %end frame
tt1=(endf1-startf1)/(fs1*freqscale1); %total time in seconds
F1=Forcexyz1(startf1:endf1, 7:9)./realBW1;

[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);
load([pathname, filename], 'Forcexyz1', 'tstamp', 'bhit', 'fs', 'realBW');

%k2=4;
t2=tstamp;
bhit2=bhit;
fs2=fs;
realBW2=realBW

if fs2==370
freqscale2=3
elseif fs2==100
    freqscale2=12
end

startf2=freqscale2*(bhit2-fs2);
endf2=freqscale2*(bhit2+k2*fs2);
tt2=(endf2-startf2)/(fs2*freqscale2);
F2=Forcexyz1(startf2:endf2, 7:9)./realBW2;

%%

[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);
load([pathname, filename], 'Forcexyz1', 'tstamp', 'bhit', 'fs', 'realBW');

%k3=4;
t3=tstamp;
bhit3=bhit
fs3=fs;
realBW3=realBW

if fs3==370
freqscale3=3;
elseif fs3==100
    freqscale3=12;
end

startf3=freqscale3*(bhit3-fs3);
endf3=freqscale3*(bhit3+k3*fs3);
tt3=(endf3-startf3)/(fs3*freqscale3);
F3=Forcexyz1(startf3:endf3, 7:9)./realBW3;

Figure(1)
plot(0:tt1/(endf1-startf1):tt1, F1(:,3),'k', 0:tt2/(endf2-startf2):tt2, F2(:,3),'r',0:tt3/(endf3-startf3):tt3, F3(:,3), 'b')

avgFxyz=(F1(:,1:3)+F2(:,1:3)+F3(:,1:3))./3;

stdev=sqrt(((F1-avgFxyz).^2+(F2-avgFxyz).^2+(F3-avgFxyz).^2)/2);   %standard deviation n-1, number of samples
minus 1 !!! zeros(size(F1(:,1:3)))
Figure(2) %plots Fxzeros(size(F1(:,1:3)))
```

```matlab
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,1), 'k', 'linewidth', 3); hold on
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,1)-stdev(:,1), 'k'); hold on
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,1)+stdev(:,1), 'k'); hold on

Figure(3) %plots Fy
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,2), 'r','linewidth', 3); hold on
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,2)-stdev(:,2), 'r'); hold on
h1=plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,2)+stdev(:,2),'r'); hold on
title(sprintf(name, ' average AP'))
saveas(h1, [based, name, 'AP'], 'fig')

Figure(4) %plots Fz
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,3),'b', 'linewidth', 3); hold on
plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,3)-stdev(:,3),'b'); hold on
h2=plot(0:tt1/(endf1-startf1):tt1,avgFxyz(:,3)+stdev(:,3),'b'); hold on
title(sprintf([name,' average UD']))

time=0:tt1/(endf1-startf1):tt1;

saveas(h2, [based, name, 'UD'], 'fig')


save([based, 'John_test1_FPavg'], 'avgFxyz', 'stdev', 'time')


function COV
clc
based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered\'
  [filename, pathname]=uigetfile('*.mat', 'Pick a vicon dtfa file', ...
    [based]);


[pathstr, name, ext]=fileparts(filename)

  load([based,name],'datastr1')
  load([based,name],'datastr')
  BM=datastr.BM;
  WBcom1=datastr1.WBcom1
  HEADcom1=datastr1.HEADcom1;
  lUARMcom1=datastr1.lUARMcom1;
  rUARMcom1=datastr1.rUARMcom1;
  lFARMcom1=datastr1.lFARMcom1;
  rFARMcom1=datastr1.rFARMcom1;
  lHANDcom1=datastr1.lHANDcom1;
  rHANDcom1=datastr1.rHANDcom1;
  lSHNKcom1=datastr1.lSHNKcom1;
  rSHNKcom1=datastr1.rSHNKcom1;
  lFOOTcom1=datastr1.lFOOTcom1;
  rFOOTcom1=datastr1.rFOOTcom1;
  lTHIGcom1=datastr1.lTHIGcom1;
  rTHIGcom1=datastr1.rTHIGcom1;
  TRUNKcom1=datastr1.TRUNKcom1;
```

```matlab
%%
    fs=input(sprintf('input frequency of data set:')); %100, 370
startf=input(sprintf('input startf of data:'));  %494;
endtime=input(sprintf('input end time in seconds of data:'));

if fs==370
    endf=(endtime-1)*370+startf
end
if fs==100
    endf=(endtime-1)*100+startf
end


    tf=size(WBcom1(startf:endf,:),1)
    af=tf/fs
    tpf=af/tf



    %%
    avgWBcom1(:,:)=sum(WBcom1(startf:endf,:))/tf;
    WBcom1_V=sum([(WBcom1(startf:endf,1)-avgWBcom1(1,1)).^2 (WBcom1(startf:endf,2)-avgWBcom1(1,2)).^2
(WBcom1(startf:endf,3)-avgWBcom1(1,3)).^2])/tf;
    %%
    avgHEADcom1(:,:)=sum(HEADcom1(startf:endf,:))/tf;
    HEADcom1_V=sum([(HEADcom1(startf:endf,1)-avgHEADcom1(1,1)).^2            (HEADcom1(startf:endf,2)-
avgHEADcom1(1,2)).^2 (HEADcom1(startf:endf,3)-avgHEADcom1(1,3)).^2])/tf;
    %%
    avglUARMcom1(:,:)=sum(lUARMcom1(startf:endf,:))/tf;
    lUARMcom1_V=sum([(lUARMcom1(startf:endf,1)-avglUARMcom1(1,1)).^2          (lUARMcom1(startf:endf,2)-
avglUARMcom1(1,2)).^2 (lUARMcom1(startf:endf,3)-avglUARMcom1(1,3)).^2])/tf;
    %%
    avgrUARMcom1(:,:)=sum(rUARMcom1(startf:endf,:))/tf;
    rUARMcom1_V=sum([(rUARMcom1(startf:endf,1)-avgrUARMcom1(1,1)).^2         (rUARMcom1(startf:endf,2)-
avgrUARMcom1(1,2)).^2 (rUARMcom1(startf:endf,3)-avgrUARMcom1(1,3)).^2])/tf;
    %%
    avglFARMcom1(:,:)=sum(lFARMcom1(startf:endf,:))/tf;
    lFARMcom1_V=sum([(lFARMcom1(startf:endf,1)-avglFARMcom1(1,1)).^2         (lFARMcom1(startf:endf,2)-
avglFARMcom1(1,2)).^2 (lFARMcom1(startf:endf,3)-avglFARMcom1(1,3)).^2])/tf;
    %%
    avgrFARMcom1(:,:)=sum(rFARMcom1(startf:endf,:))/tf;

    rFARMcom1_V=sum([(rFARMcom1(startf:endf,1)-avgrFARMcom1(1,1)).^2         (rFARMcom1(startf:endf,2)-
avgrFARMcom1(1,2)).^2 (rFARMcom1(startf:endf,3)-avgrFARMcom1(1,3)).^2])/tf;
    %%
    avglHANDcom1(:,:)=sum(lHANDcom1(startf:endf,:))/tf;

    lHANDcom1_V=sum([(lHANDcom1(startf:endf,1)-avglHANDcom1(1,1)).^2         (lHANDcom1(startf:endf,2)-
avglHANDcom1(1,2)).^2 (lHANDcom1(startf:endf,3)-avglHANDcom1(1,3)).^2])/tf;
    %%
    avgrHANDcom1(:,:)=sum(rHANDcom1(startf:endf,:))/tf;

    rHANDcom1_V=sum([(rHANDcom1(startf:endf,1)-avgrHANDcom1(1,1)).^2         (rHANDcom1(startf:endf,2)-
avgrHANDcom1(1,2)).^2 (rHANDcom1(startf:endf,3)-avgrHANDcom1(1,3)).^2])/tf;
    %%
    avglSHNKcom1(:,:)=sum(lSHNKcom1(startf:endf,:))/tf;
```

```matlab
    lSHNKcom1_V=sum([(lSHNKcom1(startf:endf,1)-avglSHNKcom1(1,1)).^2          (lSHNKcom1(startf:endf,2)-
avglSHNKcom1(1,2)).^2 (lSHNKcom1(startf:endf,3)-avglSHNKcom1(1,3)).^2])/tf;
    %%
    avgrSHNKcom1(:,:)=sum(rSHNKcom1(startf:endf,:))/tf;

    rSHNKcom1_V=sum([(rSHNKcom1(startf:endf,1)-avgrSHNKcom1(1,1)).^2          (rSHNKcom1(startf:endf,2)-
avgrSHNKcom1(1,2)).^2 (rSHNKcom1(startf:endf,3)-avgrSHNKcom1(1,3)).^2])/tf;
    %%
    avglFOOTcom1(:,:)=sum(lFOOTcom1(startf:endf,:))/tf;

    lFOOTcom1_V=sum([(lFOOTcom1(startf:endf,1)-avglFOOTcom1(1,1)).^2          (lFOOTcom1(startf:endf,2)-
avglFOOTcom1(1,2)).^2 (lFOOTcom1(startf:endf,3)-avglFOOTcom1(1,3)).^2])/tf;
    %%
    avgrFOOTcom1(:,:)=sum(rFOOTcom1(startf:endf,:))/tf;

    rFOOTcom1_V=sum([(rFOOTcom1(startf:endf,1)-avgrFOOTcom1(1,1)).^2          (rFOOTcom1(startf:endf,2)-
avgrFOOTcom1(1,2)).^2 (rFOOTcom1(startf:endf,3)-avgrFOOTcom1(1,3)).^2])/tf;
    %%
    avglTHIGcom1(:,:)=sum(lTHIGcom1(startf:endf,:))/tf;

    lTHIGcom1_V=sum([(lTHIGcom1(startf:endf,1)-avglTHIGcom1(1,1)).^2          (lTHIGcom1(startf:endf,2)-
avglTHIGcom1(1,2)).^2 (lTHIGcom1(startf:endf,3)-avglTHIGcom1(1,3)).^2])/tf;
    %%
    avgrTHIGcom1(:,:)=sum(rTHIGcom1(startf:endf,:))/tf;

    rTHIGcom1_V=sum([(rTHIGcom1(startf:endf,1)-avgrTHIGcom1(1,1)).^2          (rTHIGcom1(startf:endf,2)-
avgrTHIGcom1(1,2)).^2 (rTHIGcom1(startf:endf,3)-avgrTHIGcom1(1,3)).^2])/tf;
    %%
    avgTRUNKcom1(:,:)=sum(TRUNKcom1(startf:endf,:))/tf;

    TRUNKcom1_V=sum([(TRUNKcom1(startf:endf,1)-avgTRUNKcom1(1,1)).^2        (TRUNKcom1(startf:endf,2)-
avgTRUNKcom1(1,2)).^2 (TRUNKcom1(startf:endf,3)-avgTRUNKcom1(1,3)).^2])/tf;

    Pos_V(:,:)=(HEADcom1_V+ lUARMcom1_V+ rUARMcom1_V+ lFARMcom1_V+ ...
        rFARMcom1_V+ lHANDcom1_V+ rHANDcom1_V+ lSHNKcom1_V+ rSHNKcom1_V+ ...
        lFOOTcom1_V+  rFOOTcom1_V+ lTHIGcom1_V+ rTHIGcom1_V+ TRUNKcom1_V)

    COV(:,:)=(Pos_V(:,:)-WBcom1_V(:,:))./Pos_V(:,:)


save([based, name, 'V'], 'fs','WBcom1_V','Pos_V','COV')


function COV_avg_stdev
 %calculates average covariance for each subject

clc
based='C:\Users\Shichun\Documents\Spring2012\Gems\recovered/';

[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]);
[pathstr, name, ext]=fileparts(filename)
load([pathname, filename], 'COV')
```

```matlab
COVsum(1,:)=COV


[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]); %
[pathstr, name, ext]=fileparts(filename)
load([pathname, filename], 'COV')
COVsum(2,:)=COV

[filename, pathname]=uigetfile('*.mat', 'Pick a data file', [based]); %
[pathstr, name, ext]=fileparts(filename)
load([pathname, filename], 'COV')
COVsum(3,:)=COV


    COVavg=(COVsum(1,:)+COVsum(2,:)+COVsum(3,:))./3
    COVstdev=std(COVsum, 1,1)


save([based, filename], '-append', 'COVavg', 'COVstdev')
```

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