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AGE RELATED CHANGES IN SKELETAL MUSCLE ACTIVATION
FOLLOWING SHORT-TERM RESISTANCE TRAINING

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

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"*There are no secrets to success. It is the result of preparation, hard work, and learning from failure.*" -Colin Powell

Any project such as this is not the result of any one individual. This document represents the culmination of ten years of higher education, and could not have been possible without significant contributions by my family, friends, and colleagues. Thank you for your continued support and understanding throughout this lengthy process.

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ABSTRACT

Current research suggests that older adults do not possess the same ability to fully activate skeletal muscle of the lower limb as do young adults. However, it is not known at what age these changes may negatively affect the improvement in neuromuscular activation associated with resistance training. **Purpose:** To determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age. **Methods**: Forty-six normal healthy males volunteered to participate in this research study. Subjects were designated into one of five groups, classified as individuals aged between 20-29 years (n=10), 30-39 years (n=10), 40-49 years (n=7), 50-59 years (n=9), and 60-79 years (n=10). Subjects participated in three supervised resistance training sessions over the course of seven days, performing four lower body exercises during each training session. Subjects were assessed for muscle cross-sectional area, muscular strength, and muscle activation via twitch interpolation and surface electromyography (SEMG) before and after the experimental training. Three-way and two-way repeated measures ANOVA, as well as a one-way ANOVA, was used to determine group differences and changes with training. **Results:** Analysis of baseline muscular strength data revealed only a significant difference ($p=0.02$) in muscle strength between Group 2, 30-39 years (132.4 ± 5.4) and Group 5, 60-79 years (99.8 ± 7.5) for plantarflexion maximal strength. No significant differences ($p>0.05$) were observed for muscle cross-sectional area, dorsiflexion muscular strength, muscle activation assessed via twitch

interpolation, or antagonist co-activation between age groups. Statistical analysis revealed no significant differences ($p>0.05$) in SEMG RMS amplitude or median frequency between age groups. However, comparison of muscle groups revealed a significant difference ($p=0.003$) in RMS amplitude between the soleus (SOL; 145.8 ± 10.2 μV) and medial gastrocnemius (MG; 254.2 ± 17.7 μV) muscles. Following training, there was no significant change ($p>0.05$) in muscle cross-sectional area, muscular strength, muscle activation assessed via twitch interpolation, or antagonist co-activation for any age group. Examination of SEMG data determined significant main effects for muscle group ($p=0.001$) and time ($p=0.013$) between SOL and MG for RMS amplitude. A significant decrease for the time main effect ($p=0.001$) in SEMG median frequency was also observed post-training. **Conclusions:** A similar pattern of response in all groups was observed in most variables assessed during the present study. The results from the present study indicated that there were no significant pre-test to post-test changes in muscle size, muscular strength, muscle activation, or antagonist co-activation following the experimental training period. These findings were unlike those from previous investigations of the leg extensors that have reported increases in performance after only two or three training sessions. This information may be useful for those involved in rehabilitative programs. Specifically, the muscles of the lower limb (i.e. calf) could require more than three training sessions to elicit the strength improvements and neuromuscular adaptations that typically occur during the early stages of a resistance training program.

CHAPTER I: INTRODUCTION

Study Rationale

Sarcopenia is a multifaceted condition that results in a progressive age-related loss of muscular size and strength (Roubenoff, 2001). Decreased muscle function in the elderly may contribute to the high incidence of accidental falls and may compromise quality of life (Chandler et al., 1988; National Center for Health Statistics, 2001). In the year 2000, the estimated direct healthcare cost attributable to sarcopenia in the United States was $18.5 billion ($10.8 billion in men, $7.7 billion in women), which represented about 1.5% of total health care expenditures for the entire year (NCHS, 2001).

Perhaps more important than the financial burden associated with sarcopenia, is the detrimental effect on quality of life that it imparts. Normal daily activities, and recreational activities, can be affected as a result of age-related loss of muscle mass and strength (Dawson et al., 1997). It has been demonstrated that the average 80- year-old no longer retains the capacity to rise unassisted from a chair (Dawson et al., 1997). Even more striking are recent data demonstrating that the degree of sarcopenia evident among the aged serves as a significant predictor of all-cause mortality (Metter et al., 2002). Thus, sarcopenia affects not only the quality, but also the quantity of life among the aged.

Normal aging results in decreased muscle mass caused by reduced number of muscle fibers and decreased size of individual muscle fibers (Lexell et al., 1988). However, losses in muscle mass alone can not fully account for the decrease in

strength associated with normal aging. Progressive deterioration of the nervous system with increasing age has been shown to have a significant impact on the structure and function of the neuromuscular system and muscular performance ultimately impairing the ability of older adults to voluntarily activate skeletal muscle.

Decreased strength may be the most apparent consequence of aging. Strength is a crucial component of the quality of life. Without adequate strength levels, even the most basic tasks become difficult or impossible to perform without assistance (Metter et al., 1997; Hruda et al., 2003). As life expectancy grows, the decline in muscle strength with aging becomes a matter of increasing importance. Research suggests that from ages 30 to 80 years; back, leg, and arm strength decrease 30 to 40% (Metter et al., 1997), while Hruda et al. (2003) observed an approximate 30% decline in strength and muscle mass in male subjects between age 30 and 70 years. The ability to maintain physical function and independence is heavily influenced by the ability to maintain strength levels.

Although research of aging muscle is vast and has become more refined, only recently have these methods been executed to better understand methods to prevent these degenerative processes. Resistance training has been proposed for older adults as a method to control the age-related decline in muscle mass and strength (Fiatrone et al., 1990; Hunter et al., 1995; Hunter et al., 2004). The initial increase in muscular strength has been related to improvements in the neuromuscular system, and occurs in absence of changes in muscle size (Moritani

and deVries, 1979). Adaptive changes in the neuromuscular system in response to resistance training include increased activation of motor units (Moritani and deVries, 1979; Herbert and Gandevia, 1988; Hakkinen et al., 1998), decreased co-activation of antagonist muscle groups (Carolan and Caffarelli, 1992), increased motor unit firing rate (Kamen et al., 1995; Knight and Kamen, 2004), and in some instances increased motor unit synchronization (Milner-Brown, 1975).

A primary question in human muscle physiology research is to what extent are individuals able to fully activate (contract) their muscle fibers during maximal voluntary contractions. To answer this question it is necessary to determine the activity level of the motor neuron pool. Surface electromyography (EMG) records the electrical action potentials produced during muscular contraction and is often used as a noninvasive measure of neuromuscular activation. The amplitude of EMG signal represents muscle activation, as it relates to the number of motor units recruited and the firing rates of active motor units (Basmajian and De Luca, 1985). The frequency of the EMG signal is related to the firing rate and conduction velocities of the muscle action potential (Hermes et al., 1992).

An additional method of determining motor unit excitation involves comparing the amount of voluntary excitation relative to maximal excitation of the motor neuron pool. This can be done by comparing the increment in muscle force produced when an electrical stimulus is delivered to a muscle during a voluntary contraction with the force increment produced when the same stimulus is delivered to the resting muscle (Merton, 1954; Allen et al., 1995). This process is referred to

as twitch interpolation (Merton, 1954). The twitch interpolation (TI) technique has been used extensively in the research of limitations to muscle force production (Allen et al., 1995; Behm et al., 1996; Todd et al., 1999), mechanisms of fatigue (Kent-Braun et al., 2001; Maffiuletti et al., 2002), and neural adaptations associated with resistance training (Knight and Kamen, 2001; Scaglioni et al., 2002; Morse et al. 2004, 2006). The TI technique allows researchers to quantify the percentage of voluntary activation of a specific muscle or muscle group.

It has been demonstrated that older adults do not possess the same level of voluntary activation as do young adults (Jakobi et al., 1999; Morse et al., 2004). Possible mechanisms for this age related decrease in neuromuscular activation include decreased number of motor units (Tomlinson and Irving, 1977), decreased motor unit firing rates (Kamen et al., 2004), decreased nerve conduction velocity (Norris et al., 1953), and morphological changes at the neuromuscular junction (Cardasis and Lafontaine, 1988).

Research suggests that short-term resistance training (3-4 training sessions) has produced significant improvements in muscular strength (Staron et al., 1994; Akima et al., 1994; Prevost et al., 1999) in healthy, young adults; limited research also exists demonstrating these changes in healthy, older adults (Knight and Kamen, 2001 and 2004). However, it has been shown that the magnitude of change in older adults is significantly less than that in the young. Furthermore, little is known of what time point these changes become significant.

Study Purpose

The purpose of this study was to determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age.

Significance of the Study

The neuromuscular system undergoes numerous adaptations with increased age and has a significant impact on muscle performance. The mechanisms of adaptation associated with the initial stages of resistance training are not fully understood. Research suggests that the early adaptations to a resistance training program are related to improvements in neuromuscular efficiency, which may be linked to increased ability to voluntary activate skeletal muscle. Additionally, current research suggests that older adults do not posses the same ability to fully activate skeletal muscle of the lower limb as do young adults. However, it is not known at what age these changes become readily apparent, or at what age these changes may negatively affect the improvement in neuromuscular activation associated with resistance training.

Significant changes in muscular strength and neuromuscular performance following short-term resistance training may also have implications in clinical settings. Improvements in muscle function that are apparent in as little a three training sessions may advance the knowledge of rehabilitation following injury or debilitating pathology.

Research Questions

1. Are there significant differences in peak torque, voluntary activation, and surface electromyography in the triceps surae between adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years?
2. Does short-term resistance training improve peak torque, voluntary activation, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years?

Research Sub-Questions

A. Do changes in peak torque, voluntary activation of skeletal muscle, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years following short-term resistance training occur in absence of changes in muscular hypertrophy?

B. Does antagonist muscle group co-activation contribute to changes in peak torque, voluntary activation of skeletal muscle, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years?

Research Hypotheses

1. Individuals 40 years of age and older will have significantly reduced ability to voluntarily recruit skeletal muscle when compared to younger subjects.

Changes within the peripheral nervous system of older adults, including decreased number of motor units, decreased motor unit firing rates, decreased nerve

conduction velocity, and morphological changes at the neuromuscular junction, may lead to a reduced ability to voluntarily recruit skeletal muscle.

2. There will be a significant improvement in the ability to voluntarily recruit skeletal muscle of the lower limb following short-term resistance training, with younger adults demonstrating the greatest increase.

Younger adults posses greater ability to increase voluntary activation with resistance training through increased activation of motor units, and in some instances increased motor unit synchronization. Older adults may not experience similar effects due to reduced efficiency within the nervous system.

Research Sub-Hypotheses

A. No significant changes in muscle hypertrophy will be apparent following short-term resistance training in adult males.

Muscle hypertrophy occurs as a result of chronic resistance training, and has been demonstrated to occur only after five to eight weeks of continuous training.

B. A reduction in antagonist muscle co-activation will contribute to the significant increase in peak torque, voluntary activation of skeletal muscle, and surface electromyography of the triceps surae.

Limited research suggests that there will be a significant reduction in antagonist muscle group activity following the three training sessions. This reduction will be related to the increase in force production by the agonists.

Delimitations

1. The inclusion of all apparently healthy males in the designated age categories.
2. The exclusion of all individuals with a history of chronic resistance training (>2 days/week) or physical activity greater than 3-hours per week for the last 12-months.
3. The exclusion of all individuals with any degenerative neuromuscular or joint disorders.
4. The exclusion of females from the study.

Limitations

1. Subject selection was based on volunteer participation and is not a random sample.
2. Medical information and health history was obtained through self-report.
3. The muscular assessment was limited to the triceps surae muscle group and may not be generalized to other muscle groups.
4. Neuromuscular and strength assessment was determined using an isometric contraction and may not be generalized to other types of muscular contractions.
5. As they are volunteers, subjects participating in the study are often interested in physical performance, and thus may not be representative of a normal population.

Assumptions

1. The twitch interpolation technique is a valid method of determining voluntary skeletal muscle activation.
2. Maximal effort was given during each trial and testing session.
3. All subjects understand the testing protocol.
4. The information provided in the health history questionnaire was honest and accurate.
5. All equipment was calibrated and accurate for all testing sessions.
6. Contributions of muscle(s) other than the triceps surae (i.e. vastus lateralis or biceps femoris) are negligible.

Operational Definitions

Maximal Voluntary Contraction (MVC): the maximum amount of force one can voluntarily exert by a muscle or group of muscles.

Voluntary Activation: the percentage of muscle mass that can be recruited voluntarily, without means of tissue stimulation.

Surface Electromyography (EMG): the recording of neural activation of the contracting muscle fibers from the surface of the skin.

Muscular Strength: the amount of force produced by a muscle or group of muscles.

Twitch Interpolation: The extent of activation can be quantified by expressing the interpolated twitch as a percentage of the twitch evoked in resting muscle; involves delivering an electrical pulse to a nerve while the subject attempts to produce a maximum voluntary contraction.

CHAPTER II: REVIEW OF LITERATURE

Introduction

As we as a society grow older many medical conditions associated with aging are becoming more prominent. One such condition is sarcopenia. Sarcopenia can be defined as the age-related loss of muscle mass (Roubenoff, 2001). In 1989, the term sarcopenia was coined by Rosenberg to describe the loss of muscle mass that occurs with age. The name sarcopenia comes from the Greek words "sarca" for flesh and "penia" for loss. Loss of muscle mass may account for decreases in basal metabolic rate, decreased activity levels, and decreased muscular strength and function in older individuals (Frontera et al., 1991; Hunter et al., 2001; Landers et al., 2001). The loss of muscle strength with age has attributed to the 30% of community-dwelling people 65 years or older falling at least once a year (Sayer et al. 2006). Falls are responsible for the largest proportion of injury deaths at people > 75 years old. Direct medical costs for fall injury in 2000 were $0.2 billion for fatal injuries and $19 billion for non-fatal injuries (Dellinger and Stevens, 2006).

Perhaps most importantly, research has shown that those entering their sixth and seventh decade of life are capable of benefiting from resistance training that challenges the triceps surae muscles to adapt to the stress of exercise (Scaglioni et al., 2002). Adaptations of such are helpful in the prevention of gait abnormalities and falls (Hageman and Thomnas, 2002). Moreover, these potential strength gains can be weaved into activities of daily living to create and or preserve a functional healthy lifestyle. Falls occur in about one in three older adults per year (Satton et al.

1990). These fall incidences have been related to disease states (Hausdorff et al., 2006), cognitive function, balance and mobility skills, depression (Kose et al., 2005), and atrophy of the plantar flexors (Simoneau et al., 2005; Winegard et al., 1996). Despite quantifiable research demonstrating these changes in muscle mass and strength with aging for nearly 200 years (Quetlet, 1835); the precise mechanisms are still unclear.

Muscle Physiology

Examination of age-related changes in the most fundamental unit of neuromuscular control, the motor unit (MU), can provide insight regarding the consequences of aging on muscle performance. A MU is a lower, α-motor neuron and all the muscle fibers it innervates (Brooks, Fahey, and White, 1996). Different than γ-motor neurons, which provide efferent innervation to the reflex-mediating muscle spindle; α-motor neurons provide efferent innervation to skeletal muscle fibers. The MU relays motor messages from the central to peripheral nervous systems resulting in activation of skeletal muscle (Brooks, Fahey, and White, 1996). The number of fibers innervated by a particular motor neuron is referred to as the innervation ratio. Essentially, if a motor neuron is lost, a motor unit is lost.

The consensus view from both animal and human studies is that motor units are lost with age. Early studies of Gutmann and Hanzlikova (1995) demonstrated a significant loss of motor units in aged rats. Additionally, Edstrom and Larsson (1987) found that the average number of motor units in soleus declined from 49 in 3- to 6-month-old rats to 29 in 20- to 24-month-old rats, a reduction of about 40%.

Einsiedel and Luff (1992) found a reduction in motor unit number in the rat medial gastrocnemius (MG) from an average of 93 to 66. Consistent with these results, the number of motor neurons in a particular motor neuron pool was found to decline with age. Hashizume and Kanda (1995) found a significant decrease in the number of MG motor neurons from an average of 132 in middle-aged rats to 121 in aged rats (27 months). There was no change in the number of motor neurons supplying the ulnar nerve in the rat forelimb. In addition the mean soma size of both motor neuron pools was reduced with age.

Muscle Strength

Numerous studies have shown that strength is diminished in aged muscle (Frontera et al., 1988; Cunningham et al., 1987; Fiatrone et al., 1990; Porter et al., 1995; Hunter et al., 1995; Trappe et al., 2001). This is true for both men and women (Porter et al., 1995), as well as in the muscles of the lower and upper extremities (Cunningham et al., 1987). Cross-sectional studies indicate that muscular strength reaches its peak at about 30 years of age and is well maintained through the 50th year of life (Frontera et al., 1988). Although a decline in strength occurs between 50 and 60 years of age, a much more rapid rate of loss is evident beyond the age of 60 years (Frontera et al., 1988).When averaged beyond the fifth decade of life, research indicates that strength decreases at a pace of nearly 15% per decade (Hakkinen et al., 1995).

The decline in maximal voluntary force in the elderly is related to a number of alterations affecting the musculoskeletal and nervous systems. Aging is

associated with reduced muscle mass due to the loss of muscle fibers (Frontera et al., 1991; Lexell, 1993) and atrophy of type II fibers (Lexell, 1993). A concomitant slowing of muscle contractile properties has also been observed with advancing age (Baudry et al., 2005; Vandervoort and McComas, 1986; Winegard et al., 1997). The slower contractile kinetics are primarily caused by a reduced rate of cross-bridge cycling (D'Antona et al., 2003; Hook et al., 2001) and alterations in excitation–contraction coupling (Hunter et al. 1999; Kent-Braun and Ng, 1999; Payne and Delbono, 2004), in addition to enhanced tendon compliance which can also reduce the rate of force development (Narici and Maganaris, 2006). Age-related adaptations recorded at the whole muscle level are also associated with remodelling of the MU structure (Roos et al., 1997), which consists of a motor neuron, its axon, and the muscle fibers that the axon innervates. The number of MUs is reduced with aging due to the progressive death of motor neurons. However, MU size (Doherty and Brown 1993; McNeil et al., 2005) and innervation ratio (Campbell et al., 1973) are greater in elderly compared with young adults due to the reinnervation of some denervated muscle fibers by surviving motor neurons.

Hakkinen et al. (1994) found that strength increases into the fourth decade and then decreases thereafter at an accelerated rate. Interestingly, 29% of the middle-aged and 15% of older subjects in their study showed no decline in grip strength. Men 11 to 70 years old were studied by Larsson et al. (1997). Isometric and dynamic strength increased to the third decade, remained stable to the fifth decade, and thereafter decreased with age. The strength decrease was not related to

visual muscle atrophy, which could be a result of the fat infiltration into muscle masking visual muscle loss (Larsson et al., 1997). Quadriceps muscle biopsy revealed decreased proportions and selective atrophy of type II fibers with age. A significant correlation between the strength decrease and type II fiber area was determined, but statistical analysis failed to support fiber area as a predictor of muscle strength. A reduction in Type I and II muscle fiber area with age was observed in men and women 20–70 years old by Tomlinson et al. (1997). This change was most evident after age 60. Loss of muscle mass can lead to a loss of strength and physical function, which is of primary concern for the elderly.

Recent longitudinal investigations have revealed a greater rate of age related strength reduction than what is apparent in cross-sectional studies. Frontera et al. (1991) detected decreases of 2.5% per year in the leg strength of older men followed for a 12-year period. Other longitudinal studies report strength reductions approaching 5% per year in aged muscle (Larsson et al., 1978). Much of the strength deficit observed among the aged can be explained by the loss of muscle mass that occurs in a near parallel fashion with the loss of strength (Frontera et al., 1991). Indeed, it has been estimated that the process of sarcopenia accounts for more than 90% of age-related strength diminution (Frontera et al., 1988).This implies that other minor factors contribute to strength decrements noted in aged muscle.

Hakkinen et al. (1994) suggested that other factors besides muscle mass decline influence strength loss with age. In their study involving subjects 20 to 100

years old, residual analysis showed that muscle size alone failed to explain the strength of the young subjects or the weakness of the old. Klitgaard et al. (1999) also observed an inability of the elderly to activate all muscle mass present. Schulte et al. (2001) have demonstrated the importance of the neural aspect of strength performance.

At lower force levels, activation of smaller/slower MUs occurs by summated recruitment. With the demand for higher force, larger MUs are recruited. Because the generation of force at high levels entails the sequential recruitment of larger MUs along with additive recruitment of smaller MUs, loss of the large MUs would decrease force generation as fewer large MUs would be available for recruitment. Additionally, Type II fibers formerly innervated by large motor axons but now remodeled into slow MUs exhibit the physiologic characteristics of slow MUs and show a reduced capacity for generating force (Macaluso and De Vito, 2004). Changes at the level of the MU appear to contribute significantly to the magnitude of strength loss observed with aging.

Muscle Activation

Voluntary Activation

In addition to changes within the muscle, alterations in the central neural command that result in impaired agonist activation and/or increased antagonist co-activation (Bilodeau et al., 2001; Izquierdo et al., 1999; Macaluso et al., 2002; Morse et al., 2004) might contribute to the decline in maximal force capacity commonly observed in older adults. Whereas a consensus exists in the literature

regarding alterations within the muscle of elderly adults, results related to the ability of the central nervous system to fully activate a muscle during a maximal voluntary contraction (MVC) are conflicting (Bilodeau et al., 2001; De Serres and Enoka, 1998; Kent-Braun and Ng, 1999; Klass et al., 2005; Macaluso and De Vito, 2004; Morse et al., 2004; Pousson et al., 2001; Roos et al., 1999; Simoneau et al., 2005; Stevens et al., 2003).

Maximal activation of muscle by the nervous system is influenced by the excitability of cortical neurons and motor neurons at the spinal cord. Using single transcranial magnetic stimulation, Eisen et al. (1991) observed a reduced motor evoked potential and Pitcher et al. (2003) reported that higher intensities are required to achieve the same maximal motor output in elderly subjects compared with young adults. Although both these studies suggest changes in the excitability of the cortico-spinal pathway, the results do not necessarily reflect submaximal activation during a MVC in elderly adults.

Voluntary activation, commonly defined as the level of neural drive to muscles during a maximal contraction (Allen et al., 1998), has been assessed by different methods. However, no definitive answer can be drawn from the existing literature as to whether voluntary activation during MVC is modified with aging. Part of the discrepancy may be ascribed to differences in the age and physical condition of the elderly and young groups that were compared. Other factors that make it difficult to compare the results of existing studies include differences in the

sensitivity of the method used to assess voluntary activation, the muscle group that is tested, and the type of contraction that is performed.

Voluntary activation of skeletal muscle requires proper functioning of both the central (CNS) and peripheral (PNS) pathways. The CNS processes involve the activation of the motor portions of the cerebral cortex and motor neuron pool in the ventral gray matter of the spinal cord. A motor neuron has a cell body which resides in the spinal cord, and an axon which extends from the spinal cord to the muscle, with each branch terminating on a single muscle fiber.

Peripheral activation begins with the transmission of the action potential along the peripheral motor nerve axon, continues across the neuromuscular junction to the muscle membrane and ends with cross-bridge formation between the myosin heads and actin filaments. A motor neuron excites its muscle fibers by conducting nerve impulses down its axon and axonal branches. Through the twitch interpolation technique, it may be possible to estimate the total number of available motor units, and the number of motor units activated during a voluntary contraction.

The amplitude of the interpolated twitch declines with increasing contraction intensity, so it has been used to measure the level of recruitment of motor units, also referred to as voluntary activation (VA). If the electrical stimulation does not evoke any additional torque, the muscle is considered to be fully activated, whereas voluntary activation is considered to be sub-maximal when torque is increased by the stimulation. The magnitude of voluntary activation is usually quantified by the ratio of the superimposed torque during the MVC to the evoked torque measured at

rest either before or after the MVC (IT ratio). Voluntary activation is typically expressed as a percentage and is calculated as follows: (1−superimposed torque/control torque)×100 (Allen et al., 1995).

The method has also been used to estimate the muscle force that could be produced if voluntary activation were complete. During a maximal voluntary contraction, if a subject manages to completely occlude the interpolated twitch, (no increase in force when stimulated) it is assumed all motor neurons have been excited.

Twitch interpolation has been used to investigate: limitations to muscle force production (voluntary activation), mechanisms of fatigue, and neural adaptations associated with resistance training. Most research using twitch interpolation assesses voluntary activation during isometric MVC. Research using the twitch interpolation technique has determined that the adductor pollicis, biceps brachii, and brachialis are capable of complete activation in healthy subjects. Other muscle groups, such as plantarflexors and quadriceps femoris, may rarely be fully activated. Clear deficits in voluntary activation have also been observed in elderly adults who are less physically active (Harridge et al., 1999) or affected by disease (e.g. osteoarthritis; Hurley and Newham, 1993).

Perhaps the premiere study on the reliability of the twitch interpolation technique was performed by Allen et al. (1995). This study questioned the findings of previous research suggesting that skeletal muscle could be fully activated in the biceps brachii muscle. The purpose of this study was to determine the repeatability

in voluntary activation of the biceps brachii over time and between subjects. Maximal voluntary activation varied ranged from 90.3 ± 2.26% to 99.8 ± 0.26%. Maximal voluntary activation is typically not observed consistently in the biceps brachii muscle. Between subject variability varies, but within subject testing is reproducible between days.

Very few studies have identified the differences in voluntary activation between muscle groups and between age-grouped subjects. A study by Jakobi and Rice (2001) attempted to determine the differences between voluntary activation of the elbow flexors and extensors in young and old adults. Six young men (24 ± 1 years) and six old men (83 ± 4 years) performed 5 isometric MVCs for elbow flexors and elbow extensors over 2 separate test sessions. No significant differences in voluntary muscle activation were observed between the young and old men for either muscle group (Y: EF 96%, EE 99%; O: EF 98%, EE 98%), despite a significant difference in MVC value. A greater variability was observed in the ability to maximally voluntarily contract between the age groups and muscle groups. These findings suggest that old males are capable of voluntarily recruiting muscle similar to young men, but have greater variability and may require more attempts.

It has been proposed that maximal VA as determined via twitch interpolation increases following resistance training. Several authors have offered suggestions as the increase in VA including: increased motor unit firing rate, increased activity as measured by surface EMG, neuromuscular cross-education, and enhanced reflex potential. Some studies using the twitch interpolation technique have reported no

change in percent of VA following resistance training. Three main reasons exist for these discrepancies: (1) Early studies determined full activation prior to training, as the technology was not sophisticated to determine small changes in muscle activation. (2) The principle of specificity suggests that exercise testing should resemble exercise training. Many studies utilize dynamic resistance training as an intervention, while isometric testing is used to measure VA. (3) Only small change in improvement (i.e. from 98% to 99%) was observed in some muscle groups as VA was high to begin the study.

Decreased neural drive has been associated with increased age, and is generally accepted as a cause for decreased muscle size and strength. Scaglioni et al. (2002) attempted to determine the changes in voluntary neural drive in older adults following 16-weeks of strength training. Fourteen male subjects between 60 – 85 years participated in a 16-week resistance training study. Voluntary activation of the plantar flexor muscle group was assessed before and after training; in addition to resting measures of neuromuscular function (H-reflex, M-wave). Twitch interpolation was used to asses voluntary activation during 3, 5-second isometric MVCs; and during submaximal isometric contractions. Sixteen weeks of strength training improved voluntary activation of the plantar flexors in older adults (94.8 ± 6.7% pre, 97.7 ± 2.1% post; $p=0.03$). Both pre- and post-training values were significantly different than 100% voluntary activation ($p=0.015$ and 0.002 respectively). Comparison of resting neuromuscular properties and nerve conduction velocity determined a significant difference between older adult males

and a younger control group ($p = 0.02$). Following training, there was no improvement in these properties.

It is well known that muscle mass and muscular strength decline with increased age. Morse et al. (2004) attempted to determine the relationship between muscle activation on the specific torque of the plantar flexors in young and old men. 14 young men (24.7 ± 4.7 years) and 21 elderly men (73.7 ± 3.6 years) volunteered for this cross-sectional study. Measurement of muscle size was assed via MRI to determine cross-sectional area of the triceps surae (lateral and medial gastroc, and soleus). Voluntary activation was assessed using twitch interpolation during an isometric MVC. Specific torque was determined as the ratio of peak torque and muscle volume. Muscle size and strength were significantly lower in the old men compared to the young men. Activation capacity was also significantly lower in old men. Reduced specific torque (PT / Vol) in older males is related to reduced activation capacity. Reduced muscle mass and activation capacity limit the ability to produce force in the plantar flexors. Possible future research could attempt to determine the changes in these properties through training.

As discussed earlier, it is not uncommon to observe individuals who are unable to recruit 100% of their available motor units or muscle. This observation is also present in older populations (Kamen et al., 2000). Muscle strength and activation were studied in 11 very elderly subjects (8 women and 3 men; age range, 85-97 years) who completed 12 weeks of strength training of the knee extensor muscles. Training increased maximum voluntary isometric muscular strength

(134%; $P < 0.05$).The twitch interpolation technique identified muscle activation during a maximal voluntary isometric contraction was shown to be incomplete in all subjects before training (ranging from 69% to 93%) and was not significantly increased after training.

Research by Knight and Kamen (2001) measured motor unit discharge rates in 15 older adults. Subjects performed isometric knee extension contractions at 10%, 50%, and 100% of maximal voluntary contraction or effort (MVC) on two separate occasions. Participants then completed a 6-week resistance exercise training protocol. Significant increases in maximal force were observed as early as 1 week after the first baseline testing session, and these were accompanied by increases in the motor unit discharge rate. Motor unit discharge rates at 100% of maximal effort were significantly greater in the young than in the older adults. Furthermore, the young adults also exhibited significantly greater discharge rates at 50% MVC, but there were no differences at the 10% force level. The early increase in maximal motor unit discharge rate with repeated maximal force assessment may comprise an important neural mechanism mediating early, rapid gains in muscular force capability.

Surface Electromyography

Another technique often used to quantify changes in voluntary activation of the agonist or antagonist muscles is surface electromyography (EMG). This technique measures the electrical activity of MUs located beneath recording electrodes that are placed on the skin overlying the muscle belly. The amplitude and

the power spectrum of the surface EMG depend on the propagation of action potentials along the muscle fibers (Farina et al., 2004). The advantage of this technique is that it is non-invasive and provides a global estimate of muscle activation without the need to apply electrical stimulation. Although the inherent nature of the signal implies that there are limitations involved with interpreting surface EMG amplitude and frequency data (Farina et al., 2004), EMG has been a valuable tool for investigating neuromuscular adaptations to resistance training. However, there are several limitations: (1) surface EMG is influenced by both central and peripheral factors which are difficult to differentiate; (2) surface EMG underestimates the activation signal sent from the spinal cord to muscle due to cancellation of the positive and negative phases of MU action potentials (Farina et al., 2004; Keenan et al., 2005); and (3) comparisons of surface EMG between subjects are limited by a variety of factors including differences in the thickness of subcutaneous tissues and the distribution of MU territories in the muscle (Farina et al., 2004; Keenan et al., 2005).

Due to changes in fat accumulation with aging, the comparison of raw EMG signals between young and elderly subjects is not recommended. However, the decrease in average EMG amplitude (Esposito et al., 1996; Macaluso et al., 2002) and mean frequency of the power density spectrum (Esposito et al.,1996) observed during isometric contractions in older adults has been sometimes associated with possible change in voluntary activation. In addition to a reduction in the number and maximal discharge rate of MUs (McNeil et al., 2005) that is often reported with

aging (Connelly et al., 1999; Kamen et al., 1995), these authors nevertheless suggested that these age-related changes were partly due to greater skinfold thickness in the older adults. The same conclusion was reached when EMGs were normalized to the M-wave amplitude obtained in response to supramaximal electrical stimulation of the motor nerve (Klass et al., 2005). This normalization procedure controls for age-related differences in muscle membrane ionic processes and, therefore, provides an indirect measure of the subject's ability to maximally activate the muscle group. These results are consistent with those previously reported using the superimposed stimulation technique (Klass et al., 2005) and support the idea that elderly and young subjects achieve similar levels of voluntary activation for the ankle dorsiflexor muscles.

Antagonist Co-activation

Greater antagonist co-activation (ANTCO) can reduce the performance of agonist muscles both through the opposing mechanical action of the antagonist muscles (Carolan and Cafarelli, 1992), and also by reciprocal inhibition (Croce and Nielsen, 1989). Nevertheless, a small level of ANTCO is usually considered to be useful in the stabilization of the joint (Baratta et al., 1988). The magnitude of ANTCO during MVCs is typically assessed by expressing EMG activity in the antagonist muscle as a percentage of its activity when acting as an agonist during a maximal contraction (Kellis, 1998). Similar to the conflicting reports of changes in voluntary activation with ageing, the literature regarding alterations in ANTCO is highly variable.

Some of the studies that have measured antagonist activity showed a higher level of ANTCO during maximal isometric (Izquierdo et al., 1999; Klein et al., 2001; Valkeinen et al., 2002) and concentric (Izquierdo et al., 1999) contractions in elderly compared with young adults. In contrast, some authors did not observe any difference between age-groups during dynamic (Klass et al., 2005; Ochala et al., 2004; Pousson et al., 2001) or isometric (Klass et al., 2005; Morse et al., 2004; Pousson et al., 2001; Simoneau et al., 2005) contractions either for upper or lower limb muscles. As discussed by Macaluso et al. (2002), these contrasting results seem to be partly related to the muscle group investigated because increased ANTCO was observed in elders during maximal knee extension, but not during knee flexion. Simoneau et al. (2005) have also reported conflicting results for the ankle plantar- and dorsi-flexor muscles. Interestingly, these authors reported lower ANTCO in elderly compared with young subjects during maximal plantar flexion, and similar levels of ANTCO during dorsiflexion. In both age-groups, the level of ANTCO appeared to be positively related to the torque produced. Another factor that could explain part of the discrepancy between results is the contraction modality. Burnett et al. (2000) reported greater ANTCO of intrinsic hand muscles during submaximal concentric and eccentric contractions in the elderly, with no corresponding differences in ANTCO during isometric contractions. In contrast, comparable levels of ANTCO were observed in elderly and young adults during maximal contraction of the ankle dorsiflexors, regardless of the contraction modality and velocity (Klass et al., 2005).

Resistance Training

Resistance exercise should be the primary focus of a program targeted against sarcopenia. Other modes of exercise do not provide sufficient overload to produce increases in muscular size and strength. Kaneko et al. (1989) observed loss of strength per unit of muscle with increasing age. They suggested that to maintain muscle efficiency, people should make a special effort to resistance train as they get older. After measuring manual laborers at retirement and at 1 year after, LaStoy et al. (1999) suggested that maintenance of physical activity in the elderly is important. A 4% reduction in thigh muscle area and a 5% reduction in the ratio of muscle to body mass were observed.

Research by Greelund et al. (1995) suggested that the elderly are capable of participating in a properly designed resistance training program. Active women over 60 were compared to active college-age women on the parameters of exercise-induced muscle damage and the ability of older muscle to repair and adapt to this damage. Exercise resulted in similar damage, repair, and adaptability patterns in young and old. No significant differences in isometric strength occurred between young and old subjects, suggesting that physical activity counteracts the age-related decline in strength.

Short-Term Strength Training

Recent studies (Brown and Whitehurst, 2003; Coburn et al., 2006; Prevost et al., 1999) have suggested that very short-term training programs (2-3 training sessions) may be useful for increasing strength and muscular performance. For

example, Prevost et al. (1999) reported a 22.1% increase in isokinetic leg extension peak torque following just two training sessions. Brown and Whitehurst (2003) also examined the effects of two training sessions and found significant improvements in the rate of velocity development during maximal concentric isokinetic leg extensions. In addition, Coburn et al. (2006) reported significant increases in isokinetic leg extension PT after just three training sessions. The potential for very short-term training to increase strength and/or muscular performance has implications for allied health fields such as physical medicine, physical therapy, and occupational therapy, where access to patients is an important factor in the design of rehabilitation programs. Specifically, if a patient's rehabilitation goals can be met with 1 or 2 weeks of training, they may be more likely to comply with the therapy program. In addition, in certain situations, very short-term training may provide a cost-effective alternative to surgery or long-term therapy programs (Coburn et al., 2006).

Increases in muscular strength during a resistance training program are usually attributed to two general factors: a) neural adaptations such as increased activation of agonist and/or synergist muscles involved in the muscle action, improved coordination, and reduced co-activation of antagonist muscles, and b) increases in muscle fiber size (hypertrophy) (Moritani and deVries, 1979). It is generally believed that neural factors account for most of the increases in strength during the first 1-3 weeks of a resistance training program, while muscle fiber hypertrophy becomes the dominant factor underlying strength gains after

approximately 3-5 weeks of training. Theoretically, the improvements in strength or muscular performance that have been reported following very short-term training occur too quickly to be attributed to muscle fiber hypertrophy (Moritani and deVries, 1979).

All previous investigations of short-term resistance training (Brown and Whitehurst, 2003; Coburn et al., 2006; Prevost et al., 1999) have assessed only the quadriceps femoris muscle group and only two (Brown and Whitehurst, 2003; Coburn et al., 2006) have examined neuromuscular responses. Thus, it is unclear if the increases in strength found following very short-term training are specific to the muscle(s) being tested and if the characteristics of the muscle (i.e. fiber type composition, muscle architecture, etc.) influence the responses.

Conclusion

In conclusion, the age-related decline in force results mainly from alterations within the muscle, whereas the contribution of voluntary activation deficits during MVC of a single muscle group in healthy and active elderly adults seem to be variable. Additionally, despite similar experimental approaches, results comparing the co-activation of agonist and antagonist muscles in elderly and young subjects are also highly variable. Further experiments are needed to investigate potential impairments in voluntary activation during multi-joint movements and following short-term strength training in both young and older adults.

CHAPTER III: METHODOLOGY

Subject Information

Forty-six normal healthy males between 20 and 79 years of age volunteered to participate in this research study. Subjects were designated into one of five groups, classified as individuals aged between 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years. Participants were recruited through flyers, television advertisements, and by word of mouth. Flyers were placed on campus in high traffic areas, as well as other well-traveled areas around the Norman – Oklahoma City metropolitan area.

All subjects had similar histories of physical activity and were considered active, but not currently engaged in a chronic exercise program (< 3 hours/week of moderate physical activity). Twenty-four of the 46 participants reported engaging in 1.5-3 hours of aerobic exercise, 32 of 46 reported 1.5 – 3 hours of resistance exercise, and 15 of 46 reported 1– 3 hours of recreational sports per week (golf, disc golf, basketball, etc.).

All subjects were medically screened using a health history questionnaire (Appendix) prior to inclusion in this study. The exclusion criteria included cardiovascular, myopathic, neurological, and joint diseases or disorders. Health histories were evaluated using American College of Sports Medicine guidelines. Any subject over the age of 59 years, or who had a contraindicative health history, was required to receive medical clearance from a physician prior to participation in this study (Appendix). All procedures were approved by the University of

Oklahoma Institutional Review Board (IRB #11309), and written informed consent was obtained from each participant.

Experimental Protocol

This study used a mixed cross-sectional and longitudinal research design which compares the neuromuscular adaptations following short-term resistance training betweens groups of subjects based upon chronological age. Subjects were asked to participate in three lower-body resistance training workouts to determine the changes in muscular strength and voluntary muscle activation of the lower limb during the initial stages of a resistance training program. Measurements of muscle cross-sectional area, isometric force production, and voluntary activation assessed via surface electromyography and the twitch interpolation technique were performed before and after an experimental training period. Testing of subjects consisted of six total visits to the Neuromuscular Research Laboratory within the Department of Health and Exercise Science at the University of Oklahoma.

Physical Characteristics

Chronological age was determined via subject self-report to be the age, in years, during the subject's initial visit to the testing laboratories. Upon arrival to the laboratory during the initial familiarization visit, subjects' were assessed for height and body mass. Height was measured to the nearest 0.5 cm using a wall-mounted stadiometer (Novel Products Inc., Rockton, IL). Body mass was measured to the nearest 0.1 kg using an electronic scale (Tanita Corp., Tokyo, Japan).

Familiarization

All subjects underwent a familiarization session prior to preliminary testing. This session was used to familiarize subjects to the testing procedures and involved subjects performing submaximal and maximal isometric muscular contractions involving plantar flexion of the right leg. The goal of this session was for subjects to produce reliable measures of plantar flexion torque. An additional goal of the familiarization sessions was to introduce subjects to neural stimulation, as used during the twitch interpolation procedure. Subjects were exposed to low-amplitude, percutaneous stimulation applied to the tibial nerve. Stimulation occured when the muscles were at rest, and during submaximal and maximal isometric muscular contractions.

Subjects were also familiarized and instructed to the dynamic isotonic resistance training equipment utilized during the three training sessions. Subjects were instructed on proper exercise technique by a certified instructor and required to perform two sets of 15 repetitions at a self-determined training load.

Muscle Size

Muscle volume of the triceps surae muscle group (medial and lateral gastrocnemius and soleus) was estimated by measuring muscle cross-sectional area (CSA) of the right calf. Muscle CSA was calculated using calf circumference and correcting for subcutaneous fat. Limb circumferences were measured to the nearest millimeter using a tension-gauged measuring tape (Gulick II; Country Technology, Inc., Gays Mills, WI). Measurements of skinfolds were taken from the medial and

lateral surfaces of right calf. Skinfolds were measured in millimeters using Harpenden calipers (British Indicators; West Sussex, UK) at the point of greatest circumference. The measurements were taken in triplicate and averaged. The skinfold and circumference measurements were then used in the formula: CSA = (C - ∏S) ² / 4∏ where C was defined as the circumference of the limb and S was the average of one-half of the medial and lateral skinfolds (Gurney and Jelliffe, 1973).

Muscle Strength

Muscular torque during voluntary isometric contractions (MVC) was collected using an isokinetic dynamometer (KinCom). Each participant was seated in an upright position in the dynamometer chair and secured with restraining straps around the trunk and hips in accordance with the dynamometer user manual (KinCom). The hip and knee were positioned at 180° of full extension. The right ankle was positioned at the dynamometer's axis of rotation and secured to the dynamometer's lever arm proximal and distal to the ankle. The foot was secured tightly to the footplate to minimize heel displacement, and the subjects performed three submaximal isometric plantarflexion (PF) and dorsiflexion (DF) contractions as a warm up. Two isometric maximal voluntary DF contractions were performed to obtain maximal DF data for calculation of antagonist co-activation in the tibialis anterior. Three isometric maximal voluntary PF contractions were performed. These PF MVC trials were used to assess maximal torque (before the twitch interpolation technique) and used to calculate voluntary activation.

All muscle contractions were performed with the ankle at 0° of plantar flexion. For each isometric strength assessment, each participant performed MVCs lasting 3-5 seconds in duration, with at least 1-minute rest between trials. The participants were instructed to give a maximum effort for all trials, and strong verbal encouragement was provided by the investigators.

Muscle Activation

Twitch Interpolation

The twitch interpolation (TI) technique involved delivering an electrical pulse to a nerve while the subject attempts to produce a maximum voluntary contraction. The extent of activation could be quantified by expressing the interpolated twitch as a percentage of the twitch evoked in resting muscle (Merton, 1954; Allen et al., 1995).

The percutaneous electrical stimulus was a rectangular pulse (1-ms duration) delivered by a high-voltage constant-current stimulator (Digitimer DS7a, Herthfordshire, UK). The cathode was a metal probe (8 mm diameter) with the tip covered in a saline-soaked sponge, which was pressed into the poplitea fossa (posterior to the knee joint). The anode was a 9 x 5 cm rectangular self-adhesive electrode (Durastick Supreme, Chattanooga Group, Hicton, TN) that was positioned over the patella (anterior surface of the knee). Single stimuli were used to determine the optimal probe location (30 mA) and the maximal compound muscle action potential (M-wave) with incremental amperage increases (30-300 mA). Once a plateau in the peak-to-peak M-wave was determined, despite amperage increases,

20% was added to the amperage that yielded the highest peak-to-peak M-wave to assure a supramaximal stimulus.

Doublets were administered with the supramaximal stimulus intensity during the MVC trials to increase the signal-to-noise ratio and minimize the series elastic effects on torque production (Desbrosses et al., 2006). In accordance with the twitch interpolation procedure, a supramaximal doublet was administered 3-5 seconds into the MVC plateau (superimposed twitch) and then again 3-5 seconds after the MVC trial at rest (potentiated twitch). %VA was calculated with the following equation (Allen et al., 1995): %activation = (1 - superimposed twitch amplitude / control twitch amplitude) * 100

Surface Electromyography

Surface electromyography (EMG) was used to detect the electrical potential generated during muscular contraction. The surface EMG signal was generated by a summation of the action potentials from the active motor units within the recording area of the electrodes (Farina et al., 2004). Thus, it has been suggested that EMG amplitude was influenced primarily by the level of muscle activation, inclusive of the number of active motor units and their firing rates (De Luca, 1997).

The muscles associated with plantar flexion (soleus and medial gastrocnemius) and dorsiflexion (tibialis anterior), to measure antagonist co-activation, were measured using with three separate bipolar (20 mm center-to-center) surface electrode (circular 4 mm diameter silver/silver chloride, Biopac Systems, Inc., Santa Barbara, CA) arrangements. Prior to placement of the

electrodes, the skin was shaved to remove hair and the recording sites were rubbed lightly using an abrasive pad and cleaned using isopropryl alcohol swabs to reduce inter-electrode impedance. To ensure that EMG recordings were made beyond the motor point of the muscle, all electrode placements were in accordance with Zipp (1982). A single pre-gelled, disposable electrode (Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) served as a reference electrode and was placed over the right medial epicondyle of the femur.

Antagonist Co-activation

Surface EMG activity of tibialis anterior was recorded while performing both maximal isometric PF and DF contractions. The level of co-activation of the tibialis anterior was assessed using the RMS amplitude of the raw EMG signal, which was integrated over the peak MVC torque during PF, this was then expressed as the percentage of activity recorded from the tibialis anterior during maximal DF (Morse et al., 2006).

Signal Processing

The EMG and torque signals were recorded simultaneously with a Biopac data acquisition system (MP100a, Biopac Systems, Inc., Santa Barbara, CA) during each isometric MVC trial. The torque (Nm) signal from the dynamometer and the EMG (μV) signal recorded from the active muscles were sampled at 2 kHz. All signals were stored on a personal computer (Dell Inspiron 8200, Dell, Inc., Round Rock, TX), and processing was completed off-line using custom written software (LabVIEW v 7.1, National Instruments, Austin, TX). The EMG signal was digitally

filtered (zero-phase 4th-order Butterworth filter) with a pass band of 10-500 Hz and 5-100 Hz, respectively. The torque signal was low pass filtered with a 10 Hz cutoff (zero-phase 4th-order Butterworth filter) and gravity corrected so that the baseline values was 0 Nm. All subsequent analyses were performed on the filtered signals.

Isometric MVC torque (Nm) was calculated as the average torque value during the 0.5s epoch taken immediately prior to the superimposed twitch. The same 0.5 s epochs were selected from the EMG signal to calculate the time and frequency domain estimates during the MVC trials. For each EMG signal epoch during the MVC trials, the time domain was represented as the root mean square (RMS) amplitude value. For the frequency domain, each epoch was processed with a Hamming window and a discrete Fourier transform. The median power frequency (MDF) was calculated as described by Kwatny et al. (1970) to represent the power spectrum based on the recommendations of Hermens et al. (1999) due to the high signal-to-noise ratios of the EMG signals in the present study.

Resistance Training Protocol

All subjects participated in three supervised resistance training sessions over the course of 7-days. All training sessions were separated by a minimum of one day of rest. Each exercise session began with five minutes of warm-up on either a bicycle or a treadmill at a low, self-selected intensity followed by general calisthenics performed ad libitum. Subjects performed four lower body exercises during each training session. Each subject performed three bilateral calf exercises: (1) standing smith-machine calf raise, (2) seated calf raise, and (3) calf raise

performed on the prone leg press. An additional lower body exercise, (4) prone leg press was also performed.

During the pre-test visit to the laboratory, subjects were assessed for one repetition maximum (1RM) on the seated calf raise and prone leg press. 1RM was defined as the greatest amount of weight move through a complete range of motion. Training load for the standing smith-machine calf raise was determined as the subject's pre-test bodyweight plus up to an additional 10 kilograms. Training load for the calf raise performed on the prone leg press was 50% of the subject's 1RM on the prone leg press. During training, each exercise consisted of one warm-up set at 50% of the subject's 1RM for 10 repetitions, followed by four sets of 10 repetitions with 70% of the subject's 1RM. Two minutes of rest are given between sets and three minutes between exercises.

Statistical Analysis

All data were expressed as mean ± standard error in the text, figures, and tables. All performance measures pre-to-post training were analyzed using Statistical Package for the Social Sciences (SPSS v14.0 software, SPSS Inc., Chicago, IL). At baseline, potential differences between groups were tested using a one-way analysis of variance (ANOVA) for each dependent variable. Two way [group (age) x trial (pre-post)] repeated-measures ANOVA was used to determine the effects of the training protocols on the dependent variables. The complete model was used to examine surface EMG data, using a three way [muscle (SOL - MG) x trial (pre-post) x group (age)] repeated-measures ANOVA, to determine the

effects of the training protocol. When significant F-ratios were observed in comparisons of main effects, the Holm's Sequential Bonferroni post-hoc test was used to determine significance. To examine percent change for each dependent variable a one-way ANOVA was used.

Based on the results from previous studies (Knight and Kamen, 2001), a priori analyses were used to determine sample sizes that yielded power values of 0.80 or greater for the isometric MVC data. An alpha level of $p \leq 0.05$ was considered statistically significant for all comparisons.

CHAPTER IV: RESULTS and DISCUSSION

RESULTS

The purpose of this study was to determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age. The findings of the study are presented in the following order:

I. Cross-sectional analysis between groups;

II. Longitudinal analysis (pre-post training) between groups;

III. Comparison of percent change between groups.

I. Cross-Sectional Analysis between Groups

Physical Characteristics

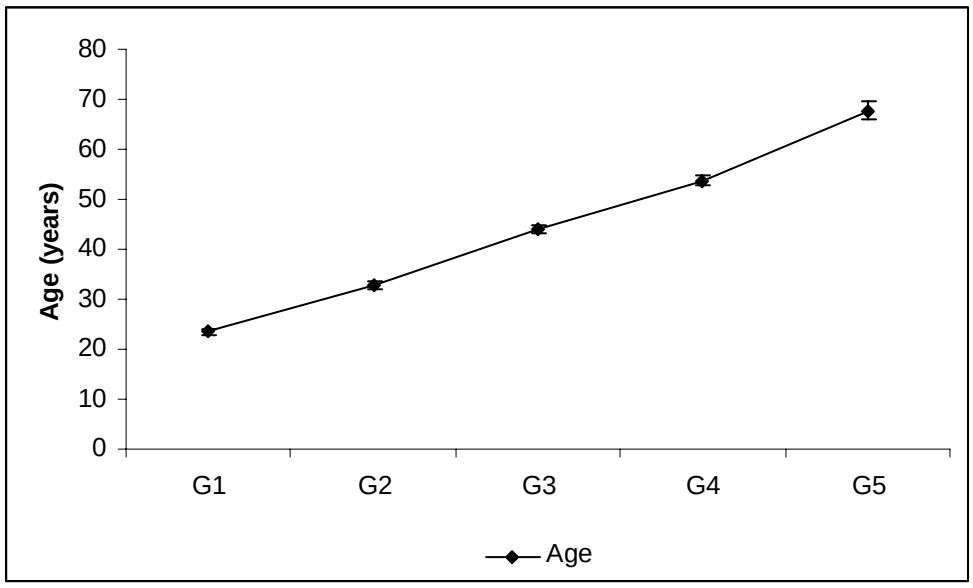
A total of 46 healthy male subjects participated in this study. Subjects were assigned to one of five groups based upon chronological age. The five groups were Group 1 (G1, 20-29 years; n = 10), Group 2 (G2, 30-39 years; n = 10), Group 3 (G3, 40-49 years; n = 7), Group 4 (G4, 50-59 years; n = 9), and Group 5 (G5, 60-79 years; n = 10). Subject characteristics of chronological age, standing height, and body weight are displayed in Table 1. Statistical analysis revealed no significant differences between standing height and body weight. Age group differences were observed between all groups ($p<0.05$).

Table 1. Baseline Comparison of Physical Characteristics

Group (Age Range)	Sample	Age (years)	Height (cm)	Weight (kg)
G1 (20-29 years)	n = 10	23.5 ± 0.5*	179.8 ± 2.2	80.7 ± 5.0
G2 (30-39 years)	n =10	32.8 ± 0.7*	176.0 ± 2.2	86.3 ± 5.2
G3 (40-49 years)	n = 7	44.0 ± 0.8*	175.6 ± 1.9	76.8 ± 3.8
G4 (50-59 years)	n = 9	53.7 ± 1.0*	178.9 ± 2.7	81.9 ± 3.9
G5 (60-79 years)	n = 10	67.7 ± 1.8*	172.7 ± 1.5	81.7 ± 2.4

* indicates significant differences ($p<0.05$) between age groups

Figure 1. Baseline Comparison of Chronological Age



Muscle Size

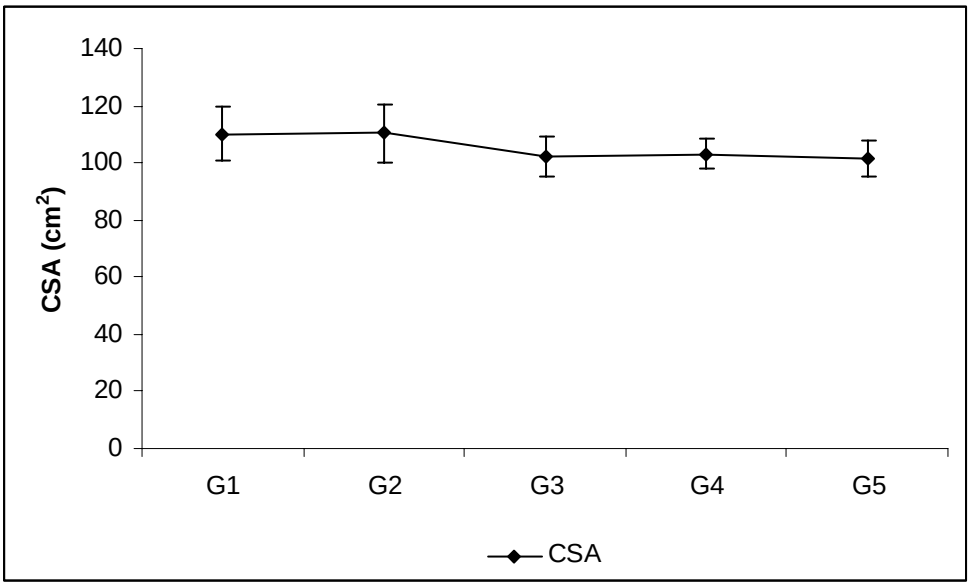
Muscle cross-sectional of the triceps surae data are displayed in Table 2. Statistical analysis revealed no significant differences ($p>0.05$) in muscle size between age groups. However, a decrease in muscle CSA following the 4th decade was observed.

Table 2. Baseline Comparison of Muscle Cross-Sectional Area

Group (Age Range)	CSA (cm^2)
G1 (20-29 years)	110.1 ± 9.6
G2 (30-39 years)	110.3 ± 10.3
G3 (40-49 years)	102.4 ± 7.0
G4 (50-59 years)	103.3 ± 5.2
G5 (60-79 years)	101.8 ± 6.3

CSA: muscle cross-sectional area

Figure 2. Baseline Comparison of Muscle Cross-Sectional Area



CSA: muscle cross-sectional area

Muscle Strength

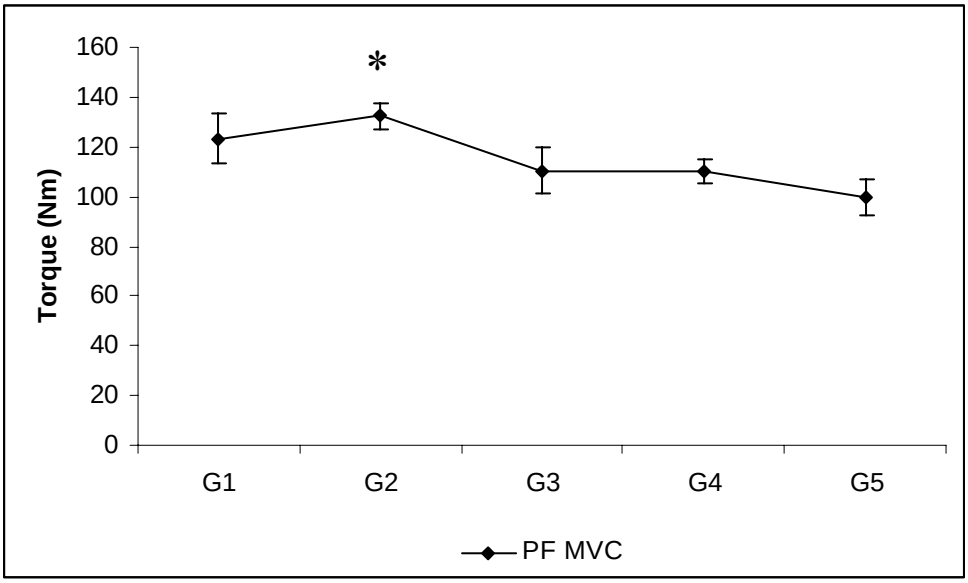
Muscular strength data are displayed in Table 3. Statistical analysis revealed a significant difference ($p=0.02$) in muscle strength between G2 (132.4 ± 5.4) and G5 (99.8 ± 7.5) for plantarflexion maximal strength. No significant differences ($p>0.05$) were observed for dorsiflexion.

Table 3. Baseline Comparison of Muscle Strength

Group (Age Range)	PF MVC (nm)	DF MVC (nm)
G1 (20-29 years)	123.4 ± 9.8	22.6 ± 2.2
G2 (30-39 years)	132.4 ± 5.4*	26.4 ± 1.4
G3 (40-49 years)	110.4 ± 9.1	22.9 ± 1.7
G4 (50-59 years)	110.2 ± 4.7	23.4 ± 1.0
G5 (60-79 years)	99.8 ± 7.5	20.9 ± 1.7

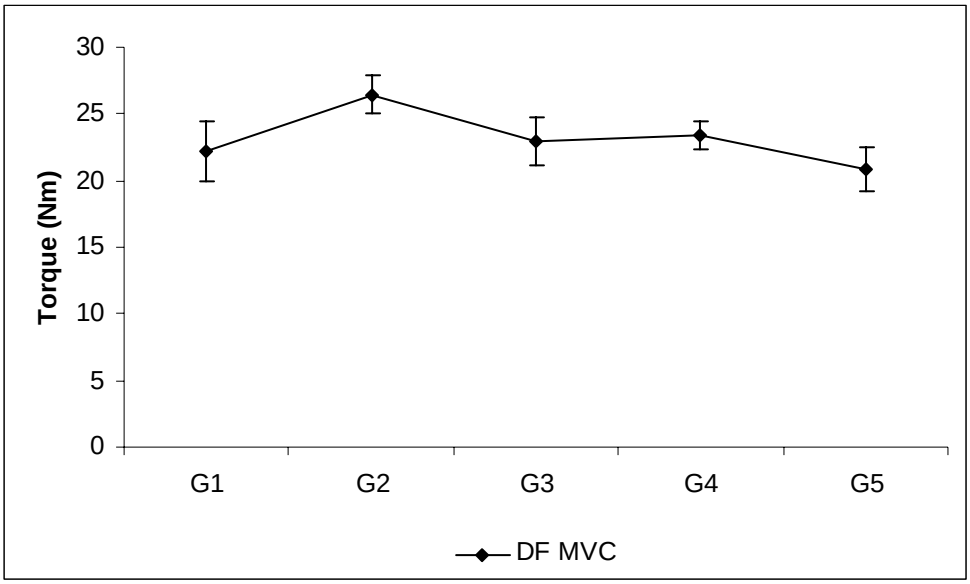
* indicates significant difference ($p<0.05$) between G2 and G5
PF: plantarflexion; DF: dorsiflexion; MVC: maximal voluntary contraction

Figure 3. Baseline Comparison of Plantarflexion MVC



* indicates significant difference ($p<0.05$) between G2 and G5
PF: plantarflexion; MVC: maximal voluntary contraction

Figure 4. Baseline Comparison of Dorsiflexion MVC



DF: dorsiflexion; MVC: maximal voluntary contraction

Muscle Activation

Voluntary Activation

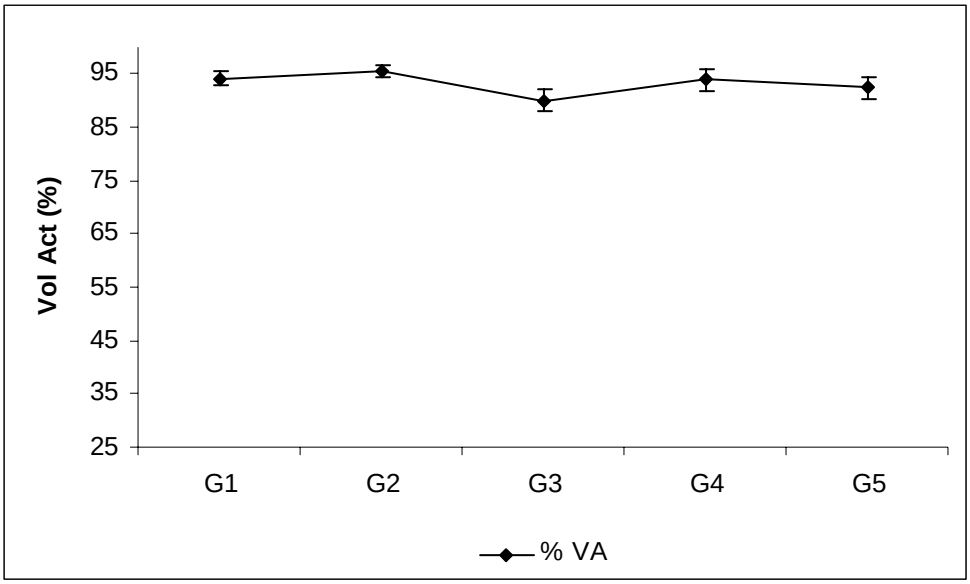
Voluntary activation, measured by twitch interpolation, data is displayed in Table 4. Statistical analysis revealed no significant differences ($p>0.05$) in activation between age groups. The highest levels of activation were observed in the two youngest groups (G1 and G2).

Table 4. Baseline Comparison of Voluntary Activation

Group (Age Range)	Vol Act (%)
G1 (20-29 years)	94.2 ± 1.5
G2 (30-39 years)	95.5 ± 1.1
G3 (40-49 years)	90.0 ± 2.1
G4 (50-59 years)	93.9 ± 2.1
G5 (60-79 years)	92.3 ± 1.9

Vol Act: voluntary activation

Figure 5. Baseline Comparison of Voluntary Activation



Vol Act: voluntary activation

Surface Electromyography

SEMG Root Mean Squared Amplitude

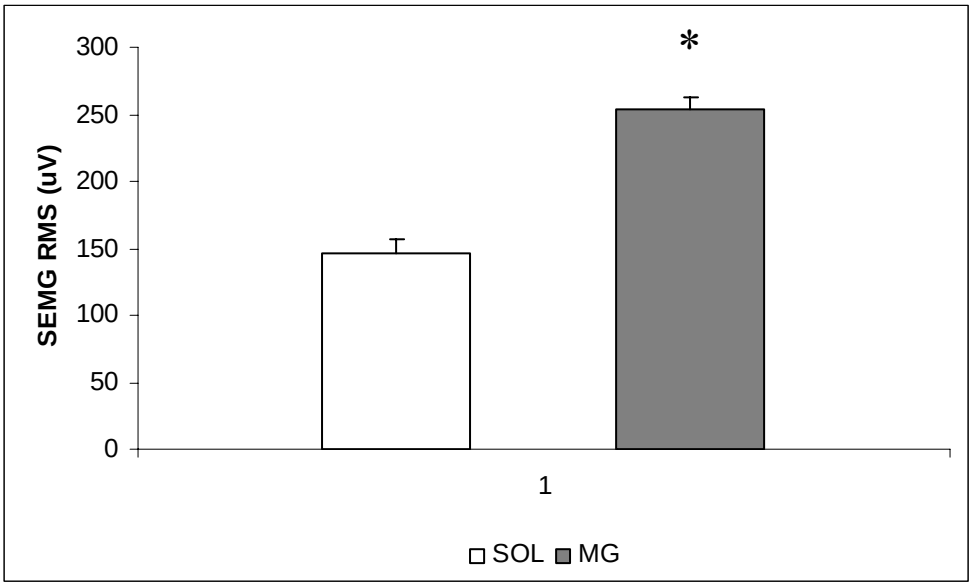
Surface electromyography (SEMG) root mean squared (RMS) amplitude data is displayed in Table 5. Statistical analysis revealed no significant differences ($p>0.05$) in SEMG amplitude between age groups. Comparison of muscle groups revealed a significant difference ($p=0.003$) in RMS amplitude between the soleus (SOL; 145.8 ± 10.2 μV) and medial gastrocnemius (MG; 254.2 ± 17.7 μV) muscles.

Table 5. Baseline Comparison of SEMG Amplitude

Group (Age Range)	SOL RMS (μV)	MG RMS (μV)
G1 (20-29 years)	197.68 ± 37.0	263.20 ± 48.89
G2 (30-39 years)	138.52 ± 17.53	301.34 ± 43.54
G3 (40-49 years)	112.55 ± 14.65	199.59 ± 16.88
G4 (50-59 years)	157.4 ± 17.01	292.92 ± 43.58
G5 (60-79 years)	113.87 ± 11.03	204.42 ± 19.03
Mean	145.8 ± 10.2	254.2 ± 17.7*

* indicates significant difference ($p<0.05$) between muscle groups
SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
RMS: root mean square amplitude

Figure 6. Baseline Comparison of SEMG Amplitude



* indicates significant difference ($p<0.05$) between muscle groups
SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
RMS: root mean square amplitude

SEMG Median Frequency

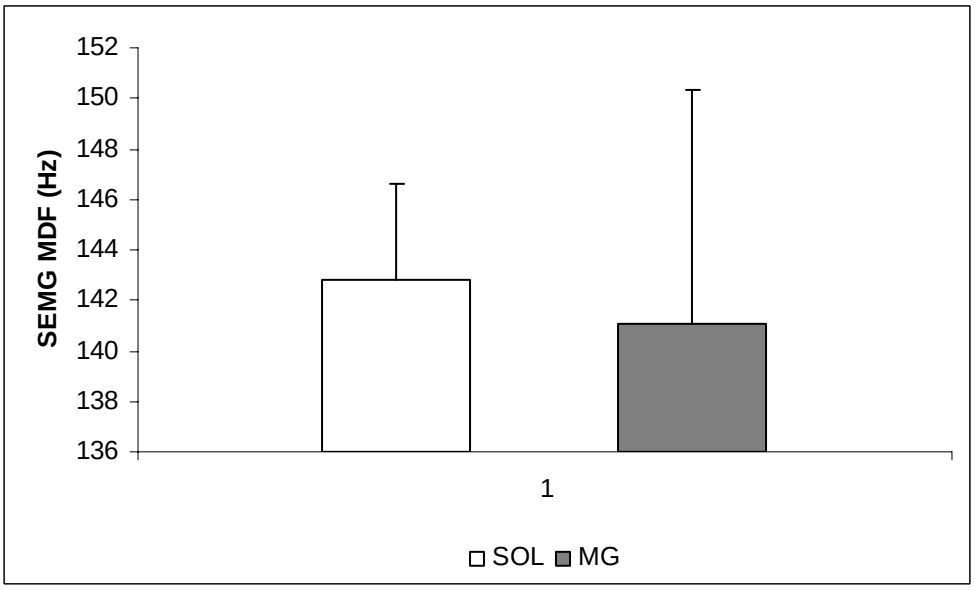
SEMG median frequency data is displayed in Table 6. Statistical analysis revealed no significant differences ($p>0.05$) in SEMG median frequency between age groups or between muscle groups.

Table 6. Baseline Comparison of SEMG Frequency

Group (Age Range)	SOL MDF (Hz)	MG MDF (Hz)
G1 (20-29 years)	132.25 ± 12.2	133.03 ± 8.34
G2 (30-39 years)	144.46 ± 7.68	139.73 ± 7.74
G3 (40-49 years)	145.99 ± 4.97	138.94 ± 6.83
G4 (50-59 years)	140.52 ± 5.14	144.04 ± 14.12
G5 (60-79 years)	151.32 ± 8.47	149.40 ± 8.31
Mean	142.8 ± 3.82	141.1 ± 4.15

SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
MDF: median frequency

Figure 7. Baseline Comparison of SEMG Frequency



SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
MDF: median frequency

Antagonist Co-activation

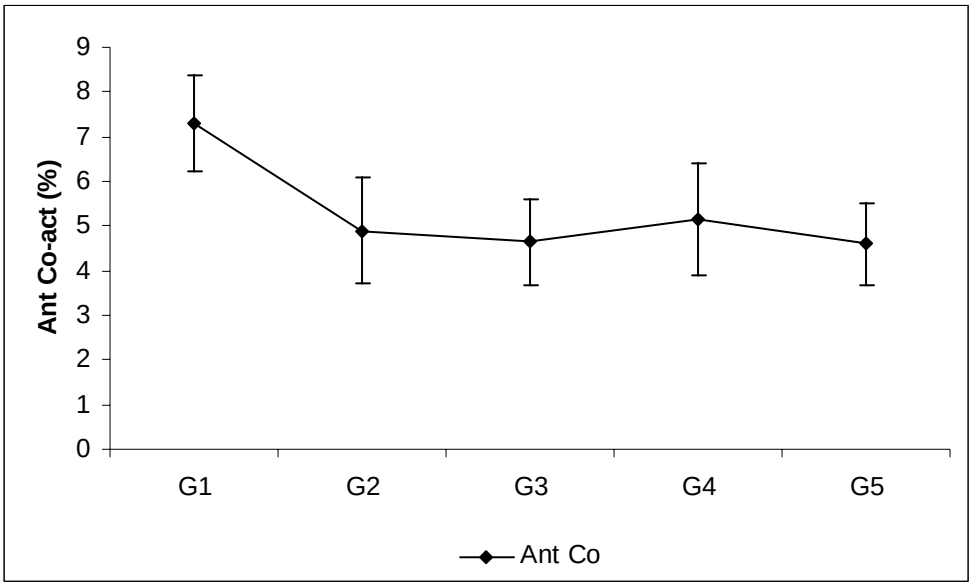
Antagonist co-activation data is displayed in Table 7. Statistical analysis revealed no significant differences ($p>0.05$) in activation between age groups.

Table 7. Baseline Comparison of Antagonist Co-activation

Group (Age Range)	Ant Co-act (%)
G1 (20-29 years)	7.3 ± 1.1
G2 (30-39 years)	4.9 ± 1.2
G3 (40-49 years)	4.6 ± 0.9
G4 (50-59 years)	5.2 ± 1.3
G5 (60-79 years)	4.6 ± 0.9

Ant Co-act: antagonist co-activation

Figure 8. Baseline Comparison of Antagonist Co-activation



Ant Co-act: antagonist co-activation

II. Longitudinal Analysis between Groups

Muscle Size

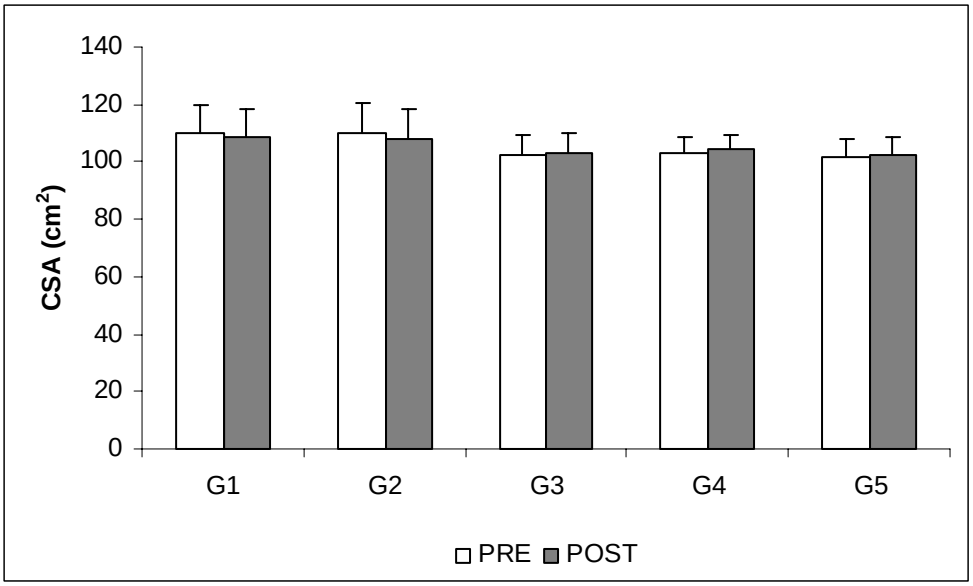
Following the experimental training protocol, no change in muscle size was noted between age groups ($p>0.05$).

Table 8. Changes in Muscle Cross-Sectional Area

	CSA (cm^2)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	110.1 ± 9.6	108.9 ± 9.2	-0.9 ± 0.6
G2 (30-39 years)	110.3 ± 10.3	107.8 ± 10.3	-2.3 ± 1.5
G3 (40-49 years)	102.4 ± 7.0	102.9 ± 7.1	0.4 ± 0.7
G4 (50-59 years)	103.3 ± 5.2	104.3 ± 5.2	1.0 ± 0.4
G5 (60-79 years)	101.8 ± 6.3	102.3 ± 6.1	0.6 ± 0.8

CSA: muscle cross-sectional area

Figure 9. Changes in Muscle Cross-Sectional Area



CSA: muscle cross-sectional area

Muscle Strength

Following the experimental training protocol, an increase in plantarflexion maximal strength was observed in most age groups. However, none of these changes were significantly greater ($p>0.05$) then the baseline pre-testing measures. No change ($p>0.05$) was also observed in maximal dorsiflexion strength.

Table 9. Changes in Muscular Strength

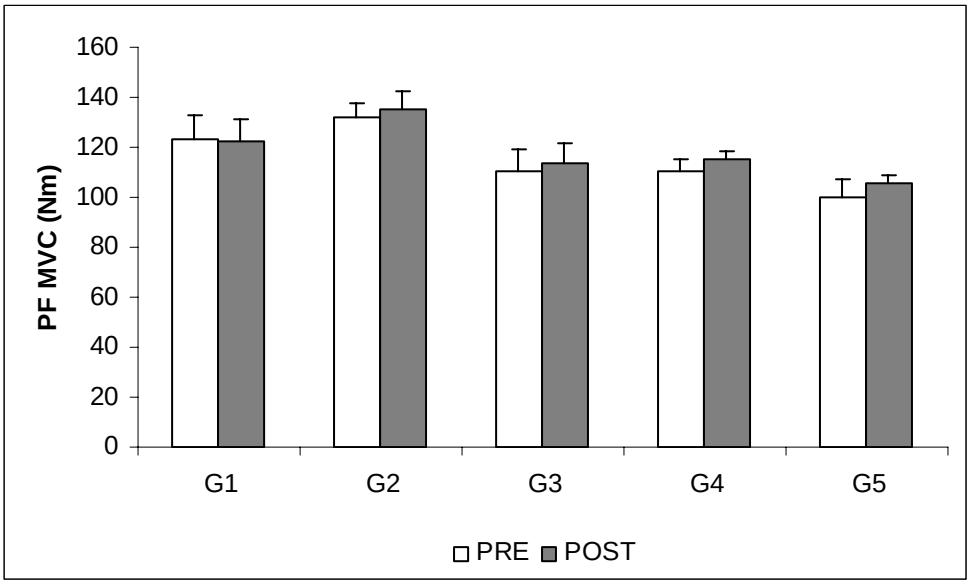
	PF MVC (Nm)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	123.4 ± 9.8	122.3 ± 9.2	0.3 ± 4.0
G2 (30-39 years)	132.4 ± 5.4	135.2 ± 7.5	5.1 ± 3.6
G3 (40-49 years)	110.4 ± 9.1	113.8 ± 7.5	4.3 ± 3.8
G4 (50-59 years)	110.2 ± 4.7	114.9 ± 3.7	5.1 ± 3.6
G5 (60-79 years)	99.8 ± 7.5	106.0 ± 2.8	12.3 ± 9.3

PF: plantarflexion; MVC: maximal voluntary contraction

	DF MVC (Nm)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	22.6 ± 2.2	22.1 ± 2.2	-0.7 ± -0.8
G2 (30-39 years)	26.4 ± 1.4	26.6 ± 1.4	0.8 ± 0.7
G3 (40-49 years)	22.9 ± 1.7	22.9 ± 2.0	-0.8 ± -1.2
G4 (50-59 years)	23.4 ± 1.0	23.9 ± 1.0	2.3 ± 1.0
G5 (60-79 years)	20.9 ± 1.7	20.9 ± 1.6	0.5 ± 0.9

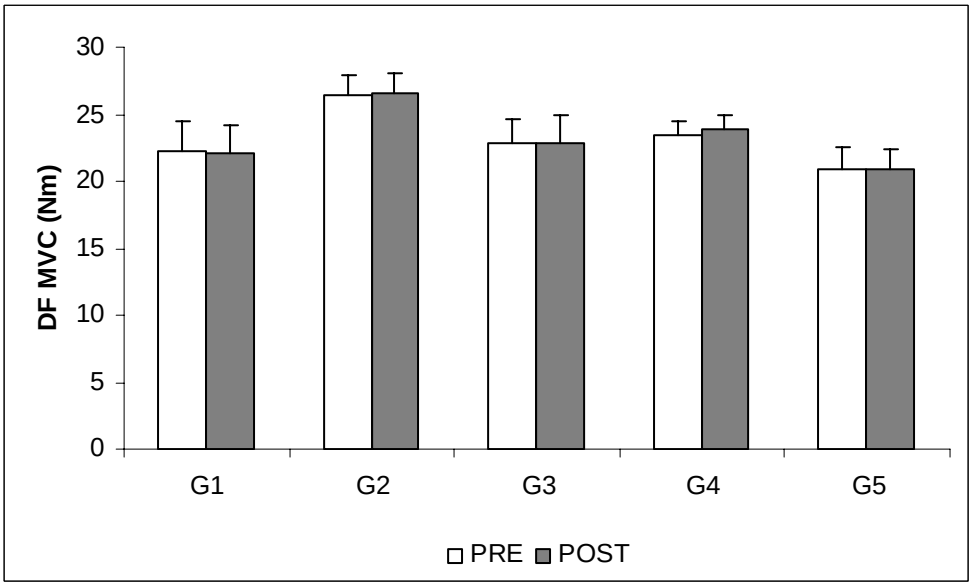
DF: dorsiflexion; MVC: maximal voluntary contraction

Figure 10. Changes in PF Muscular Strength



PF: plantarflexion; MVC: maximal voluntary contraction

Figure 11. Changes in DF Muscular Strength



DF: dorsiflexion; MVC: maximal voluntary contraction

Muscle Activation

Voluntary Activation

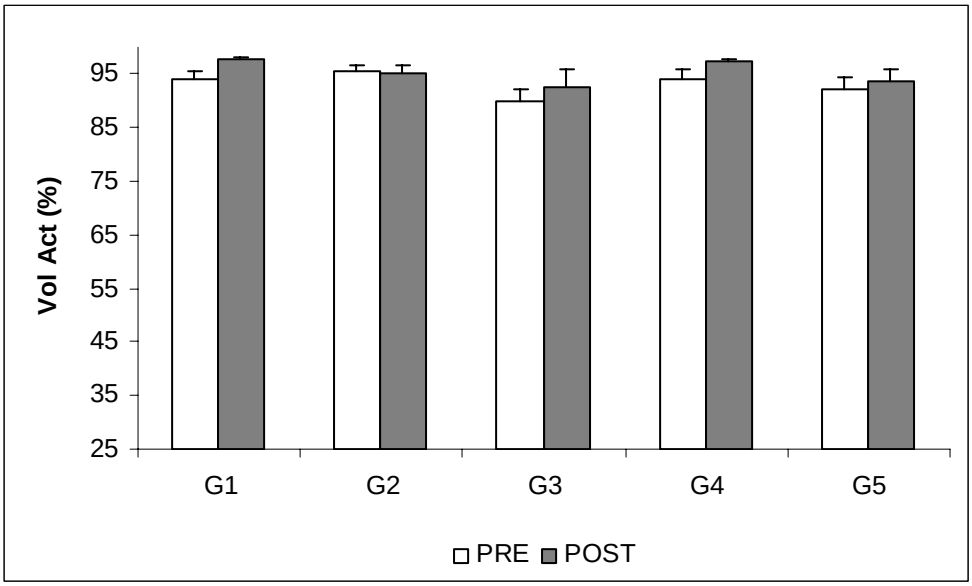
Following the experimental training protocol, an increase in voluntary activation assessed by twitch interpolation was observed in most age groups. However, none of these changes were significantly greater ($p>0.05$) then the baseline pre-testing measures.

Table 10. Changes in Voluntary Activation

	Vol Act (%)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	94.2 ± 1.5	97.8 ± 0.5	4.0 ± 1.5
G2 (30-39 years)	95.5 ± 1.1	95.2 ± 1.3	-0.2 ± 1.7
G3 (40-49 years)	90.0 ± 2.1	92.7 ± 3.1	3.2 ± 3.2
G4 (50-59 years)	93.9 ± 2.1	97.4 ± 0.5	4.1 ± 2.2
G5 (60-79 years)	92.3 ± 1.9	93.5 ± 2.3	1.4 ± 2.2

Vol Act: voluntary activation

Figure 12. Changes in Voluntary Activation



Vol Act: voluntary activation

Surface Electromyography

Examination of SEMG data determined significant main effects for muscle group ($p=0.001$) and time ($p=0.013$) between SOL and MG for RMS amplitude. A significant decrease for the time main effect ($p=0.001$) in SEMG MDF was also observed post-training. No significant ($p>0.05$) interactions between muscle and group or time and group were determined for either RMS amplitude or MDF. As such, individual comparisons between time (pre-post) and group (age) have also been performed for each muscle (SOL and MG) and domain (RMS and MDF).

Surface Electromyography SOL RMS

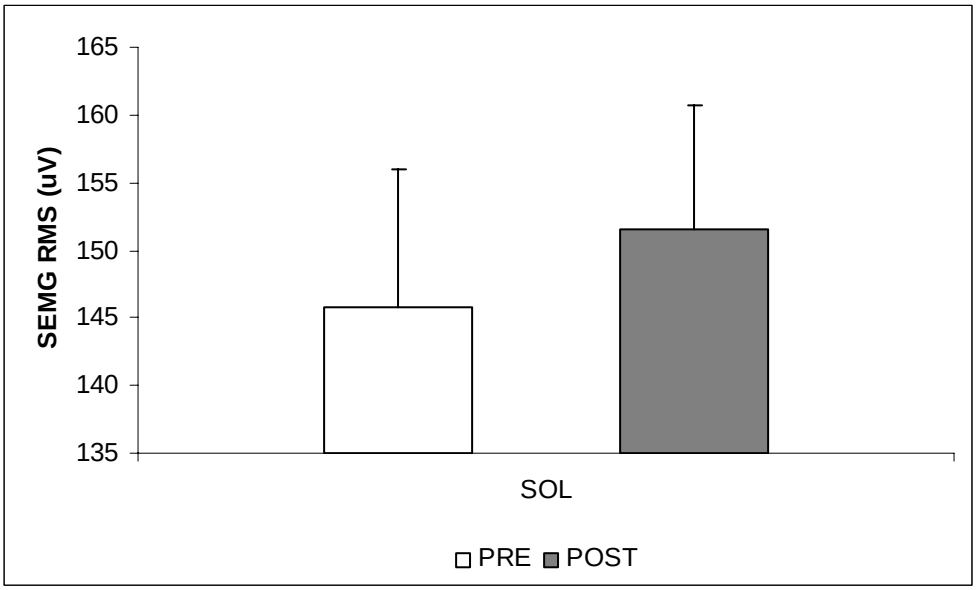
There was no significant change ($p>0.05$) in SOL RMS amplitude following training. No group differences were observed.

Table 11. Change in SEMG SOL RMS

	SEMG SOL RMS (μV)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	197.68 ± 37.0	193.54 ± 56.76	-4.94 ± 10.25
G2 (30-39 years)	138.52 ± 17.53	150.36 ± 13.88	17.24 ± 11.44
G3 (40-49 years)	112.55 ± 14.65	117.60 ± 9.86	8.77 ± 10.25
G4 (50-59 years)	157.4 ± 17.01	153.34 ± 10.74	2.87 ± 8.24
G5 (60-79 years)	113.87 ± 11.03	132.47 ± 9.41	21.7 ± 8.89
Mean	145.8 ± 10.2	151.46 ± 13.13	11.2 ± 1.10

SEMG: surface electromyography; SOL: soleus;
RMS: root mean square amplitude

Figure 13. Change in SEMG SOL RMS



SEMG: surface electromyography; SOL: soleus;
RMS: root mean square amplitude

Surface Electromyography SOL MDF

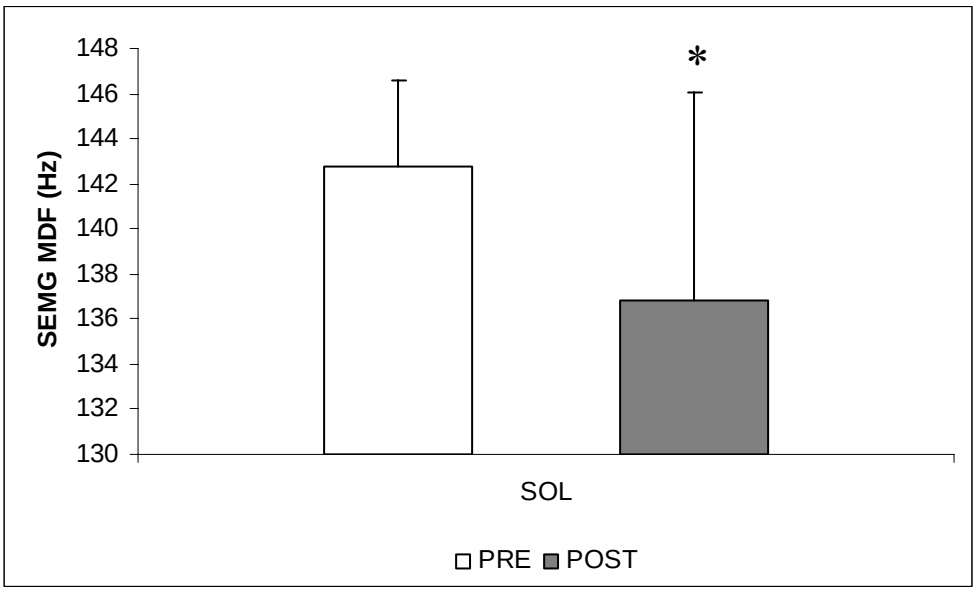
There was a significant decrease (p=0.004) in SOL MDF post-training. No group differences were observed.

Table 12. Change in SEMG SOL MDF

	SEMG SOL MDF (Hz)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	132.25 ± 12.2	131.1 ± 11.07	-0.45 ± 4.08
G2 (30-39 years)	144.46 ± 7.68	136.04 ± 7.39	-5.29 ± 3.08
G3 (40-49 years)	145.99 ± 4.97	141.65 ± 3.76	-2.78 ± 1.46
G4 (50-59 years)	140.52 ± 5.14	132.02 ± 8.72	-6.51 ± 4.13
G5 (60-79 years)	151.32 ± 8.47	144.41 ± 9.81	-5.03 ± 2.22
Mean	142.76 ± 3.82	136.86 ± 3.93*	-4.1 ± 1.31

* indicates significant differences (p<0.05) post-training
SEMG: surface electromyography; SOL: soleus; MDF: median frequency

Figure 14. Change in SEMG SOL MDF



* indicates significant differences (p<0.05) post-training
SEMG: surface electromyography; SOL: soleus; MDF: median frequency

Surface Electromyography MG RMS

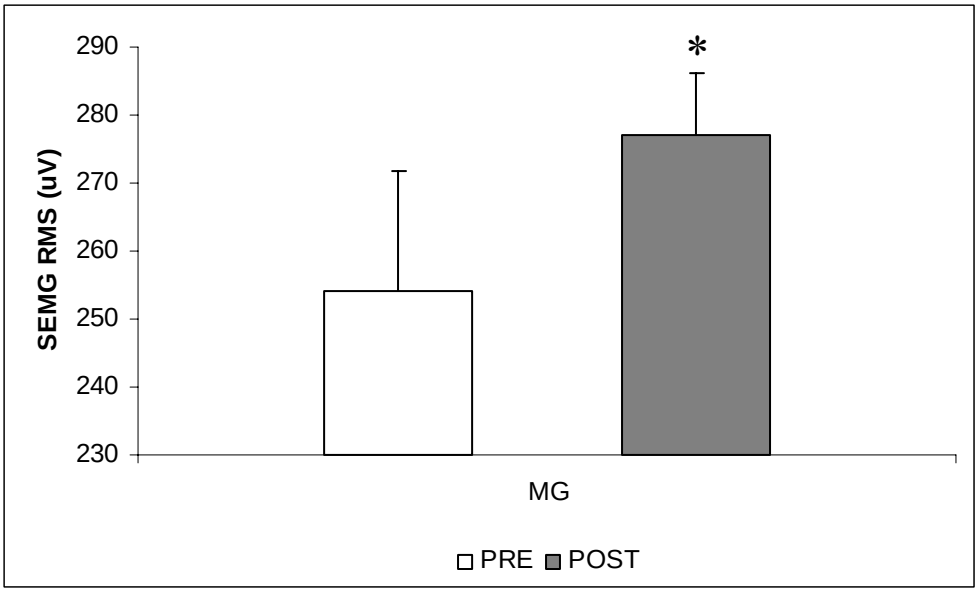
Following the experimental training, there was a significant increase (p=0.001) in RMS in the MG muscle group. No group differences were observed.

Table 13. Change in SEMG MG RMS

	SEMG MG RMS (μV)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	263.20 ± 48.89	277.69 ± 41.92	8.78 ± 6.68
G2 (30-39 years)	301.34 ± 43.54	323.03 ± 36.11	12.24 ± 5.16
G3 (40-49 years)	199.59 ± 16.88	241.57 ± 12.47	27.08 ± 13.85
G4 (50-59 years)	292.92 ± 43.58	288.83 ± 29.81	3.20 ± 5.27
G5 (60-79 years)	204.42 ± 19.03	245.10 ± 16.29	25.68 ± 10.13
Mean	254.85 ± 17.71	277.14 ± 14.1*	19.25 ± 3.83

* indicates significant differences ($p<0.05$) post-training
SEMG: surface electromyography; MG: medial gastrocnemius;
RMS: root mean square amplitude

Figure 15. Change in SEMG MG RMS



* indicates significant differences ($p<0.05$) post-training
SEMG: surface electromyography; MG: medial gastrocnemius;
RMS: root mean square amplitude

Surface Electromyography MG MDF

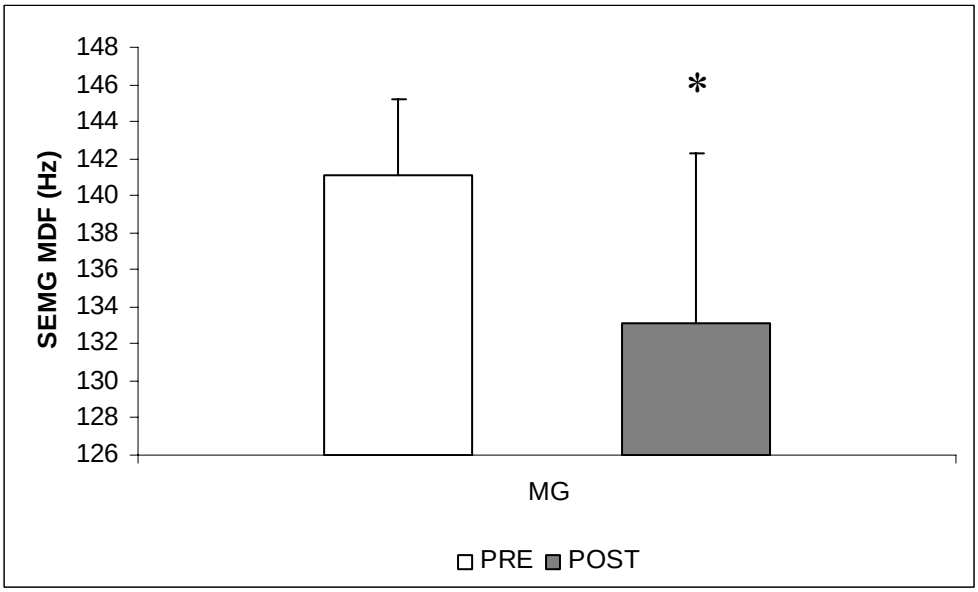
Following the experimental training, there was a significant decrease (p=0.001) in MDF in the MG muscle group. No group differences were observed.

Table 14. Change in SEMG MG MDF

	SEMG MG MDF (Hz)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	133.03 ± 8.34	123.48 ± 6.17	-6.26 ± 2.58
G2 (30-39 years)	139.73 ± 7.74	139.33 ± 6.63	0.58 ± 3.12
G3 (40-49 years)	138.94 ± 6.83	135.36 ± 9.29	-2.91 ± 3.53
G4 (50-59 years)	144.04 ± 14.12	133.41 ± 10.56	-5.19 ± 3.65
G5 (60-79 years)	149.40 ± 8.31	134.45 ± 5.63	-9.31 ± 2.15
Mean	141.1 ± 4.15	133.06 ± 3.35*	-5.9 ± 0.84

* indicates significant differences (p<0.05) post-training
SEMG: surface electromyography; MG: medial gastrocnemius;
MDF: median frequency

Figure 16. Change in SEMG MG MDF



* indicates significant differences (p<0.05) post-training
SEMG: surface electromyography; MG: medial gastrocnemius;
MDF: median frequency

Antagonist Co-activation

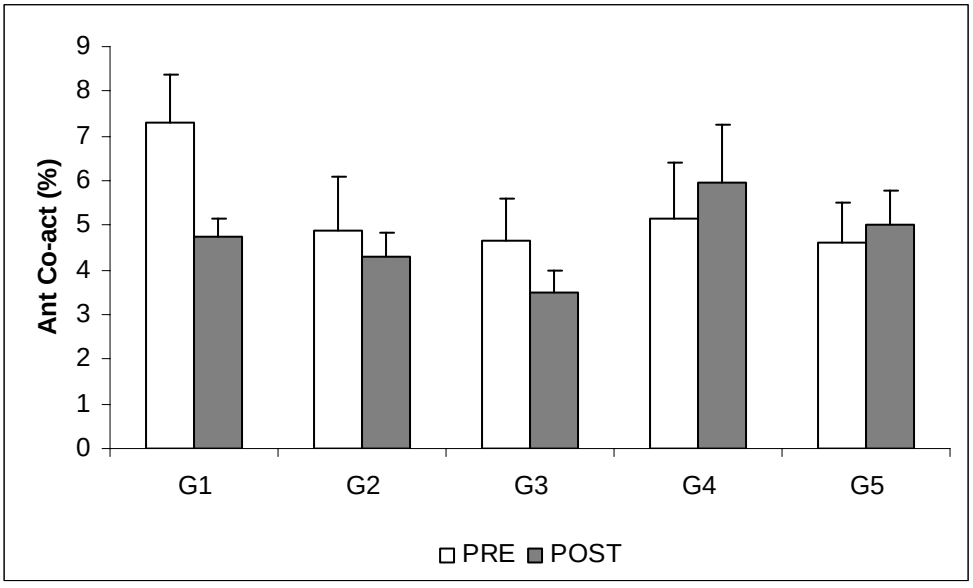
Following the experimental training protocol, no change in antagonist co-activation was noted between age groups ($p>0.05$). In the three youngest groups (G1-G3), a decrease in ANTCO was noted between pre and post-testing, whereas the older groups (G4 and G5) experienced an increase in ANTCO.

Table 15. Change in Antagonist Co-activation

	Ant Co-act (%)		
Group (Range)	**PRE**	**POST**	**% Change**
G1 (20-29 years)	7.3 ± 1.1	4.8 ± 0.4	-22.3 ± 14.0
G2 (30-39 years)	4.9 ± 1.2	4.3 ± 0.5	-10.3 ± 12.1
G3 (40-49 years)	4.6 ± 0.9	3.5 ± 0.5	-11.7 ± 15.6
G4 (50-59 years)	5.2 ± 1.3	6.0 ± 1.3	10.6 ± 17.2
G5 (60-79 years)	4.6 ± 0.9	5.0 ± 0.8	5.5 ± 11.4

Ant Co-act: antagonist co-activation

Figure 17. Change in Antagonist Co-activation



Ant Co-act: antagonist co-activation

III. Comparison of Percent Change between Groups

Muscle Strength

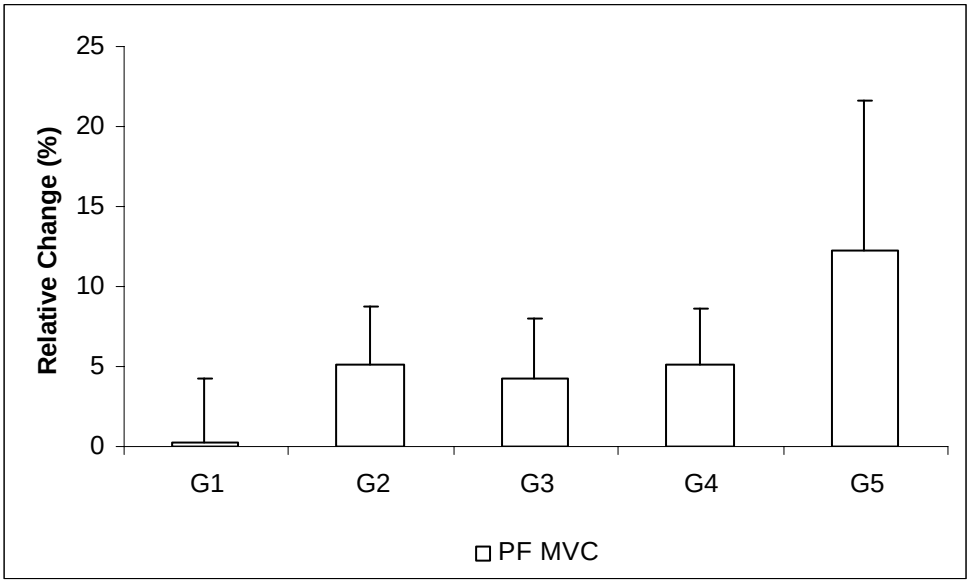
When examining the relative percent change following training, no significant differences ($p>0.05$) in muscle strength was observed for either maximal plantarflexion or dorsiflexion.

Table 16. Percent Change of Muscular Strength

Group (Age Range)	PF MVC (%)	DF MVC (%)
G1 (20-29 years)	0.3 ± 4.0	-0.7 ± 0.8
G2 (30-39 years)	5.1 ± 3.6	0.8 ± 0.7
G3 (40-49 years)	4.3 ± 3.8	-0.8 ± 1.2
G4 (50-59 years)	5.1 ± 3.6	2.3 ± 1.0
G5 (60-79 years)	12.3 ± 9.3	0.5 ± 0.9

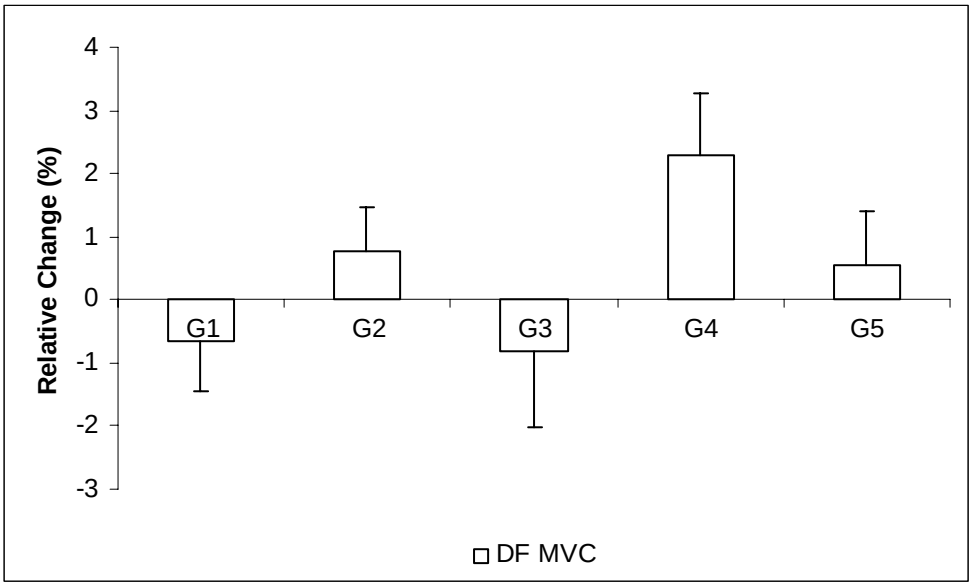
PF: plantarflexion; DF: dorsiflexion; MVC: maximal voluntary contraction

Figure 18. Percent Change of PF Muscular Strength



PF: plantarflexion; MVC: maximal voluntary contraction

Figure 19. Percent Change of DF Muscular Strength



DF: dorsiflexion; MVC: maximal voluntary contraction

Muscle Activation

Voluntary Activation

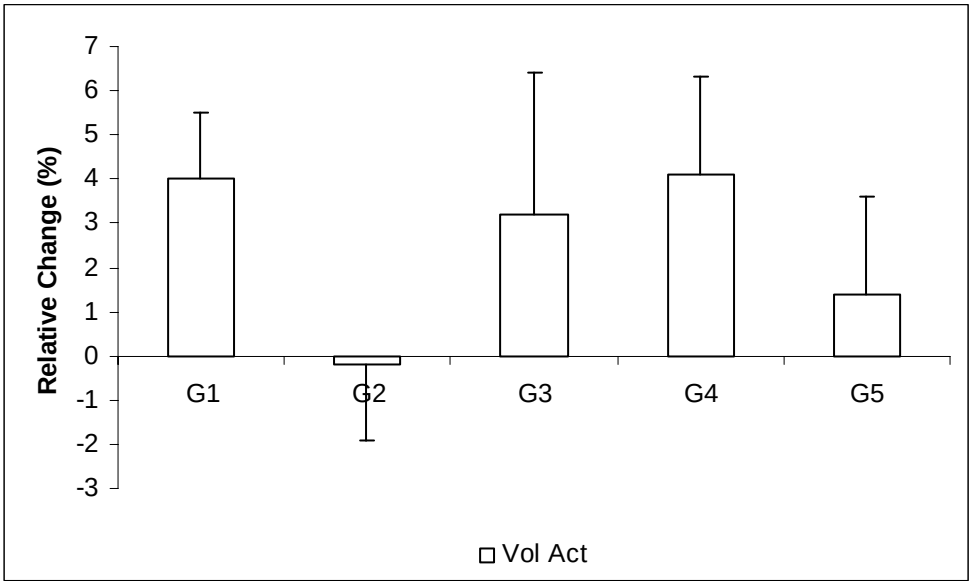
When examining the relative percent change following training, no significant differences ($p>0.05$) in voluntary activation were observed between age groups.

Table 17. Percent Change of Voluntary Activation

Group (Age Range)	Vol Act (%)
G1 (20-29 years)	4.0 ± 1.5
G2 (30-39 years)	-0.2 ± 1.7
G3 (40-49 years)	3.2 ± 3.2
G4 (50-59 years)	4.1 ± 2.2
G5 (60-79 years)	1.4 ± 2.2

Vol Act: voluntary activation

Figure 20. Percent Change of Voluntary Activation



Vol Act: voluntary activation

Surface Electromyography Amplitude

When examining the relative percent change following training, no significant differences ($p>0.05$) in SEMG amplitude was observed for either muscle group between age groups.

Table 18. Percent Change of SEMG Amplitude

Group (Age Range)	SOL RMS (%)	MG RMS (%)
G1 (20-29 years)	-4.94 ± 10.25	8.78 ± 6.68
G2 (30-39 years)	17.24 ± 11.44	12.24 ± 5.16
G3 (40-49 years)	8.77 ± 10.25	27.08 ± 13.85
G4 (50-59 years)	2.87 ± 8.24	3.20 ± 5.27
G5 (60-79 years)	21.7 ± 8.89	25.68 ± 10.13
Mean	11.2 ± 1.10	19.25 ± 3.83

SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
RMS: root mean square amplitude

Surface Electromyography Frequency

When examining the relative percent change following training, no significant differences ($p>0.05$) in SEMG frequency was observed for either muscle group between age groups.

Table 19. Percent Change of SEMG Frequency

Group (Age Range)	SOL MDF (%)	MG MDF (%)
G1 (20-29 years)	0.45 ± 4.08	-6.26 ± 2.58
G2 (30-39 years)	-5.29 ± 3.08	0.58 ± 3.12
G3 (40-49 years)	-2.78 ± 1.46	-2.91 ± 3.53
G4 (50-59 years)	-6.51 ± 4.13	-5.19 ± 3.65
G5 (60-79 years)	-5.03 ± 2.22	-9.31 ± 2.15
Mean	-4.1 ± 1.31	-5.9 ± 0.84

SEMG: surface electromyography; SOL: soleus; MG: medial gastrocnemius
MDF: median frequency

Antagonist Co-activation

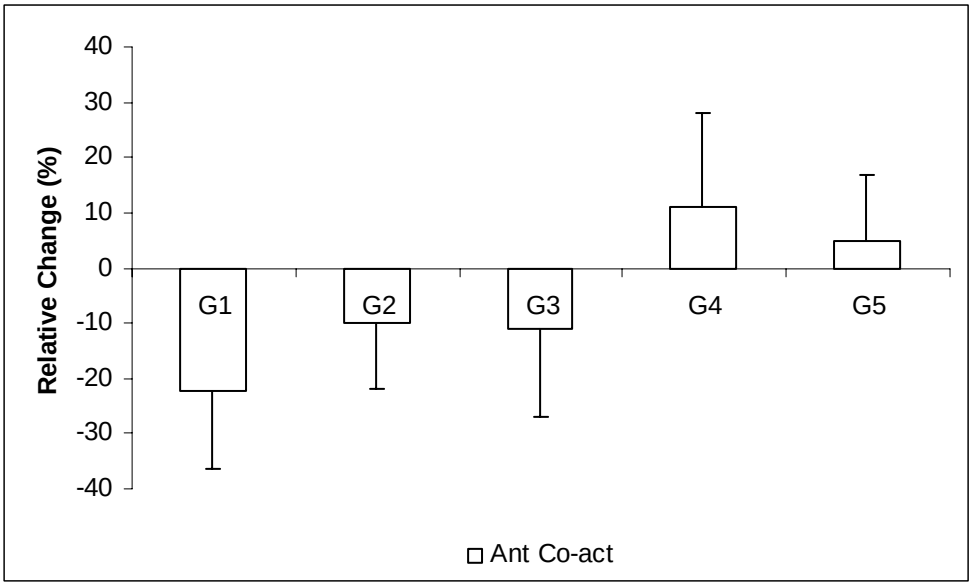
When examining the relative percent change following training, no significant differences ($p>0.05$) in antagonist co-activation was observed between age groups.

Table 20. Percent Change of Antagonist Co-activation

Group (Age Range)	Ant Co-act (%)
G1 (20-29 years)	-22.3 ± 14.0
G2 (30-39 years)	-10.3 ± 12.1
G3 (40-49 years)	-11.7 ± 15.6
G4 (50-59 years)	10.6 ± 17.2
G5 (60-79 years)	5.5 ± 11.4

Ant Co-act: antagonist co-activation

Figure 21. Percent Change of Antagonist Co-activation



Ant Co-act: antagonist co-activation

DISCUSSION

The results from the present study indicated that there were no significant pre-test to post-test changes in muscular strength, muscle activation, or muscle size following the experimental training period. Thus, the finding that three training sessions had no effect on muscle strength or activation in the present study is not entirely consistent with the results from previous investigations.

A similar pattern of response in all groups was observed in most variables assessed during the present study. Observed power for the measured dependent variables was quite low, as such a larger sample may potentially produced significant changes following training. Although the results from the present study do not support the positive findings from studies incorporating larger muscles (i.e. quadriceps), this study provides additional details into the training response of the plantarflexors to short-term resistance training.

Muscle Size

No change in muscle size is supported by previous literature suggesting muscle size adaptations take place following 5-8 weeks of chronic resistance training (Moritani and deVries, 1979). Early training-induced changes in strength are accounted largely for by neural factors with a gradually increasing contribution of muscular hypertrophy of trained muscles as training proceeds (Moritani and deVries, 1979). The increase in the cross-sectional area of trained muscles comes primarily from the increase in size of individual muscle fibers (MacDougall et al., 1977). In well-trained subjects, such as strength athletes, further improvements in

strength and training-induced muscle hypertrophy are much more limited than in untrained subjects (Häkkinen et al., 1994). Strength development and muscle hypertrophy is also dependent on the type and intensity of loading as well as volume of the strength training program.

Muscular Strength

The present study confirms the results from previous research. It has been shown that muscular strength reaches its peak at about 30 years of age and is well maintained through the 50th year of life (Frontera et al., 1988). Although a decline in strength occurs between 50 and 60 years of age, a much more rapid rate of loss is evident beyond the age of 60 years (Frontera et al., 1988). This was observed in the cross-sectional (baseline) comparison of age groups, with the 30-year old group being significantly stronger than the 60-79 year group.

When comparing the results of other short-term strength training data, differences in the results between the present study and results from previous investigations (Brown and Whitehurst, 2003; Coburn et al., 2006; Kamen and Knight, 2001; Prevost et al., 1999) are observed in muscular strength. Coburn et al. (2007) and Prevost et al. (1999) reported increases in isokinetic strength following a training program that used the same number of training sessions as in the present study (three), but a lower total training volume. Knight and Kamen (2001) reported a significant change in voluntary torque between two baseline measurements of eight days apart, even without training. Both of these studies used the leg extensors as the primary muscle group measured during the experimental training.

Thus, it is possible that this discrepancy reflects differences in the number of training sessions, total training volume, or reflects muscle-specific differences in the responses to short-term strength training.

Muscle Activation

In contrast with previous studies reporting an increase in activation with strength training in the knee extensors (Harridge et al., 1999; Knight and Kamen, 2001), there were no significant pre-test to post-test changes in muscle activation or surface EMG amplitude for the agonist and antagonist muscles in the present study. However, the small non-significant increases in most age groups were consistent with the results of research involving changes in activation of the plantar flexors (Scaglioni et al., 2002). A factor that may contribute to the increased activation of the elderly males observed in the present investigation was that prior to the onset of training, activation was lower in the present elderly than observed in those previous studies. Harridge et al. (1999) and Scaglioni et al. (2002) both reported that those elderly individuals with the lowest levels of activation prior to training showed the greatest improvements with training. In accordance with this, the lower levels of activation in the present elderly males prior to training, compared to the studies of Harridge et al. (1999) and Scaglioni et al. (2002), may represent a greater potential for improvement with training.

These findings were consistent with those of Holtermann et al. (2005), who reported that 5 days of isometric training of the dorsiflexors had no effect on EMG amplitude for the tibialis anterior muscle during an isometric MVC. Unlike the

present study, however, Holtermann et al. (2005) reported that the training resulted in a significant (approximately 15.7%) increase in the mean isometric dorsiflexion strength value. It was suggested that the training-induced increase in strength may have been due to neural adaptations in the dorsiflexor muscles that did not affect EMG amplitude. Specifically, synchronization of motor unit discharges and/or optimizing motor unit firing rates (i.e. with "doublet discharges") could potentially increase torque production without affecting EMG amplitude.

Other investigations, however, have reported significant changes in EMG amplitude for the agonist and antagonist muscles during the first 1-2 weeks of resistance training. For example, Moritani and deVries (1979) found that during an isometric MVC of the forearm flexor muscles, torque and EMG amplitude for the biceps brachii increased after just two weeks of isometric strength training. It was suggested that the training-induced increases in strength were primarily due to neural adaptations such as increased facilitation and/or disinhibition at various levels of the nervous system.

Of particular interest to this study is the significant decrease in EMG frequency following training. Changes in EMG frequency are thought to be related to action potential conduction velocity. However, some research suggests that a decrease in EMG frequency is reflective of motor unit synchronization (Milner-Brown and Stein, 1975). These authors suggested that supraspinal connections from motor cortex directly to spinal motoneurons may be enhanced as a result of training,

where they produce a significant synchronization of motor units during steady, voluntary contractions.

An issue related to the use of surface EMG to examine neuromuscular adaptations to resistance training is of interest to this study. The contention that EMG amplitude can be used to measure muscle activation and/or co-activation has been challenged in recent studies. Farina et al. (2004) have suggested that the surface EMG signal may not quantitatively reflect the activation signal sent from the spinal cord. Specifically, factors such as filtering of the signal by the tissue between the muscle and recording electrodes, amplitude cancellation, and differential amplification with a bipolar electrode arrangement can all influence EMG amplitude, independent of changes in muscle activation. Furthermore, the surface EMG signal detected with a traditional bipolar electrode arrangement provides information regarding the electrical activities of only a sample of the motor units that make up the entire muscle (Basmajian and De Luca, 1985). Thus, it has been suggested that surface EMG amplitude and frequency data provide limited information regarding the activation signal sent from the central nervous system (Farina et al., 2004). Despite these limitations, previous studies (Moritani and deVries, 1979) have reported that surface EMG amplitude is a highly reliable measure of muscle activation that is sensitive to the neural adaptations that occur during a resistance training program.

Antagonist Co-activation

There were no training-induced changes in EMG amplitude for the tibialis anterior muscle during an isometric MVC of the plantarflexors, which suggested that the training program also had no effect on co-activation in antagonist muscles. Carolan and Cafarelli (1996) reported that there were significant increases in isometric leg extension strength and decreases in EMG amplitude for the biceps femoris muscle, thus indicating a reduced level of muscle co-activation, after only one week of isometric strength training for the leg extensors. There was no change in EMG amplitude for the vastus lateralis muscle following training, and it was proposed that the increases in strength were due to training-induced decreases in antagonist (hamstring) muscle co-activation, rather than increases in the level of agonist (quadriceps) muscle activation (Carolan and Cafarelli, 1996).

A possible explanation as to why co-activation remains unchanged with training is that it may contribute to joint stability as demonstrated in the knee joint following injury (Osternig et al., 1999) and during stair descent in the elderly (Hortobagyi and DeVita, 2000). Indeed where co-activation has previously been shown to decrease as a result of training in the elderly (Hakkinen et al., 2001), it is possible that this occurs specifically in the trained movement of knee extension and remains unchanged in muscle actions involving plantarflexion.

The modifications in co-activation that occur are a topic of much debate. It is agreed upon that the co-activation phenomenon is neurological or peripheral tissue-related in scope. The three schools of thought are defined as alterations in

neural command originating/being controlled by supraspinal, spinal, or peripheral (including afferent) modifications. When shunting the central nervous system (CNS) via EMS training, Maffiuletti et al. (2002) were able to isolate training in large part the spinal and peripheral tissues of the plantarflexors. After observing no change in the H-reflex after four weeks of EMS training, the authors conclude that their results arose from probable increased volitional drive from the supraspinal centers causing greater activation of muscles that assist the prime movers.

Furthermore, advocates of a supraspinal pathway (direct descending pathway) that modulate co-activation argue that the CNS may control each muscle's motorneuron pool by a single input when both muscles are participating in a specific task. Due to co-activation being reported to increase with intensity/load to the limb movement, fatigue begins to set in (Simoneau et al., 2005, Psek and Cafarelli 1993, Aagaard et al., 2000). With fatigue, force is lost and requires more of the motor unit pool to be recruited to maintain required level of contraction. Increase in agonist EMG occurs and, with the idea of a common drive, higher levels co-activation is expected (Psek and Cafarelli, 1993), as was observed in the current study.

On the contrary, spinal adaptations may be performed by the initiation of co-activation of Renshaw cells on the Ia-inhibitory interneurons that excite the Ib interneurons from the golgi tendon organs. Attenuating any of these pathways may possible reduce co-activation (Carolan and Caffarelli 1992, Jubeau et al., 2006).

Proponents of the peripheral adaptation commonly suggest motor performance alteration was not primarily attributable to a change at the level of the

nervous command of the agonist muscle, but to the modifications at the peripheral level (Simoneau et al., 2005). After observing no increased neuromuscular excitability and nerve conduction velocity following a 16-week strength training program Scaglioni et al. (2002) suggest the roles of interneurons and afferent and efferent pathways producing the dispersion of impulses may account for the age-related deficits seen with the elderly compared to younger males. Scaglioni et al. (2003) also observed a longer reflex latency in elderly males but an unchanged contractile time in senior males. These authors propose a senile muscle peripheral neuron restructuring model that involves the dropout of the largest fibers, and segmental demyelination and remyelination process of the alpha motorneuron that would cause a consequent reduction in internodal length and an increase in conduction velocity. Even in the Scaglioni et al. (2003) study, a longer reflex latency was accompanied by an unchanged direct motor contractile time, and thus, the authors felt that the alterations are essentially focused at the afferent level. While the current study did not measure the H-reflex of the subjects, it is unlikely any axonal myelination modification occurred in three training sessions. However, the plasticity and increased efficiency of the central nervous system should not be ruled out as a factor in the non-significant decrease in percent change of co-activation from pre-to post-testing.

CHAPTER V: CONCLUSIONS

The purpose of this study was to determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age. The following conclusions were drawn from this study.

Research Questions

Are there significant differences in peak torque, voluntary activation, and surface electromyography in the triceps surae between adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years?

> No, there were no differences in peak torque, voluntary activation, and surface electromyography in the triceps surae between adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years. There was a general trend that strength and activation decreased with age, but the only significant differences were observed in peak torque between the 30-39 year old group (strongest) and the 60-79 year old group (weakest).

Does short-term resistance training improve peak torque, voluntary activation, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years.

> No, the short-term resistance training program did not improve peak torque, voluntary activation, and surface electromyography in the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-

79 years. However, there were small, non-significant improvements in peak torque in all age groups following training.

Research Sub-Questions

Do changes in peak torque, voluntary activation of skeletal muscle, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years following short-term resistance training occur in absence of changes in muscular hypertrophy?

No, there were no differences in peak torque, voluntary activation, and surface electromyography in the triceps surae between adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years that occurred, as well as no changes in muscle hypertrophy.

Does antagonist muscle group co-activation contribute to changes in peak torque, voluntary activation of skeletal muscle, and surface electromyography of the triceps surae in adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years?

No, antagonist muscle group co-activation does not contribute to changes in peak torque, voluntary activation, and surface electromyography in the triceps surae between adult males aged 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-79 years.

Significance of the Study

The neuromuscular system undergoes numerous adaptations with increased age and has a significant impact on muscle performance. The mechanisms of

adaptation associated with the initial stages of resistance training are not fully understood. Research suggests that the early adaptations to a resistance training program are related to improvements in neuromuscular efficiency, which may be linked to increased ability to voluntary activate skeletal muscle.

Significant changes in muscular strength and neuromuscular performance following short-term resistance training may also have implications in clinical settings. Improvements in muscle function that are apparent in as little a three training sessions may advance the knowledge of rehabilitation following injury or debilitating pathology.

Study Limitations

This study was not without several limitations. Subject selection was based on volunteer participation and is not a random sample. As they are volunteers, subjects participating in the study are often interested in physical performance, and thus may not be representative of a normal population. While restrictions were placed on the amount of activity the subject's currently perform (i.e. exercise program), many subjects had been well-training at point in their life.

Additionally, the sample size for this investigation was quite small. A power calculation, based on the results of previous research, performed prior to study enrollment indicated a minimum of seven subjects were need in each group. While each group had at least seven subjects, it is still quite a small number to be reflective of an entire population.

Lastly, the neuromuscular and strength assessment performed in this research was limited to the triceps surae muscle group using an isometric contraction. The response of muscle to resistance training is specific to the training being performed, and as such may not be generalized to other types of muscular contractions.

Suggestions for Future Research

Regardless of the time course of increases in muscle activation, which may be of limited functional significance without the inclusion of functionally relevant activities, the present study has shown that a short-term training program may lead to initial increases in strength and activation (albeit small). Future studies should examine the effects of very short-term training on strength and EMG amplitude in various muscles and with different types of training programs. Additionally, the use of surface mechanomyography (MMG) may also provide some insight into short-term training.

Similar to the EMG signal, the MMG represents a compound signal created by the activation of active motor units summated at the skins surface (Ataki et al. 1996). During voluntary muscle actions, the time and frequency domains of the MMG signal have been suggested to reflect motor unit recruitment and firing rate, respectively (Akataki et al. 2004). While the surface EMG amplitude and frequency parameters are thought to reflect muscle activation (motor unit recruitment and firing rate) and motor unit action potential conduction velocity, respectively.

REFERENCES

Aagaard, P., E.B. Simonsen, J.L. Andersen, S.P. Magnusson, F. Bojsen-Møller, and P. Dyhre-Poulsen. Antagonist muscle co-activation during isokinetic knee extension. *Scand J Med Sci Sports.* 10:58-67. 2000.

Akima, H., H. Takahashi, S. Kuno, K. Masuda, T. Masuda, H. Shimojo, I. Anno, Y. Itai, and S. Katsuta. Early phase adaptations of muscle use and strength to isokinetic training. *Med. Sci. Sports Exerc.* 31:588-594. 1999.

Akataki, K., K. Mita, and M.Watakabe. Electromyographic and mechanomyographic estimation of motor unit activation strategy in voluntary force production. *Electromyogr Clin Neurophysiol.* 44:489-96. 2004.

Ansved, T., and L. Larsson. Quantitative and qualitative morphological properties of the soleus motor nerve and the L5 ventral root in young and old rats. *J. Neurol. Sci.* 96:269–282. 1990.

Basmajian, J., and C.J. De Luca. Muscles Alive. Their Functions Revealed By Electromyography (5th edition). Baltimore, MD: Williams & Wilkins, 1985.

Baudry S., M. Klass, and J.Duchateau. Post-activation potentiation influences differently the nonlinear summation of contractions in young and elderly adults. *J Appl Physiol.* 98:1243–1250. 2005.

Behm D., K. Power, and E. Drinkwater. Comparison of interpolation and central activation ratios as measures of muscle inactivation. *Muscle Nerve.* 24: 925-934. 2001

Brooks, G.A., T.D. Fahey, and T.P. White. Neurons, motor unit recruitment, and integrative control of movement. In: Exercise Physiology (2nd ed.). G.A. Brooks, T.D. Fahey, and T.P. White, eds. Mountainview, CA: Mayfield Press. 1996. pp. 328–359.

Brown, L.E., and M. Whitehurst. The effect of short-term isokinetic training on force and rate of velocity development. *J. Strength Cond. Res.* 17:88-94. 2003.

Brown, W.F. A method for estimating the number of motor units in thenar muscles and the changes in motor unit count with aging. *J. Neurol. Neurosurg. Psychiatr.* 35:845–852. 1972.

Cardasis, C.A. and D.M. LaFontaine. Aging neuromuscular junctions: A morphometric study of cholinesterase-stained whole mounts and ultrastructure. *Muscle Nerve.* 10: 200-13. 1987.

Carolan, B and E. Cafarelli. Adaptations in co-activation after isometric resistance training. *J Appl Physiol.* 73:911–917. 1992.

Chandler, J.M., P.W. Duncan, G. Kochersberger, and S. Studenki. Is lower extremity strength gain associated with improvement in physical performance and disability in frail, community-dwelling elders? *Arch. Phys. Med. Rehabil.* 79: 24–30. 1988.

Coburn, J.W., T.J. Housh, M.H. Malek, J.P. Weir, J.T. Cramer, T.W. Beck, and G.O. Johnson. Neuromuscular responses to three days of velocity-specific isokinetic training. *J. Strength Cond. Res.* 20:892-898. 2006.

Connelly D.M., C.L. Rice, M.R. Roos, and A.A. Vandervoort. Motor unit firing rates and contractile properties in tibialis anterior of young and old men. *J Appl Physiol.* 87: 843-852. 1999.

D'Antona G., M.A. Pellegrino, R. Adami, R. Rossi, C.N. Carlizzi, M. Canepari, B. Saltin, and R. Bottinelli. R The effect of ageing and immobilization on structure and function of human skeletal muscle fibres. *J Physiol.* 552:499–511. 2003

De Serres S.J. and R.M. Enoka. Older adults can maximally activate the biceps brachii muscle by voluntary command. *J Appl Physiol*. 84:284–291. 1998

Doherty T.J. and W.F. Brown. Age-related changes in the twitch contractile properties of human thenar motor units. *J Appl Physiol.* 82:93–101. 1997

Dawson D.L., G. Hendershot, and J. Fulton. Aging in the eighties: functional limitations of individuals age 65 and over. National Center for Health Statistics. Hyattsville (MD): Advance Data from Vital and Health Statistics, 1987.

DeLuca, C.J. The use of surface electromyography in biomechanics. *J. Appl. Biomech.* 13:135-163. 1997.

Duchateau, J., J.G. Semmler, and R.M. Enoka. Training adaptations in the behavior of human motor units. *J Appl Physiol.* 101:1766-1775. 2006.

DeLuca C.J. and B. Mambrito. Voluntary control of motor units in human antagonist muscles: co-activation and reciprocal activation. *J Neurophysiol.* 58: 525-542, 1987.

Esposito F.M., D. Malgrati, A. Veicsteinas, and C. Orizio. Time and frequency domain analysis of electromyogram and sound myogram in the elderly. *Eur J Appl Physiol.* 73:503–510. 1996.

Farina D.P., R. Merletti, and R.M. Enoka. The extraction of neural strategies from the surface EMG. *J Appl Physiol.* 96:1486–1495. 2004.

Fiatrone, M.A., E.C. Marks, N.D. Ryan, C.N. Merideth, L.A. Lipsitz, and W.J. Evans. High intensity strength training in nonagenarians. *J. Am. Med. Assoc.* 263: 3029–3034. 1990.

Frontera, W.R., C.N. Meredith, K.P. O'Reilly, and W.J. Evans. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J. Appl. Physiol.* 64:1038 1988.

Frontera, W.R., V.A. Hughes, K.J. Lutz, and W.J. Evans. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol.* 71:644–650. 1991.

Ferri A., G. Scaglioni, M. Pousson, P. Capodaglio, J. Van Hoecke, and M.V. Narici. Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. *Acta Physiol Scand*. 177: 69-78, 2003.

Greenlund, L.J.S., and K.S. Nair. Sarcopenia—Consequences, mechanisms, and potential therapies. *Mech. Ageing Dev.* 124:287–299. 2003.

Gurney, J.M., and D.B. Julliffe. Arm anthropometry in nutritional assessment: nomogram for rapid calculation of muscle circumference and cross-sectional muscle and fat areas. *Am. J. Clin. Nutr.* 26:912–915, 1973.

Hakkinen K.J., M.Alen, M. Kallinen, M. Izquierdo M, K. Jokelainen, H. Lassila, E. Mälkiä, W.J. Kraemer, and R.U. Newton. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J. Appl. Physiol.* 84:1341-1349. 1998.

Harridge S.D.R. and M.J. White. A comparison of voluntary and electrically evoked isokinetic plantar flexor torque in males. *Eur J Appl Physiol.* 66:343–348. 1993.

Herbert R.D. and S.C. Gandevia. Twitch interpolation in human muscles: mechanisms and implications for measurement of voluntary activation. *J Neurophysiol.* 82:2271–2283. 1999.

Hruda, K.V., A.L. Hicks, and N. McCartney. Training for muscle power in older adults: Effects on functional abilities. *Can. J. Appl. Physiol.* 28:178–189. 2003.

Hunter, G.R., M.S. Treuth, R.L. Weinsier, T. Kekes-Szabo, S.H. Kell, D.L. Roth, and C. Nicholson. The effects of strength conditioning on older women's ability to perform daily tasks. *J. Am. Geriat. Soc.* 43:756–760. 1995.

Hunter, G.R., J.P. McCarthy, and M.M. Bamman. Effects of resistance training on older adults. *Sports Med.* 34: 329-348. 2004

Holtermann, A., K. Roelveld, B. Veriejken, and G. Ettema. Changes in agonist EMG activation level during MVC cannot explain early strength improvement. *Eur. J. Appl. Physiol.* 94:593-601. 2005.

Hageman P.A. and V.S. Thomas. Gait performance in dementia: the effects of a 6-week resistance training program in an adult day-care setting. *Intl J Geriatr Psychiatry*. 17: 329-334, 2002.

Henneman, E., G. Somjen, and D.O. Carpenter. Functional significance of cell size in spinal motorneurones. *J. Neurophysiol.* 28:560–580. 1965.

Hermens H.J., B. Freriks, C. Disselhorst-Klug, and G. Rau. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol.* 10:361-74. 2000.

Jakobi J.M. and E. Cafarelli. Neuromuscular drive and force production are not altered during bilateral contractions. *J Appl Physiol.* 84: 200-206, 1998.

Jakobi J.M. and C.L. Rice. Voluntary muscle activation varies with age and muscle group. *J Appl Physiol.* 93: 457-462. 2002.

Kawakami Y., H. Akima, and K. Kubo. Changes in muscle size, architecture, and neural activation after 20 days of bed rest with and without resistance exercise. *Eur J Appl Physiol.* 84:7-12. 2001

Kamen G., S.V. Sison, C.C. Duke Du, and C. Patten. Motor unit discharge behavior in older adults during maximal-effort contractions. *J Appl Physiol.* 79:1908-1913. 1995.

Kellis E. and V.B. Unnithan. Co-activation of vastus lateralis and biceps femoris muscles in pubertal children and adults. *Eur J Appl Physiol.* 79:504-511. 1999.

Klein C.S., C.L. Rice, and G.D. Marsh. Normalized force, activation, and co-activation in the arm muscles of young and old men. *J Appl Physiol*. 91: 1341-1349. 2001.

Knight C.A. and G. Kamen. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. *J Electromyo Kinesiol.* 11:405-412. 2001.

Klitgaard, H., M. Mantoni, S. Chiaffino, S. Ausoni, L. Gorza, C. Laurent-Winter, P. Schnohr, and B. Saltin. Function, morphology and protein expression of ageing skeletal muscle: A cross-sectional study of elderly men with different training backgrounds. *Acta Physiol. Scand.* 140:41–54. 1990.

Kent-Braun J.A., A.V. Ng, J.W. Doyle, and T.F. Towse. Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. *J Appl Physiol.* 93:1813–1823. 2002.

Klass M., S. Baudry, and J. Duchateau. Aging does not affect voluntary activation of the ankle dorsiflexors during isometric, concentric, and eccentric contractions. *J Appl Physiol*. 99:31–38. 2005

LaStoy, P.C., G.A. Ewy, D.D. Pierotti, R.K. Johns, and S. Lindstedt. The positive effects of negative work: Increased muscle strength and decreased fall risk in a frail elderly population. *J. Gerontol.* 58A: 419–424. 2003.

Larsson, L. Motor units: Remodeling in aged animals. *J. Gerontol.* 50A:91–95. 1995.

Larsson, L., and T. Ansved. Effects of ageing on the motor unit. *Prog. Neurobiol.* 45:397–458. 1995.

Lexell, J., C.C. Taylor, and M. Sjostrom. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J. Neurol. Sci.* 84:275–294. 1988.

Lexell, J. Evidence for nervous system degeneration with advancing age. *J. Nutr.* 127:1011S–1013S. 1997.

Macaluso A.B., M.A. Nimmo, J.E. Foster, M. Cockburn, N.C. McMillan and G. DeVito. Contractile muscle volume and agonist-antagonist co-activation account for differences in torque between young and older women. *Muscle and Nerve.* 25: 858-863. 2002.

Maffiuletti, N.A., P. Pensini, and A. Martin. Activation of human plantar flexor muscles increases after electromyostimulation training. *J Appl Physiol*. 92: 1383-1392. 2002.

Maffiuletti, N.A., A. Martin, J. Van Hoecke, and M. Schieppati. The relative contribution to the plantar-flexor torque of the soleus motor units activated by the H reflex and M response in humans. *Neurosci Letters.* 288:127-130. 2000.

Metter, J.E., L.A. Talbot, M. Schrager, and R. Conwit. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J. Gerontol.* 57A:359–365. 2002.

Merton PA. Interaction between muscle fibres in a twitch. *J Physiol.* 124: 311-24. 1954.

Milner-Brown, H.S. and R.B. Stein. The relation between the surface electromyogram and muscular force. *J. Physiol*. 246: 549-569. 1975.

Moritani, T., and H.A. de Vries. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am. J. Phys. Med.* 58:115-130. 1979.

Moritani, T. Neuromuscular adaptations during the acquisition of muscle strength, power and motor tasks. *J. Biomech.* 26:95-107. 1993.

Morse C.I., J.M. Thom, M.G. Davis, K.R. Fox, K.M. Birch, and M.V. Narici. Reduced plantarflexor specific torque in the elderly is associated with a lower activation capacity. *Eur J Appl Physiol.* 92: 219-226. 2004.

Narici M.V., C.N. Maganaris, N.D. Reeves, and P. Capodaglio. Effect of aging on human muscle architecture. *J Appl Physiol.* 95: 2229-2234. 2003.

Norris, A.H., N.W. Shock, and I.H. Wagman. Age changes in the maximum conduction velocity of motor fibers of human ulnar nerves. *J. Appl. Physiol.* 5:589–593. 1953.

National Center for Health Statistics. Health, United States. Hyattesville (MD): National Center for Health Statistics, 2001

Ochala J., D. Lambertz, M. Pousson, F. Goubel, and J. Van Hoecke. Changes in mechanical properties of human plantar flexor muscles in ageing. *Exper Gerontol.* 39: 349-358. 2004.

Porter, M.M., A.A. Vandervoort, and J. Lexell. Aging of human muscle: Structure, function and adaptability. *Scand. J. Med. Sci. Sports.* 5:129–142. 1995.

Prevost, M., A.G. Nelson, and B.K.V. Maraj. The effect of two days of velocity-specific isokinetic training on torque production. *J. Strength Cond. Res.* 13:35-39. 1999.

Roos, M.R., C.L. Rice, and A.A. Vandervoort. Age-related changes in motor unit function. *Muscle and Nerve.* 20:679–690. 1997.

Roos M.R., C.L.Rice, D.M. Connelly, A.A.Vandervoort. Quadriceps muscle strength, contractile properties, and motor units firing rates in young and old men. *Muscle Nerve.* 22:1094–1103. 1999.

Roubenoff, R. Origins and clinical relevance of sarcopenia. *Can. J. Appl. Physiol.* 26: 78–79. 2001.

Scaglioni G., M.V. Narci, N.A. Maffiuletti, M. Pensini, and A. Martin. Plantar flexor activation capacity and H reflex in older adults: adaptations to strength training. *J Appl Physiol.* 92: 2292-2302. 2002.

Scaglioni G., M.V. Narci, N.A. Maffiuletti, M. Pensini, and A. Martin. Effect of ageing on the electrical and mechanical properties of human soleus motor units activated by the H reflex and M wave. *J Physiol.* 548.2 649-661. 2003.

Simoneau E, A Martin, and J Van Hoecke. Muscular performances at the ankle joint in young and elderly men. *J Gerontol.* 60A: 439-447. 2005.

Staron, R.S., D.L. Karapdono, W.J. Kraemer, A.C. Fry, S.E. Gordon, J.E. Falkel, F.C. Hagerman, and R.S. Hikida. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J. Appl. Physiol.* 76:1247-1255. 1994.

Semmler J.G., J.W. Steege, K.W. Kornatz, and R.M. Enoka. Motor-unit synchronization is not responsible for lager motor-unit forces in old adults. *J Neurophysiol.* 84:358–366. 1999.

Simoneau E., A. Martin, and J.M. Van Hoecke. Muscular performances at the ankle joint in young and elderly men. *J Gerontol*. 60A:439–447. 2005

Satton RW. The incidence of fall injury events among the elderly in a defined population. *Amer J Epidemiol.* 131: 1028-37. 1990.

Todd G., R.B. Gorman, and S.C. Gandevia. Measurement and reproducibility of strength and voluntary activation of lower-limb muscles. *Muscle Nerve.* 29: 834-842. 2004.

Tomlinson, B.E., and D. Irving. The number of limb motor neurons in the human lumbosacral cord throughout life. *J. Neurol. Sci.* 34:213–219. 1977.

Vandervort, A.A., and T.B. Symons. Functional and metabolic consequences of sarcopenia. *Can. J. Appl. Physiol.* 26: 90–101. 2001.

Vandervoort, A.A., and A.J. McComas. Contractile changes in opposing muscles of the human ankle joint with aging. *J. Appl. Physiol.* 61:361–367. 1986.

Yue G.H., V.K. Ranganathan, V. Siemionov, J.Z. Liu, and V. Sahgal. Older adults exhibit a reduced ability to fully activate their biceps brachii muscle. *J Gerontol.* 54A:249–253. 1999.

Zipp, P. Recommendations for the standardization of lead positions in surface electromyography. *Eur. J. Appl. Physiol.* 50:41-54. 1982.

VI. Manuscript

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Journal of Strength and Conditioning Research
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Dr. Kraemer,

My co-authors and I are submitting the enclosed manuscript, "Age-related changes in skeletal muscle activation following short-term resistance training" for The Journal of Strength and Conditioning Research. The research reported in this manuscript was approved by the Institutional Review Board at the University of Oklahoma. This manuscript represents original unpublished material that is not under consideration for publication elsewhere. Furthermore, it will not be submitted for publication elsewhere until a decision is made regarding its acceptability for publication in "The Journal of Strength and Conditioning Research".

Sincerely,

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Age-Related Changes in Skeletal Muscle Activation Following Short-Term Resistance Training

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Running Head: Age-Related Changes in Skeletal Muscle Activation

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Age-Related Changes in Skeletal Muscle Activation Following Short-Term Resistance Training

ABSTRACT

Introduction: Current research suggests that older adults do not posses the same ability to fully activate skeletal muscle of the lower limb as do young adults. However, it is not known at what age these changes become readily apparent, or at what age these changes may negatively affect the improvement in neuromuscular activation associated with resistance training. The purpose of this study is to determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age. **Methods**: Forty-six normal healthy males volunteered to participate in this research study. Subjects were designated into one of five groups, classified as individuals aged between 20-29 years (n=10), 30-39 years (n=10), 40-49 years (n=7), 50-59 years (n=9), and 60-79 years (n=10). Subjects participated in three supervised resistance training sessions over the course of seven days, performing four lower body exercises during each training session. Subjects were assessed for muscle cross-sectional area, muscular strength, and muscle activation via twitch interpolation and surface electromyography (SEMG) before and after the experimental training. Two-way repeated measures ANOVA was used to determine group differences and changes with training. **Results:** Analysis of baseline muscular strength data revealed only a significant difference ($p=0.02$) in muscle strength between G2 (132.4 ± 5.4) and G5 (99.8 ± 7.5) for plantarflexion maximal strength. No significant differences ($p>0.05$) were observed for muscle cross-sectional area, dorsiflexion muscular strength, muscle activation assessed via twitch interpolation,

or antagonist co-activation between age groups. Statistical analysis revealed no significant differences ($p>0.05$) in SEMG RMS amplitude or median frequency between age groups. However, comparison of muscle groups revealed a significant difference ($p=0.003$) in RMS amplitude between the soleus (SOL; 145.8 ± 10.2 μV) and medial gastrocnemius (MG; 254.2 ± 17.7 μV) muscles. Following training, there was no significant change ($p>0.05$) in muscle cross-sectional area, muscular strength, muscle activation assessed via twitch interpolation, or antagonist co-activation for any age group. Examination of SEMG data determined significant main effects for muscle group ($p=0.001$) and time ($p=0.013$) between SOL and MG for RMS amplitude. A significant decrease for the time main effect ($p=0.001$) in SEMG median frequency was also observed post-training. **Conclusions:** A general pattern of response in all groups was observed in most variables assessed during the present study. The results from the present study indicated that there were no significant pre-test to post-test changes in muscle size, muscular strength, muscle activation, or antagonist co-activation following the experimental training period. These findings were unlike those from previous investigations of the leg extensors that have reported increases in performance after only two or three training sessions. **Practical Applications:** This information may be useful for those involved in rehabilitative programs. Specifically, the muscles of the lower limb (i.e. calf) could require more than three training sessions to elicit the strength improvements and neuromuscular adaptations that typically occur during the early stages of a resistance training program.

INTRODUCTION

Sarcopenia is a multifaceted condition that results in a progressive age-related loss of muscular size and strength [30]. Decreased muscle function in the elderly may contribute to the high incidence of accidental falls and may compromise quality of life [6, 28]. In the year 2000, the estimated direct healthcare cost attributable to sarcopenia in the United States was $18.5 billion ($10.8 billion in men, $7.7 billion in women), which represented about 1.5% of total health care expenditures for the entire year [28].

Perhaps more important than the financial burden associated with sarcopenia, is the detrimental effect on quality of life that it imparts. Normal daily activities, and recreational activities, can be affected as a result of age-related loss of muscle mass and strength [8]. It has been demonstrated that the average 80- year-old no longer retains the capacity to rise unassisted from a chair [8]. Even more striking are recent data demonstrating that the degree of sarcopenia evident among the aged serves as a significant predictor of all-cause mortality [25]. Thus, sarcopenia affects not only the quality, but also the quantity of life among the aged.

Normal aging results in decreased muscle mass caused by reduced number of muscle fibers and decreased size of individual muscle fibers [23]. However, losses in muscle mass alone can not fully account for the decrease in strength associated with normal aging. Progressive deterioration of the nervous system with increasing age has been shown to have a significant impact on the structure and

function of the neuromuscular system and muscular performance; ultimately impairing the ability of older adults to voluntarily activate skeletal muscle.

Decreased strength may be the most apparent consequence of aging. Strength is a crucial component of the quality of life. Without adequate strength levels, even the most basic tasks become difficult or impossible to perform without assistance [17, 25]. As life expectancy grows, the decline in muscle strength with aging becomes a matter of increasing importance. Research suggests that from ages 30 to 80 years; back, leg, and arm strength decrease 30 to 40% [25], while Hruda et al. (2003) observed an approximate 30% decline in strength and muscle mass in male subjects between age 30 and 70 years. The ability to maintain physical function and independence is heavily influenced by the ability to maintain strength levels.

Although research of aging muscle is vast and has become more refined, only recently have these methods been executed to better understand methods to prevent these degenerative processes. Resistance training has been proposed for older adults as a method to control the age-related decline in muscle mass and strength [10, 18, 19]. The initial increase in muscular strength has been related to improvements in the neuromuscular system, and occurs in absence of changes in muscle size [26]. Adaptive changes in the neuromuscular system in response to resistance training include increased activation of motor units [14, 16, 26], decreased co-activation of antagonist muscle groups [5], and increased motor unit firing rate [21, 22].

It has been demonstrated that older adults do not posses the same level of voluntary activation as do young adults [32]. Possible mechanisms for this age related decrease in neuromuscular activation include decreased number of motor units [34], decreased motor unit firing rates [21], decreased nerve conduction velocity [27], and morphological changes at the neuromuscular junction [4].

Research suggests that short-term resistance training (3-4 training sessions) has produced significant improvements in muscular strength [1, 26, 33] in healthy, young adults; limited research also exists demonstrating these changes in healthy, older adults [21, 22]. However, it has been shown that the magnitude of change in older adults is significantly less than that in the young. Furthermore, little is known of what time point these changes become significant.

The purpose of this study is to determine the effects of short-term resistance training on measures of muscular strength and skeletal muscle activation of the triceps surae in adult males ranging from 20-79 years of age.

METHODS

Subject Information

A total of 46 healthy male subjects participated in this study. Subjects were assigned to one of five groups based upon chronological age. The five groups were Group 1 (G1, 20-29 years; n = 10), Group 2 (G2, 30-39 years; n = 10), Group 3 (G3, 40-49 years; n = 7), Group 4 (G4, 50-59 years; n = 9), and Group 5 (G5, 60-79 years; n = 10). Subject characteristics of chronological age, standing height, and body weight are displayed in Table 1.

[Table 1 here]

All subjects were medically screened using a health history questionnaire prior to inclusion in this study. The exclusion criteria included cardiovascular, myopathic, neurological, and joint diseases or disorders. Health histories were evaluated using American College of Sports Medicine guidelines. Any subject over the age of 59 years, or who had a contraindicative health history, was required to receive medical clearance from a physician prior to participation in this study. All procedures were approved by the University of Oklahoma Institutional Review Board (IRB #11309), and written informed consent was obtained from each participant.

Experimental Protocol

This study used a mixed cross-sectional and longitudinal research design which compares the neuromuscular adaptations following short-term resistance training betweens groups of subjects based upon chronological age. Subjects were

asked to participate in three lower-body resistance training workouts to determine the changes in muscular strength and voluntary muscle activation of the lower limb during the initial stages of a resistance training program. Measurements of muscle cross-sectional area, isometric force production, and voluntary activation assessed via surface electromyography and the twitch interpolation technique were performed before and after an experimental training period. Testing of subjects consisted of six total visits to the Neuromuscular Research Laboratory within the Department of Health and Exercise Science at the University of Oklahoma.

Familiarization

All subjects underwent a familiarization session prior to preliminary testing. This session was used to familiarize subjects to the testing procedures and involved subjects performing submaximal and maximal isometric muscular contractions involving plantar flexion of the right leg. The goal of this session was for subjects to produce reliable measures of plantar flexion torque. An additional goal of the familiarization sessions was to introduce subjects to neural stimulation, as used during the twitch interpolation procedure. Subjects were exposed to low-amplitude, percutaneous stimulation applied to the tibial nerve. Stimulation occured when the muscles were at rest, and during sub-maximal and maximal isometric muscular contractions.

Subjects were also familiarized and instructed to the dynamic isotonic resistance training equipment utilized during the three training sessions. Subjects

were instructed on proper exercise technique by a certified instructor and required to perform two sets of 15 repetitions at a self-determined training load.

Muscle Size

Muscle volume of the triceps surae muscle group (medial and lateral gastrocnemius and soleus) was estimated by measuring muscle cross-sectional area (CSA) of the right calf. Muscle CSA was calculated using calf circumference and correcting for subcutaneous fat. Limb circumferences were measured to the nearest millimeter using a tension-gauged measuring tape (Gulick II; Country Technology, Inc., Gays Mills, WI). Measurements of skinfolds were taken from the medial and lateral surfaces of right calf. Skinfolds were measured in millimeters using Harpenden calipers (British Indicators; West Sussex, UK) at the point of greatest circumference. The measurements were taken in triplicate and averaged. The skinfold and circumference measurements were then used in the formula: $CSA = (C - \prod S)^2 / 4\prod$ where C is defined as the circumference of the limb and S is the average of one-half of the medial and lateral skinfolds [13].

Muscle Strength

Muscular torque during voluntary isometric contractions (MVC) was collected using an isokinetic dynamometer (KinCom). Each participant was seated in an upright position in the dynamometer chair and secured with restraining straps around the trunk and hips in accordance with the dynamometer user manual (KinCom). The hip and knee were positioned at 180° of full extension. The right ankle was positioned at the dynamometer's axis of rotation and secured to the

dynamometer's lever arm proximal and distal to the ankle. The foot was secured tightly to the footplate to minimize heel displacement, and the subjects performed three submaximal isometric plantarflexion (PF) and dorsiflexion (DF) contractions as a warm up. Two isometric maximal voluntary DF contractions were performed to obtain maximal DF data for calculation of antagonist co-activation in the tibialis anterior. Three isometric maximal voluntary PF contractions were performed. These PF MVC trials were used to assess maximal torque (before the twitch interpolation technique) and used to calculate voluntary activation.

All muscle contractions were performed with the ankle at 0° of plantar flexion. For each isometric strength assessment, each participant performed MVCs lasting 3-5 seconds in duration, with at least 1-minute rest between trials. The participants were instructed to give a maximum effort for all trials, and strong verbal encouragement was provided by the investigators.

Muscle Activation

Twitch Interpolation

The twitch interpolation (TI) technique involves delivering an electrical pulse to a nerve while the subject attempts to produce a maximum voluntary contraction. The extent of activation can be quantified by expressing the interpolated twitch as a percentage of the twitch evoked in resting muscle.

The percutaneous electrical stimulus was a rectangular pulse (1-ms duration) delivered by a high-voltage constant-current stimulator (Digitimer DS7a, Herthfordshire, UK). The cathode was a metal probe (8 mm diameter) with the tip

covered in a saline-soaked sponge, which was pressed into the poplitea fossa (posterior to the knee joint). The anode was a 9 x 5 cm rectangular self-adhesive electrode (Durastick Supreme, Chattanooga Group, Hicton, TN) that was positioned over the patella (anterior surface of the knee). Single stimuli were used to determine the optimal probe location (30 mA) and the maximal compound muscle action potential (M-wave) with incremental amperage increases (30-300 mA). Once a plateau in the peak-to-peak M-wave was determined, despite amperage increases, 20% was added to the amperage that yielded the highest peak-to-peak M-wave to assure a supramaximal stimulus.

Doublets were administered with the supramaximal stimulus intensity during the MVC trials to increase the signal-to-noise ratio and minimize the series elastic effects on torque production. In accordance with the twitch interpolation procedure, a supramaximal doublet was administered 3-5 seconds into the MVC plateau (superimposed twitch) and then again 3-5 seconds after the MVC trial at rest (potentiated twitch). %VA was calculated with the following equation (Allen et al., 1995): %activation = (1 - superimposed twitch amplitude / control twitch amplitude^{-1}) * 100

Surface Electromyography

The muscles associated with plantar flexion (soleus and medial gastrocnemius) and dorsiflexion (tibialis anterior), to measure antagonist co-activation, were measured using with three separate bipolar (20 mm center-to-center) surface electrode (circular 4 mm diameter silver/silver chloride, Biopac

Systems, Inc., Santa Barbara, CA) arrangements. Prior to placement of the electrodes, the skin was shaved to remove hair and the recording sites were rubbed lightly using an abrasive pad and cleaned using isopropryl alcohol swabs to reduce inter-electrode impedance. To ensure that EMG recordings were made beyond the motor point of the muscle, all electrode placements were in accordance with Zipp [35]. A single pre-gelled, disposable electrode (Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) served as a reference electrode and was placed over the right medial epicondyle of the femur.

Antagonist Co-activation

Surface EMG activity of tibialis anterior was recorded while performing both maximal isometric PF and DF contractions. The level of co-activation of the tibialis anterior was assessed using the RMS amplitude of the raw EMG signal, which was integrated over the peak MVC torque during PF, this was then expressed as the percentage of activity recorded from the tibialis anterior during maximal DF.

Signal Processing

The EMG and torque signals were recorded simultaneously with a Biopac data acquisition system (MP100a, Biopac Systems, Inc., Santa Barbara, CA) during each isometric MVC trial. The torque (Nm) signal from the dynamometer and the EMG (μV) signal recorded from the active muscles were sampled at 2 kHz. All signals were stored on a personal computer (Dell Inspiron 8200, Dell, Inc., Round Rock, TX), and processing was completed off-line using custom written software (LabVIEW v 7.1, National Instruments, Austin, TX). The EMG signal was digitally

filtered (zero-phase 4th-order Butterworth filter) with a pass band of 10-500 Hz and 5-100 Hz, respectively. The torque signal was low pass filtered with a 10 Hz cutoff (zero-phase 4th-order Butterworth filter) and gravity corrected so that the baseline values was 0 Nm. All subsequent analyses were performed on the filtered signals.

Isometric MVC torque (Nm) was calculated as the average torque value during the 0.5s epoch taken immediately prior to the superimposed twitch. The same 0.5 s epochs were selected from the EMG signal to calculate the time and frequency domain estimates during the MVC trials. For each EMG signal epoch during the MVC trials, the time domain was represented as the root mean square (RMS) amplitude value. For the frequency domain, each epoch was processed with a Hamming window and a discrete Fourier transform.

Resistance Training Protocol

All subjects participated in three supervised resistance training sessions over the course of 7-days. All training sessions were separated by a minimum of one day of rest. Each exercise session began with five minutes of warm-up on either a bicycle or a treadmill at a low, self-selected intensity followed by general calisthenics performed ad libitum. Subjects performed four lower body exercises during each training session. Each subject performed three bilateral calf exercises: (1) standing smith-machine calf raise, (2) seated calf raise, and (3) calf raise performed on the prone leg press. An additional lower body exercise, (4) prone leg press was also performed.

During the pre-test visit to the laboratory, subjects were assessed for one repetition maximum (1RM) on the seated calf raise and prone leg press. 1rm was defined as the greatest amount of weight move through a complete range of motion. Training load for the standing smith-machine calf raise was determined as the subject's pre-test bodyweight plus up to an additional 10 kilograms. Training load for the calf raise performed on the prone leg press was 50% of the subject's 1RM on the prone leg press. During training, each exercise consisted of one warm-up set at 50% of the subject's 1RM for 10 repetitions, followed by four sets of 10 repetitions with 70% of the subject's 1RM. Two minutes of rest are given between sets and three minutes between exercises.

Statistical Analysis

All data were expressed as mean ± standard error in the text, figures, and tables. All performance measures pre-to-post training was analyzed using Statistical Package for the Social Sciences (SPSS v14.0 software, SPSS Inc., Chicago, IL). Differences between groups were tested using a one-way analysis of variance (ANOVA) for dependent variables pre and post-testing. Two way [group (age) x trial (pre-post)] repeated-measures ANOVA were used to determine the effects of the training protocols on the dependent variables. To examine surface EMG data, a two way [muscle (SOL - MG) x trial (pre-post)] repeated-measures ANOVA were used to determine the effects of the training protocol. When significant F-ratios were observed in comparisons of main effects, the Holm's Sequential Bonferroni

post-hoc test was used to determine significance. An alpha level of $p \leq 0.05$ was considered statistically significant for all comparisons.

RESULTS

Baseline Analysis

No significant differences between standing height and body weight were observed between age groups; however, significant age differences were observed between all groups ($p<0.05$). Analysis of muscular strength revealed only a significant difference ($p=0.02$) in muscle strength between G2 (132.4 ± 5.4) and G5 (99.8 ± 7.5) for plantarflexion maximal strength. No significant differences ($p>0.05$) were observed for dorsiflexion (Figure 1).

[Figure 1 here]

Statistical analysis revealed no significant differences ($p>0.05$) in SEMG RMS amplitude or median frequency between age groups. Comparison of muscle groups revealed a significant difference ($p=0.003$) in RMS amplitude between the soleus (SOL; 145.8 ± 10.2 μV) and medial gastrocnemius (MG; 254.2 ± 17.7 μV) muscles.

No significant differences ($p>0.05$) were observed for muscle cross-sectional area, muscle activation assessed via twitch interpolation, or antagonist co-activation between age groups.

Longitudinal Analysis (Pre-Post Training)

No significant differences ($p>0.05$) were observed for muscle cross-sectional area, muscular strength, muscle activation assessed via twitch interpolation, or antagonist co-activation between age groups following training.

Analysis of SEMG data determined significant main effects for muscle group ($p=0.001$) and time ($p=0.013$) between SOL and MG for RMS amplitude. A significant decrease for the time main effect ($p=0.001$) in SEMG MDF was also observed post-training. No significant ($p>0.05$) interactions between muscle and group or time and group were determined for either RMS amplitude or MDF.

Examination of the individual muscle (SOL and MG) and domain (RMS and MDF) determined a significant increase in MG RMS amplitude post-training (19.25 ± 3.83%, $p=0.004$) with no change in the SOL. There was also a significant decrease in MDF for both the SOL and MG muscle groups (-4.1±1.3%, $p=0.001$; -5.9 ± 0.84, $p=0.001$; respectively). However, no significant group differences were observed.

DISCUSSION

A general pattern of response in all groups was observed in most variables assessed during the present study. The results from the present study indicated that there were no significant pre-test to post-test changes in muscular strength, muscle activation, or muscle size following the experimental training period. Thus, the finding that three training sessions had no effect on muscle strength or activation in the present study is not entirely consistent with the results from previous investigations.

Muscle Size

No change in muscle size is supported by previous literature suggesting muscle size adaptations take place following 5-8 weeks of chronic resistance training [26]. Early training-induced changes in strength are accounted largely for by neural factors with a gradually increasing contribution of muscular hypertrophy of trained muscles as training proceeds [26]. In well-trained subjects, such as strength athletes, further improvements in strength and training-induced muscle hypertrophy are much more limited than in untrained subjects [14]. Strength development and muscle hypertrophy is also dependent on the type and intensity of loading as well as volume of the strength training program.

Muscular Strength

The present study confirms the results from previous research. It has been shown that muscular strength reaches its peak at about 30 years of age and is well maintained through the 50th year of life [11,12]. Although a decline in strength

occurs between 50 and 60 years of age, a much more rapid rate of loss is evident beyond the age of 60 years [11, 12]. This was observed in the cross-sectional (baseline) comparison of age groups, with the 30-year old group being significantly stronger than the 60-79 year group.

When comparing the results of other short-term strength training data, differences in the results between the present study and results from previous investigations [2, 7, 22, 29] are observed in muscular strength. Coburn et al. (2007) and Prevost et al. (1999) reported increases in isokinetic strength following a training program that used the same number of training sessions as in the present study (three), but a lower total training volume. Knight and Kamen (2001) reported a significant change in voluntary torque between two baseline measurements of eight days apart, even without training. Both of these studies used the leg extensors as the primary muscle group measured during the experimental training.

Thus, it is possible that this discrepancy reflects differences in the number of training sessions, total training volume, or reflects muscle-specific differences in the responses to short-term strength training.

Muscle Activation

In contrast with previous studies reporting an increase in activation with strength training in the knee extensors [15, 22], there were no significant pre-test to post-test changes in muscle activation or surface EMG amplitude for the agonist and antagonist muscles in the present study. However, the small non-significant increases in most age groups were consistent with the results of research involving

changes in activation of the plantar flexors [32]. A factor that may contribute to the increased activation of the elderly males observed in the present investigation was that prior to the onset of training, activation was lower in the present elderly than observed in those previous studies. Harridge et al. (1999) and Scaglioni et al. (2002) both reported that those elderly individuals with the lowest levels of activation prior to training showed the greatest improvements with training. In accordance with this, the lower levels of activation in the present elderly males prior to training, compared to the studies of Harridge et al. (1999) and Scaglioni et al. (2002), may represent a greater potential for improvement with training.

These findings were consistent with those of Holtermann et al. (2005), who reported that 5 days of isometric training of the dorsiflexors had no effect on EMG amplitude for the tibialis anterior muscle during an isometric MVC. Unlike the present study, however, Holtermann et al. (2005) reported that the training resulted in a significant (approximately 15.7%) increase in the mean isometric dorsiflexion strength value. It was suggested that the training-induced increase in strength may have been due to neural adaptations in the dorsiflexor muscles that did not affect EMG amplitude. Specifically, synchronization of motor unit discharges and/or optimizing motor unit firing rates (i.e. with "doublet discharges") could potentially increase torque production without affecting EMG amplitude.

Other investigations, however, have reported significant changes in EMG amplitude for the agonist and antagonist muscles during the first 1-2 weeks of resistance training. For example, Moritani and deVries (1979) found that during an

isometric MVC of the forearm flexor muscles, torque and EMG amplitude for the biceps brachii increased after just two weeks of isometric strength training. It was suggested that the training-induced increases in strength were primarily due to neural adaptations such as increased facilitation and/or disinhibition at various levels of the nervous system.

A particularly important issue in the use of surface EMG to examine neuromuscular adaptations to resistance training is the contention that EMG amplitude can be used to measure muscle activation and/or co-activation. Recent studies [9], however, have suggested that the surface EMG signal does not quantitatively reflect the activation signal sent from the spinal cord. Specifically, factors such as filtering of the signal by the tissue between the muscle and recording electrodes, amplitude cancellation, and differential amplification with a bipolar electrode arrangement can all influence EMG amplitude, independent of changes in muscle activation. Furthermore, the surface EMG signal detected with a traditional bipolar electrode arrangement provides information regarding the electrical activities of only a sample of the motor units that make up the entire muscle [2].

Thus, it has been suggested that surface EMG amplitude and frequency data provide limited information regarding the activation signal sent from the central nervous system [9]. Despite these limitations, previous studies [26] have reported that surface EMG amplitude is a highly reliable measure of muscle activation that is sensitive to the neural adaptations that occur during a resistance training program.

Antagonist Co-activation

There were no training-induced changes in EMG amplitude for the tibialis anterior muscle during an isometric MVC of the plantarflexors, which suggested that the training program also had no effect on co-activation in antagonist muscles. Carolan and Cafarelli (1996) reported that there were significant increases in isometric leg extension strength and decreases in EMG amplitude for the biceps femoris muscle, thus indicating a reduced level of muscle co-activation, after only one week of isometric strength training for the leg extensors. There was no change in EMG amplitude for the vastus lateralis muscle following training, and it was proposed that the increases in strength were due to training-induced decreases in antagonist (hamstring) muscle co-activation, rather than increases in the level of agonist (quadriceps) muscle activation [5].

PRACTICAL APPLICATIONS

These findings were unlike those from previous investigations of the leg extensors that have reported increases in performance after only two or three training sessions. This information may be useful for coaches and athletes, as well as those involved in rehabilitative programs. Specifically, the muscles of the lower limb (i.e. calf) could require more than three training sessions to elicit the strength improvements and neuromuscular adaptations that typically occur during the early stages of a resistance training program. Improvements in muscle function that are apparent in as little a three training sessions may advance the knowledge of rehabilitation following injury or debilitating pathology.

REFERENCES

1. Akima, H., H. Takahashi, S. Kuno, K. Masuda, T. Masuda, H. Shimojo, I. Anno, Y. Itai, and S. Katsuta. Early phase adaptations of muscle use and strength to isokinetic training. *Med. Sci. Sports Exerc.* 31:588-594. 1999.

2. Basmajian, J., and C.J. De Luca. Muscles Alive. Their Functions Revealed By Electromyography (5th edition). Baltimore, MD: Williams & Wilkins, 1985.

3. Brown, L.E., and M. Whitehurst. The effect of short-term isokinetic training on force and rate of velocity development. *J. Strength Cond. Res.* 17:88-94. 2003.

4. Cardasis, C.A. and D.M. LaFontaine. Aging neuromuscular junctions: A morphometric study of cholinesterase-stained whole mounts and ultrastructure. *Muscle Nerve.* 10: 200-13. 1987.

5. Carolan, B and E. Cafarelli. Adaptations in co-activation after isometric resistance training. *J Appl Physiol.* 73:911–917. 1992.

6. Chandler, J.M., P.W. Duncan, G. Kochersberger, and S. Studenki. Is lower extremity strength gain associated with improvement in physical performance and disability in frail, community-dwelling elders? *Arch. Phys. Med. Rehabil.* 79: 24–30. 1988.

7. Coburn, J.W., T.J. Housh, M.H. Malek, J.P. Weir, J.T. Cramer, T.W. Beck, and G.O. Johnson. Neuromuscular responses to three days of velocity-specific isokinetic training. *J. Strength Cond. Res.* 20:892-898. 2006.

8. Dawson D.L., G. Hendershot, and J. Fulton. Aging in the eighties: functional limitations of individuals age 65 and over. National Center for Health Statistics. Hyattsville (MD): Advance Data from Vital and Health Statistics, 1987.

9. Farina D.P., R. Merletti, and R.M. Enoka. The extraction of neural strategies from the surface EMG. *J Appl Physiol.* 96:1486–1495. 2004.

10. Fiatrone, M.A., E.C. Marks, N.D. Ryan, C.N. Merideth, L.A. Lipsitz, and W.J. Evans. High intensity strength training in nonagenarians. *J. Am. Med. Assoc.* 263: 3029–3034. 1990.

11. Frontera, W.R., C.N. Meredith, K.P. O'Reilly, and W.J. Evans. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J. Appl. Physiol.* 64:1038 1988.

12. Frontera, W.R., V.A. Hughes, K.J. Lutz, and W.J. Evans. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol.* 71:644–650. 1991.

13. Gurney, J.M., and D.B. Julliffe. Arm anthropometry in nutritional assessment: nomogram for rapid calculation of muscle circumference and cross-sectional muscle and fat areas. *Am. J. Clin. Nutr.* 26:912–915, 1973.

14. Hakkinen K.J., M.Alen, M. Kallinen, M. Izquierdo M, K. Jokelainen, H. Lassila, E. Mälkiä, W.J. Kraemer, and R.U. Newton. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J. Appl. Physiol.* 84:1341-1349. 1998.

15. Harridge S.D.R. and M.J. White. A comparison of voluntary and electrically evoked isokinetic plantar flexor torque in males. *Eur J Appl Physiol.* 66:343–348. 1993.

16. Herbert R.D. and S.C. Gandevia. Twitch interpolation in human muscles: mechanisms and implications for measurement of voluntary activation. *J Neurophysiol.* 82:2271–2283. 1999.

17. Hruda, K.V., A.L. Hicks, and N. McCartney. Training for muscle power in older adults: Effects on functional abilities. *Can. J. Appl. Physiol.* 28:178–189. 2003.

18. Hunter, G.R., M.S. Treuth, R.L. Weinsier, T. Kekes-Szabo, S.H. Kell, D.L. Roth, and C. Nicholson. The effects of strength conditioning on older women's ability to perform daily tasks. *J. Am. Geriat. Soc.* 43:756–760. 1995.

19. Hunter, G.R., J.P. McCarthy, and M.M. Bamman. Effects of resistance training on older adults. *Sports Med.* 34: 329-348. 2004

20. Holtermann, A., K. Roelveld, B. Veriejken, and G. Ettema. Changes in agonist EMG activation level during MVC cannot explain early strength improvement. *Eur. J. Appl. Physiol.* 94:593-601. 2005.

21. Kamen G., S.V. Sison, C.C. Duke Du, and C. Patten. Motor unit discharge behavior in older adults during maximal-effort contractions. *J Appl Physiol.* 79:1908-1913. 1995.

22. Knight C.A. and G. Kamen. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. *J Electromyo Kinesiol.* 11:405-412. 2001.

23. Larsson, L., and T. Ansved. Effects of ageing on the motor unit. *Prog. Neurobiol.* 45:397–458. 1995.

24. Maffiuletti, N.A., P. Pensini, and A. Martin. Activation of human plantar flexor muscles increases after electromyostimulation training. *J Appl Physiol*. 92: 1383-1392. 2002.

25. Metter, J.E., L.A. Talbot, M. Schrager, and R. Conwit. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J. Gerontol.* 57A:359–365. 2002.

26. Moritani, T., and H.A. de Vries. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am. J. Phys. Med.* 58:115-130. 1979.

27. Norris, A.H., N.W. Shock, and I.H. Wagman. Age changes in the maximum conduction velocity of motor fibers of human ulnar nerves. *J. Appl. Physiol.* 5:589–593. 1953.

28. National Center for Health Statistics. Health, United States. Hyattesville (MD): National Center for Health Statistics, 2001

29. Prevost, M., A.G. Nelson, and B.K.V. Maraj. The effect of two days of velocity-specific isokinetic training on torque production. *J. Strength Cond. Res.* 13:35-39. 1999.

30. Roubenoff, R. Origins and clinical relevance of sarcopenia. *Can. J. Appl. Physiol.* 26: 78–79. 2001.

31. Scaglioni G., M.V. Narci, N.A. Maffiuletti, M. Pensini, and A. Martin. Plantar flexor activation capacity and H reflex in older adults: adaptations to strength training. *J Appl Physiol.* 92: 2292-2302. 2002.

33. Staron, R.S., D.L. Karapdono, W.J. Kraemer, A.C. Fry, S.E. Gordon, J.E. Falkel, F.C. Hagerman, and R.S. Hikida. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J. Appl. Physiol.* 76:1247-1255. 1994.

34. Tomlinson, B.E., and D. Irving. The number of limb motor neurons in the human lumbosacral cord throughout life. *J. Neurol. Sci.* 34:213–219. 1977.

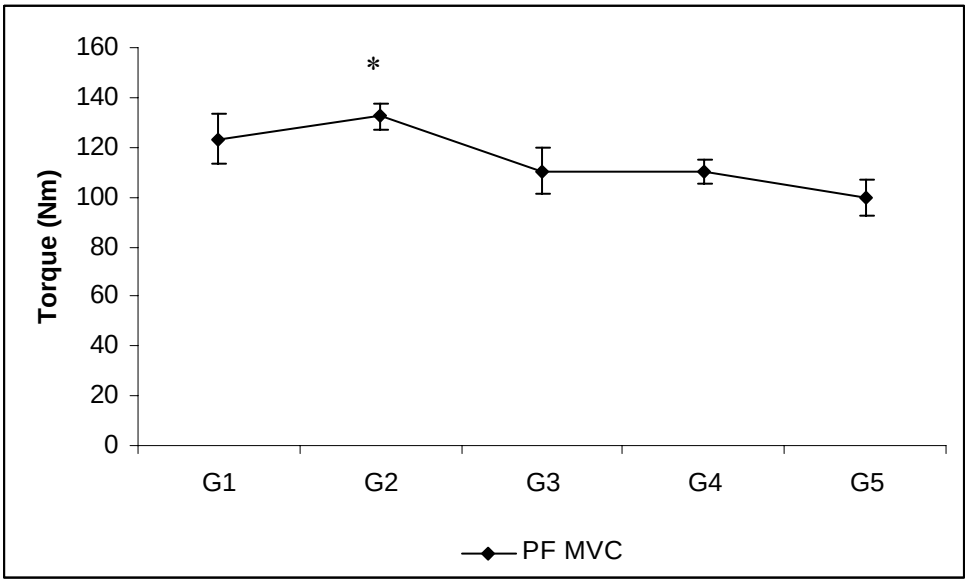
35. Zipp, P. Recommendations for the standardization of lead positions in surface electromyography. *Eur. J. Appl. Physiol.* 50:41-54. 1982.

Table 1. Baseline Comparison of Physical Characteristics

Group (Age Range)	Age (years)	Height (cm)	Weight (kg)
G1 (20-29 years)	23.5 ± 0.5*	179.8 ± 2.2	80.7 ± 5.0
G2 (30-39 years)	32.8 ± 0.7*	176.0 ± 2.2	86.3 ± 5.2
G3 (40-49 years)	44.0 ± 0.8*	175.6 ± 1.9	76.8 ± 3.8
G4 (50-59 years)	53.7 ± 1.0*	178.9 ± 2.7	81.9 ± 3.9
G5 (60-79 years)	67.7 ± 1.8*	172.7 ± 1.5	81.7 ± 2.4

* indicates significant differences ($p<0.05$) between age groups

List of Figures


160
140
120
100
80
60
40
20
0
Torque (Nm)
*
G1
G2
G3
G4
G5
PF MVC

Appendix A. Informed Consent

INFORMED CONSENT
TO PARTICIPATE IN A RESEARCH STUDY

PROJECT TITLE: Age Related Changes in Skeletal Muscle Activation Following Short-Term Resistance Training

PRINCIPAL INVESTIGATOR: Michael J. Hartman, M.S.

CONTACT INFORMATION: Department of Health and Exercise Science
1401 Asp Ave., Room 122
Phone: 405-325-3175
Email: michael.hartman@ou.edu

You are being asked to volunteer for a research study. This study is being conducted at the University of Oklahoma - Department of Health and Exercise Science. You were selected as a possible participant because you meet the criteria of a healthy, adult male between 20 and 79 years of age with no participation in strength training during the past 12-months. Please read this form and ask any questions that you may have before agreeing to take part in this study.

The sponsor of the study is: Michael G. Bemben, Ph.D.
Department of Health and Exercise Science
1401 Asp Ave., Room 120
Phone: 405-325-2717
Email: mgbemben@ou.edu

Purpose of the Research Study

The purpose of this study is to determine differences in muscle size, muscle strength, and voluntary muscle activation of the lower leg in healthy, adult males within age categories of 20-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, and 70-79 years of age following short-term strength training.

Procedures

If you agree to be in this study, you will be asked to do the following things:

You are required to complete a health history questionnaire and sign an informed consent document showing that you understand all of the testing procedures and your rights as a research subject. You will be required to attend seven separate testing or training sessions during a 2-week period. All sessions will be separated by at least 48-hours, and will be approximately 60-minutes in length (7-hours total time commitment).

Testing sessions will involve subjects performing maximal static (no movement) muscle contractions of the lower leg. Prior to testing, the lower leg will be passively moved to measure muscle stiffness. During the muscle contraction a brief electrical stimulation (1-ms) will be applied to the lower leg. Measurement of muscle activity will take place during the muscular contraction with small sensors taped to the surface of your skin. You will also be asked to track your effort on a computer monitor following the maximal contraction. Strength training sessions will involve the performance of six

strength training exercises designed to improve muscle strength of the legs and entire lower body. A pQCT scan will be conducted before and after training to measure muscle size.

Risks and Benefits of Being in the Study

The study has the following risks. You may experience muscle soreness following the muscle strength training and testing. The soreness is temporary and typically lasts less than 48 hours following testing. You will also be exposed to a small amount of radiation. To measure muscle size you will under go a peripheral quantitative computed tomography (pQCT) scan. The scanning is similar to an x-ray but at a much lower dose. The scan delivers an absorbed dose of 0.1 mRem. The pQCT results in x-ray exposure similar to the radiation exposure Americans receive in one day from natural radiation (~300 mRem/year), such as the radioactivity in soil. The amount of radiation exposure associated with 1 pQCT scan is too small to be measured directly. The pQCT scan is noninvasive and will take between 10-15 minutes to complete.

The benefits to participation are improved muscular strength and knowledge of muscle size and muscle activation.

Compensation

No compensation will be provided for participation in this research study. In the unlikely event that physical injury occurs as a result of participating in this study, emergency medical treatment is available. However, you or your insurance company may be expected to pay the usual charge for this treatment. No funds have been set aside by the University of Oklahoma Norman campus, to compensate you in the event of injury.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate will not result in penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you are free to not answer any question or withdraw at any time.

Confidentiality

The records of this study will be kept private. In published reports, there will be no information included that will make it possible to identify the research participant. Research records will be stored securely in a locked file cabinet in the principal investigator's (Michael Hartman) office. All subject-related materials and data will be held confidential and will be stored in the PI's office for a period not less than 5 years following publication. After this time, all subject-related materials and data will be shredded and only approved researchers will have access to the records.

Contacts and Questions:

The researcher conducting this study (Michael Hartman, Principle Investigator) can be contacted at 405-325-3175 or by email at michael.hartman@ou.edu. You are encouraged to contact the researcher or sponsor (Michael Bemben, 405-325-2717) if you have any questions.

If you have any questions about your rights as a research participant, you may contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405.325.8110 or irb@ou.edu.

You will be given a copy of this information to keep for your records. If you are not given a copy of this consent form, please request one.

STATEMENT OF CONSENT

I have read the above information. I have asked questions and have received satisfactory answers. I consent to participate in the study.

Signature	Date

Appendix B. HIPPA Document

IRB No.:[Provide IRB number]

AUTHORIZATION TO USE or DISCLOSE
PROTECTED HEALTH INFORMATION FOR RESEARCH

An additional Informed Consent Document for Research Participation may also be required. Form 2 must be used for research involving psychotherapy notes.

Title of Research Project: **Age Related Changes in Skeletal Muscle Activation Following Short-Term Resistance Training**

Leader of Research Team: **Michael J. Hartman, M.S.**

Address: **Dept. of HES; 1401 Asp Ave., Room 122; Norman, OK 73019**

Phone Number**: 405-325-3175**

If you decide to join this research project, University of Oklahoma (OU) researchers may use or share (disclose) information about you that is considered to be protected health information for their research. Protected health information will be called private information in this Authorization.

Private Information To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your private information. If you give permission, the researchers may use or share with the people identified in this Authorization any private information related to this research from your medical records and from any test results. Information, used or shared, may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form, medical records and charts, name, address, telephone number, date of birth, race, and government-issued identification number.

Purposes for Using or Sharing Private Information. If you give permission, the researchers may use your private information to compare the effects of short-term strength training to other healthy men with similar levels of activity of different ages.

Other Use and Sharing of Private Information. If you give permission, the researchers may also use your private information to develop new procedures or commercial products. They may share your private information with the research sponsor, the OU Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA) and the Department of Health and Human Services (HHS). The researchers may also share your private information with Michael G. Bemben, Ph.D. and Joel T. Cramer, Ph.D. who are co-investigators.

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. Any person or organization receiving the information based on this authorization could re-release the information to others and federal law would no longer protect it.

YOU MUST UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING ANY CONDITIONS CONSIDERED AS A COMMUNICABLE OR VENEREAL DISEASE WHICH MAY INCLUDE, BUT ARE NOT LIMITED TO, DISEASES SUCH AS HEPATITIS, SYPHILIS, GONORRHEA, AND HUMAN IMMUNODEFICIENCY VIRUS ALSO KNOWN AS ACQUIRED IMMUNE DEFICIENCY SYNDROME (AIDS).

Voluntary Choice. The choice to give OU researchers permission to use or share your private information for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OU researchers to use or share your private health information if you want to participate in the research and if you revoke your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care from OU.

Revoking Permission. If you give the OU researchers permission to use or share your private information, you have a right to revoke your permission whenever you want. However, revoking your permission will not apply to information that the researchers have already used, relied on, or shared.

End of Permission. Unless you revoke it, permission for OU researchers to use or share your private information for their research will end one year following graduation of the principal investigator. You may revoke your permission at any time by writing to:

Privacy Official
University of Oklahoma
660 Parrington Oval, Room 318 Evans Hall, Norman, OK 73019
If you have questions call: (405) 271-2511

Giving Permission. By signing this form, you give OU and OU's researchers led by Michael Hartman, permission to share your private information for the research project called Age Related Changes in Skeletal Muscle Activation Following Short-Term Resistance Training.

Subject Name: _____

_____

Signature of Subject or Parent if Subject is a child — Date

Or

_____

Signature of Legal Representative** — Date

**If signed by a Legal Representative of the Subject, provide a description of the relationship to the Subject and the Authority to Act as Legal Representative:

OU may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Subject or the Legal Representative at the time this signed form is provided to the researcher or his representative.

IRB No.:
[Provide IRB number]

Appendix C. Health and Exercise Questionnaire

PRE-EXERCISE TESTING
HEALTH & EXERCISE STATUS
QUESTIONNAIRE

The University of Oklahoma

Name _____ Date_____

Home Address _____

Work Phone _____ Home Phone _____

Person to contact in case of emergency _____

Emergency Contact Phone _____ Birthday (mm/dd/yy)____/_____/_____

Personal Physician _____ Physician's Phone_____

Gender _____ Age _____(yrs) Height _____(ft)_____(in) Weight_____(lbs)

Does the above weight indicate: a gain____ a loss____ no change____ in the past year?
If a change, how many pounds?_____(lbs)

A. JOINT-MUSCLE STATUS (✓Check areas where you currently have problems)

Joint Areas	Muscle Areas
( ) Wrists	( ) Arms
( ) Elbows	( ) Shoulders
( ) Shoulders	( ) Chest
( ) Knees	( ) Buttocks
( ) Ankles	( ) Thighs
( ) Feet	( ) Lower Leg
( ) Other_____	( ) Feet

B. HEALTH STATUS (✓Check if you currently have any of the following conditions)

( ) High Blood Pressure
( ) Heart Disease or Dysfunction
( ) Peripheral Circulatory Disorder
( ) Lung Disease or Dysfunction
( ) Arthritis or Gout
( ) Edema
( ) Acute Infection
( ) Diabetes or Blood Sugar Level Abnormality
( ) Anemia
( ) Hernias
( ) Thyroid Dysfunction
( ) Pancreas Dysfunction

** NOTE: If any of these conditions are checked, then a physician's health clearance will required.*

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination_____

Physical problems noted at that time_____

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _____YES _____NO
If YES, what limitations were recommended?_____
_____

D. CURRENT MEDICATION USAGE

MEDICATION	**CONDITION**
_____	_____

E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ✓Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED		PA	SED	
( )	( )	Chest Pain	( )	( )	Nausea
( )	( )	Heart Palpitations	( )	( )	Light Headedness
( )	( )	Unusually Rapid Breathing	( )	( )	Loss of Consciousness
( )	( )	Overheating	( )	( )	Loss of Balance
( )	( )	Muscle Cramping	( )	( )	Loss of Coordination
( )	( )	Muscle Pain	( )	( )	Extreme Weakness
( )	( )	Joint Pain	( )	( )	Numbness
( )	( )	Other_____	( )	( )	Mental Confusion

F. FAMILY HISTORY (✓Check if any of your blood relatives have or had any of the following)

( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

G. EXERCISE STATUS

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)?

How long have you engaged in this form of exercise? _____ years _____ months

How many hours per week do you spend for this type of exercise? _____ hours

Do you regularly lift weights?

How long have you engaged in this form of exercise? _____ years _____ months

How many hours per week do you spend for this type of exercise? _____ hours

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)?

How long have you engaged in this form of exercise? _____ years _____ months

How many hours per week do you spend for this type of exercise? _____ hours

Appendix D. Medical Clearance Form

Name of Participant _____ Date _____

Department of Health and Exercise Science – University of Oklahoma – Norman Campus

Resistance Training – Medical Clearance Form

To the Attending Physician of:_____

This individual has indicated that he wishes to participate in a research study investigating the age related changes in skeletal muscle activation following short-term resistance training. This project has been approved by the Institutional Review Board at the University of Oklahoma. The purpose of this study is to determine differences in muscle size, muscle strength, and voluntary muscle activation of the lower leg in healthy, adult males within age categories of 20-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, and 70-79 years of age following a 1-week strength training program.

Description of the Study

Before entering the study, subjects are required to obtain medical clearance from the physicians associated with this project. The following laboratory-based tests will be conducted:

- Testing sessions will involve subjects performing maximal static (no movement) muscle contractions of the lower leg. Three 5-second maximal contractions will be performed before and after the strength training program. During the muscular contraction a brief electrical stimulation (1-ms) will be applied to the lower leg. Measurement of muscle activity will take place during the muscular contraction with small sensors taped to the surface of the skin. Subjects will also be asked to track their effort on a computer monitor following the maximal muscle contraction.

- Strength training sessions will involve the performance of six strength training exercises designed to improve muscle strength of the legs and entire lower body during three separate sessions. The resistance training protocol will consist of a 5-10 minute warm-up (cycling, walking, stretching) followed by 4 sets of 10 repetitions at a workload of approximately 70% of maximum. The exercises and the muscle groups targeted include:
    - Seated Leg Flexion targeting the hamstrings
    - Seated Leg Extension targeting the quadriceps
    - Supine Leg Press targeting the lower body
    - Standing Calf Raise, Seated Calf Raise, and Supine Calf Raise targeting the muscles of the calf involved with plantar flexion (gastrocnemius and soleus).

- Measurement of muscle cross-sectional area will be conducted before and after the three strength training sessions using measures of circumfrence and skin fold assessment of the lower limb.

- Questionnaires-Health Status and Physical Activity

Please advise the investigators regarding any physical limitations and/or contraindications that this patient might have for engaging in this exercise study.

Please check one of the following conditions:

To my knowledge, there is no reason why this patient,_____, should not be allowed to participate in this study.

I recommend that this patient, _____, be allowed to participate in the study with the following restrictions:

I recommend that this patient,_____, should **not** be allowed to participate in the study for the following reasons:

Physician' Name_____ Date_____
(printed)

Physician's Signature_____

If you have any question about this form, please contact: Michael G. Bemben, Ph.D., Professor, Neuromuscular Research Laboratory Supervisor at (405) 325-2717.

Appendix E. Data Collection Sheet

the university of OKLAHOMA
Department of Health and Exercise Science
Neuromuscular Research Laboratory

Subject: _____

Familiarization: _____

Position: _____ Location: _____ MVC: _____ Twitch: _____

Pre-Testing: _____

Bodyweight: _____

Muscle Size: Distance: _____ Cir: _____ _____ Msf: _____ _____ Lsf: _____ _____

Shave & Prep: SOL: _____ MG: _____ TA: _____
Distance: SOL: _____ MG: _____ TA: _____
IED: SOL: _____ MG: _____ TA: _____

Seat Position: _____ Tibialis Anterior: _____ _____

Resting Twitch: Start: _____ Finish: _____ Supra-Maximal: _____

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Trial 1: _____ Trial 2: _____ Trial 3: _____

Muscle Strength: Leg Press 1-RM: _____ Seated Calf: _____

Training Loads: Leg Press: 50 _____ 70 _____ Seated: 50 _____ 70 _____ Stand: _____ Supine: _____

Post-Testing: _____

Bodyweight: _____

Muscle Size: Distance: _____ Cir: _____ _____ Msf: _____ _____ Lsf:

_____ _____

Shave & Prep: SOL: _____ MG: _____ TA: _____
Distance: SOL: _____ MG: _____ TA: _____
IED: SOL: _____ MG: _____ TA: _____

Seat Position: _____ Tibialis Anterior: _____ _____

Resting Twitch: Start: _____ Finish: _____ Supra-Maximal: _____

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Trial 1: _____ Trial 2: _____ Trial 3: _____

Appendix F. Recruitment Advertisement

Television and Print Media Advertisement:

Strength Training
Research Study

Healthy, adult males between 20-79 years of age are asked to volunteer to participate in a Strength Training Research study conducted at the University of Oklahoma.

Testing and training will take place during 6 visits to the laboratory over a 2-Week period.

For more information contact:
Michael Hartman
michael.hartman@ou.edu
405-325-3175

Appendix G. Raw Data

Subject	ID	Group	Age	Ht	Wt
00	MK	2	34	175.26	79.5
01	CH	2	31	182.88	83.0
02	KK	1	27	185.42	84.1
03	CJ	4	51	190.5	86.4
04	DN	4	53	185.42	84.1
05	JM	1	25	172.72	78.3
06	MT	2	34	170.18	77.2
07	SF	2	36	180.34	81.8
08	SD	1	23	177.8	80.6
09	SL	1	23	170.18	77.2
10	BS	1	23	190.5	86.4
11	MT	1	21	175.26	79.5
12	DK	1	24	177.8	80.6
13	MB	1	23	177.8	80.6
14	PM	3	41	177.8	80.6
15	IP	2	33	175.26	79.5
16	PH	1	24	190.5	86.4
17	FB	1	22	180.34	81.8
18	JW	2	31	167.64	76.0
19	TO	5	60	172.72	78.3
20	MC	4	51	175.26	79.5
21	SC	3	46	180.34	81.8
22	AP	6	71	175.26	79.5
23	HL	6	70	182.88	83.0
24	JJ	3	47	175.26	79.5
25	CJ	5	63	167.64	76.0
26	FL	6	76	170.18	77.2
27	KJ	5	66	167.64	76.0
28	JL	6	73	170.18	77.2
29	LK	3	43	165.1	74.9
30	HR	4	55	175.26	79.5
31	MR	3	45	175.26	79.5
32	FD	4	53	185.42	84.1
33	JY	4	51	180.34	81.8
34	WR	3	44	175.26	79.5
35	BW	4	58	182.88	83.0
36	LO	5	61	175.26	79.5
37	GH	4	42	167.64	76.0
38	SS	5	64	170.18	77.2
39	JC	4	59	167.64	76.0
40	GP	2	34	185.42	84.1
41	BC	2	30	165.1	74.9
42	LA	2	30	175.26	79.5
43	EF	6	73	175.26	79.5
44	KF	2	35	182.88	83.0
45	ST	3	42	180.34	79.4

Avg Pre

Cir	MSf	LSf	CSA	MVC	SI Tw	P Tw	% VA
36.45	5.5	7.45	80.57	106.61	0.20	1.87	97.80
39.25	13.2	13.7	99.27	120.46	-0.02	1.74	100.00
43.55	9.9	11.9	78.17	113.97	0.01	1.85	99.75
40	4.1	4.3	71.24	113.18	-0.03	2.42	98.00
37.5	5.9	8.4	119.13	97.10	-0.06	1.48	99.24
34	7.1	5.9	98.96	149.05	0.00	1.55	100.00
40	4.1	4.3	88.30	113.56	0.04	1.97	98.89
35.5	11	12.5	105.47	117.37	-0.01	1.86	99.18
33.9	7.95	8.4	81.32	87.85	0.03	1.31	88.38
31.75	3.9	7.8	128.20	60.96	0.06	1.12	84.08
40	4.1	4.3	98.96	156.15	-0.04	2.47	90.86
35.5	11	12.5	81.32	125.31	0.11	0.00	92.49
35.5	6.8	7.2	97.68	85.11	-0.05	1.15	98.28
37.5	5.9	8.4	106.46	106.62	0.02	1.41	93.16
37	4.9	9.2	105.47	75.14	0.33	1.77	82.76
38.5	6	7.4	94.31	112.40	0.09	1.94	95.16
38.5	6	7.4	119.13	144.95	-0.03	2.13	86.45
39	11	12.5	119.13	104.05	0.06	1.50	92.32
38.6	5.5	7.45	101.59	125.41	0.11	0.01	92.49
42	9.2	8.3	80.57	102.65	0.02	1.74	98.23
39.5	9.3	9.6	96.34	106.26	0.08	1.21	82.21
41	13.5	9	70.23	105.46	0.02	1.32	92.21
43	12	12.2	98.96	106.90	0.06	1.61	93.85
34.25	6.8	5	122.35	49.73	0.13	1.42	96.03
37	7.8	8.2	122.67	156.15	-0.04	2.47	90.86
36.45	5.5	7.45	111.77	125.31	0.11	0.00	92.49
39.25	13.2	13.7	94.70	85.11	-0.05	1.15	98.28
43.55	9.9	11.9	94.31	106.07	0.02	1.44	98.57
40	4.1	4.3	119.13	75.14	0.33	1.77	82.76
37.5	5.9	8.4	106.26	112.40	0.09	1.94	95.16
34	7.1	5.9	111.77	144.95	-0.03	2.13	86.45
42	9.2	8.3	98.96	103.61	0.06	1.53	96.64
39.5	9.3	9.6	106.26	115.02	0.06	1.56	97.53
41	13.5	9	81.32	102.65	0.02	1.74	98.23
43	12	12.2	83.57	106.26	0.08	1.21	82.21
34.25	6.8	5	128.20	104.83	0.02	1.36	98.51
37	7.8	8.2	122.67	115.02	0.06	1.56	97.53
36.45	5.5	7.45	94.70	102.65	0.02	1.74	98.23
39.25	13.2	13.7	94.31	106.26	0.08	1.21	82.21
43.55	9.9	11.9	97.68	104.83	0.02	1.36	98.51
40	4.1	4.3	128.20	106.85	0.06	1.62	97.80
37.5	5.9	8.4	83.57	149.73	0.13	1.42	96.03
34	7.1	5.9	122.35	156.15	-0.04	2.47	90.86
33.5	12	12.2	119.13	125.31	0.11	0.00	92.49
38.25	6.975	9.125	70.23	115.10	0.06	1.55	91.31
33.5	12	12.2	97.68	114.12	0.08	0.97	92.97

RMS sol	MDF sol	RMS mg	MDF mg	RMS ta	MDF ta	TA MVC	TA rms	TA mdf
102.02	158.09	367.47	165.16	36.47	67.92			
207.74	113.37	604.53	106.12	265.77	101.98			
165.25	77.80	158.92	91.54	18.32	109.04			
184.95	151.19	452.13	75.59	45.09	69.66			
258.51	156.08	337.71	204.87	108.90	55.86			
483.63	68.07	496.88	160.08	163.66	26.01			
164.99	125.11	395.76	109.60	91.41	87.15			
251.46	115.65	368.28	128.33	85.48	69.54			
317.77	103.70	236.78	129.12	72.50	69.52	17.80	109.49	158.04
125.34	141.40	53.52	129.86	118.35	61.09	12.52	110.90	157.90
104.09	143.40	201.26	129.38	27.63	91.26	30.98	108.45	157.93
107.24	195.97	153.43	182.13	50.53	83.24	26.74	129.34	157.93
155.10	162.65	298.09	140.53	123.61	57.07	17.56	122.00	171.41
175.14	141.13	243.87	135.56	81.36	74.12	21.77	116.04	160.64
68.97	128.47	118.06	108.78	25.79	65.71	15.36	104.28	157.10
115.56	157.69	250.39	156.72	90.16	48.70	25.09	106.57	157.87
184.63	146.86	557.32	97.09	126.59	103.59	29.23	117.74	157.99
158.56	141.52	231.94	135.00	76.68	70.74	21.46	113.38	159.85
107.25	195.98	153.44	182.13	50.54	83.24	26.76	129.35	157.93
128.02	115.01	193.38	185.68	18.17	44.23	22.83	107.35	157.60
76.90	138.32	216.50	144.70	35.16	26.54	22.42	127.48	157.93
176.83	143.80	218.56	139.89	79.68	71.95	21.56	116.04	160.64
137.40	142.83	263.79	129.21	80.28	75.43	22.02	113.94	160.11
65.59	138.70	148.61	155.40	8.78	86.23	9.95	101.15	204.39
104.09	143.40	201.26	129.38	27.63	91.26	30.98	108.45	157.93
107.24	195.97	153.43	182.13	50.53	83.24	26.74	129.34	157.93
155.10	162.65	298.09	140.53	123.61	57.07	17.56	122.00	171.41
163.75	141.47	239.21	130.41	76.52	76.85	21.65	116.04	160.64
68.97	128.47	118.06	108.78	25.79	65.71	15.36	104.28	157.10
115.56	157.69	250.39	156.72	90.16	48.70	25.09	106.57	157.87
184.63	146.86	557.32	97.09	126.59	103.59	29.23	117.74	157.99
149.45	141.79	228.21	130.88	72.81	72.92	21.36	113.38	159.85
128.48	153.79	259.68	135.00	74.40	75.20	23.80	114.92	160.12
128.02	115.01	193.38	185.68	18.17	44.23	22.83	107.35	157.60
76.90	138.32	216.50	144.70	35.16	26.54	22.42	127.48	157.93
163.54	144.19	213.11	133.88	74.04	75.13	21.41	116.04	160.64
128.48	153.79	259.68	135.00	74.40	75.20	23.80	114.92	160.12
128.02	115.01	193.38	185.68	18.17	44.23	22.83	107.35	157.60
76.90	138.32	216.50	144.70	35.16	26.54	22.42	127.48	157.93
163.54	144.19	213.11	133.88	74.04	75.13	21.41	116.04	160.64
136.36	142.86	263.36	128.75	79.84	75.68	22.01	113.94	160.11
65.59	138.70	148.61	155.40	8.78	86.23	29.95	101.15	204.39
104.09	143.40	201.26	129.38	27.63	91.26	30.98	108.45	157.93
107.24	195.97	153.43	182.13	50.53	83.24	26.74	129.34	157.93
130.10	153.74	260.35	135.74	75.10	74.81	23.82	114.92	160.12
96.04	168.51	164.18	162.26	34.37	85.99	23.60	117.07	169.54

Avg Post

Wt	Cir	MSf	LSf	CSA	MVC	Sl Tw	P Tw	% VA
73.03	36.25	4.50	7.70	80.57	103.17	0.04	1.97	90.16
86.86	39.00	13.30	13.20	99.27	160.60	-0.09	1.53	100.06
109.54	43.55	9.70	12.10	84.36	96.69	0.00	1.99	99.27
76.88	40.00	4.30	4.90	70.85	139.88	0.05	1.65	101.95
93.89	38.00	6.00	8.50	119.13	109.03	0.00	0.86	98.37
69.40	34.50	6.63	6.30	98.96	159.62	-0.01	1.78	99.35
75.30	40.00	4.10	4.30	88.30	125.09	0.00	1.79	97.86
86.64	35.50	11.00	12.50	105.47	126.06	0.01	1.61	99.36
63.05	35.00	7.20	8.40	83.94	81.99	0.15	1.21	97.20
59.87	31.70	3.90	8.00	128.20	66.49	0.18	1.24	95.61
97.52	40.00	4.10	4.30	101.61	156.63	0.21	2.47	101.52
82.55	35.50	11.00	12.50	83.94	109.02	-0.07	2.11	94.68
73.94	35.50	6.80	7.20	96.64	111.56	0.02	1.32	103.70
73.94	37.50	5.90	8.40	70.27	109.05	0.07	1.68	98.56
74.84	37.00	5.20	10.90	105.47	95.08	0.31	1.35	75.03
76.43	38.50	6.00	7.40	93.86	114.25	0.09	1.70	93.67
88.45	38.50	6.00	7.40	119.13	123.74	0.28	2.15	100.87
88.91	39.00	11.00	12.50	118.35	108.17	0.10	1.65	95.72
73.94	33.51	12.01	12.21	101.59	109.12	-0.06	2.12	94.68
78.47	41.50	8.70	8.00	80.57	114.23	0.03	1.30	98.17
90.49	40.25	10.00	9.80	94.61	107.00	0.17	1.46	94.36
90.95	42.00	13.00	9.00	70.23	106.38	0.08	1.66	98.68
102.97	43.00	12.00	12.20	101.61	113.54	0.07	1.73	95.84
76.20	34.50	6.80	5.20	122.35	90.31	0.06	1.16	89.09
83.92	37.50	7.40	7.40	120.34	156.63	0.21	2.47	101.52
81.65	36.25	4.50	7.70	118.30	95.52	-0.07	2.11	94.68
85.28	39.00	13.30	13.20	98.52	111.56	0.02	1.32	103.70
80.74	43.55	9.70	12.10	93.86	108.26	0.07	1.71	98.61
85.28	40.00	4.30	4.90	118.35	95.08	0.31	1.35	75.03
78.02	38.00	6.00	8.50	109.83	114.25	0.09	1.70	93.67
68.95	34.50	6.63	6.30	118.30	123.74	0.28	2.15	100.87
85.73	41.50	8.70	8.00	101.61	107.54	0.10	1.67	95.76
85.73	40.25	10.00	9.80	109.83	115.01	0.13	1.83	95.44
63.50	42.00	13.00	9.00	83.94	114.23	0.03	1.30	98.17
59.42	43.00	12.00	12.20	84.70	107.00	0.17	1.46	94.36
97.52	34.50	6.80	5.20	128.20	105.46	0.09	1.69	98.73
82.55	37.50	7.40	7.40	120.34	115.01	0.13	1.83	95.44
73.94	36.25	4.50	7.70	98.52	114.23	0.03	1.30	98.17
73.94	39.00	13.30	13.20	93.86	107.00	0.17	1.46	94.36
85.73	43.55	9.70	12.10	96.64	105.46	0.09	1.69	98.73
124.74	40.00	4.30	4.90	128.20	113.47	0.07	1.73	95.84
93.89	38.00	6.00	8.50	84.70	168.31	0.06	1.16	89.09
70.31	34.50	6.63	6.30	122.35	156.63	0.21	2.47	101.52
73.94	33.50	12.00	12.20	118.35	109.02	-0.07	2.11	94.68
97.52	38.25	6.98	9.13	70.23	115.12	0.13	1.82	95.43
79.83	33.50	12.00	12.20	96.64	109.49	0.03	1.96	94.99

RMS sol	MDF sol	RMS mg	MDF mg	RMS ta	MDF ta	TA MVC	TA rms	TA mdf
181.59	118.46	372.51	170.52	65.38	87.47			
138.48	119.71	588.87	120.13	166.79	94.30			
92.74	101.09	185.47	90.16	16.87	123.67			
188.54	175.59	378.21	89.24	58.29	63.71			
159.90	123.61	345.00	196.03	62.04	48.93			
697.02	59.94	502.71	121.07	142.24	105.05			
150.34	128.71	381.27	117.51	76.83	92.29			
257.71	117.79	358.53	122.80	71.26	86.73			
149.21	116.41	231.49	121.59	30.82	89.60	17.00	113.49	152.81
102.58	142.59	40.61	119.72	55.88	105.03	12.81	103.18	158.25
102.67	140.08	267.52	136.61	32.73	74.71	29.74	101.44	164.24
159.35	193.62	224.01	154.97	66.20	109.45	26.72	107.01	157.86
144.37	152.54	338.65	136.00	51.36	80.94	17.53	101.88	159.41
152.32	141.68	263.15	129.89	55.01	91.25	21.74	105.40	158.51
80.25	127.02	237.12	93.62	29.73	26.99	14.28	119.12	158.01
131.95	140.96	281.87	176.91	38.00	60.98	26.14	114.34	158.92
192.11	122.93	460.81	93.81	60.04	70.80	29.27	109.04	157.88
143.07	140.14	262.42	130.96	50.78	81.80	21.73	108.23	158.50
159.35	193.62	224.02	154.97	66.21	109.45	26.88	107.02	157.86
172.23	94.78	232.95	149.64	112.15	63.26	22.31	105.46	158.00
92.43	137.15	181.85	135.17	15.60	45.23	23.16	109.11	157.83
152.65	143.84	243.47	131.95	51.38	91.08	21.23	105.40	158.51
134.08	141.21	288.91	128.89	57.84	83.50	22.01	107.48	159.31
111.35	114.13	171.22	133.61	34.32	90.13	10.62	101.89	158.87
102.67	140.08	267.52	136.61	32.73	74.71	31.99	101.44	164.24
159.35	193.62	224.01	154.97	66.20	109.45	25.97	107.01	157.86
144.37	152.54	338.65	136.00	51.36	80.94	17.83	101.88	159.41
136.06	144.15	256.93	126.48	52.07	92.18	21.52	105.40	158.51
80.25	127.02	237.12	93.62	29.73	26.99	15.73	119.12	158.01
131.95	140.96	281.87	176.91	38.00	60.98	25.54	114.34	158.92
192.11	122.93	460.81	93.81	60.04	70.80	29.27	109.04	157.88
130.06	142.12	257.45	128.24	48.43	82.54	21.13	108.23	158.50
135.25	145.90	295.28	131.20	47.16	73.72	24.05	108.32	159.26
172.23	94.78	232.95	149.64	112.15	63.26	24.21	105.46	158.00
92.43	137.15	181.85	135.17	15.60	45.23	22.16	109.11	157.83
133.68	146.73	236.21	127.98	47.94	92.16	22.51	105.40	158.51
135.25	145.90	295.28	131.20	47.16	73.72	23.90	108.32	159.26
172.23	94.78	232.95	149.64	112.15	63.26	22.91	105.46	158.00
92.43	137.15	181.85	135.17	15.60	45.23	22.42	109.11	157.83
133.68	146.73	236.21	127.98	47.94	92.16	21.41	105.40	158.51
132.60	141.44	288.34	128.58	57.57	83.58	22.01	107.48	159.31
111.35	114.13	171.22	133.61	34.32	90.13	29.95	101.89	158.87
102.67	140.08	267.52	136.61	32.73	74.71	30.98	101.44	164.24
159.35	193.62	224.01	154.97	66.20	109.45	26.74	107.01	157.86
137.57	145.55	296.16	131.68	47.58	73.59	23.82	108.32	159.26
133.18	160.36	221.69	145.04	49.86	95.93	23.60	104.34	159.70

Training Load

Leg Press 50%	Leg Press 70%	Leg Press Max	Seated Calf 50%	Seated Calf 70%	Se Calf max	Standing Calf	Supine Calf
63.5	88.9	127.0	24.9	34.9	49.9	72.8	63.5
77.1	108.0	154.2	29.5	41.3	59.0	86.2	77.1
104.3	146.1	208.7	46.5	65.1	93.0	108.9	104.3
79.4	111.1	158.8	34.0	47.6	68.0	78.5	79.4
90.7	127.0	181.4	38.1	53.3	76.2	93.0	90.7
88.5	123.8	176.9	37.1	52.0	74.3	68.9	88.5
113.4	158.8	226.8	47.6	66.7	95.3	70.3	113.4
86.2	120.7	172.4	36.2	50.7	72.4	85.7	86.2
68.0	95.3	136.1	28.6	40.0	57.2	63.5	68.0
68.0	95.3	136.1	28.6	40.0	57.2	59.4	68.0
113.4	158.8	226.8	47.6	66.7	95.3	97.5	113.4
108.9	152.4	217.7	45.7	64.0	91.4	82.6	108.9
108.9	152.4	217.7	45.7	64.0	91.4	73.9	108.9
81.6	114.3	163.3	34.3	48.0	68.6	73.9	81.6
59.0	82.6	117.9	24.8	34.7	49.5	75.8	59.0
72.6	101.6	145.2	30.5	42.7	61.0	76.4	72.6
90.7	127.0	181.4	38.1	53.3	76.2	88.5	90.7
108.9	152.4	217.7	45.7	64.0	91.4	90.0	108.9
68.0	95.3	136.1	28.6	40.0	57.2	63.5	68.0
54.4	76.2	108.9	22.9	32.0	45.7	77.1	54.4
63.5	88.9	127.0	26.7	37.3	53.3	90.9	63.5
59.0	82.6	117.9	24.8	34.7	49.5	90.3	59.0
54.4	76.2	108.9	22.9	32.0	45.7	100.2	54.4
45.4	63.5	90.7	19.1	26.7	38.1	76.7	45.4
72.6	101.6	145.2	30.5	42.7	61.0	84.6	72.6
74.8	104.8	149.7	31.4	44.0	62.9	81.6	74.8
54.4	76.2	108.9	22.9	32.0	45.7	85.3	54.4
63.5	88.9	127.0	26.7	37.3	53.3	80.7	63.5
59.0	82.6	117.9	24.8	34.7	49.5	85.3	59.0
95.3	133.4	190.5	40.0	56.0	80.0	77.6	95.3
45.4	63.5	90.7	19.1	26.7	38.1	68.9	45.4
99.8	139.7	199.6	41.9	58.7	83.8	70.3	99.8
74.8	104.8	149.7	31.4	44.0	62.9	85.7	74.8
54.4	76.2	108.9	22.9	32.0	45.7	63.5	54.4
63.5	88.9	127.0	26.7	37.3	53.3	59.4	63.5
59.0	82.6	117.9	24.8	34.7	49.5	97.5	59.0
54.4	76.2	108.9	22.9	32.0	45.7	82.6	54.4
45.4	63.5	90.7	19.1	26.7	38.1	73.9	45.4
72.6	101.6	145.2	30.5	42.7	61.0	73.9	72.6
74.8	104.8	149.7	31.4	44.0	62.9	85.7	74.8
113.4	158.8	226.8	47.6	66.7	95.3	124.7	113.4
113.4	158.8	226.8	47.6	66.7	95.3	93.9	113.4
72.6	101.6	145.2	30.5	42.7	61.0	70.3	72.6
54.4	76.2	108.9	22.9	32.0	45.7	73.9	54.4
90.7	127.0	181.4	38.1	53.3	76.2	97.5	90.7
72.6	101.6	163.3	30.5	42.7	61.0	79.4	72.6