Effects of Supersets Versus Traditional Strength Training Methods on Muscle Adaptations, Recovery, and Selected Anthropometric Measures

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This dissertation titled
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ABSTRACT

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Effects of Supersets Versus Traditional Strength Training Methods on Muscle Adaptations, Recovery, and Selected Anthropometric Measures

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Resistance training has proven to be beneficial for individuals of all ages at improving muscular strength and endurance, increasing muscle size, and improving performance and body image among other factors. Specific intensities, volumes, and rest periods have been suggested through resistance training research as a means of targeting a particular variable such as muscle strength or power. Modifications to the arrangement of exercises during a resistance training program may promote speedier gains or enhanced muscle development. Individuals would likely be more inclined to participate in a resistance training regimen if this were the case.

In order to determine whether changing exercise arrangement during a resistance training program will elicit superior gains in muscle and body development, 31 young women were divided into three groups: control (C), traditional (T), and compound supersets group (SS). Supersets are coupled resistance training exercises that target either the same muscle group (agonist-agonist/compound superset) or opposing muscle groups (agonist-antagonist/reciprocal supersets). The women were tested pre-training for muscle strength (MS), muscle endurance (ME), vastus lateralis cross-sectional area (CSA) and thickness, body composition (BC), and thigh girth. The women then trained for 12 weeks. Post workout soreness and workout time per session was also monitored.
The T training group had significant improvements in MS, ME, CSA, and thickness, but not for body composition. The SS training group also demonstrated significant improvements in MS, ME, and CSA but the improvements in BC and thickness were not significant for the SS group. The SS group did differ significantly from the C group for post 1RM squat and post leg press ME, while the T group did not differ significantly from the C group for those measurements. Also, the SS group demonstrated superior workout efficiency (weight lifted/time). Post workout soreness was not different between training groups.

The results suggest that SS training is a more time efficient method of resistance training that elicits thigh muscle strength and endurance gains similar to or above T training in young women.

Approved: _____________________________________________________________

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“It always seems impossible until it’s done” (Nelson Mandela-1993 Nobel Prize for Peace winner and the first fully representative democratically elected state president of South Africa in 1994).

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This is dedicated to Diann Jeanette Darby, January 17, 1943-June 17, 2003.
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I. RESISTANCE TRAINING

A. Background

Weightlifting has long been a part of American culture. Since the mid nineteenth century, “strongmen” were routinely part of circus acts; later on in the century, strength testing was a general evaluation used in the armed forces and in physical education programs of higher education (Hitchcock & Seeyle, 1887). Resistance training is a type of strength training in which muscular efforts are performed against resistive forces, typically weights or even one’s own body weight. There are several types of resistance training equipment that utilize a variety of muscle actions to improve the function of muscle through the principle of overload. Some examples of the equipment are free weights, weight machines, and elastic bands. Muscle actions are either static or isometric (no observable change occurs in muscle fiber length) or dynamic (movement of the skeleton occurs). Resistance training generally leads to increases in muscle strength, power, and size by having muscles contract against a resistance, such as a dumbbell or barbell; this can result in muscle cells adapting by enlarging. The gradual and progressive overloading of muscles leads to adaptive responses, which are well documented in numerous studies (Hartman, Phillips, & Tang, 2006; Petrella, Jeong-su, Tuggle, & Bamman, 2007; Staron et al., 1991, Yang, Wang, Lin, Chu, & Chan, 2006). Initially, gains in strength are facilitated by more coordinated recruiting of the available muscle and nerve cells (motor units) (Moritani & DeVries, 1979); soon thereafter, there can be an increase in size of the trained muscles. Possible explanations for the neural adaptations
seen with resistance training include: more efficient neural recruitment patterns, inhibition of muscle tension receptors, improved synchronization of motor units, and increased activation of the central nervous system (Gabriel, Kamen, & Frost, 2006).

Resistance training is an integral component of a total conditioning program. Many studies have delineated the numerous physiological adaptations to resistance training (Hakkinen & Kallinen, 1998; Martyn-St. James & Carroll, 2009; Tsolakis, Vagenas, & Dessypris, 2004). Examples of the physiological adaptations resulting from resistance training are: increased muscle fiber size and strength, increased capillary density, increased carbohydrate metabolism, increased tendon and ligament strength, improved body composition, and increased bone mineral density. Studies have also shown that a program of consistent resistance training can improve athletic performance, have a positive psychological impact, and increase energy expenditure while simultaneously reducing the risk of injury and certain types of disease, and aiding in the recovery from a variety of complications (Pearson, Faigenbaum, Conley, & Kraemer, 2000). This makes resistance training beneficial for a wide variety of populations, such as the athlete (to improve performance), the elderly (to increase strength and stave off age-related loss of muscle mass (sarcopenia), the rehabilitation patient (to restore normal function), and the healthy general population.

B. Populations and Resistance Training

Athletes utilize resistance training to gain an advantage in sporting ventures, while both athletes and rehabilitation populations use resistance training to assist
recovery (Fletcher et al., 1996). For years, athletes have routinely used resistance training to improve performance and to reduce the risk of injury. Resistance training improves joint stability by strengthening tendons and ligaments, as well as the muscles that surround the joints. Resistance training can also be psychologically beneficial to athletes because reaching training goals and being bigger, faster or stronger than opponents can provide a psychological advantage (Adamsen et al., 2009; Dionigi, 2007). The number of sports and athletes that seriously utilize resistance training continues to rise. Strength coaches are now hired regularly, even at the middle school level, to train adolescents properly. Sports that traditionally had little or no resistance training involved such as golf are now benefitted by the effects of resistance training (Lehman, 2006).

The elderly, rehabilitation, and general populations also benefit from resistance training because it improves body composition, increases lean mass and bone density, reduces disease and injury risks, and assists with daily living activities (Menkes et al., 1993). The goals of athletes and younger individuals using resistance training tend to be different than the goals of the elderly. The life expectancy in the United States has increased substantially in the last half century, and technological advances in medicine and other areas will likely prolong this trend. With aging and poor health, normal living tasks become increasingly difficult in part due to muscle weakness. The elderly require adequate muscular strength for safety, independence, and injury prevention. Skeletal muscle mass peaks in the mid to late twenties and begins to decrease every decade thereafter (Lexell, Taylor, Sjostrom, 1988; Trappe, 2009). In the latter stages of life, humans generally see a reduced cross-sectional area in muscle and a substantial decrease
of up to 40% in muscle strength as compared to peak years (Rantanen et al., 1998).

Fortunately, elderly men and women can attain positive results from resistance training as demonstrated by studies (Coggan, Spina, King, Rogers, & Brown, 1992; Roman et al., 1993; Yarasheski & Zachwieja, 1993) that have reported increases in muscle mass, cross-sectional area, and peak torque production in elderly populations. Even though the response to training may be blunted in comparison to younger populations (Moritani & deVries, 1980), the benefits of training elderly populations cannot be ignored. As humans age, they encounter many physiological issues such as decreased bone mass, loss of sight, loss of hearing, and loss of muscle mass to name a few. Sarcopenia can be reduced by mechanically loading skeletal muscle. Several studies have supported the idea of resistance training in elderly people by producing results that show respectable increases in muscle mass (~10%) and maximal strength (a combination of an improved neural component and increased cross-sectional area) (Aniansson, Hedberg, Henning, & Grimby, 1986; Frontera, Meredith, O’Reilly, Knuttgen, & Evans, 1988; Moritani & deVries, 1980). Charette et al. (1991) found that elderly women (mean age of 69) undergoing a 12-week resistance training program for the legs had a 20% increase in cross-sectional area of type II muscle fibers as measured via biopsy when compared to pre-training. Therefore, increased age does not encumber the hypertrophy process.

C. Resistance Training and Disease

Conditions such as obesity, diabetes, cardiovascular problems, arthritis, and bone fractures related to low bone mass are all primary health concerns presently in the United
States. Each of these conditions (and many others) may be benefited and/or rehabilitated by resistance training, and resistance training is considered an important component of a comprehensive, health-related fitness program (Allison, Fontaine, Manson, Stevens, & VanItallie, 1999; Layne & Nelson, 1999; Stewart, Cutler, & Rosen, 2009). Resistance training can increase energy requirements by reducing the body’s fat mass and increasing metabolically active tissue. Sipila and Suominen (1995) found that intense and regular strength training induces hypertrophy even in the elderly while leading to a relative reduction in the amount of intramuscular fat. Currently, over 60% of Americans are overweight and more than 30% are obese. Overweight is defined as a body mass index (BMI) score of 25 to 29.9 while obesity is a BMI equal to or greater than 30, according to the National Heart Lung and Blood Institute. Also, obesity is the second leading cause of preventable deaths in the United States, resulting in over 300,000 deaths per year (www.obesity.org). Annually, over 40 billion dollars is spent on products targeting weight reduction and control, some of which are unsafe or lead to harmful behavior (Rosenbaum, Leibel, & Hirsch, 1997).

Obesity is the most common chronic disorder amongst children, and obese and overweight individuals have an increased risk of complications from many diseases and illnesses (Gunnell, Frankel, Nanchahal, Peters, & Davey-Smith, 1998) such as diabetes, coronary artery diseases, and arthritis. It is well accepted that resistance training can have a significant impact on body composition, although not to the extent of aerobic training. An increase in lean mass due to training combined with proper dieting may lead to the following benefits: an increase in metabolically active tissue, improved insulin sensitivity
and glucose tolerance, decreased joint pain, improved circulation, reduced atherosclerosis risk, and increased energy. A study by Nindl et al. (2000) showed that periodization of resistance training, which involves progressive cycling of various aspects of a program so that training leads to peak performance at competition, significantly reduced body fat as shown through magnetic resonance imaging (MRI). When resistance training is combined with endurance training, the benefits are even greater. A recent study (Sillanpaa et al., 2009) examined the effects of 21 weeks of either endurance only, strength only, or a combination of strength and endurance training on middle-aged and older women. All training groups improved lean body mass, while only the resistance training groups demonstrated slightly improved insulin sensitivity. Total body fat as measured by dual energy x-ray absorptiometry did not differ between the training groups. The strength and endurance group lost more body fat than the strength-only group. This and other studies (LeMura et al., 2000) have shown that traditional methods of strength training alone generally are not ideal for the reduction of body fat or improvement in the blood lipid profile.

Abnormally high blood pressure (hypertension) leads to increased strain on the cardiovascular system and eventually damages the arteries (Lloyd-Jones, Evans, Larson, O’Donnell, & Levy, 1999). Systolic blood pressure is an accurate predictor of risks connected to hypertension, a condition that affects more than 50 million Americans (www.americanheart.org). A meta-analysis of randomized trials on the effects of exercise on blood pressure (Whelton, Chin, Xue, & Jiang, 2002) mentions that a significant reduction in systolic blood pressure of 3 mmHg or more for persons with normal blood
pressure reduces heart-related complications by about 5%, stroke by up to 14%, and all natural cause death by 4%. With heavy resistance training, there is a large temporary increase in blood pressure due to muscle contractions constricting blood vessels and breath holding. Acutely, the systolic blood pressure response seen in resistance training is directly related to the training intensity and the amount of muscle mass used (Hill & Butler, 1991). Regular resistance training over time has been shown to decrease the blood pressure rise seen with the onset of resistance exercise (Fleck, 1988). Heffernan, Sae Young, Edwards, Kelly, and Fernhall (2007) found that performing 3 sets of an eight repetition maximum (8RM) on 7 upper and lower body exercises for 20 weeks facilitated significant reductions in systolic and diastolic blood pressures, with no effects on arterial stiffness. Studies performed by several authors have shown that certain resistance training protocols can lower blood pressure (Kelley & Kelley, 2000; Wiley, Dunn, Cox, Hueppchen, & Scott, 1992), and even increase vasodilatory capacity better than aerobic training (Collier et al., 2008). Both of these adaptations can have a tremendous impact on heart health. It is still generally accepted that aerobic exercise, in comparison to resistance training, is the preferred method of exercise for lowering blood pressure.

Finally, bone mineral density preservation and/or increase due to resistance training has been documented, even though no recommendations for optimum volume or intensity of training to improve bone mineral density has arisen from the literature (Layne & Nelson, 1999). Bone and muscle mass peak around the age of 30 and decline every decade of life thereafter as circulating hormone levels, physical activity, and powerful
movements decrease. Resistance training of muscles increases strain placed on bone, causing improved upkeep of bone tissue and decreased risk of fracture and osteoporosis.

D. Other Variables and Resistance Training

Elements other than the acute program variables (volume, intensity, frequency, mode/exercise choice, and rest period) and population group (athlete, elderly, rehabilitation, etc.) factor into the goals and outcomes an individual realizes during resistance training protocols. Genetics, psychological factors, age, gender, experience, and recovery from training all influence the results obtained from resistance training (Fleck & Kraemer, 2004; Bird, Tarpenning, & Marino, 2005). Some examples of the consequences of the aforementioned variables on resistance training outcomes are as follows:

1.) Individuals with different variants of the angiotensin converting enzyme gene have been found to have varied outcomes in terms of strength gains from resistance training (Colakoglu et al., 2005). Certain variants were more likely than other variants to result in strength gains with the performance of a single set versus multiple sets.

2.) Rest periods affect the amount of adenosine triphosphate available for lifting and the levels of circulating anabolic hormones, such as testosterone (Kraemer et al., 1991).
3.) Gender-specific response differences to resistance training are based on the relative hormone response, specifically testosterone, witnessed in men as compared to women (Kraemer et al., 1993).

4.) Soreness and delayed onset of muscle soreness (DOMS) can last for 3 days or more and depends on the intensity, duration, and type of exercise performed. The variety of ways soreness can be induced include: damage to contractile machinery, tears in muscle tissue which allow the release of enzymes and cell components, fluid retention, or a combination of these factors, but the precise cause of muscle soreness is not known.

In a study by Teague and Schwane (1995) subjects rated post-exercise muscle soreness and it was found that greater soreness was associated with eccentric exercise rather than concentric exercise.

The purpose of this dissertation research was to examine the role of exercise arrangement and its impact on resistance training outcomes and adaptations. There are very few scholarly works that look solely at exercise arrangement and training outcomes. Systematically comparing different arrangements of resistance training exercises will further the knowledge in the area of resistance training and allow the exercise professional to provide informed training recommendations.
II. PRINCIPLES OF RESISTANCE TRAINING

In order to design and provide optimal resistance training programs, individuals must be familiar with the foundations and principles of resistance training, the components of the training session, the energy system(s) involved, the equipment utilized for training, the types of muscle actions, and acute program variables. Other factors, such as specificity, training status, periodization, and progression also have a significant impact on the outcomes and adaptations realized from a training program. Fitness gains will be seen only if the stimulus is effective enough to cause adaptations to occur (Fleck & Kraemer, 2004). This is the premise of the overload principle. Compiling the knowledge an individual has in the aforementioned principles into a precise and individualized training program is essential to resistance training success and the prevention of overtraining.

A. Program Variables and Design

1. Mode/Exercise Selection

The equipment used, types of muscle actions, and the choice of exercises performed refers to the mode of exercise. The mode(s) used during a resistance training program is influenced by personal goals, experience, awareness of training exercises, and the equipment available for use. Equipment for resistance training consists of free weights, machines, and bands. Exercises used for resistance training include traditional weight training exercises such as the squat and the bench press, plyometrics or stretch-
shortening cycle training, calisthenics, and many other products and exercises being created regularly. Muscle actions involved in the majority of resistance training programs tend to be dynamic, isometric, or isokinetic (rarely). Dynamic means that force is applied and changes in muscle length occur, while isometric actions involve force application with no change in muscle length or joint movement. Isokinetic actions involve controlling the speed of contraction throughout the entire range of motion.

*Free Weights Versus Machines*

Using one’s own body weight, resistive bands, and machines are safer than free weights. Machines target core exercises (one or more large, primary muscle group) and assistance exercises (smaller usually single joint exercises). Machines usually do not require “spotters” to assist with lifts because machines limit the movement of the weights involved. Normally the only safety considerations of machines are that users are correctly positioned on the machine and do not try to engage more weight than they are capable of lifting. On the other hand, free weights must be controlled throughout the entire range of motion and in all movement planes (Fleck & Kraemer, 2004). Free weights also require increased balance, focus, and stabilization since there are no cams or guides to aid in movement control as there are with machines. Also, free weights generally allow for specificity of training in comparison to machines. This is because free weights permit the performance of multi joint exercises that are similar to numerous skills performed in a variety of sports and activities, hence the specificity. These facts inherently make free weights more difficult than machines and, therefore, it is imperative that individuals who
wish to use free weights take the time to learn proper lifting technique. Beginners should perform training exercises on a machine or with a band while experienced lifters may perform similar exercises via free weights. Research by Stone, Johnson, and Carter (1979) has demonstrated superior strength outcomes when free weights were used instead of machines, especially in short to moderate duration training programs.

Specificity

When designing a specific training program, the mode selected for each exercise is usually specific to the goal, muscle group, and muscle action, and takes training level, equipment available and safety into consideration. If an individual wishes to improve biceps strength or elbow flexibility and stability, then bicep training exercises must be performed. This is an example of specificity. The adaptations seen due to training are specific to the muscles used, the energy system used, the type of muscle actions performed, and the speed of movement or contraction (Fleck & Kraemer, 2004). Ideally, training should be sport or activity specific. This means training should replicate the sport or activity by including the muscles, muscle actions, speed of movement/contraction, and the energy system used during the sport or activity. Doing so will promote superior transfer of what was learned during training to the actual activity. Energy system specificity is important for performance and is inherently related to muscle fiber type. Humans have two types of skeletal muscle fibers, fast twitch and slow twitch. Fast twitch fibers are commonly called type II (IIa and IIb/x) and slow twitch fibers are referred to as
type I. These fiber types differ in terms of blood supply, metabolism, and strength production.

Slow twitch fibers have a greater capillary density, and as a result have a greater blood supply when compared to type II fibers. This increased blood supply is needed because type I fibers rely heavily on aerobic metabolism in order to create energy (Gollnick et al., 1973). The blood supply provides the much needed oxygen that is required for cellular respiration to take place in type I fibers, and removes the byproducts of respiration, such as carbon dioxide. Type II fibers, on the other hand, do not have nearly the capillary density or aerobic capacity of type I fibers. Therefore, blood supply is diminished in type II fibers and, because type II fibers do not have the oxidative capacity of type I fibers (type IIb being even less oxidative than IIa), less oxygen is needed and the blood supply primarily removes byproducts such as lactate. Hence, type I fibers are specifically trained with endurance activities, and the larger and more powerful type II fibers are associated with muscle strength and power (Karlsson, Sjodin, Thorstensson, Hulten, & Frith, 1975).

The metabolism or energy systems used by each fiber type is also different. Type I fibers, as mentioned, receive a higher blood supply as compared to type II fibers, and are associated with lower intensity and endurance activities. These activities necessitate the use of an energy pathway that can provide large quantities of energy for a sustained period of time. Therefore, type I fibers will rely heavily on aerobic respiration for its energy supply. Type II fibers rely on aerobic and/or anaerobic metabolism. These fibers are associated with high intensity activities such as resistance training, which can be
sustained for only a short duration. There are two anaerobic energy system pathways that type II fibers prefer to use for these high intensity activities of short duration. One of the pathways is the phosphagen system. This system can only meet the energy demands of active muscle for short durations (~10 seconds) because the stores of the human energy sources of ATP and phosphocreatine, are limited in skeletal muscle (Trump, Heigenhauser, Putman, & Spriet, 1996). The second pathway available for the high intensity activities of type II fibers is the anaerobic glycolysis pathway. Because the intensity of activity is great when type II fibers are recruited and oxygen supply is low, oxygen is not available to be the final hydrogen ion acceptor. Therefore, hydrogen ions are combined with pyruvate to form lactate (Hogan, Gladden, Kurdak, & Poole, 1995). Unfortunately, extended use of this energy pathway can cause muscle lactate and hydrogen ion build up, and decreased ATP regeneration, which can inhibit exercise capacity and strength production (Jacobs, Hermiston, & Symons, 1993).

Finally, contractile velocity and force production differences between fiber types also exist. Type II fibers are called fast twitch because the isoform of myosin found in them promotes high myosin ATPase activity, allowing faster contraction. Fast twitch fibers have a fast form of myosin ATPase, promoting fast ATP breakdown and therefore, fast shortening of sarcomeres (the functional unit of the muscle fiber). Fast twitch fibers also demonstrate speedy calcium release and reuptake. These aforementioned factors support the rapid energy generation and the high velocity of contraction seen in type II fibers. Slow twitch fibers have low myosin ATPase activity and a decreased ability to
release and reuptake calcium, leading to a slower speed of contraction (Bottinelli et al., 1994).

**Muscle Actions**

Resistance training exercises are further classified by the type of muscle actions involved. Generally, weight training involves three types of muscle actions; isometric, isokinetic, and dynamic. Isokinetic machines control speed so that it is constant throughout the range of motion. Because skeletal muscle produces different amounts of force at different joint angles, isokinetic machines match the force generated by the muscle at each joint angle by controlling speed. Isokinetic actions do not occur during “real world” activities and therefore have limited specificity (Fleck & Kraemer, 2004). Isokinetic equipment is excellent for strength testing through the full range of motion and is highly reliable, but equipment is expensive.

Isometric actions are muscular contractions that occur without a change in joint angle. Therefore, the effects of isometric training are joint angle specific. There is no change in joint angle because the force of muscle contraction is equal to the resistance, or produced against an immovable object. As mentioned earlier, skeletal muscles produce different amounts of force at different joint angles. Because isometric training can only improve a singular joint angle per contraction, it is often beneficial to use isometric training to improve strength at weaker joint angles or for sports that include isometric elements.
Dynamic actions (or dynamic constant external resistance, DCER) occur when muscle actions lead to joint angle and muscle length changes. This usually occurs against a fixed external resistance and in two phases: concentric and eccentric. The concentric phase is when muscles contract and shorten. The eccentric phase is when a muscle action occurs but the muscle is lengthened. These actions coincide with a reduction or an increase in joint angle. Dynamic actions are the most common type of resistance training muscle actions and are both sport and activity specific (Fleck & Kraemer, 2004).

2. Intensity

Intensity with weight training is based on the load (amount of weight lifted). It is usually estimated and expressed as a percent of one repetition maximum (1RM). The 1RM is the most weight that can be lifted one time with proper form and/or technique and it will vary between exercises, muscle groups, and training statuses. A study by Stone et al. (1981) showed that training at certain percentages of 1RM will lead to different muscle adaptations. If strength gains are desired, the training intensity should be greater than 85% of 1RM. If endurance is the primary goal, training should occur at less than 67% of 1RM. For a combination of strength and endurance (hypertrophy), training should occur between 67% and 85% of 1RM (Baechle & Earle, 2008). It is worth noting that the intensities required to achieve gains in untrained populations are different (usually lower) than in trained populations. Furthermore, training outside of the recommended ranges of intensity to attain gains in strength, endurance, or a combination of both may be beneficial in certain populations, such as elderly women (Fleck & Kraemer, 2004).
For many exercises, multiple repetitions or repetition maximums (RM) are used instead of a percent of 1RM. The RM is the highest load that can be lifted for a specific number of repetitions. The 5RM is the most weight than can be lifted properly five times. Using the RM is beneficial because there is no need for individuals to load maximally to test 1RM, which can improve safety (Fleck and Kraemer, 2004). Furthermore, the intensity of training can impact circulating hormone levels (Kraemer, 1991).

3. Volume

The volume of training refers to the total volume of weight lifted in a period of time. To calculate the volume for a period of training, sets and repetitions are routinely used; occasionally, load is also factored in for volume measurement. A set is a group of repetitions, or completed work movements, of an exercise (Fleck & Kraemer, 2004). If 5 sets of 10 repetitions are performed during a training session, then the repetition volume is 50 repetitions. If the load for each of the repetitions is 100 units, then the product of multiplying the repetition volume (50) with the load (100) will provide the load volume (5,000 units). To account for work performed, one additional calculation can be done. Work is force (Newtons) applied over a distance (meters), and the distance covered during the repetitions can be multiplied by the load to figure the volume of work done (Baechle & Earle, 2008).

The volume of work done depends on goals and training status. Higher volumes are needed in order to see gains in size; to promote muscle adaptations, higher volumes eventually will be required in order to continue to improve strength during a continuous
resistance training program. If the goal of resistance training is strength, recommendations for volume are different for untrained as compared to trained athletes. A single set per muscle group of an 8 to 12 repetition maximum (8-12 RM) may benefit untrained persons trying to increase strength, but is generally not enough of a stimulus for trained athletes. As individuals begin to realize gains from a training program, volume will need to be increased in accordance with the training goals. If training for strength, it is recommended that 2 to 6 sets of less than 6 repetitions are performed.

The lower number of repetitions recommended for strength training reflects the principle of specificity. In order to train strength, one must use heavier loads; therefore, the number of repetitions that can be performed will be low. If the goal of training is endurance, it is recommended that 2 to 3 sets of greater than 12 repetitions are performed. Since more repetitions are needed for specificity with endurance training, lighter weights have to be used. For hypertrophy training, 3 to 6 sets of 6 to 12 repetitions are recommended. The hypertrophy recommendations have the highest repetition volume, which is most beneficial for muscle size gains (Baechle & Earle, 2008).

4. Rest Periods

The rest period is the down time between consecutive sets of an exercise or between different exercises. Rest periods should depend on the goal of the training, and generally are longer when heavier loads are used. The amount of rest between exercises impacts the amount of recovery and the hormonal response to training (Kraemer, 1991). Longer rest promotes more energy recovery and an increased ability to perform high
intensity work during subsequent sets, which is ideal for strength training. Shorter rest periods do not allow for much recovery to occur, which will lead to less weight being lifted during a training session. National Strength and Conditioning Association (NSCA) guidelines call for a 2 to 5 minute rest period between sets when training for strength, and 30 seconds to 1.5 minutes when training for hypertrophy. When training for muscle endurance, a rest period of less than 30 seconds is optimal. Many studies (Ahtiainen, Pakarinen, Alen, Kraemer, & Hakkinen, 2005; Garcia-Lopez et al., 2007; Richmond & Godard, 2004) have focused on rest intervals between sets to examine effects on muscle strength, hypertrophy, endurance, and hormonal changes. The results vary and are not definitive due to varying subject populations, the types of training, or length of the rest periods utilized.

5. Frequency

How often training occurs is the frequency of training. Training frequency is determined primarily by training status and load volume. With athletes, whether or not they are in-season influences resistance training frequency, because being in-season requires a focus on sports skills for success. Also, resistance training frequency is affected by the amount of concomitant training (i.e., endurance training) in which an individual might be participating. It is generally recommended for novices to train a muscle group 1 to 2 times per week with 24 to 48 hours of rest between training the same muscle group. Up to six training sessions per week may be recommended for more experienced lifters (even though these groups will probably alternate training so that each
muscle group is not trained more than 3 times per week). The premise for the differences in training frequency between beginners and more experienced lifters is that beginners need more time to recover and adapt to training. Experienced lifters should avoid a prolonged lapse in training as it could lessen training status (Hoffman et al., 1991).

If high training loads are used or total volume is high, more recovery time will be needed between sessions. The increased recovery time will ensure adequate muscle repair prior to the next training session. Many exercise professionals are weary of overtraining and will have a heavy volume or load session only once a week while the remaining weekly sessions are at a decreased intensity and/or volume. Also, it is possible that upper body and smaller muscles recover faster than thigh musculature when comparable volumes are used (Hoffman et al., 1990).

Table 1

<table>
<thead>
<tr>
<th>Goal</th>
<th>Sets</th>
<th>Repetitions</th>
<th>Intensity</th>
<th>Rest Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertrophy</td>
<td>3-6</td>
<td>6-12</td>
<td>67-85% 1RM</td>
<td>30-90 sec</td>
</tr>
<tr>
<td>Strength</td>
<td>2-6</td>
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<td>≥85% 1RM</td>
<td>2-5 min</td>
</tr>
<tr>
<td>Endurance</td>
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<td>≥12</td>
<td>≤67% 1RM</td>
<td>≤30 sec</td>
</tr>
<tr>
<td>Power</td>
<td>3-5</td>
<td>1-5</td>
<td>75-90% 1RM</td>
<td>2-5 min</td>
</tr>
</tbody>
</table>

6. Arrangement

A thorough understanding of resistance training variables is necessary for achieving positive results from weight training. Varying program variables is important in resistance training in order to avoid overtraining and to encourage recovery and adaptations. Variation can be achieved in a training program simply by adjusting sets, repetitions, frequency of training, rest periods, or selected exercises. Also, variation can be achieved by more complex practices such as changing exercise order, using eccentric only protocols, or by adding supersets or cluster sets (Haff et al., 2008). Numerous studies have attempted to discern the effects of manipulating some of the variables mentioned above.

Schroeder, Hawkins, and Jaque (2004) found that 16 weeks of upper and lower body eccentric only training in young women led to a 20-40% increase in strength and had positive effects on total lean body mass and bone mineral content. Schroeder’s results showed the tremendous effects of resistance training even when traditional training methods are not used. Several studies have evaluated the effect of varying the exercise order. Spreuwenberg et al. (2006) trained 9 male subjects to perform the back squat either immediately before or after a whole body resistance training regimen. As expected, the subjects who performed the back squats prior to the whole body training completed more repetitions of squats than the subjects who performed squats after training. The group performing the back squats as the last training exercise of the regimen had higher average power outputs as measured by calibrated transducers on the ends of the barbell. Because power is equal to work done over time (Newton\(\times\)meters\(\times\)seconds\(^{-1}\)), the authors
postulated that the increases in power seen by the aforementioned group were due to the post activation potentiation (acute enhancement in force output during explosive movements after heavy resistance training is done) that occurred from the previous exercises.

Some other accepted practices for exercise order include: a) power training followed by core and supplemental exercises, b) push then pull or alternating between pushing exercises and pulling exercises and c) multi joint or multiple muscle group exercises followed by single joint or small muscle group exercises (Fleck & Kraemer, 2004).

There are also arrangements that minimize rest between sets. These include supersets and superset/compound sets. Supersets (agonist-antagonist, also known as reciprocal) in resistance training are sets where an exercise is performed by an agonist muscle group for a certain number of repetitions, followed immediately by another exercise for the antagonist group for a certain number of repetitions without rest between the exercises. An example would be performing arm curls followed by triceps extensions, two exercises that work the biceps and triceps, respectively. A superset/compound set (agonist-agonist) is a set where two different exercises are used consecutively to train the same muscle group with no rest between the two different exercises. An example of a super set/compound set would be performing overhead triceps extensions immediately followed by dumbbell triceps kickbacks, which both focus on the triceps muscle (Bird et al., 2005).
Numerous studies have examined the effects of traditional resistance training on muscular strength, power, and endurance, and upon anthropometric measures such as lean mass, body composition, and bone density (Delorme, 1948; Kelley & Kelley, 2000; Nelson et al., 1994; Wiley et al., 1992). However, there is relatively little information about how resistance training arrangements influence muscle gains and anthropometric measures. Furthermore, it is not known which arrangement may be more practical and effective for various populations. It is common to find suggestions or exercise recommendations that use supersets or supersets/compound sets in popular weight training magazines—the source of training information for the vast majority of society. The arrangement of supersets or supersets/compound sets is largely ignored in the research literature. Improvement of knowledge in this area is necessary for exercise prescription purposes.
There are a variety of methods and equipment available to individuals to practice resistance training. Training variations allow for focus on particular aspects of muscular development. For example, individuals who desire strength and power gains will train differently than those who are training for hypertrophy or endurance. It is generally recommended that multi-joint exercises performed near 1RM should be used to develop strength and explosive power. To increase muscle mass, high volume protocols are often utilized, which are often quite time consuming.

With resistance training, untrained individuals initially experience a quick increase in strength, which is then followed by attenuation in strength improvements. This initial increase in strength is due to enhanced neural adaptation and occurs regardless of training form and without much increase in muscle size (Staron et al., 1994). This suggests that more motor units are recruited to perform contractions and that the nerves innervating the muscle fibers fire more frequently and are better coordinated (Kraus, Torgan, & Taylor, 1994; Staron et al., 1994). Other possible neural adaptations include: the inhibition of muscle receptors that respond when high forces are generated in muscle; increases in the size and transmission of the neuromuscular junction; and, enhanced stretch reflex response (Deschenes et al., 1993). With time, the muscle cells respond to resistance training by growing in size.
A. Muscle Hypertrophy

There is a minimal stimulus needed to initiate muscle adaptations. Skeletal muscle can quickly gain mass in response to repeated overload (Staron et al., 1994). This gain in mass due to overload has been reproduced in numerous training studies (Kraemer et al., 1991; Moritani & deVries, 1979; Staron et al., 1994) and is due to a variety of physiological, structural, functional, and biochemical changes.

Hypertrophy is an increase in fiber size that occurs in all fiber types, without an increase in the number of fibers. The increase in fiber size is due to an increase in muscle mass and protein content, which leads to a larger cross-sectional area of the muscle as a whole. Within recent years, many studies (Mayhew, Rothstein, Finucane, & Lamb, 1995; Staron et al., 1994) have shown that hypertrophy can be seen as early as 2 to 4 weeks into the training program. Significant increases in cross-sectional area of muscle fibers have been seen with concentric training as early as 4 weeks into training, with increases in whole muscles as early as 3-6 weeks into training (Seynnes et al., 2007).

The process of muscle hypertrophy in adult human skeletal muscle is a process that can be influenced by numerous factors: age, gender, hormone levels, workout design, and recovery time, to name a few. The stress of mechanically overloading skeletal muscle leads to activation of signaling pathway that eventually leads to new protein synthesis in the muscle (Hameed et al., 2003; Leger et al., 2006). The result is an increase in muscle size, mass, and cross-sectional area (without an increase in muscle fiber number) regardless of age or gender, which coincides with an improvement in functional capacity and tension generation. The structural, functional, and biochemical changes seen in
muscle due to overload have been thoroughly researched and recorded (Bassey & Ramsdale, 1995; Tesch & Karlsson; 1985, Welle, Bhatt, Thornton, 1999).

The prevailing theory on skeletal muscle hypertrophy is based on the function of satellite cells. Satellite cells only make up about 5% of the total available nuclei in each muscle fiber (which has hundreds of nuclei). Satellite cells become activated when there is damage to the muscle, when growth is stimulated, or often after strength training (Hikida et al., 2000). Damage to muscles can result from a variety of events that occur physically and physiologically. Growth of adult muscle is usually the result of intense and regular resistance training, which leads to the muscle adapting to the increased stress being placed upon it. It has been shown that both single bouts of intense exercise as well as long term training can lead to satellite cell activation (Kadi et al., 2004).

When a resistance training program is undertaken, as mentioned before, neurological adaptations will be seen. Also, due to the increased stresses being placed upon muscles activated during resistance training, another adaptation that will be seen is increased regenerative processes, such as damaged tissue removal. Eventually muscle growth will occur as satellite cells are activated. These muscle nuclei precursors stay in a quiescent state until they become activated by resistance training and the need for the muscle to adapt. The role of satellite cells is to provide nuclei for differentiated skeletal muscle fibers. Skeletal muscle fibers are large cells formed by numerous proteins and contain thousands of nuclei. It is believed that each nucleus has control over a limited area within the muscle fiber called the myonuclear domain. If fiber size is to be increased, there will be need for new myonuclei and proteins. Since skeletal muscle
nuclei are post mitotic tissue (meaning they can no longer divide), satellite cells are needed to provide nuclei and increase fiber size (Kadi et al., 2004, Zammit, Partridge, Yablonka-Reuveni, 2006). Once incorporated, the new myonucleus is able to express transcription factors for further fiber development (protein addition) and maintain the nucleus to cytoplasm ratio. Adequate nutrient intake is necessary for protein synthesis.

B. Muscle Strength

The maximum force or tension generated by a single muscle or groups of related muscles is known as muscular strength. Maximal muscular strength can be assessed in a variety of ways: a) dynamometers; b) one repetition maximum; c) computer assisted and electromechanical methods. It is reported as weight lifted in pounds or kilograms, force, torque, or based on displacement and acceleration. Many factors influence muscular strength production including gender, age, and even familiarity with a specific type of lift. There have been numerous studies that look at strength production as it relates to gender; several studies examined gender’s relationship with muscle cross-sectional area (Ikai & Fukunaga, 1968), muscle architecture (Lieber, Jacobson, Fazeli, Abrams, & Botte, 1992), relative muscle strength (Castro, McCann, Shaffrath, & Adams, 1995), and absolute force produced (Heyward, Johannes-Ellis, & Romer, 1986). The data show that there is no significant difference in relative strength between men and women, and the differences seen in absolute strength between men and women reflect differences in hormones, muscle mass distribution, and greater cross-sectional area of skeletal muscle in males (Castro et al., 1995).
Human muscle can maximally generate approximately 30 Newtons of force per centimeter squared (Enoka, 1988). Numerous studies (Hakkinen, Newton et al., 1998; Kraus et al., 1994) have demonstrated the significant role of the nervous system in the early phase resistance training strength gains of untrained subjects. Early phase (approximately first 8 weeks) training studies have also documented muscle hypertrophy and fast fiber type conversion. Staron et al. (1994) used an 8-week training program for the lower body to evaluate muscle adaptations in men and women. With the use of muscle biopsies, the researchers analyzed the trained fibers for fiber type, cross-sectional area, and myosin heavy chain content while sampling their subjects’ blood for hormone levels. The research group found that only about 4 weeks of training, twice a week, provided enough of a stimulus for maximal dynamic strength to increase, and the training also had a concomitant effect of reducing the percentage of type IIx fibers.

C. Other Muscular Adaptations Due to Resistance Training

Cross-sectional area along with muscle architecture (i.e., sarcomere alignment and length) directly relates to force production. Greater cross-sectional area usually leads to greater force production. Pennation (angling the orientation of muscle fibers) results in decreased force capacity of fibers because the fibers do not run parallel to the muscle’s long axis, as is seen in fusiform muscle. But within a given volume of muscle more sarcomeres are seen in a pennate muscle as compared to a fusiform muscle, leading to greater cross-sectional area and power production in the pennate muscle. Also, training
might increase the angle of pennation which will allow for more muscle growth to occur, because there will be increased space for adding protein (Blazevich, 2003).

Training can change muscle enzyme levels, and energy storage and availability as glycogen storage seems to be improved (Tesch, 1987). Also, reductions in mitochondrial density most likely will be seen as the total number of mitochondria does not change but muscle size increases. A similar effect is seen with capillary density (Staron et al., 1989). A final adaptation seen due to resistance training is improved removal and recycling of lactic acid. Lactic acid production causes a decrease in pH which can lead to fatigue, and training can lead to significant improvements in lactic acid buffering and, therefore, improved performance (Bell & Wenger, 1988).
IV. STUDY SIGNIFICANCE

As mentioned earlier, resistance training protocols must be designed to elicit optimal gains in strength, power, and muscle mass swiftly and efficiently. Individuals may also wish to increase bone mass, and decrease fat mass and blood pressure through exercise training. Finding the most efficient resistance training methods or program designs to accomplish these goals would be extremely beneficial. Furthermore, health professionals may see a patient only a few times. Studies have shown that short-term resistance training for just a few sessions can lead to gains in strength proportional to the gains seen after weeks of training (Staron et al., 1994). Short-term and more efficient resistance training methods may facilitate superior results more rapidly, and may improve adherence to the exercise program. Also, short term physical therapy treatment with resistance training to quickly improve strength and return function may be a realistic alternative to other types of treatment. Lastly, even though there is a vast amount of resistance training information in peer-reviewed literature, few studies have rigorously compared the effects of different training methods/designs. The literature also lacks studies that isolate individual program variables. A recent review article by Wernbom, Augustsson, & Thomee (2007) on strength training mentions that future research should “isolate the impact of each of the resistance training variables and investigate interactions between them, as well as the effects of various training strategies” (p. 241).
A. Statement of the Problem

Thus far, the benefits of performing supersets or supersets/compound sets instead of traditional resistance training in a moderate to high intensity resistance training program have not been thoroughly examined. The purpose of this study was to compare workouts that utilized either supersets/compound sets with traditional strength training methods over a 12 week training period. The variables of interest were muscle strength, muscle endurance, muscle hypertrophy (as measured by thickness and CSA), extremity girth, body composition, workout time, and recovery. By comparing the two training methods one can determine the most effective method for attaining desirable results for each measure.

The specific aims of the research were to inspect:

1. To identify which method of strength training arrangement was most efficient at improving muscle strength and repetitions to fatigue.

2. To compare the effect strength training arrangement on muscle hypertrophy and/or local fat loss by using muscle ultrasound and girth measurements.

3. To determine which arrangement of resistance training, whether traditional or supersets/compound sets, was more effective at improving selected anthropometric measures (thigh girth, body composition, lean mass).

4. To describe the effects of performing each strength training arrangement on recovery variables such as muscle soreness.

The null hypotheses that were investigated:
Ho1: There is no difference between training methods in terms of their respective effect on muscle strength, repetitions to fatigue, body composition, and lean mass.

Ho2: Both training methods will lead to comparable muscle hypertrophy and no differences will be seen between pre and post girth and ultrasound measurements between groups.

Ho3: There is no difference in recovery effects in terms of subjective muscle soreness between both training methods.

Ho4: The amount of time required for each training method is not significantly different.
V. METHODOLOGY AND DESIGN

A. Experimental Procedure

1. Subjects

Young women, aged 18 to 31 years who had not participated in any regular resistance training within the last 2 years were recruited for the study. Signs, posters and recruiting sessions were utilized to obtain participants. The 2006 edition of ACSM’s Guidelines for Exercise Testing and Prescription states that for low risk, apparently healthy and younger individuals (younger implies less than 45 years old for males and 55 years old for females) a medical exam and physician supervision are not needed for maximal or sub maximal testing.

After thorough explanation of the study design, timeframe, requirements and expectations, the subjects were asked to sign and approve an informed consent form and to complete a health history questionnaire. All information was kept confidential. The subjects were asked not to perform any additional resistance/weight training while participating in the study. Subjects were excluded from the study if it was determined from their health history questionnaire (see Appendix I) or a prior medical examination that they were at of risk of injury due to cardiovascular, metabolic, pulmonary or musculoskeletal problems (including a low bone density scan), were pregnant, or if they did not satisfactorily pass joint integrity tests performed by a licensed and experienced athletic trainer. Also, participants had to be healthy nonsmokers, have regular menstruation, have no obvious disease or debilitating conditions, or signs of drug or
steroid use. Markedly overweight (body mass index [BMI] greater than 27), underweight (BMI less than 19) and hypertensive individuals (blood pressure greater than 140 mmHg systolic and 90 mmHg diastolic) were eliminated from consideration for the study. These parameters were approved by the Institutional Review Board of Ohio University.

The subjects were pair matched based on BMI and randomly put into one of the following groups: a) a superset/compound set group, b) a traditional strength training group, or c) a comparison group.

Researchers did not control diet or supplementation, birth control usage, aerobic training by the comparison group, or the amount of aerobic exercise, although the subjects were asked not to participate in aerobic exercise more than three times per week. These, along with other variables (such as alcohol and drug use, sleep and physical activity) that might affect performance are difficult to monitor in a free living sample population.

2. Design

This study compared 12 weeks (twice a week) of supersets/compound sets to traditional strength training methods for muscle strength, repetitions to fatigue, muscle hypertrophy, body composition, thigh girth, workout time and recovery. By comparing the training methods, one can attempt to determine the most effective method for attaining desirable results from resistance training.

The study was conducted over a 15-week period, beginning in January of 2009 with recruitment of subjects, informed consent, and subject training and assistant
scheduling. The first week was committed to testing joint integrity by a licensed athletic trainer to ensure joint stability of subjects, and a physician reviewing health history questionnaires. If the subjects satisfactorily passed the battery of joint integrity tests, then they were scheduled for a week of lift orientation. During the week of orientation, each subject had to accumulate at least 3 hours in the weight room for the purpose of watching, learning, and working on the lifts that were involved in the study: the ~45° seated leg press and the Smith Machine squat. The Smith Machine is a barbell affixed to rails that only allows straight up and straight down movement. By affixing the barbell to the rails, lifters are safer because there is less need for a “spotter”, and the weight cannot fall forward or backward or drop too low toward the ground. Lift orientation was incorporated to ensure safety and to diminish any learning effect on training since subjects had little or no experience with the training exercises. After the 3-hour orientation, subjects were required to perform satisfactory minimal weight (bar only) lifts on each training apparatus, evaluated by a strength coach who was a certified strength and conditioning specialist (NSCA CSCS). After the judge deemed multiple lifts (5 minimum) acceptable, the subjects were required to hold the lifts at the fully flexed position (90°) in order to record the depth levels on each apparatus via markers on the leg press machine and a bracket created for the Smith Machine (see Appendices II & IV). On both apparatuses, the depth level recorded was found when there was a right (90°) angle at the knee joint. After lift orientation was completed, the subjects had to provide pretest values for body composition via skinfolds and BOD POD®, resting (10 minutes
sitting minimum) blood pressure, relaxed thigh girth, weight, height, and muscle cross-sectional area and thickness.

After the values were recorded and BMI calculated, subjects were randomly placed into one of the two previously mentioned experimental groups or the control group based on pair matching for BMI. Subjects were then scheduled for determination of one repetition maximum (1RM) and repetitions to fatigue. To complete the muscle strength and endurance testing, all subjects had to show up on either Monday and Thursday or Tuesday and Friday of the same week in order to allow at least 48 hours of recovery between testing. All maximal testing followed procedures similar to those recommended by the NSCA for 1RM testing (see Appendix III). On the first day of testing, subjects were assisted in determining their Smith Machine squat maximum (1RM) followed by a 15-minute rest before performing as many repetitions as possible at 60% of that 1RM. Subjects returned on either Thursday or Friday to perform the same testing and procedures on the seated leg press.

After the maximal values (1RM) were determined, 70% and 80% of 1RM were determined for training during the study. The group training with supersets/compound sets performed squats lifts on the Smith Machine and immediately followed with the seated leg press. This constituted one set, hence the name superset/compound set. The superset/compound sets group performed 3 sets of this arrangement for the first 7 weeks and then 4 sets of this arrangement for the last 5 weeks. During weeks 1 and 2, there were 8 repetitions per set, weeks 3 and 4 had 10 repetitions per set, weeks 5 and 6 had 12 repetitions per set. All sets were performed at 70% of the initial 1RM. Week 7 had 3 sets.
to complete, but the intensity was raised to 80% of the initial 1RM and repetitions dropped back down to 8 repetitions per set. Week 8 saw an increase in the number of sets to 4 sets per session but stayed at 8 repetitions per set. Weeks 9 and 10 also had 4 supersets/compound sets but increased the number of repetitions to 10. Finally, weeks 11 and 12 had 4 sets and 12 repetitions. Once again, there was no pause between the two exercises for the superset/compound sets group (other than the 6.3 seconds on average it took subjects to walk from the Smith Machine to the leg press and be seated). The only rest between sets was 2:30 min when 3 sets were to be completed, and 2:20 min when 4 sets were to be completed. The rest between sets was changed to make sure the cumulative rest for the two experimental groups was the same.

The traditional training group trained by performing sets on the Smith Machine squat with 1-minute rest between each set. After completing the sets on the Smith Machine, a 1-minute rest was taken. This was followed by sets on the seated leg press with 1-minute rest between each set. The 1-minute rest between sets was the same for this group for the duration of the study. Traditional training subjects performed 3 sets of this arrangement for the first 7 weeks and then 4 sets for the last 5 weeks. During weeks 1 and 2, there were 8 repetitions per set, weeks 3 and 4 had 10 repetitions per set, and weeks 5 and 6 had 12 repetitions per set. All exercises were performed at 70% of the initial 1RM. Week 7 consisted of 3 sets, but the intensity was raised to 80% of the initial 1RM and repetitions dropped back down to 8 repetitions per set. Week 8 saw an increase in the number of sets to 4 sets per session but stayed at 8 repetitions per set. Weeks 9 and 10 also had 4 sets but increased the number of repetitions to 10. Finally, weeks 11 and 12
consisted of 4 sets and 12 repetitions on each respective training apparatus. The comparison group did not resistance train with the study.

Prior to each session, subjects performed a 5-minute low intensity warm-up on a cycle ergometer. When subjects were ready to begin lifting, they informed a researcher to clock them in. After completing the last repetition of the last exercise, a researcher clocked the subject out. All subjects performed the squat as the first exercise, regardless of training group. The design of the training was created to be effective but simplistic, and to resemble what the general population is instructed to do in regards to resistance training—find approximately an 8RM, continue to train until 12RM can be completed, and then increase weight and repeat from 8RM. Therefore, neither time at flexion or extension, nor repetition speed was controlled. There was a 1 week layoff after 9 weeks into the study due to spring break vacation. Subjects were asked to refrain from all resistance training during break.

After training data were completely collected for the study, the subjects were retested on the same measurements and in the same manner as the pretest. Subjects once again had to provide measures for body composition using skinfolds and BOD POD®, resting (10 minutes sitting minimum) blood pressure, relaxed thigh girth, weight, height, and muscle cross-sectional area and thickness. All subjects were tested on either Monday and Thursday or Tuesday and Friday of the same week for muscle strength and endurance posttraining measurements. Similar to the pretesting, all maximal testing followed procedures comparable to those recommended by the NSCA for 1RM testing (see Appendix III). On the first day subjects were assisted in determining their Smith Machine
squat maximum (1RM) followed by a 15-minute rest before performing as many repetitions as possible at 60% of the pretest 1RM (same weight as pretest to see change in absolute endurance). Subjects returned on either Thursday or Friday to perform the same testing and procedures on the seated leg press.
The schedule that was utilized is summarized as follows:

**Week 1-2** – pretests, measures and training orientation

**Weeks 2-15** – resistance training protocol (week 9 break with no training)

Following the testing days, the subjects began to train for 12 weeks. The training routines are delineated below:

<table>
<thead>
<tr>
<th></th>
<th>Superset/compound sets</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weeks 2-7</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>2 days/week</td>
<td>2 days/week</td>
</tr>
<tr>
<td>Intensity</td>
<td>70% of 1RM</td>
<td>70% of 1RM</td>
</tr>
<tr>
<td>Sets (total)</td>
<td>3</td>
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</tr>
<tr>
<td>Weeks 1-2 reps</td>
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<tr>
<td>Weeks 3-4 reps</td>
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<tr>
<td>Weeks 5-6 reps</td>
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<tr>
<td><strong>Week 8</strong></td>
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</tr>
<tr>
<td>Frequency</td>
<td>2 days/week</td>
<td>2 days/week</td>
</tr>
<tr>
<td>Intensity</td>
<td>80% of 1RM</td>
<td>80% of 1RM</td>
</tr>
<tr>
<td>Sets</td>
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<td>6</td>
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<tr>
<td>Repetitions</td>
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<tr>
<td><strong>Weeks 9-14</strong></td>
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<td></td>
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<tr>
<td>Frequency</td>
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<td>2 days/week</td>
</tr>
<tr>
<td>Intensity</td>
<td>80% of 1RM</td>
<td>80% of 1RM</td>
</tr>
<tr>
<td>Sets</td>
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<td>8</td>
</tr>
<tr>
<td>Week 8 reps</td>
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<tr>
<td>Weeks 9-10 reps</td>
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<tr>
<td>Weeks 11-12 reps</td>
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<tr>
<td><strong>Exercises (order)</strong></td>
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<td></td>
<td>Back squat</td>
<td>Back squat</td>
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<tr>
<td><strong>Week 15</strong></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>post test measures</td>
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B. Measurements and Analysis

1. Muscle Strength and Endurance

Muscle strength testing was performed pre-training and post-training. One repetition maximum (1 RM) and muscle endurance measurements were performed for both exercises (squat and leg press) with a rest of 72 hours between the assessments for each exercise. Firstly, each subject had to complete a 5-minute warm-up on a cycle ergometer prior to testing. The procedures utilized to determine one repetition maximum (1 RM) for each subject and exercise were identical. The initial pre maximum set was performed for each exercise by having the subject execute 8-10 repetitions at 40-60% of expected 1 RM. After a brief rest, the subjects then performed a set of three to five repetitions (75% of estimated 1 RM), followed by another 2-minute rest period and then a set of one to three repetitions (80-90% of estimated 1 RM). After the completion of these sets, the subject was allotted up to 4 minutes of rest and then made the first attempt at the one repetition maximum. If the lift was successful, 4 more minutes of rest was given while the weight was increased and another 1 RM was attempted. If the lift attempt failed, a second try at a 1RM with a decreased weight was attempted after 4 minutes of rest. This method was repeated as necessary with the 1 RM eventually being arrived at within five attempts. Only the attempts completed within the approved range of motion (by monitoring the bracket for the Smith Machine and the markers for the leg press, see Appendix II) for each subject and exercise were deemed successful.

Muscular endurance tests were conducted pre training and post training after the conclusion of the 1RM tests. After each 1RM was ascertained for a given exercise, the
subjects were provided 15 minutes of rest to prepare for repetitions to fatigue. The intensity was then put to 60% of each subject’s 1RM on both training machines and the subjects executed as many correct repetitions as possible, until fatigue. Repetitions were successful and counted only if proper form was maintained throughout the repetition. Subjects also were instructed that a pause for longer than 3 seconds after completion of a repetition or a significant loss of form would be the end of the test. The total number of repetitions performed sufficed as the measure for absolute muscular endurance (Rana et al., 2008)

2. Body Composition

Body composition was estimated by way of skinfolds and by BOD POD ® (Life Measurement, Inc., Concord, CA). Skinfolds (measured only on the right side of the body) measure subcutaneous body fat in millimeters. The sum of the three sites (triceps, suprailiac, and thigh) was put into a formula (Jackson, Pollock, & Ward, 1980) to predict body density (BD):

\[ BD = 1.099421 - 0.0009929(\Sigma \text{of skinfolds}) + 0.0000023(\Sigma \text{of skinfolds})^2 - 0.0001392(\text{age}) \]

Once body density was found, percent body fat was estimated using female population specific formulas (Heyward & Stolarczyk 1996):

\[ \%BF = (4.81/BD)-4.34 \text{ native} \]

\[ (4.85/BD)-4.39 \text{ black} \]

\[ (4.87/BD)-4.41 \text{ Hispanic} \]

\[ (5.01/BD)-4.57 \text{ white} \]
The BOD POD® uses air displacement plethysmography for determining percent fat and fat-free mass. The BOD POD® test comprises measuring body weight via electronic scale, and body volume, which is determined by measuring the interior volume of the empty chamber, then measuring volume again when the subject is secured inside. Throughout the volume measurement period of approximately 5 minutes, the chamber door is secured and a diaphragm oscillates during testing. This causes changes to the volume inside the chamber, of which the pressure response to these small volume changes is measured. A correction is made on all subjects for the volume of air contained in the lungs and thorax during respiration. Once the subject's mass and volume are determined, body density (body mass/body volume) is calculated and the relative proportions of fat and fat-free mass are estimated via the Siri equation (body fat percent = ((495/body density)-450)) (Siri, 1956; Life Measurement, Inc).

Subjects were required to wear the same clothing for pretesting and posttesting and required to not exercise the day before, or eat or drink for 2 hours prior to body composition testing. Subjects were also required to void prior to testing.

3. Blood Pressure

Blood pressure was measured by a cuff being wrapped around the upper arm and inflated by a sphygmomanometer. The properly inflated cuff compressed the brachial artery in the right arm, momentarily stopping blood flow and preventing audible sound. A stethoscope used for auscultation was placed on the antecubital fossa of the elbow.
Once there was no audible sound, the sphygmomanometer was slightly opened so air in the cuff was released and systolic and diastolic pressures were recorded.

Systolic pressure is the pressure the blood exerts when the heart beats and was signified by the pressure when the first sound was heard. Diastolic pressure is the pressure when the heart relaxes and was signified by the pressure when the last sound was heard. Blood pressure was measured for all subjects with this method pre training and post training and before and after several training sessions, mostly for safety purposes. The post session training measurements occurred following the resistance training and after resting five minutes post exercise. The pretesting and posttesting blood pressure measurements occurred after a 10-minute rest in a room with no activity (television, windows, etc.) so the subject could be as relaxed as possible. Subjects were instructed to avoid any stimulants such as caffeine, non prescribed drugs or supplements, and get 8 hours of sleep the night before blood pressure measurements. Pressure was recorded in millimeters of mercury (mmHg).

4. Extremity Girth

The girth measurement provides the circumference measure at select body sites, which in this study was the right leg. The girth of the right leg for each subject in all groups was measured along with the other pretest and posttest variables. Measures were taken in a relaxed muscle state, facilitated by having the subjects lying supine and flexing their knees to approximately 35-45° as measured by goniometer, and then resting the
weight of the leg on the heel. The measures for leg girth were taken at the following locations:

- Site 1 is halfway between the proximal patella and the anterior superior iliac spine (ASIS), measured in centimeters
- Site 2 is one-half of the distance between the proximal knee and site 1

For all measurements, Gulic tape measure (Power Systems, LLC, Jupiter, FL) with a tension spring was utilized. The tension spring ensures that a uniform amount of tension is applied for each measurement and prevents excessive compression of body tissue. Measurements were repeated three times for accuracy and then averaged.

5. Ultrasound Imaging

Measurement of muscle thickness and cross-sectional area (CSA) (est.) was taken via ultrasound. CSA measures via ultrasound had not been fully validated as of this study, but muscle thickness has been validated against MRI scans in humans (Juul-Kristensen, Bojsen-Moller, Holst, & Ekdaahl, 2000). Ultrasound allowed the study to quantify muscle hypertrophy in vivo and several studies have used ultrasound to measure muscle thickness and/or fascicle length (Chleboun, Busic, Graham, & Stuckey, 2007; Kawakami, Abe, Kuno, & Fukunaga, 1993). Ultrasound is a commonly used (Blazevich, 2003; Kubo et al., 2006), non-invasive technique for imaging inside the body. There are no known risks of ultrasound imaging.

The study used two dimensional B-mode ultrasound imaging (eSaote BioSound MyLab 25, Biosound Esaote, Inc., Indianapolis, IN) with a 5-cm linear transducer
(7.5MHz, axial resolution < 0.5mm). Direct measurement of muscle thickness and estimations of CSA were attained from sonographs, which clearly show the aponeuroses and muscle by using reflected echoes that delineate muscle structures (skin and adipose tissue, muscle fascicles, aponeuroses, and bone) for measurement. The sonographs were then imported into digitizing software (Scion Image for Windows, www.scioncorp.com) which allowed researchers to find landmarks and make measurements (see Appendix V).

To measure the vastus lateralis muscle, subjects lay supine with their upper legs elevated and relaxed and knees slightly flexed. The subjects lay supine for a minimum of 15 minutes to reduce fluid shifts and to ensure uniformity in testing. All scans were done on the right leg only. Sonographs were taken at the same sites as girth measurement, or at 25% and 50% of thigh length respectively. A water soluble conductor gel was placed on the site of measurement to improve transducer contact and to reduce the chance of touching skin, which may lead to deformation of the muscle. The transducer, which uses sound waves to penetrate the skin and produces a reflection of the muscle that is read by the computer and converted to an image, was placed perpendicular to the skin and parallel to the muscle fascicles as they were seen on screen for muscle thickness. For cross-sectional area, the transducer was placed at the site of measurement (site 1) and surrounded by double sided tape to guide the transducer as it scanned the entire segment of the lateral thigh to take multiple pictures from every angle of the vastus lateralis, and then superimposed the pictures to create a cross-sectional model of the muscle. Several measurements were taken at each site for muscle thickness, which was calculated as the mean distances between the superficial and deep aponeuroses at the ends and center of
each 5 cm wide sonograph. Site 2 was used to measure CSA, and the average value of three measurements was used. Due to an error with the settings on the ultrasound machine, several control group thickness measurements were unable to be analyzed on account of loss of pixilation of the pictures. The problem was corrected, but 8 out of the 10 subjects from the control group do not have any pretest or posttest muscle thickness measurements and therefore no statistics were run that included the control group’s muscle thickness. The remaining two control group subjects that had useful muscle thickness data are referred to for comparison purposes only in the “discussion” section.

6. Workout Time and Recovery

Each subject’s workout time was monitored and recorded for each session by clocking in and out for sessions. Clock-in time was after the warm-up was completed and the subject made contact with the barbell of the Smith Machine. The experimental groups performed the allotment of exercises with their respective rest periods between sets and when the last repetition of the leg press was completed, clock out time was recorded. A soreness scale (see Appendix VI) was provided to subjects so they could subjectively provide their post workout soreness rating for 2 days following a session.

7. Statistical Analysis

Statistical analyses were performed using SPSS 17.0 for Windows. Repeated measures mixed model (between/within) ANOVAs and one-way ANOVAs were used to determine whether there were differences between or within groups, pre training and post
training for all variables. Significance was bound by alpha level of $p \leq 0.05$. If a significant interaction was detected then simple effects were examined by Tukey’s honest significant difference (HSD) post hoc analysis. Separate paired $t$-tests were also used to compare groups for pretest to posttest changes. Statistical significance for $t$-tests was determined by using Bonferroni adjusted alpha levels (a reduction in type 1 error was considered more important than a reduction in type 2 error) of $p < 0.05$. One-way ANOVA was used to compare training time between groups and the nonparametric $L$ statistic was used to compare subjective soreness between groups post workout.
VI. RESULTS

A. Population

Thirty-four female subjects began the study and 3 of these subjects failed to complete the study, preventing their data from being utilized. The remaining subjects in each group were: traditional (T), 12 subjects; superset (SS), 8 subjects; and control, (C) 11 subjects. The subjects ranged from 18 to 31 years of age (20.72 ± 2.232) at the time of the study. The subjects’ weights ranged from 50.113 to 84.546 kilograms (61.8 ± 8.62 kg) and the heights ranged from 1.473 to 1.753 meters (1.647 ± .0693 m). Subject characteristics are presented in Table 2.

Table 2

Subject Characteristics (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Age (yrs)</th>
<th>Height (m)</th>
<th>Pre Weight (kg)</th>
<th>Post Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>20.64 ± 1.28</td>
<td>1.65 ± 0.06</td>
<td>61.52 ± 8.61</td>
<td>61.84 ± 5.53</td>
</tr>
<tr>
<td><strong>Traditional</strong></td>
<td>20.92 ± 3.42</td>
<td>1.63 ± 0.087</td>
<td>61.42 ± 9.62</td>
<td>62.33 ± 8.84</td>
</tr>
<tr>
<td><strong>Superset</strong></td>
<td>20.63 ± 1.06</td>
<td>1.65 ± 0.056</td>
<td>62.28 ± 11.0</td>
<td>63.30 ± 9.53</td>
</tr>
</tbody>
</table>

B. Muscle Strength

Regardless of training type, a 2 X 3 repeated measures mixed model ANOVA showed significant interaction (p < 0.001) for absolute muscle strength on the leg press
and squat in the traditional and superset groups respectively. Also, a significant training
effect (p < 0.001 for T and SS, for both leg press and squat) was found. Furthermore, a
significant main effect (p = 0.006 for leg press and 0.010 for squat) between groups was
detected. Post hoc analysis by Tukey’s HSD confirmed the difference was between the
two training groups and the control group, with the significant differences from the
control group similar (T p = .013; SS p = .016) on leg press. The difference between
groups on the squat strength was significant between the C group and the SS (p = 0.010)
but not between the T and the C groups (p = 0.073) according to Tukey’s HSD. There
was no significant difference between the two training groups for improvement in 1RM
for either exercise. Paired *t-test* performed at a Bonferroni adjusted alpha of p = 0.0167
showed a significant increase for the T and SS groups, respectively.

The results for *relative* leg press and squat strength (weight lifted, divided by
body weight) were also analyzed by a 2 X 3 repeated measures mixed model ANOVA.
Significant interaction (p < 0.001 for relative leg press and squat strength, respectively), a
significant training effect (p < 0.001 for relative leg press and squat strength,
respectively), and a significant main effect between groups (p = 0.009 for relative leg
press strength and p < 0.001 for relative squat strength) were detected. Post hoc analysis
by Tukey’s HSD confirmed the difference was between the two training groups and the
control group, with the significant differences from the control group similar on leg press
(T p = 0.019; SS p = 0.024). The difference between groups for squat strength was highly
significant between the C group and the SS (p < 0.001) and between the T and the C
groups (p = 0.001) according to Tukey’s HSD. Paired *t-test* performed at a Bonferroni
adjusted alpha of $p = 0.0167$ showed a significant increase in strength for the T and SS groups due to training. There was no significant difference between the two training groups for improvement in 1RM on either exercise according to one-way ANOVA. A summary of the results of absolute and relative strength changes with percent increases for each group are shown in Table 3, and Figures 1 and 2.

Table 3

*Relative and Absolute Muscular Strength* (Mean ± SD in kg)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Absolute Strength, Leg Press</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kgs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>152.69 ± 27.26</td>
<td>158.47 ± 33.97</td>
<td>1.7%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>158.52 ± 21.23</td>
<td>227.84 ± 27.45</td>
<td>§43.7%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>155.97 ± 30.56</td>
<td>236.99 ± 38.90</td>
<td>§51.9%*</td>
<td></td>
</tr>
<tr>
<td><strong>Absolute Strength, Squat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kgs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>51.24 ± 14.95</td>
<td>53.31 ± 14.67</td>
<td>4.0%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>50.38 ± 6.34</td>
<td>74.81 ± 6.39*</td>
<td>48.5%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>55.11 ± 9.70</td>
<td>80.97 ± 11.20* §</td>
<td>46.9%*</td>
<td></td>
</tr>
<tr>
<td><strong>Relative Strength, Leg Press</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kgs lifted/kg body weight)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2.48 ± 0.38</td>
<td>2.55 ± 0.41</td>
<td>2.8%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>2.61 ± 0.39</td>
<td>3.70 ± 0.54* §</td>
<td>41.7%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>2.58 ± 0.69</td>
<td>3.81 ± 0.84* §</td>
<td>47.7%*</td>
<td></td>
</tr>
<tr>
<td><strong>Relative Strength, Squat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kgs lifted/kg body weight)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.84 ± 0.22</td>
<td>0.86 ± 0.21</td>
<td>2.4%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>0.83 ± 0.08</td>
<td>1.21 ± 0.14* §</td>
<td>45.8%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>0.91 ± 0.20</td>
<td>1.30 ± 0.26* §</td>
<td>42.9%*</td>
<td></td>
</tr>
</tbody>
</table>

*Pre vs. post significance

§Significantly different from C
Figure 1. Pretest versus posttest leg press 1RM (+SE) in kilograms for traditional, superset, and comparison groups.
C. Muscle Endurance

The results of the muscle endurance assessments for leg press and squat and their percent changes are presented in Table 4. A repeated measures mixed model ANOVA showed significant interaction (p < 0.001) for muscle endurance on the leg press and squat in both the traditional and superset groups. The repeated measures mixed model ANOVA also showed a significant training effect (p < 0.001 for both the leg press and squat endurance) and a significant main effect between groups (p = 0.009 for leg press endurance and p < 0.001 for squat endurance) was found. The Tukey’s HSD post hoc
analysis revealed that the differences were between the superset training group and the control group for both leg press endurance and squat endurance. Tukey’s HSD for leg press endurance revealed that the difference from the control group was significant for the SS (p = 0.014) but not for the T (p = 0.078). As for squat endurance, Tukey’s HSD showed that the two training groups were similarly different from the control group (SS p < 0.001; T p = 0.001). There was a significant increase in both training groups’ repetitions to fatigue pre-study versus post-study for leg press repetitions (T pretest 27.08 ± 11.41, posttest 101.45 ± 36.36 and SS pretest 41.88 ± 15.80, posttest 110.25 ± 51.09) and squat repetitions (T pretest 15.00 ± 3.977, posttest 64.25 ± 31.13 and SS pretest 19.13 ± 8.823, posttest 74.00 ± 25.718), with no significant change for C. Figures 3 and 4 compare the pre and post means and standard deviations for repetitions to fatigue for each group and exercise.
Table 4

*Absolute Muscular Endurance* (Mean ± SD Repetitions to Fatigue)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Repetitions at 60%, Leg Press</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>38.64 ± 18.30</td>
<td>43.09 ± 24.41</td>
<td>11.5%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>27.08 ± 11.41</td>
<td>101.45 ± 36.36*</td>
<td>275%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>41.88 ± 15.80</td>
<td>110.25 ± 51.09*§</td>
<td>163%*</td>
<td></td>
</tr>
<tr>
<td><strong>Repetitions at 60%, Squat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>13.91 ± 6.77</td>
<td>18.27 ± 9.51</td>
<td>31.3%</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>15.00 ± 3.98</td>
<td>64.25 ± 31.13*§</td>
<td>328%*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>19.13 ± 8.82</td>
<td>74.00 ± 25.72*§</td>
<td>286%*</td>
<td></td>
</tr>
</tbody>
</table>

*Pre vs. post significance
§Significantly different from C
Figure 3. Pre-test versus post-test 60% of 1RM leg press repetitions to fatigue (+SE) for traditional, superset, and comparison groups.
Figure 4. Pre-test versus post-test 60% of 1RM squat repetitions to fatigue (+SE) for traditional, superset, and comparison groups.

D. Body Composition

Tables 5 and 6 show the results for body composition based on skinfolds and BOD POD®, respectively. A 2 X 3 repeated measures mixed model ANOVA showed no significant interaction for BOD POD® or skinfolds. A significant training effect was found for BOD POD® (p = 0.019) and for skinfold (p < 0.001) body fat percentage, but no significant main effect between groups was detected.

The traditional training group (-14.5 percent change skinfolds, -4.04% change BOD POD®) showed the highest percent change from pretesting to posttesting in both
the skinfolds and BOD POD® (SS -9.4 percent change skinfold, -3.1% change BOD POD®; C -5.8 % change skinfold, -1.1 % change BOD POD®) with skinfold change being significant.

Table 5

*Skin Fold Body Composition Percent (Mean ± SD)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin-fold Percentage</td>
<td>C</td>
<td>29.67 ± 4.57</td>
<td>27.91 ± 4.77</td>
<td>1.75 ± 2.69</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>30.40 ± 6.79</td>
<td>25.99 ± 4.15*</td>
<td>4.41 ± 3.38</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>27.17 ± 6.62</td>
<td>24.61 ± 5.58</td>
<td>2.56 ± 3.69</td>
</tr>
</tbody>
</table>

*Pre vs. post significance

Table 6

*BOD POD® Body Composition (Mean ± SD)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD POD® Percentage</td>
<td>C</td>
<td>26.34 ± 5.52</td>
<td>26.05 ± 5.34</td>
<td>0.28 ± 0.70</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>29.17 ± 4.49</td>
<td>27.99 ± 4.86</td>
<td>1.13 ± 1.92</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>27.02 ± 6.82</td>
<td>26.18 ± 7.25</td>
<td>0.84 ± 2.07</td>
</tr>
</tbody>
</table>
E. Extremity Girth

The results for extremity girth from both sites [(site 1 was halfway between the proximal patella and the anterior superior iliac spine (ASIS), measured in centimeters, and site 2 was one-half (½) of the distance between the proximal knee and site 1)] were analyzed by a 2 X 3 repeated measures mixed model ANOVA. Significant interaction (p = 0.039 for site 1 and p = 0.020 for site 2) and a significant training effect (p < 0.001 for site 1 and p < 0.001 for site 2) were revealed, but there was no significant main effect between groups (p = 0.918 for site 1 and p = 0.983 for site 2) detected. One way ANOVAs showed no difference between groups pre-test or post-test.

Paired *t-tests* were performed at a Bonferroni adjusted alpha of p = 0.0167 to determine which groups showed a significant effect of training on girth. The T training group was the only group to show significant difference between their pre-test and post-test extremity girths at both sites (p = 0.001 at site 1; p < 0.001 at site 2) as indicated by paired T-tests. No other group showed significant differences via *t-test* in pre-test versus post-test girth measurements, with the SS training group p = 0.049 for site 1 and p = 0.023 at site 2. A summary of the results of extremity girth changes with percent increases for each group are shown in Table 7.
Table 7

Lower (Site 2) and Mid (Site 1) Thigh Extremity Girth (Mean ± SD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site 2 Girth (cm)</strong></td>
<td>C</td>
<td>17.38 ± 1.25</td>
<td>17.47 ± 1.24</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>17.07 ± 1.26</td>
<td>17.62 ± 1.15*</td>
<td>3.2%*</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>17.36 ± 1.29</td>
<td>17.78 ± 1.09</td>
<td>2.4%</td>
</tr>
<tr>
<td><strong>Site 1 Girth (cm)</strong></td>
<td>C</td>
<td>20.74 ± 1.54</td>
<td>20.87 ± 1.45</td>
<td>0.6%</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>20.51 ± 1.71</td>
<td>21.20 ± 1.63*</td>
<td>3.4%*</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>20.70 ± 1.71</td>
<td>21.18 ± 1.80</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

*Pre vs. post significance

F. Ultrasound Imaging

1. Reliability of Measures

Reliability of ultrasound measurements was found by calculating the intraclass correlation coefficient for all images from the 2 sites (site 1 and site 2). The formula used was:

\[ R = MS_S - MS_E / MS_S \]

where \( R \) is the intraclass correlation coefficient, \( MS_S \) is the mean square for subjects, and \( MS_E \) is the mean square for error. \( MS_E \) was calculated as follows:

\[ MS_E = \frac{\text{sum of squares for trials} + \text{sum of squares for residual}}{\text{degrees of freedom for trials} + \text{degrees of freedom for residual}} \]
(Baumgartner & Jackson, 1991) The intraclass correlation coefficients were fairly high for muscle thickness, with the site 1 ICC being 0.923 and site 2 was 0.887. The intraclass correlation coefficient for the measurement of the cross-sectional area images was 0.965.

2. Muscle Thickness

Muscle thickness was measured at the same sites as girth. All measures were taken along the lateral face of the thigh to assess the vastus lateralis. Regardless of training type, a 2 X 2 repeated measures mixed model ANOVA (2 X 2 ANOVA since the control group data for muscle thickness was incalculable) showed no significant interaction (site 1 p = 0.077; site 2 p = 0.424). There was a significant training effect (p = 0.001 for site 1 and p = 0.011 for site 2), but a significant main effect between groups was not detected. Once again, due to error with equipment, the control group’s muscle thickness pictures were immeasurable. Therefore, paired t-tests were run with a Bonferroni adjusted alpha of 0.025 (a reduction in type 1 error was considered more important than a reduction in type 2 error) to determine if there was a significant effect of training type on muscle thickness. The T training group showed significant difference between their pretest and posttest muscle thickness with site 1 p = 0.008, and site 2 p = 0.021. No significant differences via t-test in pretest versus posttest muscle thickness were found for the SS training group. A summary of the results of muscle thickness changes with percent increases for each group are shown in Table 8.
Table 8

_Vastus Lateralis Ultrasound Muscle Thickness (Mean ± SD)_

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site 1 Thickness (cm)</strong></td>
<td>T</td>
<td>1.87 ± 0.23</td>
<td>2.16 ± 0.22*</td>
<td>15.5%*</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>1.99 ± 0.21</td>
<td>2.10 ± 0.023</td>
<td>5.5%</td>
</tr>
<tr>
<td><strong>Site 2 Thickness (cm)</strong></td>
<td>T</td>
<td>2.16 ± 0.22</td>
<td>2.37 ± 0.22*</td>
<td>9.7%*</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>2.23 ± 0.15</td>
<td>2.34 ± 0.25</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

*Pre vs. post significance

3. Cross-Sectional Area

The results for cross-sectional area (CSA) were analyzed by a 2 X 3 repeated measures mixed model ANOVA. Significant interaction (p < 0.001) and a significant training effect (p < 0.001) were found. A significant main effect between groups was narrowly missed (p = 0.052). The post hoc analysis by Tukey’s HSD showed no significant difference (p = 0.059) between the T and C groups. The paired t-tests showed a significant increase in CSA for the T (p < 0.001) and SS (p = 0.008) groups, respectively. A summary of the results of CSA with percent increases for each group are shown in Table 9.
Table 9

*Vastus Lateralis Ultrasound Cross-sectional Area (Mean ± SD)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectional Area (cm²)</td>
<td>C</td>
<td>2.89 ± 0.65</td>
<td>2.93 ± 0.60</td>
<td>1.4%</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>3.15 ± 0.53</td>
<td>3.80 ± 0.65*</td>
<td>20.6%§</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>3.08 ± 0.059</td>
<td>3.76 ± 0.49*</td>
<td>22.1%§</td>
</tr>
</tbody>
</table>

*Pre vs. post significance
§Significant percent change

G. Workout Time and Recovery

Each subject’s workout time was monitored and recorded for each session by clocking in and out for sessions. The T training group averaged 8 min 37 sec to complete training when three sets of each exercise were performed and 11 min 22 sec when there were 4 sets to complete. The T group was given 1 min rest between all sets. The SS training group averaged 8 min 54 sec to complete training when three sets of each exercise were performed, with 2 min 30 sec rest between sets. SS needed 11 min 48 sec when there were 4 sets to complete, with 2 min 20 sec rest between sets. One way ANOVAs showed no significant group differences between the T and SS time to completion of workouts. If rest time is equaled between training groups at 1 min, the SS group is significantly faster (p = 0.024) to completion than the T group, according to one way ANOVA.

Soreness scales were provided to subjects so they could subjectively provide their post workout soreness rating for 48 hours following a session. Calculation of the non-
parametric $L$ statistic showed there were no significant differences between groups for subjective soreness at 12 ($p > 0.80$), 24 ($p > 0.50$), or 48 ($p > 0.30$) hours post workout.
VII. DISCUSSION

A. Design

Twelve weeks was chosen as the time frame to ensure that hypertrophy could occur due to training. Several studies have shown hypertrophy could occur in as little as 4 to 6 weeks (Staron et al. 1991, 1994). In the study by Staron et al. (1994), 33 men and women trained their lower body for 8 weeks in a progressive resistance training program. Every 2 weeks during the study, muscle biopsies were taken from the vastus lateralis to determine CSA and muscle fiber type. Also hormone levels and maximum strength were measured. The study found that there were gradual yet not statistically significant increases in CSA due to training over the 8-week period. At the end of 8 weeks, training did not lead to a significant difference in CSA from control, but there was fiber enlargement. The study also showed that men had a more substantial increase in CSA than women due to training, possibly due to hormone differences between genders, but women still responded to training comparably to men. The current study did not utilize the invasive muscle biopsy technique to monitor increases in muscle size.

Two training sessions per week were carried out because it is recommended (Baechle & Earle, 2008) that individuals train a muscle group 2 to 3 times per week with at least 24-48 hours rest between training the same muscle group. Since the study used untrained subjects, researchers wanted to ensure enough time for recovery and prevent injuries from occurring. No subjects reported any injuries related to training in either
training group, signifying that performing only supersets is no more rigorous on the body than traditional training over a 12-week period.

The study was conducted over a 15-week period beginning with a week of lift orientation. During the week of lift orientation, each subject had to accumulate at least 3 hours in the weight room for the purpose of watching, learning, and working on the lifts that were used in the study: the ~45° seated leg press and the Smith Machine squat. This orientation was incorporated to ensure safety since subjects had little or no experience with the training exercises. Subjects were untrained and unfamiliar with the lifts involved in the study, and many could not perform the lifts well initially. The subjects were also apprehensive about performing the lifts. This could have negatively affected performance during measures such as the 1RM. The repeated exposure to the lifts during lift orientation was meant to decrease anxiety among subjects and to minimize any learning effect on study results. When individuals have more experience at a task they become more efficient at performing it. Repeated measure program designs often encounter problems such as a learning effect, and fatigue or boredom, due to the redundancy of performing the same lifts in a training program for 12 weeks. Due to this learning effect, the actual intensity of training may have been somewhat lower for subjects than the 70% or 80% used. Also, speed of movement was not controlled. Subjects were allowed to perform the lifts at a rate of movement that was comfortable for them. For some subjects, faster lifting may have been more comfortable, but others may have been more deliberate in there lift speed. Studies have shown that the rate of lifting can impact muscle adaptations (Rana et al. 2008, Keeler, Finkelstein, Miller, & Fernhall, 2001). Rana et al.
(2008) compared 34 untrained adult females who trained with resistance in a traditional strength, traditional endurance, or a low velocity training group. Each group performed the seated leg press, the knee extension and the squat during training sessions for 2 days per week for the first week and 3 days per week for the last 5 weeks. The sets and repetitions performed by each group in that study were consistent with strength and endurance training recommendations. The traditional strength group used 6 RM and 1-2 seconds for the eccentric and concentric components of the lifts. The traditional endurance group performed 20 RM with 1-2 seconds for the eccentric and concentric components of the lifts. The low velocity group trained using a 6 RM also, but the eccentric component of the lifts was 4 seconds and the concentric component was 10 seconds. Rana et al. found that while the low velocity group did improve muscle strength on all lifts, the improvement seen was not as substantial as the traditional strength group. Also, for endurance measures, the low velocity group did improve but not to the levels of the traditional endurance and traditional strength groups. For other measures such as body composition, oxygen consumption, and muscle power, the low velocity group did not differ from the control group.

Keeler and colleagues (2001) performed a study similar to Rana et al. (2008). In the Keeler study, 14 women trained using 1 set of 8 exercises 3 times per week for 10 weeks in either a traditional training or superslow training group. The traditional training group trained at a lift speed of 2 seconds concentric and 4 seconds eccentric, while the superslow group trained at 10 seconds concentric and 5 seconds eccentric with both training groups using an 8-12 RM. Similarly to the Rana study, the slow training group of
Keeler improved strength but not nearly as well as the traditional strength training group. The results of the studies by Rana et al. (2008) and Keeler et al. (2001) show that low velocity training is less effective for strength and endurance gains when compared to traditional strength training. One thing worth noting is that both of the slow training studies had to utilize significantly lower training loads for the slow training groups in comparison to the traditional strength groups, in order to have the subjects perform the desired amount of repetitions. Also, a study by Coyle, Cote, Feiring, Roby, & Rotkis (1981) leads one to assume that using a high speed of training while performing repetitions will increase force production at training speed and all speeds below. So individuals training at a slow velocity may be limited by the speed of training and the lower resistance that is usually used with slow training. Future studies should ensure that speed of lift and load are similar between training groups in order to isolate desired variables.

B. Muscle Strength

Muscle strength testing was performed pre training and post training. Total volume (sets, repetitions and percent of 1RM) and cumulative rest were kept identical for the two training groups during the study. The two training groups were significantly different in pretest versus posttest muscle strength for both exercises. The two training groups were significantly different from the C group for post leg press maximum strength, but only the SS group improved squat strength significantly more than the C group posttest. A possible reason for this is that the SS group had a longer rest period (2
min 30 sec for weeks 1-7 of training and 2 min 20 sec weeks for 8-12 vs. 1 min for T for entire study), which allows for more complete recovery of the phosphagen energy system. Longer rest periods decrease fatigue and maintain force production when training, and guidelines call for a 2 to 5 minute rest period between sets when training for strength and 30 seconds to 1.5 minutes when training for a combination of strength and hypertrophy (Baechle & Earle, 2008). In the current study, the T group was given a 1-min rest period, and to keep cumulative rest the same between groups, the SS group was given either 2 min 30 sec rest (3 supersets) or 2 min 20 sec rest (4 supersets) between sets. When the T group performed 3 sets of squat and 3 sets of leg press with 1-min rest between sets, the cumulative rest for that workout session was 5 min. When the SS group performed 3 supersets of squat and leg press, there was 2 min 30 sec of rest between sets so the SS group also had 5 min of cumulative rest per session.

Creatine phosphate levels decrease by approximately 60% within the first 6 seconds of high intensity exercise. Post exercise recovery times of 3 to 5 minutes allow full recovery of muscle ATP stores and about 90% regeneration of creatine phosphate (Hultman & Sjoholm, 1986). There is still no consensus on whether or not long rest periods (≥ 3 min) are advantageous to shorter rest periods (≤ 3 min) in increasing strength, but longer rest periods seem to be appropriate when performing lifts at or near maximum. Kay et al. (2000) showed that with almost no rest between muscle actions, there is a concomitant decrease in peak torque seen during sets of isokinetic-concentric exercises. The Kay study had 12 subjects perform sets of 100 sec in duration to fatigue (the 100 sec set was broken down into “epochs” of different time frames where
contractions were performed followed by slight rest) using either isometric contractions, isokinetic-concentric contractions or isokinetic-eccentric contractions on a force dynamometer. The isokinetic-concentric trial group decreased peak torque by 57% when comparing the first and last “epochs” while the isokinetic-eccentric trial showed no decrease in torque. A similar effect may have been seen in the current study even though the current study had no isokinetic focus and had modest rest periods. The group with the shorter rest periods (T group) may have compromised force production more so than the SS group during subsequent sets of training.

The impact of rest periods on muscular adaptations was also studied by Goto, Ishii, Kizuka, and Takamatsu (2005). In their research the two training groups performed either 5 sets of 10 continuous repetitions of knee extensions at 75% of 1RM twice a week (non-split), or 5 sets with 5 repetitions followed by a 30 second rest before completing the remaining 5 repetitions in each set of knee extensions at 75% of 1RM twice per week (split). The volume of training was identical between the two groups, but less effort was needed for the split group. The design by Goto et al. is somewhat similar to the design of this current research as the SS group trained continuously on two exercises and the T group was split by a 60 second rest before completing the same amount of repetitions as the SS group. The results of Goto et al. showed more quadriceps hypertrophy for the non split group and suggested to them that the non split group required the recruitment of more motor units and also had a greater hormonal response than the split group. Each of these factors would contribute to more strength production for the non split group and
may have contributed to the SS group’s significant difference from the C group on squat 1RM in this current research.

A final possibility to explain the SS group’s significant difference and the lack of significant difference for the T group from the C group for squat strength is provided by Folland, Irish, Roberts, Tarr and Jones (2002). In that study, it was found that traditional strength training with multiple sets and short rest periods (30 sec) caused noteworthy delayed onset muscle soreness (DOMS) during the first week of training. The DOMS, since it came along with repeated exercise sessions, may have been indicative of overtraining. In the present research, the rest period for the untrained T group was only 60 seconds with high intensity lifting and may have promoted some level of overtraining initially, but the researchers saw no signs of overtraining.

Maynard and Ebben (2003) performed prefatiguing of the hamstrings before testing rate of force development, peak torque and power in the quadriceps muscle group. The study’s design was similar to agonist-antagonistic supersetting as it used 20 NCAA athletes who performed 5 maximal leg extensions on an isokinetic dynamometer with and without 5 maximal leg curls prior to the knee extension. Prefatiguing the hamstrings prior to performing the leg extensions led to decreased rate of force development, peak torque and power in the quadriceps and increased EMG activity of the hamstrings during knee extensions. Maynard’s results suggested that force development may be impaired during agonist-antagonist supersets. The current study did not monitor EMG activity or power and torque development, so it may be of value to examine the aforementioned variables in an agonist-agonist superset (compound superset) design.
C. Muscle Endurance

Muscular endurance tests were conducted pre training and post training after the conclusion of the 1RM tests in this study. During training, total volume and cumulative rest were identical for both training groups. Primary differences between the training groups were the amount of rest between sets and the number of repetitions to complete a set (16-24 repetitions per set for SS and 8-12 repetitions per set for T). These differences are worth noting in regards to muscle endurance, as high repetitions (15-20) with short rest periods (60 sec or less) are recommended to train muscle endurance (Baechle & Earle, 2008). The posttest data showed each training group was significantly different from the pretest number of repetitions performed at 60% of 1RM on both exercises. This was expected, in part due to the fact that there would be increased efficiency of performing the exercises since the training groups performed so many repetitions of the exercises during the twelve week training period. This alone was expected to affect posttest muscle endurance. The two training groups were both significantly different than the C group for posttest squat muscle endurance, but only the SS group improved leg press muscle endurance significantly more than the C group posttest. Since both training groups lifted similar amounts of weight and performed the same amount of total repetitions in each training session, the difference in leg press endurance may be explained by the fact that within one set the SS group performed the recommended number of repetitions to train muscle endurance (15-20) while the T group never reached the recommended 12 repetitions in a single set. The results show that traditional strength-hypertrophy training can enhance muscle endurance, as shown by many other studies.
(Rana et al., 2008, Garcia-Lopez et al., 2007), but supersetting for strength-hypertrophy training seems to have more benefit than traditional training in terms of muscle endurance.

The initial exercise performed during compound supersets inherently prefatigues active muscles prior to performing the second exercise. The results of the current research also show that the prefatiguing of the quadriceps via squatting prior to performing the leg press during the SS group training had minimal effect on muscle strength and endurance on the leg press. This result differs from what other studies have found. Augustsson et al. (2003) used ten repetition maximum (10RM) of knee extensions to pre-exhaust the quadriceps muscle group prior to 10RM on the leg press to examine the effects of prefatiguing on muscle activation. The study used 17 men and each subject performed a leg press 10RM with and without a knee extension 10RM prior to the leg press. That research group surprisingly found that in the pre-exhausted state there was significantly less electromyogram (EMG) activity of the quadriceps during the leg press than in a nonfatigued state. It would be expected that more EMG activity would be seen in a prefatigued state since more muscle would need to be activated to get the same work done (due to already fatigued fibers and non fatigued fibers being activated). They also found that significantly fewer repetitions of the leg press could be performed in the pre-exhausted state. The findings of Augustsson and colleagues (2003) may differ from this investigation’s findings because they used a single joint exercise in the knee extension to prefatigue the quadriceps, while this study used a multi joint exercise in the squat prior to performing the leg press. The single joint exercise puts a focus on the muscle group...
involved in the activity while a multi joint activity spreads the load to various muscle
groups. Furthermore, Augustsson’s research had subjects perform 10RM of knee
extensions so a weight was used that only allowed the subjects to perform 10 repetitions
prior to moving on to the leg press, while this current study used a weight on the squat
that did not completely fatigue the involved muscles prior to moving on to the leg press.

D. Body Composition

This investigation found an effect due to training for both training groups on body
composition as measured by skinfolds and the BOD POD ®. Both training groups had a
slight decrease in body fat percent with an increase in lean body mass, and both training
groups gained body weight with the slight decrease in body fat. A decrease in body fat
and/or intramuscular fat due to resistance training has been found in numerous studies
(Sillanpaa et al., 2009; Sipila & Suominen, 1995) and most studies show that untrained
subjects fare better than trained subjects in body fat percent reduction due to resistance
training. A study by LeMura et al. (2000) used a demographic (48 untrained females,
mean age 20.4 years) similar to this current study to examine various modes of training
and body composition over a 16-week period. The training groups were aerobic training,
weight training, or a combination of both aerobic and weight training. In the LeMura
study, the resistance training group showed a decrease in percent fat but no significant
difference from the control group post-training on body composition. The findings of
LeMura are consistent with the findings of this current study and other studies. A factor
that may have played a role in body composition of the subjects in this study is that this
study did not control for diet as subjects were simply instructed to not change dietary habits. Also, toward the end of this study many subjects (22) went on a weeklong spring break vacation. During extended vacations individuals tend to alter their dietary habits and this may have impacted the final body composition measurements which occurred only a few weeks after the vacation.

E. Extremity Girth

Findings for thigh girth (site 1 was halfway between the proximal patella and the anterior superior iliac spine (ASIS) measured in centimeters and site 2 was one-half of the distance between the proximal knee and site 1) revealed that only the T training group showed significant difference between the pre-test and post-test extremity girths at both sites as indicated by paired *t*-tests. Girth is based on the total thigh compartment including the skin, subcutaneous fat, intramuscular fat, muscle and bone as shown by MRI or computed tomography. Therefore, it is difficult to pinpoint in this current study what training may have done to affect thigh girth. For example, training may have increased muscle mass while decreasing local fat mass or may have increased muscle mass with no impact on local fat mass. A study completed by Sillanpaa et al. (2009) showed that training of middle-aged to elderly women for muscle endurance impacted local arm fat mass while strength training did not alter the fat mass after 21 weeks of training. Another study carried out by Overend et al. (1992) showed that young and elderly men had similar thigh girths but the elderly men had greater thickness measurements for skin and subcutaneous fat, and more non muscle tissue within the
muscles. If girth measurements are to be of use for study purposes then measurement of each compartment that composes the girth should be measured and analyzed individually for changes. Extremity girth measurement may be the only tool the normal population has access to and can be used to determine if size is changing, but the extremity girth will not indicate which compartment (fat, skin, muscle, etc) is being gained or lost.

F. Ultrasound Imaging

Muscle thickness and CSA were measured via ultrasound at the same sites as girth. Soon after this study was concluded, a study indicated that measurement of CSA of the proximal and mid-thigh quadriceps via ultrasound was valid and reliable (Noorkoiv, Nosaka, & Blazevich, 2010). Numerous studies have utilized ultrasound (Chleboun et al., 2007, Kawakami et al., 1993) to measure in vivo muscle architecture and thickness, but the technique does have limitations. Firstly, the ultrasound technician must have experience with the machine and locating the target of measurement; if not, poor measures will occur, decreasing the reliability of the echoes. One cannot tell the source of an ultrasound picture from simply looking at the image. Only the individual taking the sonograph knows the location or source of an image. The intraclass correlation coefficient (ICC), which provides an estimate of systematic and error variance, ranges from a level of 0.00 to 1.00. The closer the ICC is to 1.00, the less error variance is involved in the repeated measures. Also, inexperience can lead to too much pressure being put on the area of measurement by the transducer, which could lead to muscle deformation. Furthermore, the transducer must be oriented in the correct plane, or
measures will be inaccurate (Oda et al., 2007). Lastly, inexperience can lead to the technician not measuring the same site in pre-testing and post-testing or the technician placing the subject in a position that may cause too much fascicle curvature, both of which can decrease reliability of measures.

There are other limitations of the ultrasound machine that are independent of user experience. The ultrasound penetrates bone and gas poorly, so lungs and boney areas are not ideal for sonographs. Also, heavy weight and obesity can be an issue for the ultrasound machine. Heavy individuals may need an ultrasound machine that can penetrate deeper than normal to acquire the necessary sonograph/s. In order to penetrate deeper, the ultrasound machine must be switched to a lower frequency, which will result in lower resolution imaging. To avoid being affected by the aforementioned limitations, the researchers in this study were familiarized with the ultrasound machine and performed pilot trials prior to pretesting in this study. Also, the study was restricted to subjects with a BMI of 27 kg/m² or less.

1. Muscle Thickness and Cross Sectional Area

The T training group showed a significant difference between their pretest and posttest muscle thickness with site 1 and site 2, but there was no significant difference in pretest versus posttest muscle thickness for the SS training group. The difference in muscle thickness may be the result of the amount of rest between sets. For one set, the SS group performed the recommended number of repetitions to train muscle endurance (16-24) and then rested for a longer period than the T group, which had less repetitions per set
and rest between sets. Kraemer et al. (1991) suggested that decreased rest between heavy weight training sets increases muscle work and makes continuing to perform the exercise more rigorous, leading to increased testosterone, growth hormone, and blood lactate levels, each of which promote muscle growth. The length of the current study (12 weeks of training) was enough time to see muscle hypertrophy. Staron et al. (1994) found that the hypertrophy process can be seen as early as 2 weeks into training, and other studies (Mayhew et al., 1995; Staron et al., 1991) have shown significant muscle hypertrophy due to training in similar time frames.

Cross-sectional area of the vastus lateralis muscle had increased significantly for both training types at the end of the study, with the T group increasing CSA by 20.6% and the SS group increasing CSA by 22.1%. Numerous training studies have demonstrated similar results. A study by Rafeci (1999) showed an 18% increase in quadriceps CSA due to 6 weeks of concentric only training, an increase similar to what was seen in this current study. As mentioned previously, Goto et al. (2005) used training groups that performed either 5 sets of 10 continuous repetitions of knee extensions at 75% of 1RM twice a week (non split set training group), or 5 sets with 5 repetitions followed by a 30 second rest before completing the remaining 5 repetitions in each set of knee extensions at 75% of 1RM twice per week (split set training group). The design is similar to the design of this paper’s research as the SS group trained continuously on two exercises and the T group rested for 60 sec before completing the same amount of repetitions as the SS group. Quadriceps hypertrophy was greater for the non split group suggesting that the non split group required the recruitment of more motor units, which
led to a greater hormonal response than the split group. This current study differs from Goto et al., since the SS and T groups both saw similar increases in CSA and neither training group was significantly different from the other for posttest CSA.

G. Workout Time and Soreness

The T training group averaged 8 min 37 sec to complete training when three sets of each exercise were performed and 11 min 22 sec when there were 4 sets to complete. The T group was given 1 min rest between sets. The SS training group averaged 8 min 54 sec to complete a training session when three sets of each exercise were performed, with 2 min 30 sec rest between sets. SS needed 11 min 48 sec when there were 4 sets to complete, with 2 min 20 sec rest between sets. The similarities seen between groups for time to complete a session of training suggest that time under tension for both training groups was similar. This occurred even though repetition speed was not controlled. If rest time is equalized at 1 min between training groups, the SS group would be significantly faster to completion than the T group. There is the possibility that the SS group may not be able to complete the prescribed repetitions each set or have an increased risk of overtraining if rest time between sets is reduced (Folland, 2002). Robbins, Young, Behm, Payne, & Klimstra (2010) found that when a paired set protocol (which is similar to reciprocal supersets) was compared to a traditional strength training program, and volume was matched between training methods, the paired set protocol was more efficient in terms of volume per time than the traditional training.
In this study, soreness scales were provided to subjects so they could subjectively provide their post workout soreness rating for 48 hours following a session. There was no difference in subjective soreness between groups, but this outcome may have been different if the SS group only used 1 min of rest between sets. A study by Kelleher, Hackney, Fairchild, Keslacy, and Ploutz-Snyder (2010) showed that reciprocal supersets increased energy expenditure more than traditional training methods if both training methods were matched for time, repetition speed, and volume. While the findings of this study and Kelleher and colleagues do not indicate that supersets will lead to more soreness in a given timeframe than traditional training, more work being done in less time is likely to lead to more demand on the body via supersets. This is something that should be taken into consideration when developing the exercise prescription, especially when adherence to the training program is crucial.
VIII. CONCLUSIONS AND FUTURE DIRECTION

Antagonist-agonist training has been shown to be a useful method to develop strength and other performance measures such as peak power when compared to traditional strength training (Robbins et al., 2010). This longitudinal study demonstrates that compound supersets can also induce gains in hypertrophy, muscle strength, muscle endurance, and body composition similar to traditional strength training in young untrained women when training volumes and cumulative rest are matched. Compound superset training led to a significant difference in absolute squat strength and leg press muscle endurance from the control group, while traditional training was narrowly above the alpha level for significant difference from the control group.

When volume and rest periods between sets are matched, workout efficiency (volume per time) for supersets is superior to that of traditional training, which confirms prior studies (Kelleher et al., 2010; Robbins et al., 2010). Since the increases in performance measures were similar in both training groups, compound supersets may be better than traditional strength training for short, yet still effective, workouts that could benefit individuals with limited time for exercise. This may also benefit trainers and rehabilitation specialists by improving exercise adherence and providing variety to workouts without compromising workout effectiveness.

Studies have shown detrimental changes in arterial compliance (Cortez-Cooper et al. 2008) using high intensity and volume resistance training, but studies with stable, low volume supersetting (Rakobowchuk et al., 2005) did not have the same effect.
Rakobowchuk also found that 12 weeks of weight training by young men leads to increased arterial diameter and either angiogenesis or increased endothelial function. Flow-mediated dilation of vessels has been shown to improve with endurance training. It would be interesting to determine whether supersets could have similar effects. Superset training may not be the best resistance training method for cardiac patients, as energy expenditure and work on the heart may be higher per set with superset training than compared to traditional strength training.

The training load for this study was 70-80% of 1RM and rest between sets was 1 min to 2 min 30 sec, which are both consistent with hypertrophy (combination of strength and endurance) training recommendations. Further studies should match supersets and traditional training for either strength or endurance training. Future studies could also target the effect of supersets on power development. The amount of work done in a set period of time is greater with supersets than with traditional strength training and therefore, may lead to greater fatigue within the same amount of training time. This could influence speed of movement, and inherently affect power. This study may have mitigated the effect of fatigue by having relatively long rest periods between sets for the compound superset group. Fatigue of the targeted muscles due to supersetting also may have led to the enhanced development and firing of synergist muscles and an EMG study may assist in determining this. Future studies should look at the possibility of overtraining with high intensity compound supersets, similar effects seen in the upper body, effects of compound supersets on bone density, and finally determine the effects of compound supersets on trained individuals.
REFERENCES


APPENDIX I: HEALTH HISTORY QUESTIONNAIRE

Please fill out ALL information! Please PRINT!

PERSONAL INFORMATION

ID# ________________

Name ___________________________ Today’s Date ________________

Date of Birth: ______ / ______ Age: ________ (year) ________ (months)

Gender: ________________ Ethnic Group: Caucasian / Asian / Black / Hispanic / Other
(circle as many as apply)

Address: ________________________________________________________

(street) ________________________________________________________

(City) ____________________________ (State) __________ (Zip)

Best Phone Number To Contact: ________________________________

E-mail Address: _____________________________________________

a. Persistent high blood pressure
   yes, continues today / yes, but does not exist today / no, since ____________

b. Congenital heart condition
   yes, continues today / yes, but does not exist today / no, since ____________
      Please specify ________________________________________________

c. Heart murmur
   yes, continues today / yes, but does not exist today / no, since ____________

d. Mitral valve prolapse
   yes, continues today / yes, but does not exist today / no, since ____________

e. Other heart conditions
   yes, continues today / yes, but does not exist today / no, since ____________
      Please specify ________________________________________________

f. Rheumatic fever
   yes, continues today / yes, but does not exist today / no, since ____________

  g. Pregnancy
     Is there any possibility that you may be pregnant?  yes / no
2. Organ condition
   a. Blood disorder
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   b. Nervous system disorder
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   c. Gastrointestinal disease
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   d. Kidney disease
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   e. Gall bladder or liver disease
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   f. Lung disease
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
   g. Cancer
      yes, continues today / yes, but does not exist today / no, since __________
      Please specify _____________________________________________
3. Other conditions
   a. Thyroid disorder
      yes, continues today / yes, but does not exist today / no, since __________

      Please specify ___________________________________________
   
   b. Hypoglycemia
      yes, continues today / yes, but does not exist today / no, since __________
   
   c. Diabetes mellitus (sugar diabetes)
      yes, continues today / yes, but does not exist today / no, since __________
   
   d. Diabetes insipidus (increased urination)
      yes, continues today / yes, but does not exist today / no, since __________
   
   e. Hirsutism (increase in body hair)
      yes, continues today / yes, but does not exist today / no, since __________
   
   f. Hyperprolactinemia (increased levels of prolactin in blood)
      yes, continues today / yes, but does not exist today / no, since __________
   
   g. Epilepsy 
      yes, continues today / yes, but does not exist today / no, since __________
   
   h. Recurrent urinary tract infections
      yes, continues today / yes, but does not exist today / no, since __________
   
   i. Anorexia nervosa
      yes, continues today / yes, but does not exist today / no, since __________
   
   j. Bulimia nervosa
      yes, continues today / yes, but does not exist today / no, since __________
   
   k. Stress fracture
      yes, continues today / yes, but does not exist today / no, since __________
   
   l. Other condition
      yes, continues today / yes, but does not exist today / no, since __________
4. Recent medical and personal problems. Circle the appropriate response for each item.
   a. Hepatitis    yes, in last 6 months / yes, but not in last 6 months / never occurred
   b. Anemia       yes, in last 6 months / yes, but not in last 6 months / never occurred
   c. Frequent headaches yes, in last 6 months / yes, but not in last 6 months / never occurred
   d. Frequent indigestion or upset stomach yes, in last 6 months / yes, but not in last 6 months / never occurred
   e. Injuries     yes, in last 6 months / yes, but not in last 6 months / never occurred
                   Please specify ____________________________

5. Please estimate as closely as possible your use of the following in the past six (6) months.
   a. Aspirin or other non-prescription pain relievers
daily or almost daily / several times per month / several times / never
   b. Prescription pain reliever (e.g., codeine)
daily or almost daily / several times per month / several times / never
   c. Prescription drugs to relax you (valium, librium)
daily or almost daily / several times per month / several times / never
   d. Prescription anti-depressants
daily or almost daily / several times per month / several times / never
   e. Recreational drugs (e.g., marijuana, cocaine, LSD, heroin)
daily or almost daily / several times per month / several times / never
   f. Diet or “pep” pills daily or almost daily / several times per month / several times / never
   g. Sleeping pills    daily or almost daily / several times per month / several times / never
   h. Diuretics        daily or almost daily / several times per month / several times / never
   i. Laxatives        daily or almost daily / several times per month / several times / never
   j. Medication for indigestion daily or almost daily / several times per month / several times / never
   k. Anti inflammatory drugs (e.g., Motrin, Naprosyn, Indocin) for inflammatory pain daily or almost daily / several times per month / several times / never
1. Anabolic steroids  daily or almost daily / several times per month / several times / never

m. Other prescribed medication  
daily or almost daily / several times per month / several times / never

Please specify ____________________________________________

n. Vitamins  daily or almost daily / several times per month / several times / never

o. Iron supplements  daily or almost daily / several times per month / several times / never

p. Calcium supplements  daily or almost daily / several times per month / several times / never

q. Other mineral supplements  daily or almost daily / several times per month / several times / never

r. Energy producing products (e.g., amino acids, creatine, protein powder, etc.)  
daily or almost daily / several times per month / several times / never

6. Please estimate as closely as possible your use of the following in the past six (6) months.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Frequency Options</th>
<th>Family member(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Alcohol</td>
<td>several times / once daily / several times / rarely or never per day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per week / per month</td>
<td></td>
</tr>
<tr>
<td>b. Coffee</td>
<td>several times / once daily / several times / rarely or never per day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per week / per month</td>
<td></td>
</tr>
<tr>
<td>c. Tea</td>
<td>several times / once daily / several times / rarely or never per day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per week / per month</td>
<td></td>
</tr>
<tr>
<td>d. Soft drinks</td>
<td>several times / once daily / several times / rarely or never per day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per week / per month</td>
<td></td>
</tr>
</tbody>
</table>

7. Circle following medical conditions that have occurred in your family in the last two generations. Answer the question with respect to your closest genetic relatives: paternal grandfather, paternal grandmother, maternal grandfather, maternal grandmother, father, mother, sister, brother.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Response Options</th>
<th>Family member(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. High blood pressure</td>
<td>yes / no / unknown</td>
<td></td>
</tr>
<tr>
<td>b. Heart disease</td>
<td>yes / no / unknown</td>
<td></td>
</tr>
<tr>
<td>c. Stroke</td>
<td>yes / no / unknown</td>
<td></td>
</tr>
<tr>
<td>d. Osteoporosis</td>
<td>yes / no / unknown</td>
<td></td>
</tr>
</tbody>
</table>
Exercise / Training

1. Currently how often do you exercise/training in a week?  
seldom / 1 / 2 / more than 3 times

2. How long do you exercise at each time?  

3. What type of exercises/training do you do? (list all)

4. Are you most physically active now?  
   yes / no
   If no,
   a. When were you most physically active?

   b. What type of exercise/training did you do? (list all)
APPENDIX II: SMITH MACHINE & SQUAT DEPTH POSITION BRACKET

Photo by: Jason White.
APPENDIX III: PROTOCOL FOR 1RM TESTING

For the 1RM testing, the subjects will perform warm-up sets (8-10 repetitions/set at 40% and 60% of the predicted 1RM, 3 repetitions at 75% of the predicted 1RM, and one repetition at 90% of the predicted 1RM weight) followed by an attempt at the target 1RM. The load will be increased after each successful lift until failure. Periods of rest (approximately 4-5 minutes) will be allowed between each 1RM attempt to assure adequate recovery. A test will be considered valid if the subject uses proper form and completes the entire lift or prescribed exercise in a controlled manner without assistance. Once the 1RM is determined, 60% of this value will be calculated for the local muscular endurance test. After a recovery period of 15 minutes, the subjects will perform as many repetitions as possible with the 60% 1RM load until failure. The number of total repetitions will be recorded.
APPENDIX IV: LEG PRESS MACHINE AND POSITION MARKERS

Photo by: Jason White.
Photo by: Jason White.
Visual of a cross-section of the thigh (skin, sub-dermal fat, muscle and bone). Photo by: Robert Hikida.
Visual of the technique used to take cross-sectional sonographs. Photo by: Robert Hikida.
Taking a guided cross-sectional ultrasound of the thigh. Photo by: Robert Hikida.
Visual and transducer placement for a thickness measurement of the thigh (vastus lateralis). Photo by: Robert Hikida.
APPENDIX VI: SORENESS SCALE

Please mark the sentence below that best describes your level of **THIGH** muscle soreness over the past 12, 24, and 48 hr periods.

<table>
<thead>
<tr>
<th>Workout Date:</th>
<th>12h</th>
<th>24h</th>
<th>48h (circle one)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] 0</td>
<td></td>
<td></td>
<td>A complete absence of soreness</td>
</tr>
<tr>
<td>[ ] 1</td>
<td></td>
<td></td>
<td>A light pain felt only when touched / a vague ache</td>
</tr>
<tr>
<td>[ ] 2</td>
<td></td>
<td></td>
<td>A moderate pain felt only when touched / a slight, but persistent pain</td>
</tr>
<tr>
<td>[ ] 3</td>
<td></td>
<td></td>
<td>A light pain when walking up or down stairs</td>
</tr>
<tr>
<td>[ ] 4</td>
<td></td>
<td></td>
<td>A light pain when walking on a flat surface / painful</td>
</tr>
<tr>
<td>[ ] 5</td>
<td></td>
<td></td>
<td>A moderate pain, stiffness, or weakness when walking / very painful</td>
</tr>
<tr>
<td>[ ] 6</td>
<td></td>
<td></td>
<td>A severe pain that limits my ability to move</td>
</tr>
</tbody>
</table>