Effect of Acute Dynamic and Static Stretching on Maximal Muscular Power in a Sample of College Age Recreational Athletes

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Submitted to the Graduate Faculty of

Health and Physical Activity in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy in Exercise Physiology

University of Pittsburgh

2008

UNIVERSITY OF PITTSBURGH

[SCHOOL OF EDUCATION]

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July 28, 2008

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EFFECT OF ACUTE DYNAMIC AND STATIC STRETCHING ON MAXIMAL MUSCULAR POWER IN A SAMPLE OF COLLEGE AGE RECREATIONAL ATHLETES

Jeffrey Christopher Murphy, Ph.D.

The purpose of the study was to determine the effect of dynamic and static stretching on muscular peak power production and hip and knee range of motion in a sample of college age recreational males. Forty-two males (aged 18-24) healthy, physically active volunteers from a University of Pittsburgh physical education class participated as subjects in this investigation. Subjects performed pre and post test measures of sit and reach, hip and knee goniometry measures, and vertical jump test. A one repetition maximum leg press was performed prior to pre-tests to determine group differences in strength. Subjects were randomly assigned to one of three stretch groups (dynamic, static, and control). All subjects began with a five minute warm-up on an upright cycle that elevated the heart rate to 110 beats per minute. Following the warm-up period, subjects immediately began their stretching program (dynamic or static), or remained seated for 12 minutes. A one-way ANOVA was conducted to detect group differences in strength levels conducted during pre-tests. A 3x2 factorial ANOVA was conducted to determine between and within group differences in treatment groups. Statistical significance was set at $\alpha = 0.05$. Results of the investigation showed significant time effects for all dependent measures ($p < 0.05$). Significant time x treatment interactions were found for maximum jump height, maximum peak power, and sit and reach in the DS and SS + DS groups, respectively ($p < 0.05$). However, there was no time x treatment interactions for mean jump height, mean peak power, knee range of motion, or hip range of motion. The results of the present study suggest that static

and dynamic stretching for 20 seconds prior to a vertical jump can improve mean vertical jump height, mean peak power, and hip and knee range of motion in a sample of male college age recreational athletes. Future research is needed to investigate the effect of intensity of stretch on force production, and the relationship between stretch intensity and duration on force production to establish a dose-response relationship between stretching and its effect on force production.

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PREFACE

The author would like to acknowledge the committee members: Dr’s Elizabeth Nagle-Stilley, Robert Robertson, Jean McCrory, and Ray Burdett for their continued support throughout this investigation. I would like to extend a special thanks to Dr. Nagle who has advised me, guided me through many trials, always inspired me to persevere, and to always remember to have fun. I would like to thank Dr. Elaine Rubenstein for her help in the statistical analysis component of this investigation. I would also like to thank Marilyn Ross and Gabe Lambright for their help in facility scheduling and equipment purchasing, and my research assistants (Nate, Megan, Jason, Suzy, Adrienne, Adam, and Domenic) of this investigation for their help in data collection. Finally, I would like to thank my family and friends for continuously supporting me during this educational undertaking. I would especially like to thank my parents, Dennis and Diane, for always being there to support me in every aspect of my life, and for teaching me the value of hard work, perseverance, and most importantly faith in achieving success.

1.0 INTRODUCTION

The warm-up prior to the performance of physical activity is widely accepted as a contributor to achieving maximal muscular power production, and ultimately, optimal athletic performance (74). An active warm-up prepares the body to increase elasticity and contractibility of muscles, increase the efficiency of respiratory and cardiovascular systems, and improve coordination (48). Warm-ups typically contain two components: 1) low intensity aerobic activity; and 2) stretching. Low intensity aerobic activity is widely accepted as a method that gradually raises metabolism by increasing cardiorespiratory demand, and allows for increased work output in strength and power activities such as weight training or jumping (6,11, 23). Stretching promotes increased range of motion, muscle temperature, and decreased stiffness of the exercised muscle.

It is believed that increased joint range of motion will decrease joint stiffness and improve power production through the enhancement of elastic strain energy of the muscle tendon unit. Bergh (11), et al. and Davies (23) have demonstrated that higher muscle temperatures (37-39 degrees Celsius) increased nerve conduction velocity compared to lower muscle temperatures (30-32 degrees Celsius) that resulted in a greater force and power production for a vertical jump. The issue of joint range of motion and power production and how each is related to the force-velocity curve is of particular interest for those individuals who may require muscular power for athletic events or certain activities of daily living (21, 65).

An individual's ability to produce the greatest amount of force in the shortest amount of time is highly predictive of performance in activities that require stretch shortening properties of the muscle-tendon unit, such as vertical jumping or sprinting (58, 73). Active dynamic stretching prior to power activities has been shown to improve power performance in collegiate recreational fit and athletic male sample populations. Yamaguchi (73), et al. showed significant improvements in leg extension power following a five minute stretching treatment compared to no stretching in a sample population of healthy male college students. In a sample population of male rugby players, active stretching prior to a 20 meter sprint showed significant time improvements compared to passive stretching (30). Therefore, incorporating dynamic stretching into a warm-up may be considered advantageous to power performance.

The most common stretching types used prior to exercise are static and dynamic. Static stretching methods are classified as active and passive and are used to develop static flexibility. Static active stretching involves taking a limb to its fullest range of motion and holding it without any external force (3). This method uses tension of the agonists and synergists while the antagonists are being stretched. Static passive stretching involves taking a limb into its fullest range of motion and holding it by the use of external force. This method uses one's own bodyweight or the use of a partner to maintain a stretched position. The effectiveness of static passive stretching of the lower limbs prior to maximal knee extension and vertical jump has been demonstrated by increased range of motion and decreasing stiffness at a joint (46, 52). In contrast, passive static stretching has shown decreased force production, velocity, as well as power production suggesting a decline in performance (46, 58, 70).

Dynamic stretching involves moving the limb repeatedly through its fullest range of motion by gradually increasing distance and speed of movement. Unlike static stretching, the agonist and synergist muscles actively contract (shorten and lengthen) while an antagonist relaxes. Dynamic stretching does not appear to decrease power production, and in most cases has shown improvements in power production relative to vertical jump and sprint performance (30, 58, 73).

The apparent mechanisms for performance improvements from dynamic stretching may be due to increased range of motion, avoidance of golgi tendon organ activation, greater muscle spindle activation, and increased muscle temperature (33). The increase in range of motion due to dynamic stretching attributes to decreased muscle stiffness in addition to an increase in stretch tolerance (9, 64). In a study by Yamaguchi (73), et al., a sample population of male recreational athletes improved leg extension power following five dynamic stretching exercises that totaled 4 minutes in duration. Studies of similar sample populations have demonstrated improvements in vertical jump and sprinting following 10 minutes of dynamic stretching (30, 58). The benefits of dynamic stretching are believed to be the result of greater muscular temperatures and voluntary contraction of the antagonist muscle leading to greater recruitment of fast twitch muscle fibers (30).

To date, no study has examined the effects of an acute bout of dynamic or static stretching on range of motion and power performance in male recreational college age population. Based on previous literature, dynamic stretching appears to have no power performance decrements compared to static stretching (30, 58, 74). The change in range of motion and power due to an acute dynamic stretching protocol prior to maximal vertical jump may offer insight to neuromuscular adaptations associated with execution of maximal muscular power exercise movements. By identifying the most beneficial type of stretching for a given exercise bout, coaches and trainers can utilize techniques to enhance stretches as they relate to strength and power performance.

1.1 Statement of problem

The purpose of this investigation was to determine the effect of dynamic and static stretching on muscular peak power production, peak jump height, and range of motion in a sample of college age recreational males.

1.2 Hypothesis

It was hypothesized that:

1) Dynamic stretching prior to a vertical jump will produce increased power compared to static or no stretch condition.
2) Dynamic stretching and static stretching will increase range of motion compared to a no stretch condition.
3) Dynamic stretching will increase jump height compared to a static or no stretch condition.

2.0 LITERATURE REVIEW

2.1 Introduction

It is common for coaches of various sports to incorporate warm-up as part of preparation for an athletic event since warming up prior to a specific event has been shown to increase performance (13). A warm-up prepares systems of the body by improving elasticity and contractibility of muscles, increasing efficiency of the respiratory and cardiovascular systems, and improving coordination (48). Classification of a warm-up falls into two major categories: (1) Passive warm-up; and (2) Active warm-up. Passive warm-up involves raising muscle temperature or core temperature by external means (hot showers, saunas, heating pads, static stretching). Active warm-up involves raising muscle and core temperature through dynamic (with movement) exercise (jogging, calisthenics, cycling, dynamic stretching). Research suggests that active warm-up is superior to passive warm-up for improving sports performance because it raises body temperature through muscular effort, and prepares the body for exercise (12, 37, 68).

The purpose of active warm-up is to increase the body's core and muscular temperature in order to protect and prepare the body for more intense physical activity (48). Active warm-up results in the following physiological benefits: (1) Decreased friction of sliding filaments during muscular contractions; (2) Increased aerobic metabolism and decreased accumulation of blood and muscle lactate; and (3) Increased dilation of intramuscular blood vessels resulting in greater oxygen extraction at the working muscle (37, 40, 68).

An active warm-up may focus on one or more of three components: 1) general; 2) neural; and; 3) specific. While the use of all three will ensure the greatest potential for maximal performance in a particular exercise session, a decision to use any component may depend on the type and intensity of the activity (33). For low intensity activities such as jogging or biking, a general warm-up may be sufficient to provide the best results. However, for higher intensity activities such as basketball or sprinting, a progression from general to specific warm-up is highly recommended (40). A proper warm-up must progress from general to specific to ensure the safety of the individual.

The general warm-up component involves the use of low to moderately intense cardiovascular exercise such as jogging, cycling, or jumping rope. Low to moderately intense cardiovascular exercise prepares the heart for the physiological demands by increasing blood flow to the muscles, and raising the body's core and muscle temperature (33, 40). This increase in temperature allows for an increased sliding of actin and myosin filaments, greater cross bridge formation during contraction, and greater oxygen availability to the muscle.

The neural component involves the use of stretching exercises such as toe touches or leg swings for the purpose of raising the level of excitation of the nervous system (33). Sale's Ramp theory of motor unit and muscle fiber recruitment states that "As force increases gradually, there is a gradual and increasing recruitment of more muscle fibers. Therefore, as one progresses from joint mobility exercises to general movement patterns, additional muscle fibers will be recruited to allow for greater force production at the time one performs the specific activity" (33). A proper progression of stretching exercises begins with joint mobility exercises (e.g. neck rotations or arm circles) and progresses to general movement patterns (e.g. leg and arm swings).

A specific warm-up involves movement that resembles an actual physical activity. Examples include performance of squat jumps prior to vertical jump test, or swinging a baseball bat prior to playing baseball. The use of a specific warm-up is a continuation of the neural component, which ensures that the maximal numbers of muscle fibers are recruited prior to physical activity. A neural specific warm-up will enhance motor unit recruitment while continually increasing the body core and active muscle temperatures (33).

2.2 Rationale for Stretching with an Active Warm-up

Typically, stretching exercises are incorporated into an exercise program with the purpose of increasing range of motion or flexibility about a joint. Within an active warm-up, the purpose of a stretching exercise is to further raise core body and muscle temperature so an increase in the mechano-elastic properties of the muscle-tendon unit can occur (30, 48). The muscle demonstrates the ability to store mechanical energy in the tendon during an active lengthening (eccentric contraction) that can be reused as elastic energy by the muscle during a subsequent active shortening (concentric contraction) also known as stretch shortening cycle) (6). An example of the stretch shortening cycle is a countermovement jump, in which the jumper performs a quick eccentric muscle contraction (downward phase) followed by an immediate, quick concentric muscle contraction (upward phase). Therefore, the muscle and tendon act as one unit to store and release energy during the countermovement jump (stretch shortening cycle).

The elastic components of muscle have an ability to store mechanical energy from an active muscle lengthening for use towards a subsequent muscle shortening (also known as stretch shortening cycle). Muscle contains a parallel elastic, series elastic, and contractile component (42). The parallel elastic component is composed of intramuscular connective tissue and sarcolemma. The series elastic component is composed of the tendon that has the ability to store elastic energy during stretch shortening cycle exercise. The contractile component is composed of actin and myosin filaments that form cross-bridges during muscle contraction. The ability of the muscle-tendon unit to work effectively during stretch shortening cycle is dependent on muscle temperature and compliance of the muscle-tendon unit.

It appears the temperature change due to warm-up has an effect on the compliance of the series elastic component of muscle. Several studies have shown that an elevated muscle temperature (37-39 degrees Celsius) shown following fifteen to twenty minutes of cycling at greater than 45% of VO_2 peak can improve vertical jump height compared to a no warm-up (lower muscle temperatures) condition (6, 11). It is believed that a warm muscle is able to contract with greater force and increased vertical jump height as a result of greater storage of elastic energy in the series elastic component (tendon) due to increased compliance of the muscle-tendon unit. This suggests that vertical jump height difference may be related to the effects of muscle temperature on elastic properties of muscle.

However, temperature is not the only factor that affects the contractile properties of the muscle. The degree of adaptation within an elastic component from a warm-up also depends highly on the method of warm-up (6, 11, 33). Passive warm-up methods such as external heating have been found to improve vertical jump performance when compared to cold exposure condition; however no significant changes occurred when compared to a control condition that remained at rest (23). It was suggested that temperature change alone does not enhance the contractile properties of the muscle. This in turn, supports the use of warm-up methods that incorporate active muscular contractions.

2.3 Stretching Methods

Two primary methods of stretching within an active warm-up are passive static and active dynamic. Flexibility is a measure of the maximum range of motion available to a joint and is used synonymously with the term stretching. The term stretching will be used throughout this paper. To expand on these methods, further clarification is needed on the nature and characteristics of these types.

There are six types of stretching methods 1) Dynamic active below pain threshold; 2) Dynamic passive below pain threshold; 3) Dynamic passive above pain threshold; 4) Static active below pain threshold; 5) Static passive below pain threshold; and 6) Static passive above pain threshold. The six types of stretching can be further divided into two categories: dynamic and static. Dynamic stretching refers to "the ease of movement within the maximum range of motion" (35). The primary measure of dynamic stretching is stiffness, which is defined as the resistance of a structure to deformation. Dynamic stretching is measured by quantifying force at the same time as the joint angle where the slope of a force deformation curve at any point will represent the stiffness of the joint (35). Static stretching is the range of motion available to a joint. The primary measure of static stretching is relaxation (i.e. the ability of a muscle to decrease tension over time). Static stretching is typically measured using a goniometer in a clinical setting, or by the sit and reach test in a field setting (35).

Stretching is divided into the two categories of active or passive. Active stretching is the ability of the muscles to move through its full range of motion without any assistance from an external force (i.e. swinging of the leg in flexion to extension while standing erect). Passive stretching is the ability of the muscles to move through its full range of motion with the use of an external force (i.e. having assistance to swing a leg in flexion to extension while standing erect) (3, 48).

Stretching can also be divided into the two categories: below pain threshold or above pain threshold. Below pain threshold stretching involves the ability of the muscles to move through a full range of motion without producing a pain response. Above pain threshold stretching involves the ability of the muscles to move through a full range of motion while producing a pain response (48).

It is important to note that the following section provided an in depth description of all stretching methods available. The following sections will focus on dynamic active and static passive stretching methods because these are the most common methods used within an active warm-up.

2.3.1 Static Stretching Methods

Static stretching involves stretching a muscle to a point above or below pain threshold for an extended period of time with the intent of developing static flexibility. The pain threshold is identified as reaching the maximal limit of motion permitted by pain tolerance (3). The stretch may be performed by active or passive means depending on requirements of a particular movement (3, 48).

Static active stretching involves moving a limb into a stretch, and holding the stretch using only the tension of the muscle agonist in movement. The advantage to this stretching method is improvement of both static active and passive flexibility. Several disadvantages to this stretching method include limited specificity to movement, and a greater strength required to perform the stretch. Few activities require holding a limb in an extended position except in gymnastics or figure skating. It has been found that holding a limb in an extended position can place large compression forces on the spine, apply pressure to intervertebral discs, or increase lordosis (3, 48). Due to possible risks of static active stretching and its limited application to movement, it may be safer to perform static passive stretching.

Static passive stretching can be performed by two methods: relaxed stretching or isometric stretching. Relaxed stretching involves relaxing a limb into a stretch and holding it by the weight of the limb or some external force such as a person pushing on the limb. Isometric stretching, also known as proprioceptive neuromuscular facilitation (PNF) stretching, involves the same position as relaxed stretching with the additional contraction of the antagonist or agonist muscle group applied by a partner (3).

Two PNF techniques primarily used are the contract-relax technique (CR) and the contract-relax-agonist-contract technique (CRAC). The CR technique involves stretching an antagonist muscle group to its full passive range of motion, followed by a contraction of that muscle group, therefore allowing the muscle to increase its range of motion after a brief relaxation period. The CRAC technique involves the same stretch as the CR technique with the addition of a contraction of the agonist muscle group (3, 48). PNF stretching is the most effective method for increasing range of motion, but requires expertise of the partner to perform the stretch correctly and judge intensity of stretch to prevent injury (3). The acute affects of static passive stretching on temperature and elasticity are explained in the next section.

2.3.2 Acute Affects of Static Passive Stretching on Temperature and Elasticity

Static stretching is a passive method that involves muscle contraction with no eccentric or concentric contraction, resulting in less heat production from the sliding filaments compared to active stretching. Evans (28), et al. found that a five minute warm-up using static stretching produced a lower muscle temperature compared to a five minute jog at 4 mph. Since lower muscle temperatures are associated with a decreased stretch-shortening cycle performance, a passive stretch such as static stretching is beneficial for developing static flexibility associated with muscle relaxation.

The muscle-tendon unit during static passive stretching displays viscoelastic behavior. Viscous behavior refers to the property of the muscle to lengthen when a force is applied (i.e. stretch). Elastic behavior refers to the property of the muscle to lengthen over time when a force is applied, and return to its original length when the force is taken away (35). The properties of the intramuscular connective tissue contribute to the length change relationship of the muscle-tendon unit (38). The viscous component of the muscle-tendon unit is dependent on the rate of the applied stretch, and the elastic component is dependent on the force of the applied stretch. The measurement of viscoelastic behavior during stretch is stiffness, which measures a muscle's ability to resist change in length. A muscle that is placed under a repeated static passive stretch will increase in length. This may in part be due to a decrease in passive resistance of the intramuscular connective tissue, therefore decreasing the muscular stiffness (35).

The muscle tissue consists of a series elastic (tendon), contractile (actin and myosin), and parallel elastic (intramuscular connective tissue and sarcolemma) component. When a muscle is stretched, sarcomeres are pulled to their maximum length; therefore additional stretch causes the connective tissue to take the remaining slack to maintain a new muscle length. The series elastic component functions to transfer force from the sarcomere to the tendon and bone in series, but the parallel elastic component functions to distribute stress evenly and prevent overstretching. Repeated stretching places a load on both the series and parallel elastic component thereby affecting the function of the contractile component (actin and myosin filaments). In regards to performance changes in stretch-shortening cycle exercise, it appears that when the series elastic component and contractile component are in a proper length-tension relationship force production is enhanced (29, 46, 47, 59).

Several studies have shown that a repeated passive static stretch (3-5 sets) for as little as thirty seconds alters the elastic properties of the muscle (39, 53). The increase in muscle length and decrease in stiffness is believed to be a result of changes to the parallel elastic component. The response of the parallel elastic component to repeated static stretch has been associated with a decreased force and power production (47). While muscle temperature changes were not measured in any of the studies, it is speculated that the temperature may be lowered from static stretching (58, 73).

2.3.3 Force Decrements Associated with Passive Static Stretching

Force decrements after an acute bout of repeated static stretch are associated with changes to the viscoelastic properties and nervous system control of the connective tissue. A repeated static stretch to a muscle increases the length of the muscle fiber causing less overlap between actin and myosin during cross-bridge formation. With less musculotendinous stiffness, less cross-bridge formation and a greater contractile component shortening velocity will occur, resulting in decreased force production. The nervous system regulates muscular tension; therefore it regulates the muscle length by influencing the contractile component of muscle (46, 59).

Proprioceptors located within the muscle fibers and tendons relay information about muscular tension to the central nervous system. The two proprioceptors related to stretching are muscle spindles and golgi tendon organs. Muscle spindles are located in the intrafusal fiber of the muscle, and responds to any changes in length. When a muscle is repeatedly stretched, the muscle spindle records the change in length and activates the stretch reflex thus causing a change in length through a muscle contraction. A slow, static stretch will decrease stretch reflex response causing the muscle to relax and contract with less force, as a direct result of a decrease in muscle spindle activity (27, 38).

When a muscle contracts in response to a stretch reflex from muscle spindle activity, tension is placed on the tendon. The golgi tendon organ is activated (during stretching at or beyond pain threshold) when the tension reaches a level that may tear a muscle, and the muscle is inhibited from contracting, therefore causing it to relax. Muscle relaxation traditionally is a benefit for increasing range of motion over time, yet in acute activities that require strong muscle contractions this may cause performance deficits and injury (39).

A dynamic movement such as vertical jumping requires forceful contractions of several large muscle groups. One study indicated that less stiff muscle-tendon units are more beneficial in stretch shortening cycle movements such as the rebound bench press. Wilson (71), et al. demonstrated that after 8 weeks of passive static stretching a less stiff muscultendinous unit (performed after workout) will result in a greater optimal length of the contractile component, reduced shortening velocity, and enhanced torque production. The performance of passive static stretching prior to power movements results in a less stiff muscultendinous unit. A more compliant musculotendinous unit has been associated with decreases in neural activation, resulting in a lower performance in isotonic and isokinetic movements (46, 63). Therefore the type of stretch chosen and its effect on the force-velocity relationship are very important to the performance of power activities, such as the vertical jump.

2.3.4 Effects of Passive Static Stretching on Power

The use of passive static stretching prior to performance and its effects on performance has been studied extensively. Several studies have compared passive static stretch warm-up to no warm-up prior to power performance in diverse sample populations (10,14,46,67). If power performance is negatively affected by static stretching, it is expected that measures of power such as jump height, velocity, and time will be negatively affected following static stretching compared to no stretch. However, recent studies have shown mixed results, and additional research is warranted.

In a recent study conducted on 14 male soccer players, a static stretch significantly decreased counter-movement jump height in comparison to no stretch (14). The total stretching time used was approximately five minutes (3 exercises of 3 x 30 seconds) not including rest periods with subjects randomly assigned to either group. Other studies reviewed have used equal or greater stretching times with no significant difference.

Powers (63), et al. demonstrated a non-significant decrease in vertical jump height following a static stretch (3 exercises of 3 repetitions at 45 seconds each) compared to no stretch in a sample of twenty male volunteers. The lack of a significant decrease in vertical jump height may be explained by the use of a single leg concentric only vertical jump not affected by a more compliant muscle tendon unit. Another study showed a non-significant decrease in peak vertical velocity after a static stretch (3 repetitions at 15 seconds each) compared to no stretch using heterogeneous sample of athletic and recreational fit males and females (45). The author's explanation for the lack of significance was due to the reverse placebo effect related to the subjects' prior knowledge of static stretching considered a benefit to performance and the heterogeneous population (athletes and non-athletes).

An athlete is expected to have greater power characteristics than a non-athlete, and consequently have greater stiffness in their muscle-tendon unit (71). In a recent study by Yamaguchi (73), et al., no significant differences were found in leg extension power following a static stretch and no stretch protocol. However, there were significant declines in pre to post test leg extension power. Results indicated that individuals with greater power prior to a static or no stretch protocol exhibited greater power decrements after either protocol. In the same study, dynamic stretching was found to increase leg extension power for all subjects vs. no stretch suggesting that dynamic stretching methods may improve performance when compared to static stretch.

2.3.5 Dynamic Stretching Methods

Dynamic stretching involves moving a contracted muscle through its fullest range of motion while relaxing the antagonist muscle. The purpose of dynamic stretching is to develop dynamic flexibility. The stretch can be performed by active or passive means depending on the needs of the particular activity or sport (3, 48).

Dynamic active stretching only involves use of muscles of the moving body part without any external assistance. The ability to attain maximum range of motion is dependent on the ability to combine relaxation of the extended muscle with contraction of the moving muscle. For example, the ability to swing the hip into flexion is dependent on the ability to relax the hamstrings and contract the hip flexors (4, 44).

Several athletic teams and recreational athletes incorporate dynamic active stretching into a warm-up because of its specificity to sports movement. Kurz (48) recommends that movements start slowly, and gradually increase in both range and speed. All movements are conducted with no bouncing, and repetitions per set may range from 5-15 depending on the mass of the muscle producing the movement. Therefore, larger muscle groups such as the quadriceps may require more repetitions.

Sport specific movements require dynamic muscle action through the transfer of energy from a tendon to a muscle in order to produce maximal force. A muscle that can stretch to optimal length during an eccentric contraction stores maximal energy in the tendon to be returned in the subsequent concentric contraction and produce maximal force (71). Passive static stretch appears to negatively affect this energy transfer process in force production due to the change in elastic properties and temperature of the muscle, yet active dynamic stretching does not appear to have this same effect on these properties (58,73).

2.3.6 Acute Affects of Active Dynamic Stretching on Temperature and Elasticity

There is limited research on the acute affects of active dynamic stretching on muscle temperature and elasticity. Active dynamic stretching involves full lengthening and shortening of a muscle similar to activities such as jogging or cycling. Jogging and cycling elevate muscle temperature to significant levels to allow an increase sliding of actin and myosin filaments, greater cross bridge formation during contraction, and greater oxygen available to a muscle (6; 11). The advantage to dynamic stretching within a warm-up is that it maintains and elevates muscle temperatures through the progression of non-specific stretching to specific stretching and stimulates actual movements of the sport (33, 41, 54). An example of a proper dynamic stretching progression for a baseball player are leg swings to the front and back, straight leg skips, power skips, and knee up runs (54). The progression from short range movements to full range movements is essential to motor unit recruitment and the proper innervations of the nervous system.

The major advantage to active dynamic stretching compared to passive static stretching is its effect on the nervous system, and elastic properties of the muscle during a stretch. As stated earlier, the nervous system regulation of tension and length is performed by a golgi tendon organ and muscle spindle, respectively. When a muscle is repeatedly stretched, a muscle spindle records the change in length, thus activating the stretch reflex and causing a change of muscle length through a muscle contraction. As a direct result of an increase in muscle spindle activity, a fast, dynamic stretch will increase a stretch reflex response causing an agonist muscle to contract with greater force (38).

Active dynamic stretching results in length changes similar to passive static stretch, however, due to the lower magnitude of stretch, an alpha motoneuron is stimulated to cause greater muscle contraction (3, 27, 38). The alpha motoneuron in the spinal cord is responsible for causing the agonist muscle to contract (stretch reflex), and the antagonist muscle to relax (reciprocal inhibition). Since progression of stretch from short range movements to full range movements has an effect on the series elastic component, greater recruitment and faster contraction of muscle fibers will occur at the time of the event (48). When actin and myosin filaments are at optimal length and tension, they are capable of producing the greatest amount of force and velocity. This is essential since greater recruitment and faster contraction of muscle fibers is critical to performing activities that require high rates of force production or power, such as the vertical jump.

2.3.7 Active Dynamic Stretch and Power

The use of active dynamic stretching prior to power performance and its effect on performance improvements has been explained. Active dynamic stretching compared to passive static stretch warm-up and no warm-up prior to power performance has been examined in diverse sample populations. It is speculated that if power performance is positively affected by active dynamic stretching, measures of power (jump height, velocity, and time) will also be positively affected following active dynamic stretching when compared to static stretching or a no stretch condition.

In a study by Yamaguchi (73), et al., the dynamic stretch group had significantly greater leg extension power compared to static stretch and a no stretch condition regardless of leg extension power at pre-test. Each group performed five stretching exercises for a total of four minutes. The static stretch group performed five exercises for one set (30 seconds stretch with 20 seconds rest). The dynamic stretch group performed the five exercises for one set of five repetitions (2 seconds/repetition) followed by one set of 10 repetitions (2 seconds/repetition). The benefits of dynamic stretch compared to static stretch are believed to be a result of greater muscular temperatures and voluntary contraction of antagonist muscles that contribute to greater recruitment of fast twitch muscle fibers.

A sample population of military cadets showed significant improvement in a five step vertical jump after a dynamic stretch warm-up vs. static stretch or no warm-up condition (58). In a separate study by Fletcher (30) et al. male rugby players showed a significant decrease in 20 meter sprint time following an active dynamic stretch warm-up compared to a passive and active static stretch. The static group performed seven exercises consisting of one set of twenty seconds each, and the dynamic group performed five exercises of one set of 20 repetitions at a constant, slow to medium pace. Each group performed a 10 minute jogging warm-up prior to any activity. Improvements from dynamic stretching were explained by specificity of the movement patterns, and ability to recruit greater motor units for a greater contractile force.

In a similar study on NCAA Division I athletes, a non-significant increase in vertical jump height for a no stretch group vs. static stretch group was observed (18). The no stretch group performed a body weight circuit of 10 exercises for 20 seconds that progressed from less vigorous to more vigorous in intensity. Other studies have shown non-significant differences between static stretch and sub-maximal jump warm-up in NCAA Division I athletes (16, 45). These results do not support the hypothesis that a dynamic specific warm-up prepares the nervous system better for power performance in comparison to a non-specific static warm-up. It was concluded that factors other than the stretching protocol affect the power performance such as training status and intensity of stretch routine.

2.4 Relationship Between Power and Vertical Jump Performance

Power is defined as the product of force and velocity. Force is the product of mass and acceleration, which is dependent on the bodyweight, cross-sectional area of muscle, and the velocity of movement. Velocity is highly dependent on the efficiency of the nervous system, and to a smaller degree, the cross-sectional area of muscle (22, 27). The ability to produce power is greatest in one who can produce the greatest amount of force in the shortest amount of time.

The production of power is essential to the performance of athletic, recreational, and daily activities. Power may be expressed as a relative value throughout a range of motion, or as an absolute value occurring at a particular instant (44,66). In activities that require explosive movements such as sprinting, jumping, or weightlifting peak power has been shown to be the strongest variable associated with success (17, 36). Coaches and police departments measure peak power because it can predict the ability to perform better in a particular task. The power assessment traditionally used is the vertical jump test because it is simple to administer, inexpensive, and highly predictive of power. When compared to laboratory measures, jump height measures from a vertical jump test are highly predictive of power production ($r = 0.89$-0.93) (66).

2.5 Measurements of Power and Jump Height During the Vertical Jump

The assessment of jumping power is useful in the evaluation of performance improvement, determining the effectiveness of an exercise program, identifying weaknesses, as well as those at risk for disabilities or injuries (66). Therefore, reliable and valid measures of jumping power are necessary to determine the effectiveness of a program, and selection of jumping power methods should be an important consideration. A disadvantage to calculating peak power based on jump height is the apparent inability to explain height as a mechanism responsible for changes in power. For a coach, competitive athlete, or recreational athlete, changes in the force-velocity relationship due to a stretching program are less important than performance outcomes reflected in jump height.

2.5.1 Laboratory Measures of Muscular Power and Jump Height

Power measurements during a vertical jump are assessed in laboratory or field settings. Considered to be highly accurate, the laboratory assessment of power is a force plate measure (51). Peak Power is the product of peak force and peak velocity. During the vertical jump, peak force and velocity occur during the push-off phase where the jumper moves upward by extending the knees and hips. The force plate provides an actual measure of force production (in Newtons) by measuring the ground reaction force exerted on the person while in contact with the plate. To calculate peak force from integration calculations, the velocity and vertical height of the jumper's center of mass must be known at some instant. The start position of the jump is used, where the velocity of the jumper's center of mass is zero, and the vertical height is set to zero. Peak force is calculated by subtracting the product of the jumper's mass by the acceleration due to gravity from the ground reaction force. Velocity is measured by dividing the force-time record by the jumper's body mass to obtain the acceleration-time record, and then applying integration calculations (51).

Jump height may be measured from the force plate using the flight time method, impulse-momentum method, and the work-energy method. The flight time method assumes that time and height of a center of mass during an ascent is the same as descent. A study by Aragon-Vargas (4) found the reliability of this method (r = .994) to be equal compared to a direct measure of the height of center of mass. The flight time method is the simplest to perform, but it usually overestimates the flight height because the height of the jumper's center of mass at landing is lower than that at takeoff (51).

The impulse-momentum method uses the integral of force over time producing a change in the momentum of the body. This method is the most accurate calculation of jump height, which is dependent on selection of body weight at an instance prior to the start of the jump, and the ground reaction force is equal to the jumper's body weight. The work-energy method uses the integral of force over displacement that produces a change in kinetic energy. This method is the least reliable because of the integration process to calculate the jumper's center of mass, and the sensitivity of selecting body weight at an instance prior to the start of the jump where the jumper is stationary and the ground reaction force is equal to zero (51).

Limitations of the force plate method to measuring power and vertical jump height are expense and availability. A more affordable, assessable yet valid and reliable field measure of power and vertical jump height is the jump and reach test.

2.5.2 Field Measures of Muscular Power and Jump Height

The jump and reach test traditionally was conducted by measuring the distance between chalk marks made with the reach of an outstretched arm and the mark made at the height of the jump (62). Recently, methods for measuring jump height have been developed using the Vertec and Velcro USA jump training apparatus. These jump training apparatuses use a mounting device on the wall or extension from a pole that allows for accurate measurements of vertical jump height. Test-retest reliability has ranged from (r = 0.93 to 0.99) using this test protocol (62).

A popular power prediction equation for the vertical jump is the Lewis equation (44). The Lewis equation is calculated by $P = \sqrt{4.9} \times BM \times \sqrt{h}$, where:

P = leg power (kg·m·s)

BM = mass of person (kg)

h = vertical jump height (cm)

Another equation to calculate peak power from vertical jump height uses:

$P = 60.7 \times D + 45.3 \times W - 2{,}055$, where:

P = peak power (watts)

W = body mass of the person (kg)

D = vertical jump height (cm).

Sayers, et al. developed this regression equation to calculate peak power for a countermovement jump and squat jump (stand and reach test) in a sample of 108 college-age males and females, and followed with cross-validation of the Lewis equation (66). Comparisons of actual peak power (measured with a force plate) and equation-predicted power were strongly correlated with r values ranging from $r = 0.91$ to $r = 0.93$ for the countermovement jump and squat jump, respectively.

The Lewis prediction equation uses a nomogram where jump height and body weight are used to determine power (55). There are numerous limitations of the Lewis prediction equation. It does not measure ground reaction forces directly, and the calculation of power is a product of gravity exerted on the jumper's body as it falls back to the ground (not the power exerted at takeoff or the peak power) (51, 66).

Regression analysis indicated that the Lewis formula underestimated peak power by 72.8% when using the countermovement jump, and by 73.2% when using the squat jump. Using the new regression equations, the squat jump was underestimated by 0.7% and the countermovement jump overestimated by 2.7%. The squat jump was shown to be a more accurate predictor of peak power due to less variability in the movement, however, the interchangeable use of equations was not found to affect the results significantly. It is concluded that the jump and reach test is a reliable measure of peak power and jump height, however variability exists in power and jump height measures (regardless of method) based on characteristics of the individual and the jump technique (66).

2.6 Factors that Influence Vertical Jump Performance

The height of a jump is dependent on the ability to produce maximal force over a greater distance in the shortest amount of time. As stated previously, power production is dependent on bodyweight, cross-sectional area of muscle, speed of movement, and the ability to use stored elastic energy of the muscle (2, 56, 69, 71). Vertical jump performance as measured by jump height is highly dependent on the power of an individual. Given this relationship between power and vertical jump height, an examination of variables that effect power production is necessary, including muscle mass, strength, training status, type of training of the individual, and the use of the stretch shortening cycle.

2.6.1 Effect of Muscle Mass and Strength on Vertical Jump Performance

Differences in jump height and peak power between males and females have been shown, with males greater in both measures. Greater body mass and strength have been associated with greater power production, and jump height in males due to the greater ground reaction forces and muscle mass. However, the heavier jumper does not always produce greater jump height. A heavier person may have a lower jump height due to their greater absolute strength and lower relative strength, assuming training levels are equal (48). Absolute muscular strength is the ability to produce maximal force regardless of body weight. Relative muscular strength is the ability to produce maximal force divided by body weight.

Absolute strength is typically measured by a 1 repetition maximum (1RM) test. However, several studies have shown the 1RM test to be a weak predictor of vertical jump height in sample populations of equal training status (56,69). However, tests of 1RM strength are of limited practical value because this specific type of strength is employed in only a few athletic endeavors, such as power lifting. Most sports require the explosive application of force to accelerate the body or a limb, whereas a 1 RM strength test does not require rapid acceleration to produce the necessary force (22, 25). Absolute muscular strength has been found to be a predictor of vertical jump height in untrained sample populations of males.

In a movement similar to the vertical jump, a person is required to move his or her body forcefully against only the resistance of gravity as quickly as possible. Therefore, relative muscular strength is a better predictor of vertical jump height than absolute muscular strength (48). Muscular strength contributes to vertical jump performance; and how jump performance will be improved by concentrating on improving absolute strength appears to depend on how strong an individual is at the initiation of a training program (8, 48). Several studies have shown that individuals who improve vertical jump performance after strength training had lower absolute strength at the start of the program. Individuals with higher absolute strength at the start of the program did not improve significantly in vertical jump performance (8). The difference between trained individuals in vertical jump performance with high absolute strength is related to the power production. However, the difference between untrained individuals in vertical jump performance with low absolute strength is related to absolute strength and power production.

2.6.2 Training Status and Vertical Jump Performance

Specificity of training is important in the development of muscular power and physical performance. Cross-sectional analyses of specific types of training have shown different adaptations of peak power, velocity, or jump height. In a sample population of power and Olympic lifters, the Olympic lifters were found to have significantly higher peak force, peak velocity, and jump height compared to the power lifters (56). Significant differences are attributed to the use of moderate force, high velocity weight training of the Olympic lifters compared to the high force, and low velocity weight training of the power lifters. Studies have indicated that combined heavy resistance weight training with plyometrics is an effective method of improving vertical jump height, but not as effective in improving power output combined with jump height as seen in the Olympic lifts (56, 69).

These reflect the importance of the stretch shortening cycle to performance of the vertical jump, its relation to the type of movements utilized in the activity, as well as the activity required for greater jump height or power output. For example, a volleyball player or basketball player may only need heavy resistance training combined with plyometrics to enhance jump height. In contrast, a football tackle may need Olympic lifts to produce high force and high velocity. Therefore, the ability to specifically challenge the stretch-shortening cycle of the muscle-tendon unit is of great importance in vertical jump performance.

Anthropometrics related to training status also appears to be important to the utilization of the stretch shortening cycle during a vertical jump. Several studies have demonstrated that a greater distribution of Type II muscle fibers is positively correlated with power performance and highly associated with greater muscle hypertrophy (2, 60). Negative correlations between body mass index and power production in obese men and women have indicated that lean muscle mass is a factor in power performance (65).

2.6.3 Stretch Shortening Cycle and Vertical Jump Performance

The stretch shortening cycle occurs in movements that use a quick eccentric movement or pre-stretch (downward phase) followed by a quick concentric movement (upward phase), such as the counter-movement jump. The countermovement jump is variable depending on depth of the eccentric movement, the use of arm swing, and the extension of the torso at the top of the jump. A deeper eccentric movement (up to 90 degrees), use of an arm swing, and greater extension of the torso will result in greater jump height due to greater use of the stretch shortening cycle. In contrast, the squat jump eliminates some variability because it does not use eccentric movement prior to the jump. However, it lacks the specificity of the countermovement jump typical to many sports movements (15). A significantly higher jump height in a countermovement jump is a result of pre-stretch of the muscle from the eccentric loading of the muscle. During the eccentric phase (downward phase), energy is stored in the muscles and tendons to be used in the subsequent concentric movement (upward phase) (15).

A pre-stretch cause's leg muscles to produce greater forces that decelerate the downward movement, and will reverse the direction of the movement upward. This will consequently produce greater velocity and force at takeoff and greater jump height (51). A muscle placed on stretch prior to a jump is an important factor to peak power performance, also may be related to stretching during a warm-up prior to activities that require jumping. To understand the effect of stretching on dynamic movements it is important to use tests that reflect specificity and involve dynamic muscle contractions.

2.7 Conclusions

The type of stretch prior to the vertical jump is crucial to the muscle and tendons ability to transfer force appropriately during the stretch shortening cycle. During a countermovement jump, the appropriate length-tension relationship is necessary to the achievement of maximal force and velocity at take off. A static stretch prior to a countermovement jump is believed to limit the muscle’s ability to attain maximal force and velocity due to an improper length-tension relationship. Dynamic stretch is believed to allow the appropriate length-tension relationship between the muscle and tendon. It is also believed that muscle temperature is a contributing factor to differences in power performance between static and dynamic stretch, however investigations have not explored this hypothesis.

It is evident that dynamic stretch prior to power performance is beneficial compared to static stretch alone. The question of whether a static stretch is more beneficial than no warm-up is of interest and may answer whether static stretch is beneficial to power performance. Research has indicated that the effect of static stretch on power performance is not statistically different when compared to a no warm-up, suggesting that it doesn’t improve performance. Other factors contributing to a lack of significance include strength and power characteristics of the individual. Future studies that control for the strength and power characteristics of each subject may help uncover whether static stretching may be beneficial prior to performance. Regardless of whether differences exist between static and no warm-up conditions, the lack of significance between the two suggests that static stretch prior to exercise has no value in improving performance. If a warm-up is performed with the purpose of improving neuromuscular and physiological mechanisms that increase performance, then the use of static stretch prior to performance must be explained further.

3.0 METHODS

3.1 Experimental Design

A repeated measures experimental design compared the effects of an acute stretching routine on muscular power and flexibility in a sample of recreational college age males. Subjects were randomly assigned into one of three groups: 1) General warm-up + dynamic stretch; 2) General warm-up + static stretch; and 3) Control (General warm-up + no stretch).

Dependent variables included: 1) Predicted peak power (watts); and 3) hip and knee range of motion (centimeters and degrees). All dependent variables were measured prior to and immediately following the stretching program. Independent variables included the stretching treatment program (dynamic (DS), static (SS), or control (C)).

3.2 Subjects

Forty-two male volunteers aged 18-24 were recruited from the physical education classes at the University of Pittsburgh. In order to be eligible to participate, subjects were 1) healthy; 2) physically active defined as engaging in strength training (machine or free weights) or aerobic training a minimum of two but not greater than four days per week for a minimum of one year; and 3) willing to participate in all testing sessions. Exclusion criteria for the study included: 1) responding to one or more questions on the PARQ & You questionnaire (Appendix A); 2) presence of serious or unstable medical illness within the last 12 months (Appendix B); 3) any clinical, musculoskeletal or metabolic contraindications to exercise; 4) being treated for any serious psychological disorder or having treatment, hospitalization, and emergency room within the previous six months; 5) currently taking performance enhancing substances 6) currently engaging in a plyometric or sprint training program, or flexibility training program that is performed longer than two minutes greater than 3 days/week; and 7) unwilling to perform or participate in the prescribed program or testing sessions.

3.3 Procedures

Subjects reported individually for testing on two separate days within a 14 day period of time. On the first day, subjects were provided an overview of the study. Subjects completed the Physical activity Readiness Questionnaire (PARQ & You) as well as a medical history questionnaire in order to participate. Potential risks and benefits and underlying rationale for the investigation were explained to all subjects where upon their written consent to participate will be obtained. Following Institutional Review Board consent, anthropometrics, pre-testing assessments, a practice orientation session was conducted. Following the orientation practice session, subjects were randomly assigned to one of three treatment groups. On the second day, the stretching treatment program was conducted followed by post-testing. The proposed meeting and testing schedule included the following:

Diagram #1

Day 1	Day 2

• Informed Consent
• Pre tests
  ○ Sit and reach, goniometry
  ○ Vertical jump
• Anthropometrics
• 1Repetition Maximum Leg Press
• Orientation practice session
	• General Warm-up
	• Stretch Treatment
	• Post tests
	  ○ Sit and reach, goniometry
	  ○ Vertical jump

3.3.1 Day 1

3.3.1.1 Overview of Study

Subjects reported to the Baierl Recreation Center Multi-Purpose Room at the University of Pittsburgh Petersen Events Center. Informed consent forms approved by the University of Pittsburgh Institutional Review Board were distributed. All aspects of the investigation were addressed including purpose of the study as well as risks and benefits. Questions regarding any portion of the study were answered at this time. Subjects completed the Physical activity Readiness Questionnaire (PAR-Q & You) as well as a medical history questionnaire. Each participant was instructed to maintain all normal training levels, and to not begin any new training programs throughout the study. All participants were instructed to wear spandex shorts with drawstring, t-shirt, and tennis shoes for both testing sessions. Following IRB consent, pretreatment assessments were conducted including: 1) Anthropometrics; 2) Goniometry and Sit & Reach; 3) Vertical jump; and 4) 1 repetition maximum leg press.

3.3.1.2 Anthropometrics

Height in centimeters (cm) and weight in kilograms (kg) was measured with a standard medical beam scale (Sensormedics). Body Mass Index (BMI) was determined by body weight (kg)/height (m^2). Percent body fat was determined by the skin fold method of body composition. Subjects were instructed to not exercise and fast three hours prior to the test (32). Using a Lange skin fold caliper, measures were taken on the right side of the body at the chest, abdomen, and thigh sites. All measures were taken three times on the right side of the body, and sites were rotated to allow for the skin to return to normal texture and thickness. Additional measures were taken if duplicated measures are not within 1 to 2 millimeters. The chest site was a diagonal fold taken at one-half the distance between the anterior axillary line and the nipple. The abdominal site was a vertical fold taken 2 centimeters to the right side of the umbilicus. The thigh measure was a vertical fold taken on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease. The mean value of each of the sites was used to determine body density (32). The Siri equation predicted percent fat from the calculated body density as determined from the skinfold measure (43). The same investigator performed all measures to maintain inter-test and intra-test reliability.

3.3.1.3 Leg Press Test to Assess Maximal Strength

A maximal strength test to assess lower body strength using a Cybex Leg press machine was conducted to determine leg press to weight ratio (LP/BW = 1RM score (kg)/bodyweight (kg)) (32). High and low leg press strength groupings were determined by LP/ BW values, and randomization of treatment groups followed after the orientation practice session.

To determine maximum absolute lower body strength, a one repetition maximum (1RM) leg press test was conducted using a Cybex Leg press machine. Two spotters were provided for all lifts to ensure safety of all subjects. Subjects performed a low intensity warm-up of 5 to 10 repetitions at 40 to 60% of perceived maximum. Following a 1-minute rest with light stretching, subjects completed three to five repetitions at 60% to 80% of perceived maximum. Finally, a weight of 4.5 kilograms was added, and a 1RM lift was attempted. If the lift was successful, a rest period of two to five minutes was provided. A lift will be successful when knees were at ninety degrees of flexion or more during the down phase, and the knees were fully extended at the completion of the upward phase. The goal was to reach the 1RM within two to five maximal efforts, and this process continued until a failed attempt occurred. The 1RM was reported as the weight of the last successfully completed lift (32).

3.3.1.4 Pretreatment Assessments

Vertical Jump

To prepare for vertical jump testing, subjects performed three to five submaximal practice jumps to ensure proper technique. For the actual vertical jump test, subjects performed three consecutive countermovement jumps with arm swings for maximal height with a Vertec jumping apparatus (Power Systems, Knoxville, TN). This apparatus resembled a volleyball standard with red, white, and blue markers (vanes) spaced 0.5 inches apart. Red vanes were spaced every 6.0 inches apart, blue vanes every 1.0 inches apart, and white vanes every 0.5 inches, with the exception of where might already be a red or blue vane.

Using a similar laboratory protocol of Adams et al., subjects stood with their dominant arm closest to the standard and extended upward as far as possible (1). The standard was adjusted so the tip of the tallest finger during the reach was at the bottom surface of the lowest vane on the Vertec. The highest reach was observed and recorded. After the standing reach was measured, subjects moved to a jumping position with feet approximately shoulder width apart. The feet were not permitted to deviate from this original position prior to the jump (e.g. hop or step prior to jump). Subjects were allowed one quick dip, or countermovement, of the knees and one arm swing. The depth of the squat was determined by the comfort of each subject with instructions to squat greater than 90º at the knee joint, and to avoid excessive flexion at the trunk. Subjects jumped while touching or swatting the measuring vanes at the peak of the jump. Arm reach beyond normal reach height was not allowed. The highest vane moved represented the height of the jump. Investigators calculated the number of centimeters (to the nearest 0.5 inches) to the highest vane moved. Since the Vertec was zeroed prior to the beginning of the test based on the subjects reach, the highest vane touched represented jump height that was recorded. Subjects were allowed three to five practice jumps prior to the three pre-test jumps. The average of the three pre-test jump heights was used to calculate peak power (55). Peak power was predicted using the following equation from Sayers (66), et al.:

Equation: Peak power = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2,055.

Prediction of peak power was shown to be reliable (r = 0.93) in a similar population of recreational athletes.

Sit and Reach Test

Hamstring, lower back, and gluteus maximus range of motion was measured using a sit and reach testing device (Novel Flex Tester, Creative Health Products Inc., USA). A demonstration was provided, and three to five practice trials were allowed so investigators provided feedback on technique. Subjects were asked to remove shoes and sit with legs extended in front of them with feet flat against the inside of the box. Subjects were instructed to cross one hand over the other and flex forward at the trunk while sliding hands across the top of the box (parallel to the thighs) until they can no longer stretch. The final position was held for 2 seconds. Using three trials, the subject's mean value was recorded as the flexibility score. A trial was discarded if subject's knees rose off the floor, reached excessively with their hands, or rounded their upper or lower back (32).

Goniometric Measurements

Following the sit and reach test, hamstring, gluteus maximus, and quadriceps range of motion was measured using a plastic goniometer (Baseline, Creative Health Products Inc., USA). Hamstring range of motion was measured using a passive straight leg raise. The straight leg test has been shown to be reliable (r = 0.95-0.99) in healthy adult populations (61). Subjects were asked to lie supine on a training table with both legs in extension. A trained tester aligned the axis of the goniometer with the lateral aspect of the hip joint using the greater trochanter as a reference point. The proximal arm of the goniometer was aligned with the lateral midline of the pelvis, and the distal arm was aligned with the lateral midline of the femur using the lateral epicondyle as a reference point. The subject's leg was passively moved by the tester into hip flexion with knee straight. The end range of motion occurred when resistance was felt by the tester. The tester read the goniometer in degrees of motion. Using the average of three trials for both legs, a subject's mean value was recorded to the nearest degree. Gluteus maximus range of motion was measured using the same procedures as above. The subject's leg was passively moved into hip flexion with the knee bent. All reference points were labeled with markers.

Quadricep range of motion was measured using a passive knee flexion test. The knee flexion test has been shown to be reliable (r = 0.98) in healthy adult populations (61). Subjects were asked to remain supine on the training table with both legs in extension following the straight leg raise. The same trained tester aligned the axis of the goniometer over the lateral epicondyle of the femur. The proximal arm of the goniometer was aligned with the lateral midline of the femur, using the greater trochanter as a reference point. The distal arm was aligned with the lateral midline of the fibula using the lateral malleolus and fibular head as a reference point. The tester held the subject's ankle in one hand and the upper thigh in the other hand to stabilize the thigh. The subject's thigh was moved to approximately 90 degrees of hip flexion while moving the knee into flexion. The end range of motion occurred when resistance was felt by the tester. The tester read the goniometer in degrees of motion. Using the average of three trials for both legs, the subject's mean value was recorded to the nearest degree.

3.3.1.5 Orientation Practice Session

Prior to randomization, all subjects underwent an orientation session to practice stretches used in each of the treatment groups. Timing of stretches and rest periods was monitored by the investigator. To prepare subjects for the treatment program, the practice stretch protocol consisted of 12 stretches, each performed for 20 seconds on each leg with a 10 second rest to change legs. Each subject performed stretches independently, and were instructed not to stretch to a range of motion that produces pain. Stretches addressed the major muscle groups required for vertical jumping such as the pectoralis major, deltoids, latissimus dorsi, hamstrings, quadriceps, gluteus maximus, hip flexors, and calves.

Throughout the practice stretch protocol, all subjects were led through each of the two stretch treatment programs to prevent treatment bias. Each individual stretching protocol took approximately 12 minutes and progressed from sitting to standing for appropriate neural recruitment prior to jumping. For the static stretching protocols, subjects stretched the target muscle of the right leg and hold it for 20 seconds. After a 10 second rest period the same stretch was repeated for the left leg. For dynamic stretching protocols, subjects contracted the antagonist of the target muscle. Flexion and extension of the joint occurred every two seconds for 20 seconds (approximately 10 repetitions) and allowed the target muscle to be placed on a stretch. The procedure was performed on the right leg first followed by the left leg with a rest period of 10 seconds. The purpose of a 10 second rest period was to change the subject's posture and search for limited position.

The order and description of static and dynamic stretching protocols was as followed:

1. Supine hip flexion with bent leg- *Static*- Subject will lie supine with legs extended. They will bend the knee and grab underneath the left thigh while bringing the knee into the chest to stretch the gluteus maximus (Figure 10). *Dynamic*- Subject will lie supine with legs extended. They will repeatedly bend the knee into the chest and return to full extension without pausing to stretch the gluteus maximus.
2. Supine hip flexion with straight leg- *Static*- Subject will lie supine with legs extended. They will grab underneath the left thigh and bring the straight leg into the chest to stretch the hamstrings (Figure 11). *Dynamic*- Subject will lie supine with legs extended. They will repeatedly swing the straight leg into the chest and back to the floor without pausing to stretch the hamstrings. Head and neck will remain on the floor during either stretch.

3. Knee flexion- *Static*- Subject will lie on their side with both legs extended. They will grab their left shin with their left hand and bring their heel to their buttocks to stretch their quadriceps (Figure 12). *Dynamic*- Subject will lie on the chest with arms at side and both legs extended. They will repeatedly bend their knee to touch the heel to their buttocks and back to the floor without pausing to stretch the quadriceps. Head and neck will remain on the floor during either stretch.
4. Lunge with knee on floor- *Static*- Subject will start with right knee forward and bent with the left knee back and bent on the floor to stretch the hip flexors. They will slowly push their left hip forward with their hands resting on their right thigh (Figure 13). *Dynamic*- Supine hip extension- Subject will lie on the chest with both legs extended. They will repeatedly raise one leg off the floor and back without pausing to stretch the hip flexors.
5. Supine dorsiflexion with cord- *Static*- Subject will sit on floor with left leg extended and right leg bent perpendicularly to the left knee. Subject will lean forward and place the cord around the left toes and pull the toes toward their body to stretch the calves (Figure 14). *Dynamic*- Subject will sit on floor with left leg extended and right leg bent perpendicularly to the left knee. Subject will repeatedly dorsiflex ankle toward their body without pausing and no external resistance to stretch the calves.
6. Standing hip flexion with bent knee- *Static*- Subject will stand and grab below left knee and raise their bent left leg to their chest to stretch the gluteus maximus (Figure 15). *Dynamic*- Subject will stand while repeatedly raising their bent knee into chest and back to the floor without pausing to stretch the gluteus maximus.

7. Standing hip flexion with straight leg- *Static*- Subject will stand and raise their straight leg towards their chest and place it on a platform no higher than hip level to stretch the hamstrings (Figure 16). *Dynamic*- Subject will stand and repeatedly raise their straight leg toward chest and back to the floor without pausing to stretch the hamstrings. Lower back will remain in neutral position throughout both stretches.
8. Standing knee flexion- *Static*- Subject will stand (holding on to a chair), then grab shin and bring their heel to their buttocks to stretch the quadriceps (Figure 17). *Dynamic*- Subject will stand while repeatedly bending their knee so heel will touch their buttocks and back without pausing to stretch the quadriceps. Lower back will remain in neutral position throughout both stretches.
9. Standing Lunge- *Static*- Subject will start with left leg forward and right leg in back with left knee off the floor slowly push left hip forward with hands resting on their right thigh to stretch the hip flexors (Figure 18). *Dynamic*- Standing Hip Extension- subject will stand while repeatedly extending hip (knee locked) and back to the start position without pausing to stretch the hip flexors.
10. Standing dorsiflexion- *Static*- Subject will stand arms length away from the wall with left leg forward (bent) and right leg back (straight). They will push the arms straight against the wall while pushing the left hip forward and pressing the left heel to the ground to stretch the calves (Figure 19). *Dynamic*- Subject will stand facing the wall with arms extended on wall while repeatedly raising heels off the ground and back without pausing to stretch the calves.
11. Standing shoulder flexion- *Static*- Subject will stand while raising their arms above their head and interlocking their fingers to stretch the latissimus dorsi (Figure 20). *Dynamic*-

Subject will stand while repeatedly raising arms above their head (elbow locked) and back to start position without pausing to stretch the latissimus dorsi.

12. Standing shoulder extension- *Static*- Subject will stand while extending their arms behind them to interlock the fingers and raise arms to chest level to stretch the chest (Figure 21). *Dynamic*- Subject will stand while repeatedly extending arms behind them without pausing to stretch the chest.

For a visual description of the static stretches see Appendix A.

3.3.2 Day 2

Subjects reported to the Baierl Recreation Center Multi-Purpose Room at the University of Pittsburgh Petersen Events Center within 10 days of the orientation practice session for the treatment program and post treatment assessments. Subjects reported at the same time of day within three hours before or after their previous orientation session. All treatment groups (control, static, and dynamic) began with a five minute warm-up on a upright cycle at a speed of 70 revolutions per minute and a resistance that raised the heart rate to 110 $\pm$ 5 beats per minute in order to raise muscle temperature prior to their treatment program (Cybex, Medway, MA). Following the warm-up period, subjects immediately began their stretching treatment that lasted approximately 12 minutes. The control group remained seated for the 12 minutes.

For the static stretching protocols, subjects stretched the specified muscle of the right leg and held it for 20 seconds. After a 10 second rest period the same stretch was repeated for the left leg. For dynamic stretching protocols, subjects contracted the antagonist of the target muscle. Flexion and extension of the joint occurred every two seconds for 20 seconds (approximately 10 repetitions) to allow the target muscle to be placed on a stretch. The procedure was performed on the right leg first followed by the left leg with a rest period of 10 seconds.

Following the treatment program, subjects immediately underwent the sit and reach test and goniometric measures using the previously described protocol. Vertical jump was measured within the five minutes following the sit and reach test and goniometric measurements. Two trained research assistants in addition to the principal investigator assisted in implementing both the stretching treatment and post treatment assessments. A training session was conducted a month prior to the study to instruct research assistants how to implement all treatments and assessments.

3.4 Statistical Analysis

Data analysis was performed using the SPSS 15.0 for Windows statistical software. A sample size of forty-two subjects (fourteen per group) was used with a statistical power of .80 to detect a 10% change in peak power and range of motion. Descriptive data for subject characteristics and experimental variables was calculated as mean $\pm$ SD. One-way ANOVA was conducted to detect group differences in strength levels conducted during pre-assessments. A 3x2 factorial ANOVA was conducted to determine between and within group differences in stretch groups. If significance differences occurred in strength measures analysis of covariance was conducted with strength as the covariate. A bonferroni post-hoc test was performed for significance on the treatment factor. Statistical significance was set at $\alpha = 0.05$.

4.0 RESULTS

The purpose of this investigation was to determine the effect of dynamic and static stretching on muscular peak power production, peak jump height, and range of motion in a sample of college age recreational males. It was hypothesized that: 1) dynamic stretching prior to a vertical jump would produce increased power and jump height compared to static or no stretch condition, 2) dynamic and static stretching would increase range of motion compared to a no stretch condition; and 3) dynamic stretching would increase jump height compared to a static and no stretch condition.

Forty-two subjects participated in the investigation. Following the recruitment and screening process, subjects were randomly assigned to one of three groups: control (C), static (S), and dynamic (D). An attrition rate of 4% was observed with 2 subjects dropping out due to an inability to complete post-testing. Six subjects were excluded from data analysis (1 Control, 2 Static, and 3 Dynamic) due to failure to meet the requirements of the study protocol. Anthropometric and 1RM leg press strength tests were conducted prior to pre-testing. Pre and post test assessments for vertical jump, goniometric measures, and sit and reach were conducted on Day 1 and Day 2, respectively. There were no statistically significant differences between treatment groups for any pre-test dependent variables measured.

4.1 Descriptive Statistics

Subject characteristics are presented in Table 1 and 2. There were no significant differences between treatment groups with the exception of body fat. The dynamic group had a significantly lower body fat compared to the static or control groups. Since a non-significant correlation was determined between percent body fat and jump height (r = - 0.300), percent body fat was not used as a covariate in the main analysis.

Table 1. Descriptive Statistics on Age, Weight, and Height.

Treatment	N	Age (y)	Weight (kg)	Height (cm)
Control (C)	15	21.13 ± 1.77	83.30 ± 11.82	179.11 ± 6.86
Static Stretch (S)	14	21.29 ± 1.59	81.57 ± 13.73	176.98 ± 7.89
Dynamic Stretch (D)	13	20.23 ± 1.83	73.90 ± 8.14	176.62 ± 9.38

Data are mean ± SD.

Table 2. Descriptive Statistics on Percent Body Fat and Fat Free Mass

Treatment	N	Body Fat (%)	Fat Free Mass (kg)
Control (C)	15	12.43 $\pm$ 4.73	72.70 $\pm$ 8.97
Static Stretch (S)	14	13.49 $\pm$ 4.14	70.33 $\pm$ 10.73
Dynamic Stretch (D)	13	9.36 $\pm$ 4.07*	66.95 $\pm$ 7.70

Data are mean $\pm$ SD.

*$p < 0.05$

4.2 1RM Leg Press Strength

A 1RM leg press strength test was conducted to determine group differences in relative and absolute muscular strength. Results indicated no significant differences between groups for relative or absolute 1RM leg press strength (Table 3) (Figures 1 & 2).

Table 3. Pre-Assessment Leg Press.

Treatment	N	AS (kg)	RS (kg)
Control (C)	15	263.94 ± 59.25	3.28 ± 0.82
Static Stretch (S)	14	289.77 ± 97.01	3.53 ± 1.08
Dynamic Stretch (D)	13	249.99 ± 67.78	3.39 ± 0.88

Data are mean ± SD.

RS = Relative Strength calculated as weight lifted/bodyweight.

AS = Absolute Strength calculated as total weight lifted in kg.

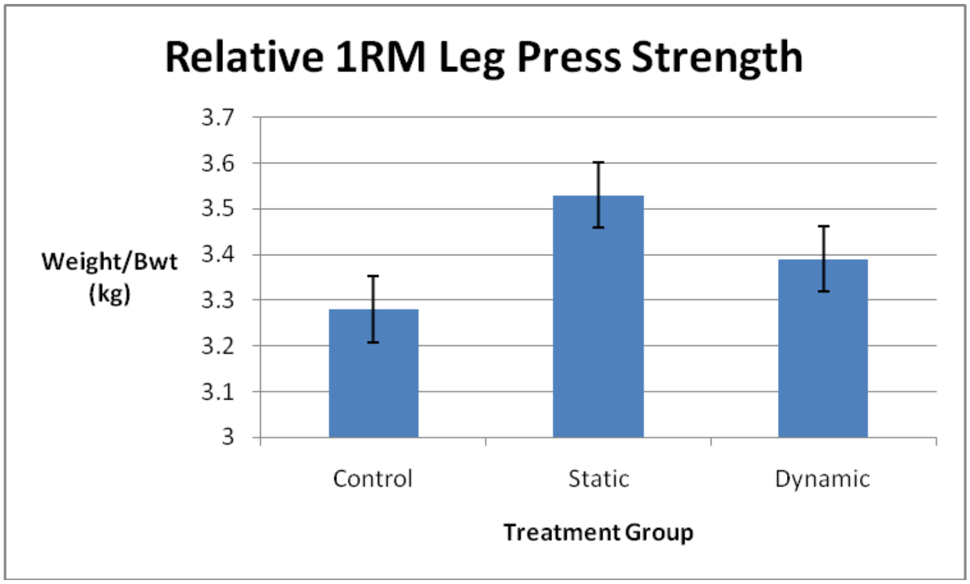

Figure 1 Difference between groups for relative 1RM leg press strength.

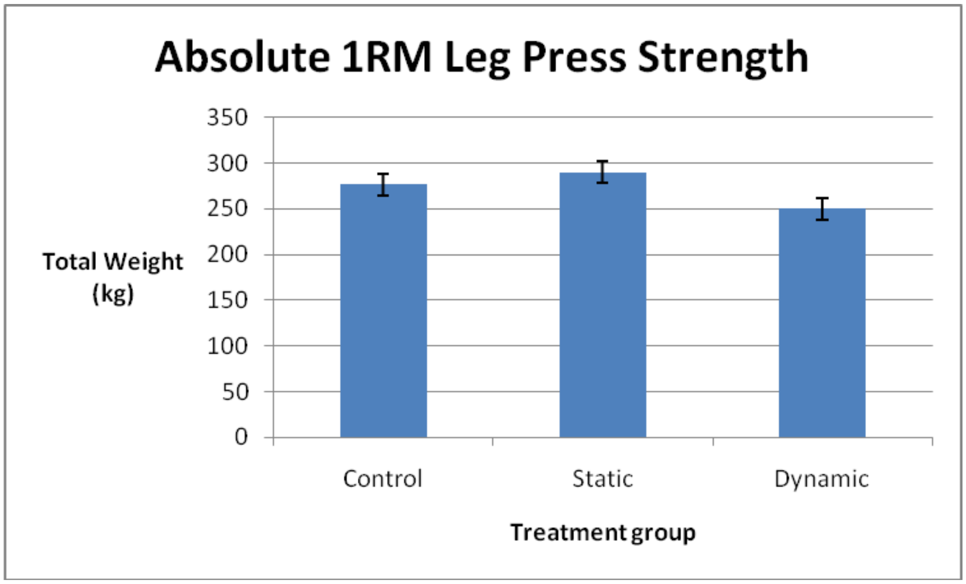

Figure 2. Difference between groups for absolute 1RM leg press strength.

4.3 Dependent Measures

Data were analyzed using a 3 (group) x 2 (time) ANOVA, with group as a between-subjects factor and time (pre vs. post) as a within-subjects factor. Pre and post test means (based on the average of three trials) on the dependent variables are presented in Table 4. A significant main effect for time was observed for all dependent measures, but a significant time x treatment interaction was found only for the sit and reach measure. Although the interaction was not significant for any of the measures except for sit and reach, differences between pre and post means were greater in the two treatment groups than in the control group for every dependent measure. To follow the significant interaction, post hoc tests were conducted for sit and reach. The Bonferroni correction was applied to determine significance between each group. Changes were significant for SS and DS group (*$p < .017$), but not for the control group.

Table 4. Means ± SD for dependent variables.

Variable	Test	C	SS	DS
Jump height	Pre	61.68 ± 7.91	59.57 ± 7.41	63.39 ± 8.58
(cm)	Post	61.57 ± 8.10	60.63 ± 7.07	64.66 ± 9.85
Peak Power	Pre	5462.65 ± 776.45	5256.22 ± 792.93	5185.95 ± 731.68
(watts)	Post	5455.92 ± 772.87	5320.46 ± 768.10	5263.14 ± 801.45
ROM Hip	Pre	66.67 ± 8.62	66.24 ± 8.08	66.16 ± 9.58
(˚)	Post	68.00 ± 6.43	69.39 ± 5.47	70.14 ± 9.10
ROM Knee	Pre	131.99 ± 6.74	132.43 ± 5.09	135.05 ± 6.46
(˚)	Post	133.09 ± 4.95	134.66 ± 5.88*	135.31 ± 5.39
Sit and Reach †	Pre	24.61 ± 10.51	23.96 ± 9.02	23.64 ± 11.11
(cm)	Post	24.73 ± 10.68	26.28 ± 8.69*	25.62 ± 11.33*

Data are mean ± SD.

* Significant change from pre to post; $p < 0.017$.

† Significant time x treatment interaction; $p < 0.05$.

C = Control, SS = Static Stretch, DS = Dynamic Stretch

4.3.1 Observed Trends for Mean Vertical Jump Height and Peak Power

Results showed a significant time effect (*$p < 0.05$) for mean jump height, but the interaction was not significant. It should be noted that the static and dynamic groups increased their vertical jump by 1.06 cm (1.8%) and 1.27 cm (2%), respectively. The control group showed a decrease of 0.11 cm (-0.18%) in vertical jump (Figure 3). Therefore the pattern of results was in the expected direction for the dynamic stretch group. Furthermore the effect size for the interaction (eta squared = .105) would be described as medium (19).

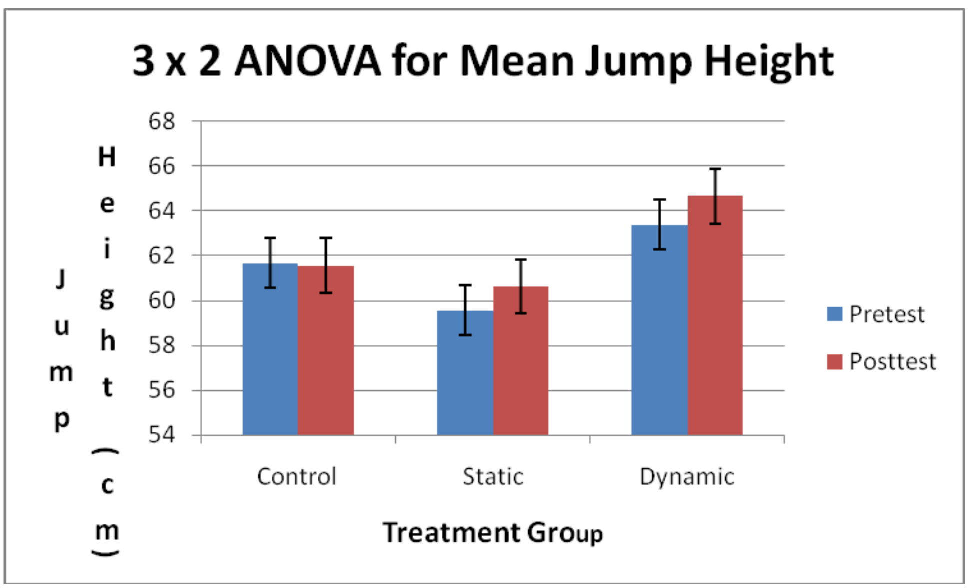

Figure 3. Change in mean vertical jump height pre and post test.

Results showed a significant time effect (*$p < 0.05$) for mean peak power, but the interaction was not significant. It should be noted that the static and dynamic groups increased their peak power by 64.24 watts (1.2%) and 77.19 watts (1.5%) respectively. The control group showed a decrease of 6.73 watts (-0.12%) in peak power (Figure 4). Therefore the pattern of results was in the expected direction for the dynamic stretch group. Furthermore the effect size for the interaction (eta squared = .105) would be described as medium (19).

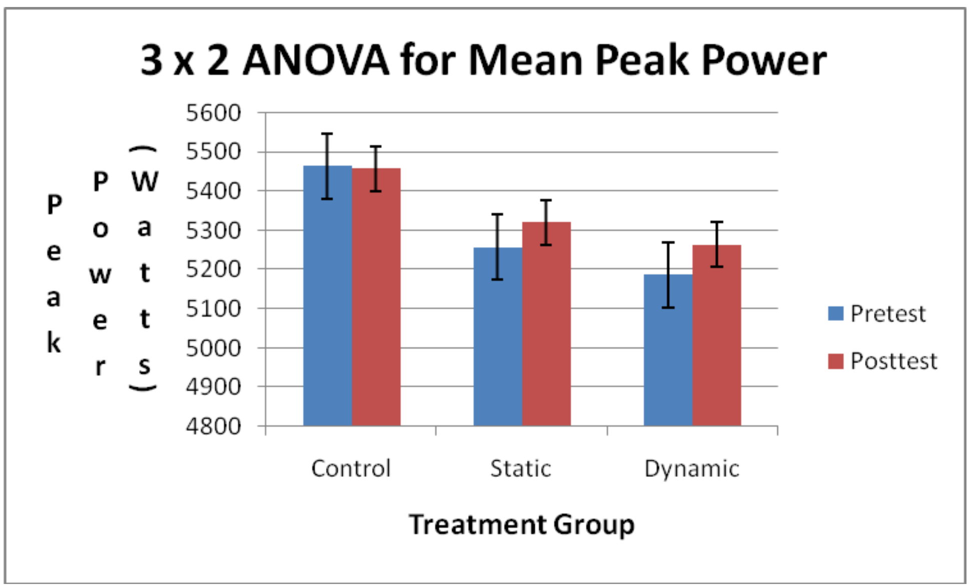

Figure 4. Change in mean peak power pre and post test

4.3.2 Observed Trends for Maximum Vertical Jump Height and Peak Power

Previous studies have reported jump height as a maximum score of three trials in order to reflect the subject's maximum effort for that particular trial (63, 73). Pre and post test maximums (based on the maximum of three trials) on jump height and peak power are presented in Table 5. A significant time x treatment interaction was observed for maximum jump height and maximum peak power. To follow up on this interaction, post hoc tests were conducted to determine significance between each group. On both dependent measures changes were significant for DS group only (*p < .017), but not for the static and control group.

Table 5. Maximum for jump height and peak power ± SD

Variable	Test	C	SS	DS
Jump height†	Pre	63.08 ± 7.58	62.05 ± 7.15	64.24 ± 8.96
(cm)	Post	63.16 ± 8.19	63.41 ± 6.80	66.57 ± 9.93*
Peak Power †	Pre	5547.04 ± 760.79	5332.92 ± 770.24	5237.72 ± 748.08
(watts)	Post	5552.38 ± 791.30	5423.28 ± 780.08	5379.25 ± 778.12*

Data are mean ± SD.

* Significant change from pre to post; p < 0.017.

† Significant time x treatment interaction; p < 0.05.

Results showed a significant time effect and time x treatment interaction (*$p < .05$) for maximum jump height. A post hoc analysis using the Bonferroni correction revealed there was a significant increase in the DS group ($p < 0.017$) compared to static and control.   The control, static, and dynamic groups increased their maximum jump height by 0.08 cm (0.13%), 1.36 cm (2.2%), and 2.33 cm (3.5%), respectively (Figure 5).

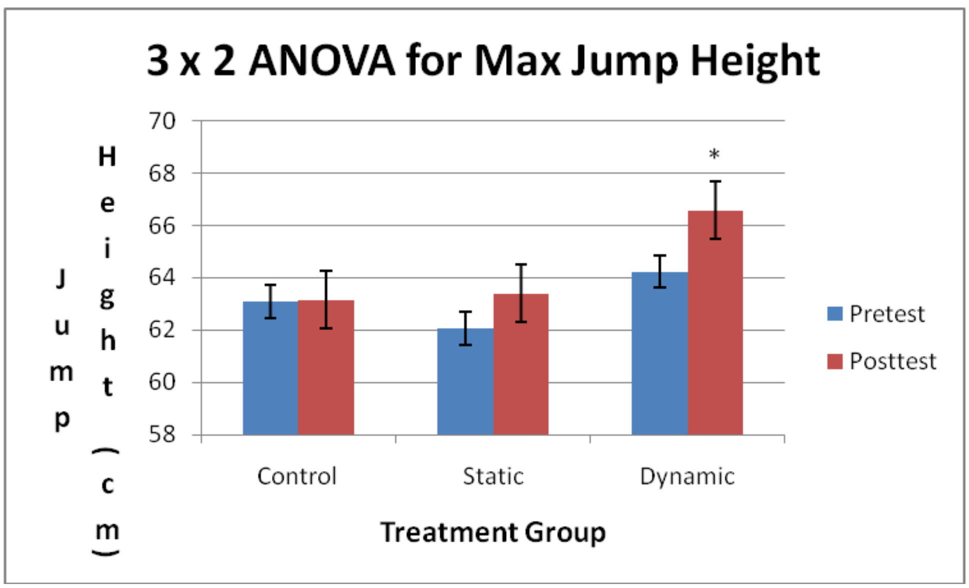

Figure 5. Change in maximum jump height pre and post test

*significant change from pre to post

Results showed a significant time effect and time x treatment interaction (*p < .05) for maximum peak power. A post hoc analysis using the Bonferroni correction revealed there was a significant increase in the DS group (p < 0.017) compared to static and control. The control, static, and dynamic groups increased their maximum peak power by 5.34 watts (0.01%), 90.36 watts (1.7%), and 141.54 watts (2.6%), respectively (Figure 6).

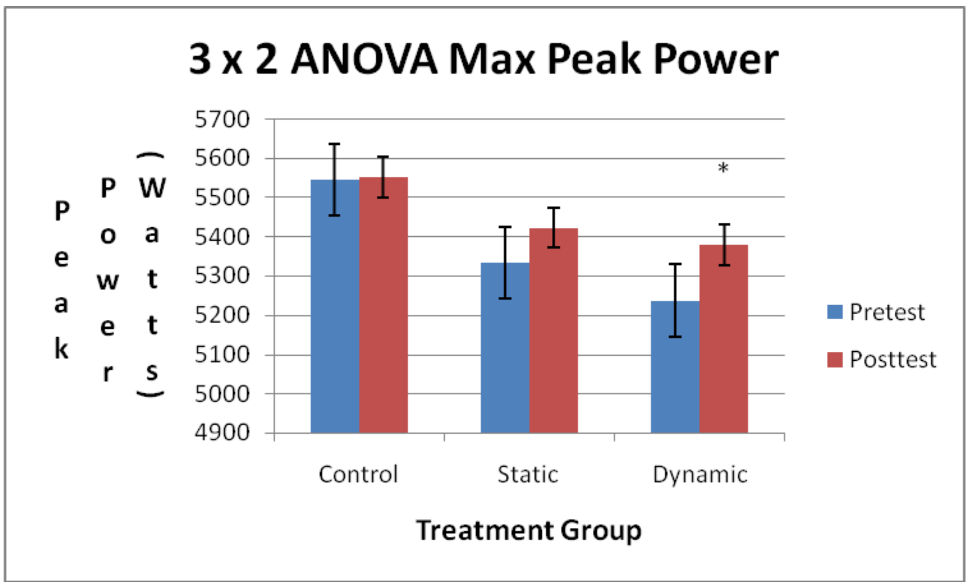

Figure 6. Change in maximum peak power pre and post

* Significant change from pre to post

4.3.3 Observed Trends in Goniometric Measurements

Results showed a significant time effect (*$p < 0.05$) for hip range of motion, but the interaction was not significant. It should be noted the control, static, and dynamic groups increased their hip range of motion by 1.33˚ (1.9%), 3.15˚ (4.7%), and 3.98˚ (6%) (Figure 7). Therefore the pattern of results was in the expected direction. Furthermore the effect size for the interaction (eta squared = .031) would be described as small (19).

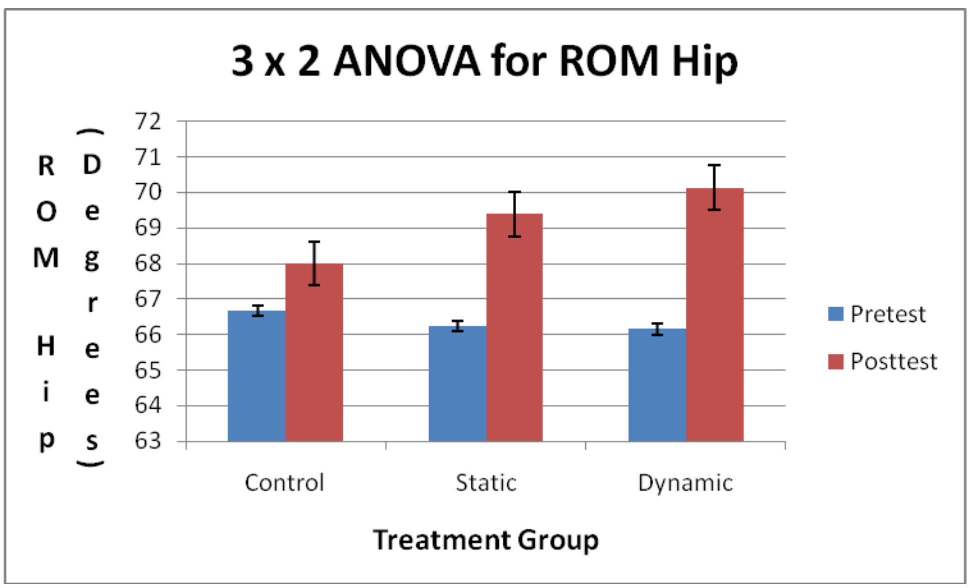

Figure 7. Change in Hip ROM pre to post.

Results showed a significant time effect (*p < 0.05) for knee range of motion, but the interaction was not significant. Although the interaction was not significant, as seen in Figure 8, the change appeared to be much greater in the static group than in the other two groups. Therefore, post hoc analysis (with the bonferroni correction) was carried out to examine change within each group. Results showed a significant change for the static group ($p = 0.010$), but no significant changes for knee range of motion within the dynamic and control groups ($p > 0.017$). The control, static, and dynamic groups increased their knee range of motion by 1.10˚ (0.08%), 2.23˚ (1.7%), and 0.26˚ (0.02%) (Figure 8).

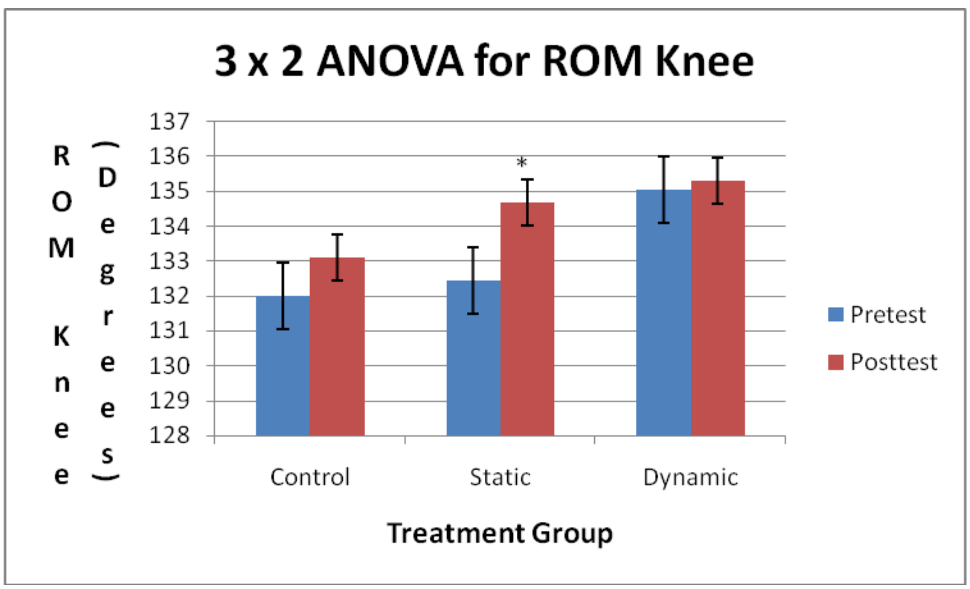

Figure 8. Change in Knee ROM pre to post.

*Significant change from pre to post ($p < 0.017$)

4.3.4 Observed Trends for Sit and Reach

Results showed a significant time and time x treatment interaction (*$p < 0.05$) for sit and reach. Post hoc analysis using the Bonferroni correction revealed significant changes for the SS group ($p = 0.004$) and DS group ($p = 0.011$), but not for the control group ($p > 0.017$). The control, static, and dynamic groups increased their sit and reach by 0.12 cm (0.05%), 2.32 cm (9.7%), and 1.98 cm (8.4%), respectively (Figure 9).

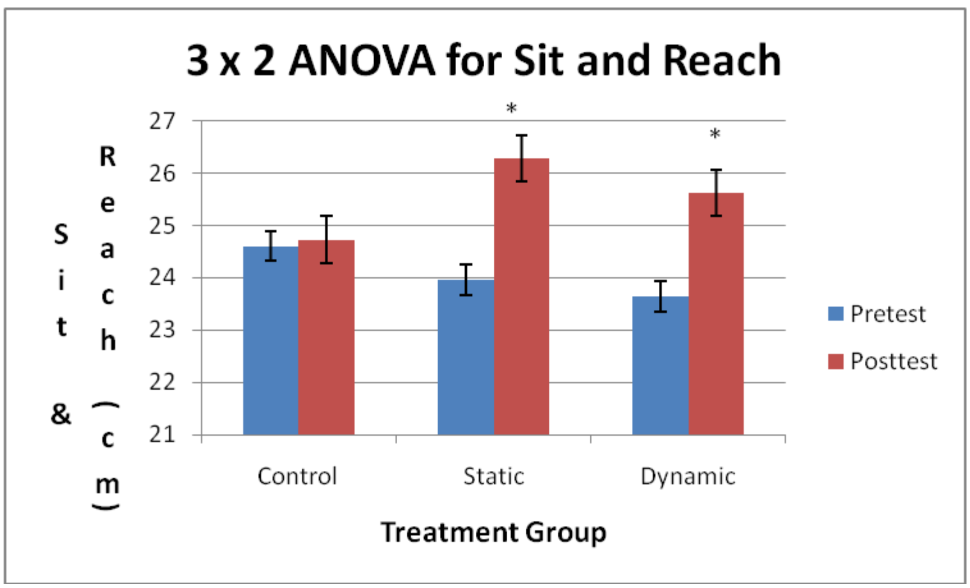

Figure 9. Change in sit and reach pre to post.

*significant change from pre to post

4.4 Intraclass Reliability

All calculations were taken using the control group. To examine the reliability of measurement, the type A ICC using an absolute agreement definition was used to measure consistency of pretest and posttest measures in the control group. The control group was chosen because no “real” pretest to posttest change would be expected. The jump height measurement between pre and posts test using the Vertec jumping apparatus had an average intraclass correlation coefficient (ICC) of R = 0.966. Goniometer measurements between pre and post test for the hip and knee had an average ICC of 0.691 and 0.781. The sit and reach measurement between pre and post test using the Novel Flex tester had an average ICC of R = 0.991.

4.5 Summary

Results of the investigation showed significant time effects for all dependent measures following a 12 minute stretching protocol. Significant time x treatment interactions was also found for maximum jump height, maximum peak power, and sit and reach. Significant changes in maximum jump height and peak power from pre to post were found in the DS group only. Significant changes in sit and reach from pre to post were found in both the SS and DS groups. However, there was no time x treatment interactions for mean jump height, mean peak power, knee range of motion, or hip range of motion.

5.0 DISCUSSION

The purpose of this study was to determine the effect of dynamic and static stretching on muscular peak power production, jump height, and range of motion in college age recreational athletes. To date, no study has examined the effects of an acute bout of dynamic or static stretching on range of motion and power performance in a male recreational college age population. Based on previous literature, dynamic stretching appears to have no power performance decrements when compared to static stretching, and may in fact contribute to power gains (30, 58, 73).

The main hypothesis was that dynamic stretching for 20 seconds would increase power and jump height compared to static stretching. Results revealed that mean peak power production, jump height, and range of motion improved following a static (SS) and dynamic (DS) stretching protocol. The DS protocol significantly improved maximum jump height and peak power, while the SS and DS protocol significantly improved sit and reach. Results for range of motion supported our secondary hypothesis that dynamic and static stretching would increase range of motion compared to control. However, results for average peak power and jump height did not support the hypothesis that dynamic stretching would increase power and jump height. Yet, maximum jump height and peak power did significantly improve from dynamic stretching compared to static stretching.

5.1 Stretching and Maximal Muscular Power

Evidence has shown that muscular peak power performance following static stretching declines compared to no stretching or dynamic stretching routines when major lower body muscle groups were statically stretched for 1-3 sets of 30 seconds with total stretching lasting between five and 10 minutes (14,30,58). Brill, et al. (14) reported that static stretching of the hamstrings, quadriceps, and calves for 4 ½ minutes (3 sets of 30 seconds) reduced vertical jump performance in male soccer players compared to a no stretch condition. Yamaguchi et al. (73) reported that static stretching of the hip and knee flexors and extensors for 5 minutes (5 exercises of 1 x 30 seconds) demonstrated lower leg extension power compared to dynamic stretching, but were not different than non-stretching. McMillian et al. (14) reported that static stretching of the major muscle groups for eight minutes (8 exercises of 1 x 20-30 seconds) demonstrated lower five step jump performance compared to a dynamic stretch warm-up, yet demonstrated a higher five step jump performance when compared to a no stretch condition.

It has been suggested that the neuromuscular factors responsible for a decline in power performance are as a result of decreased muscle activation or altered reflex sensitivity (67). Impaired muscle activation following static stretching (30-45 second stretches for a total of 20 minutes) contributes to decrease in force production using an EMG and interpolated twitch technique (10, 34). Stretch induced force deficits have also been attributed to a muscle-tendon unit length increase and decrease in muscle stiffness (67). Wilson et al (71). found that a muscle tendon unit with greater stiffness is able to transmit force more effectively than a more compliant muscle tendon unit. A more compliant muscle tendon unit could result in a loss of force production due to altered intramuscular length and velocity conditions.

In contrast to previous results, the present study revealed that static stretching of the major muscle groups for 12 minutes (1 set of 12 exercises lasting 20 seconds per exercise) demonstrated an improved vertical jump performance compared to a control. The discrepancy between the results of previous studies and those of the present study may be attributed to several factors including instrumentation and protocol selection.

Several studies directly measured force using a force plate. The present study predicted power from the vertical jump using a prediction equation by Sayers (66) et al. Although the prediction equation developed by Sayers et al. was validated using a heterogeneous sample population of athletes and non-athletes, a force plate may provide a more valid measure of force than a prediction equation developed for vertical jump. A force plate is considered a reliable measure (r = 0.994) and can measure force, velocity, acceleration, impulse, momentum, instantaneous (at take-off) and peak power, and instantaneous (at take-off) and peak velocity (44, 66).

A second factor may be due to the time and intensity of the stretching protocol. The current study used a single set of 20 seconds, where the subject controlled the intensity of stretch. Previous studies used multiple sets of 20 seconds or greater, in which an examiner controlled the intensity of stretch (46, 52). It has been shown that time under stretch may determine peak torque (defined as the highest force that will rotate an object about an axis) reductions following static stretching (67). Siatras et al. recently determined that a static stretch of the quadriceps muscle for 30 and 60 seconds reduced peak torque compared to a no stretch condition, whereas a static stretch of 10 and 20 seconds did not reduce peak torque compared to a no stretch condition. Such stretch induced deficits have been attributed to an increase in the muscle tendon unit length and a decrease in muscle stiffness (67). Therefore changes to a muscle's stiffness relate to a viscoelastic response to a stretch, and may be considered time dependent (35). While static stretching appears to decrease stiffness, it also appears to contribute to a decreased ability to produce force.

The present study used a 20 second static stretch which may have affected the peak torque. Previous studies have reported that a stiff muscle tendon unit is related to an improved concentric isokinetic torque production because contractile elements of muscle are in a more favorable length-tension relationship (29). Wilson et al (71). found that a muscle tendon unit with greater stiffness is able to transmit force more effectively than a more compliant muscle tendon unit. Since a more compliant muscle tendon unit could result in a loss of force production due to altered intramuscular length and velocity conditions, the short duration of force applied with the current static stretching protocol may not have been of sufficient duration to alter the intramuscular length and velocity conditions and contribute to decreases in force production.

In the present study, dynamic stretch slightly improved post tests of vertical jump height and peak power. Furthermore, statistically significant improvements in maximal value jump height and peak power were observed. In previous studies, muscular peak power performance following dynamic stretching increases compared to no stretching or static stretching routines when major lower body muscle groups were dynamically stretched for 1-3 sets of 30 seconds with total stretching lasting between five and 10 minutes (30,58, 73). Yamaguchi et al. (73) reported that dynamic stretching of the hip and knee flexors and extensors for five minutes (5 exercises of 1 x 30 seconds) demonstrated higher leg extension power compared to static stretching and non-stretching. McMillian et al. (58) reported that dynamic stretching of the major muscle groups for eight minutes (8 exercises of 1 x 20-30 seconds) demonstrated higher 5 step jump performance compared to a static stretch and no stretch condition.

The mechanisms associated with improvements in jump height and peak power were supported by the present study. When a muscle is repeatedly stretched, a muscle spindle records the change in length, thus activating the stretch reflex and causing a change of muscle length through a muscle contraction. As a direct result of an increase in muscle spindle activity, a fast, dynamic stretch will increase a stretch reflex response, increase muscle tone, and cause an agonist muscle to contract with greater force (38). Progression of stretch from short range movements to full range movements allows for greater recruitment and faster contraction of muscle fibers at the time of the event (48). In addition, the time under stretch (12 minutes) may have influenced the viscoelastic properties of the muscle-tendon unit more effectively for the dynamic stretching. Active dynamic stretching involves full lengthening and shortening of a muscle similar to activities such as jogging or cycling. Jogging and cycling for as little as five minutes elevates muscle temperature to significant levels to allow an increase sliding of actin and myosin filaments, greater cross bridge formation during contraction, and greater oxygen available to a muscle (6; 11).

Dynamic stretching within a warm-up is believed to maintain and elevate muscle temperatures through the progression of non-specific stretching to specific stretching and stimulates actual movements of the sport (33; 41; 54). In addition, an increase in muscle temperature has been shown to improve dynamic short duration performance (11, 12, 28). Several studies have shown that an elevated muscle temperature (37-39 degrees Celsius) shown following dynamic movement at greater than 45% of VO_2 peak can improve vertical jump height compared to a no warm-up (lower muscle temperatures) condition (7; 11). Evans (28), et al.

found that a five minute static movement using static stretching produced a lower muscle temperature compared to a five minute jog at 4 mph.

5.2 Range of Motion and Maximal Muscular Power

In the present study, static stretching for only 20 seconds did not appear to produce decrements in power. The static and dynamic groups showed a 9.7% and 8.4% significant improvement in sit and reach as result of the 12 exercise protocols ($p < 0.05$). Knee and hip goniometric measures showed even less response for both static and dynamic groups. Hip range of motion improved 4.7% and 6%, while knee range of motion improvement was 1.7% and 0.02% for static and dynamic groups. The improvements in range of motion for both the static and dynamic groups were considerably less than seen in previous studies (46, 63). The difference in the range of motion between the studies may be due to several factors such as time, intensity, and dose of the stretching protocol.

Siatras et al (67) showed that knee joint flexibility was significantly increased for only the static stretching of 30 and 60 seconds with associated knee extension force decrements. In contrast, static stretching of 10 and 20 seconds did not increase knee joint flexibility, and showed no force decrements associated with knee extension. The current study showed less than a 10% increase in sit and reach range of motion, and much less of an increase in goniometer hip and knee range of motion, which suggest time under stretch (only 20 seconds) may influence decreases in power production, and produce less improvements in range of motion.

It is important to note that subjects in the Siatras study were taken to their personal maximal range of motion at the point of pain (POP) where they reported to an examiner having reached a point of pain. The current static stretching protocol was 20 seconds per exercise, in which the subject stretched until discomfort. Discomfort was explained to subjects as "when you feel tension in the muscle, but not pain". The dynamic stretching protocol also lasted for 20 seconds, where each subject's speed was 2 seconds per stretch. For each stretch protocol, a subject controlled the intensity of stretch to reach maximal range of motion with no measure obtained for intensity or pain. Similar to time of stretch in the present study, the intensity of stretch may have affected flexibility outcomes and its consequent force production as well.

The above studies mentioned incorporated single or multiple sets of static stretching to the point of pain that showed greater than 10% increase in range of motion along with power decrements (46, 63, 67). The dose of stretching may influence range of motion and force decrements, but it appears from previous studies that dose of stretch is closely related to time and intensity of stretch. This suggests there may be a specific range of motion dependent on time, intensity, and dose of stretch where force decrements or improvements might occur.

The compliance of the muscle-tendon unit during power performance is influenced by raising or lowering of muscle temperature prior to power performance, which in turn is influenced by the method of warm-up and stretching (7, 11, 28). Several studies have shown that an elevated muscle temperature (37-39 degrees Celsius) shown following active warm-up at greater than 45% of VO_2 peak can improve vertical jump height compared to a no warm-up (lower muscle temperatures) condition (7; 11). Evans (28), et al. found that a five minute warm-up using static stretching only produced a lower muscle temperature compared to a five minute jog at 4 mph. In the current study, both stretching groups and control performed a five minute cycle warm-up prior to the stretching protocol, which may have influenced the jumping ability of the groups. To date, no study has compared muscle temperature during static and dynamic stretching protocols.

5.3 Limitations

Protocol Design

Studies using stretch protocols of 20 seconds have suggested that intensity and duration of a stretch results in a lack of significant force decrements for force production (18, 67). In the present study, it is possible that the static stretching routine was not intense or long enough to sufficiently alter the length tension relationship in order to impair muscle activation and reflex sensitivity, and decrease force production.

The dynamic stretching routine was of equal or greater duration than previous studies that showed significance (30,58, 73). Yamaguchi (73) et al incorporated a stretch duration less than the current study at a speed of 2 seconds per stretch, in which power was improved significantly over a static stretching protocol (73). It is possible that the speed of stretch (2 seconds per stretch) was not adhered to by the subjects and not reinforced consistently by the examiners.

Subject Effort

The subject's maximal range of motion caused slight discomfort but not pain. Instructions provided stated to "stretch until you feel discomfort in the target muscle, but not pain". Previous research has instructed subjects to go to levels of both discomfort and pain, where the intensity of stretch was controlled by the examiner (30,58, 73). In the present study, hip and knee range of motion goniometric and sit and reach measurements for the static stretching group reflect very small changes of 4.7%, 1.7%, and 9.7% respectively. In previous studies that have shown force decrements, the range of motion increases were between 10-16% (42, 57). These small changes in range of motion indicate that subjects may not have stretched to discomfort given a lack of training or experience with stretching.

Including a measure of pain such as the Cook Pain scale could identify an upper limit of static and dynamic stretch where subjects would feel pain. The Cook Pain scale has been found to be a valid and reliable measure of leg muscle pain during maximal cycling exercise using a sample of college age students (ICC = 0.88- 0.98) (20). The use of this scale before and after stretching exercise may help define individual variations in perception of pain during stretching exercise and provide an objective measure of pain. In addition, the use of the Adult OMNI Perceived Exertion Scale for Resistance Exercise (OMNI-RES) could prescribe stretching intensity for static and dynamic stretching routines. The OMNI-RES has demonstrated construct (r = 0.94- 0.97) and concurrent (r = 0.79- 0.91) validity using a sample of college age men and women. The use of this scale may help prescribe stretching intensities that are standard for every subject (50).

Subject Characteristics

Subjects in the dynamic group showed a lower body weight, fat free mass, and a significantly lower body fat % than the static and control groups. A previous study by Davis (24), et al. showed body fat % to be a strong predictor of vertical jump performance in a sample of male recreational athletes, which may have influenced jumping ability in the dynamic group.

Learning Effect/Skill of Subjects

Subjects post-tested a week after their pre-test may have experienced a learning effect. Due to the inexperience of the sample population, it is possible that the subjects learned to jump higher between pre and post test. Also, subjects may have improved purely based on the fact that they are expected to as part of a research protocol (Hawthorne Effect) (31, 57). Finally, all subjects were instructed to jump maximally during their test trials. Although an orientation session conducted focused on providing feedback on skill and technique of the stretching routine, no orientation session was conducted to practice the vertical jump or sit and reach tests.

Sample Size

Sample size may not have been sufficient to show significance between groups for jump height, peak power, hip range of motion, knee range of motion, and sit and reach (statistical power ranged from 0.227 to 0.759), respectively. The statistical power for time effect of jump height, peak power, hip range of motion, knee range of motion, and sit and reach was higher (statistical power ranged from 0.589 to 0.994).

Intratester Reliability

Intraclass correlation coefficient to examine reliability of measures for vertical jump was 0.966. However, different testers, inconsistency with test instruction, and calibration of the jumping device may have influenced jump height measures. It is possible that instruction and encouragement to subjects varied between testers. In addition, calibration measurement of the vertical jump device, which was zeroed at the six foot mark may have varied between testers.

Intraclass correlation coefficient of the goniometric measures may have been affected due to inexperience of the examiner, use of different assistants to passively stretch the testing leg, and inability of subjects to completely relax their muscles. Correlation coefficients showed intra-tester reliability of 0.781 and 0.691 for hip and knee, respectively.

Intraclass correlation coefficient for sit and reach was 0.991. It is possible sit and reach measures may have been influenced by different testers from pre to post, inconsistency with test instructions, or difficulty when measuring range of motion, particularly when subject was unable to reach the box.

Predicted Peak Power Equation

The predicted peak power equation used jump height as a variable within the calculation. Therefore, the peak power equation provided no additional information in comparison to jump height. The use of a force plate would have provided information such as force, velocity, and impulse that a predicted peak power equation cannot provide (51).

Protocol Implementation

Many of the subjects were considered novice level with regards to previous stretching experience. Although an orientation to stretching was provided, instructions to stretch to discomfort and at a particular cadence may not have been understood clearly. In addition, the stretching protocol was demonstrated by different testers who may have been inconsistent with the instructions related to intensity and body position. An additional practice session may have been warranted.

5.4 Recommendations for Future Research

We suggest that results of the present study are used to further examine the relationship between duration of stretching and its effect on muscular power and range of motion. A follow on study would examine the issue of stretch duration using both dynamic and passive methods, and would vary the duration of stretch while controlling for intensity of stretch.

Subject Effort and Stretching Protocol

Objective measures of intensity of stretch should be furthered explored. The investigator believes there may be a discrepancy in using the terms point of discomfort and pain especially when a subject self-selects stretch intensity and has limited skill with stretch techniques. The control of stretch intensity is a critical component to the proposed benefits of stretching. Several studies controlled stretch intensity through the use of a partner or stretching device (52, 67, 73). Other studies that allowed the subject to stretch independently used trained athletes who had experience with stretching techniques (14, 58). Additional orientation sessions could also instruct untrained subjects on proper stretching technique.

The terms point of discomfort and pain are subjective and vary by individual. Therefore, it is important to develop more objective measures for instructing subjects on stretch intensity to control for subject variability in skill and perception of discomfort or pain. The Cook Pain Scale and OMNI-RES Perceived Exertion Scale can provide an objective measure of stretch intensity, and provide a prescription to identify the upper limit for health or performance benefits. This can provide feedback to instructors or researchers on target intensities that should be maintained for a given stretching protocol. Once stretching intensity is clearly defined for each stretch protocol, a more informative decision regarding stretch duration can be recommended.

Posttest Strength Measures

Kokkonen et al (46) hypothesized that significant decreases in knee flexion and extension one repetition maximum forces following static stretching are a result of decreased

MTU stiffness, accompanied by significant increases in sit and reach range of motion (16%). Power et al. (63) found significant decreases in MVC force of the quadriceps following static stretching, also accompanied by significant increases in sit and reach range of motion (10%). Future studies that explore the effects of varied stretch protocols on changes in range of motion and strength should incorporate post test measures of strength that will examine the role of strength and its effects on stretching and power performance.

Instrumentation

A force plate can accurately measure direct force, and provide information related to the skill of the jumper, such as velocity and impulse (51). This can assist with exploring the influence of training status on force production, and providing trainers and educators with more performance variables that may be altered from stretching.

An EMG device can measure changes in muscle activity and reflex sensitivity during peak muscular power performance (34, 39, 52). The EMG device will reflect true neuromuscular changes related to stretching and its effect on peak muscular power and further explore force decrements related to muscle activation or reflex sensitivity.

An implantable thermocouple can be placed in the muscle to measure muscle temperature to provide additional information on intensity of stretch (28). Measurement of muscle temperature during stretching exercise will help determine appropriate warm-up and stretch intensity. In addition, it will help determine if changes in muscle temperature are responsible for the effects of stretching on flexibility and power.

5.5 Conclusions

The results of the present study concluded that static and dynamic stretching for 20 seconds prior to a vertical jump can slightly improve mean vertical jump height, mean peak power, and hip and knee range of motion in a sample of male college age recreational athletes. In addition, dynamic stretching for 20 seconds prior to vertical jump will significantly improve maximum value vertical jump height and maximum value peak power. From the present results it is difficult to advise the implementation of static stretching for 20 seconds prior to power performance without further examining the issue of duration and intensity of stretch.

Future research is needed to investigate the effect of intensity of stretch on force production, and how to accurately measure stretching intensity using both static and dynamic technique. In addition, it is important to investigate the relationship between stretch intensity and duration on force production to establish a dose-response relationship between stretching and its effect on force production. This research will provide physical educators, athletic trainers, physical therapists, exercise physiologists, and strength and conditioning specialists' valuable information in selecting appropriate stretching modalities within a warm-up to enhance performance. In addition, it will provide the recreational fitness participant with safe and beneficial stretching programs to improve range of motion, prevent injury, and improve quality of life.

APPENDIX A

Physical Activity Readiness Questionnaire (PAR-Q) and You

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly:

YES	NO		
☐	☐	1.	
☐	☐	2.	
☐	☐	3.	
☐	☐	4.	
☐	☐	5.	physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk

If you answered:

YES to one or more questions

Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

Delay becoming much more active:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name ___________________________________ Signature ___________________________________ Date _____________

Signature of Parent or Guardian (for participants under the age of majority)_______________________________________

Witness ____

APPENDIX B

Medical History Form & Exercise Questionnaire

ID_______ Age_______ Height_________ Weight_________

1. Have you ever been told by a doctor or other medical person that you have any of the following conditions?

   a. Heart Disease Y____ N____
   b. Angina Y____ N____
   c. Hypertension Y____ N____
   d. Heart Attack Y____ N____
   e. Stroke Y____ N____
   f. Diabetes (sugar) Y____ N____
   g. Cancer Y____ N____ if, yes explain:_________________
   h. Irregular Heart Problems Y____ N____ if, yes explain:_________________
   i. Other heart Problems Y____ N____ if, yes explain:_________________
   j. Fainting Spells Y____ N____
   k. High Cholesterol Y____ N____
   l. Thyroid Problems Y____ N____
   m. Kidney Problems Y____ N____
   n. Liver Problems Y____ N____
   o. Gout Y____ N____
   q. Drug/Alcohol Problems Y____ N____

2. Are you taking any prescription medications? Y ___ N ____
   If yes, List them here:____
3. Are you being treated by a doctor or any other medical person for any serious psychological disorder or having treatment, hospitalization, and emergency room within the previous 6 months? Y____ N____
4. Do you have any musculoskeletal injuries or disorders such as?
   a. Strains Y ____ N____
   b. Sprains Y ____ N____
   c. Tendonitis Y ____ N____
   d. Arthritis Y ____ N____
   e. Multiple Sclerosis Y ____ N____
   f. Lupus Y ____ N____
5. Have you ever had any surgeries, especially of the lower extremity? Y____ N_____
   If Yes, List them here:____
6. Do you perform weight training or aerobic training a minimum of 2 days per week and not greater than 4 days per week? Y____ N____
7. Are you currently engaging in plyometric and/or sprint training? Y_____ N____
8. Are you currently engaging in a stretching program that is performed $\geq$ 3 days/week for at least 2 minutes each session? Y____ N____
9. Are you currently taking any performance enhancement substances that include anabolic steroids, androstene, products containing ephedrine and phen-fen, and creatine? Y ___ N____

APPENDIX C

STATIC STRETCHES

Figure 10. Supine hip flexion with bent leg.

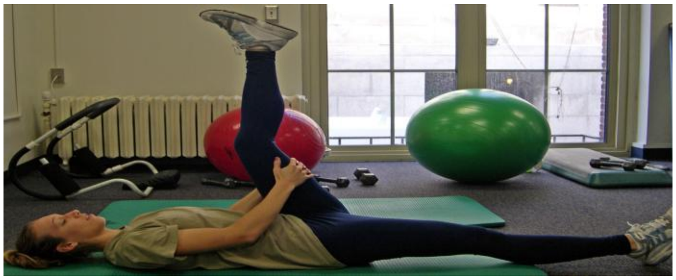

Figure 11. Supine hip flexion with straight leg.

Figure 12. Prone knee flexion.

Figure 13. Lunge with knee on floor.

Figure 14. Supine dorsiflexion with cord.

Figure 15. Standing hip flexion with bent knee.

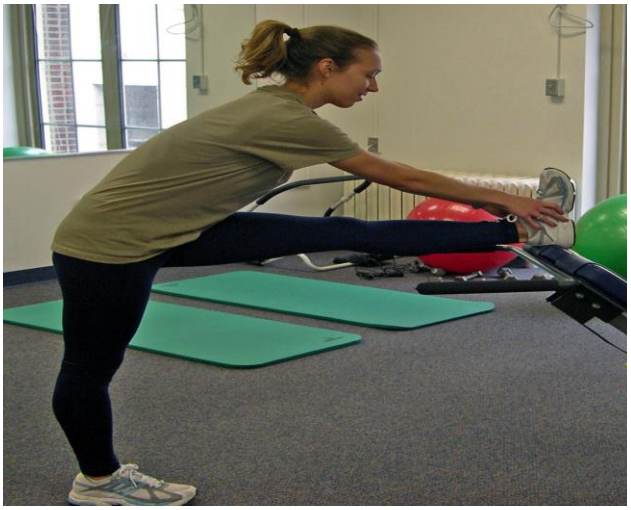

Figure 16. Standing hip flexion with straight leg.

Figure 17. Standing knee flexion.

Figure 18. Standing lunge.

Figure 19. Standing dorsiflexion.

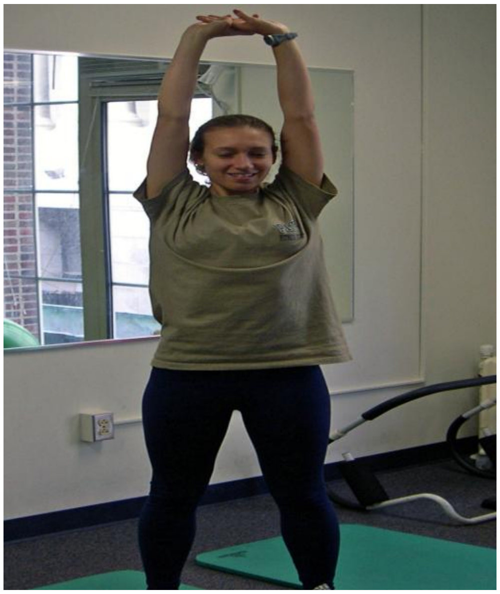

Figure 20. Standing shoulder flexion.

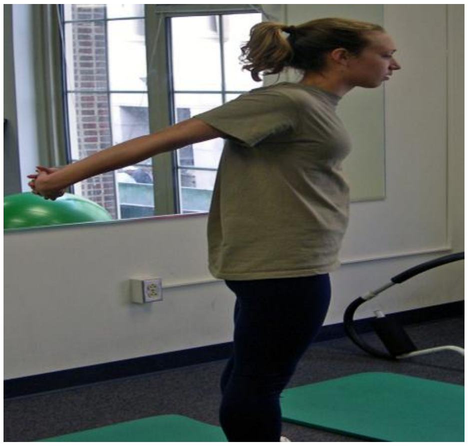

Figure 21. Standing shoulder extension.

APPENDIX D

ANOVA TABLE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	11.094	1	11.094	6.341	.016	.143	6.341	.689
	Greenhouse-Geisser	11.094	1.000	11.094	6.341	.016	.143	6.341	.689
	Huynh-Feldt	11.094	1.000	11.094	6.341	.016	.143	6.341	.689
	Lower-bound	11.094	1.000	11.094	6.341	.016	.143	6.341	.689
test * Treatment	Sphericity Assumed	7.782	2	3.891	2.224	.122	.105	4.448	.425
	Greenhouse-Geisser	7.782	2.000	3.891	2.224	.122	.105	4.448	.425
	Huynh-Feldt	7.782	2.000	3.891	2.224	.122	.105	4.448	.425
	Lower-bound	7.782	2.000	3.891	2.224	.122	.105	4.448	.425
Error(test)	Sphericity Assumed	66.486	38	1.750					
	Greenhouse-Geisser	66.486	38.000	1.750					
	Huynh-Feldt	66.486	38.000	1.750					
	Lower-bound	66.486	38.000	1.750					

Figure 22. With-in Subjects Effects for Jump Height.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Intercept	311630.498	1	311630.498	2383.976	.000	.984	2383.976	1.000
Treatment	200.601	2	100.301	.767	.471	.039	1.535	.171
Error	4967.315	38	130.719					

Figure 23. Between Subjects Effects for Jump Height.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	40969.787	1	40969.787	6.351	.016	.143	6.351	.690
	Greenhouse-Geisser	40969.787	1.000	40969.787	6.351	.016	.143	6.351	.690
	Huynh-Feldt	40969.787	1.000	40969.787	6.351	.016	.143	6.351	.690
	Lower-bound	40969.787	1.000	40969.787	6.351	.016	.143	6.351	.690
test * Treatment	Sphericity Assumed	28699.109	2	14349.555	2.225	.122	.105	4.449	.426
	Greenhouse-Geisser	28699.109	2.000	14349.555	2.225	.122	.105	4.449	.426
	Huynh-Feldt	28699.109	2.000	14349.555	2.225	.122	.105	4.449	.426
	Lower-bound	28699.109	2.000	14349.555	2.225	.122	.105	4.449	.426
Error(test)	Sphericity Assumed	245125.602	38	6450.674					
	Greenhouse-Geisser	245125.602	38.000	6450.674					
	Huynh-Feldt	245125.602	38.000	6450.674					
	Lower-bound	245125.602	38.000	6450.674					

Figure 24. With-in Subjects Effect for Mean Peak Power.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	2304221632.392	1	2304221632.392	1930.547	.000	.981	1930.547	1.000
Treatment	816506.587	2	408253.294	.342	.712	.018	.684	.101
Error	45355251.010	38	1193559.237					

Figure 25. Between Subjects Effect for Mean Peak Power.

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	Jheight.1 - Jheight.2	.11133	2.14203	.55307	-1.07488	1.29755	.201	14	.843
Static	Pair 1	Jheight.1 - Jheight.2	-1.05786	1.48690	.39739	-1.91637	-.19935	-2.662	13	.020
Dynamic	Pair 1	Jheight.1 - Jheight.2	-1.27000	1.90678	.55044	-2.48151	-.05849	-2.307	11	.041

Figure 26. Paired Samples T-test Mean Jump Height

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	ppower.1 - ppower.2	6.72800	130.02191	33.57151	-65.27573	78.73173	.200	14	.844
Static	Pair 1	ppower.1 - ppower.2	-64.23929	90.32781	24.14112	-116.39301	-12.08556	-2.661	13	.020
Dynamic	Pair 1	ppower.1 - ppower.2	-77.18750	115.79880	33.42823	-150.76254	-3.61246	-2.309	11	.041

Figure 27. Paired Samples T-test Mean Peak Power

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	32.157	1	32.157	16.201	.000	.299	16.201	.975
	Greenhouse-Geisser	32.157	1.000	32.157	16.201	.000	.299	16.201	.975
	Huynh-Feldt	32.157	1.000	32.157	16.201	.000	.299	16.201	.975
	Lower-bound	32.157	1.000	32.157	16.201	.000	.299	16.201	.975
test * Treatment	Sphericity Assumed	17.139	2	8.569	4.317	.020	.185	8.635	.716
	Greenhouse-Geisser	17.139	2.000	8.569	4.317	.020	.185	8.635	.716
	Huynh-Feldt	17.139	2.000	8.569	4.317	.020	.185	8.635	.716
	Lower-bound	17.139	2.000	8.569	4.317	.020	.185	8.635	.716
Error(test)	Sphericity Assumed	75.426	38	1.985					
	Greenhouse-Geisser	75.426	38.000	1.985					
	Huynh-Feldt	75.426	38.000	1.985					
	Lower-bound	75.426	38.000	1.985					

Figure 28. Within Subjects Effects Max Jump Height.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	330379.069	1	330379.069	2560.461	.000	.985	2560.461	1.000
Treatment	106.132	2	53.066	.411	.666	.021	.823	.112
Error	4903.181	38	129.031					

Figure 28. Between Subjects Effects Max Jump Height.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	127078.984	1	127078.984	17.838	.000	.319	17.838	.984
	Greenhouse-Geisser	127078.984	1.000	127078.984	17.838	.000	.319	17.838	.984
	Huynh-Feldt	127078.984	1.000	127078.984	17.838	.000	.319	17.838	.984
	Lower-bound	127078.984	1.000	127078.984	17.838	.000	.319	17.838	.984
test * Treatment	Sphericity Assumed	64589.542	2	32294.771	4.533	.017	.193	9.066	.738
	Greenhouse-Geisser	64589.542	2.000	32294.771	4.533	.017	.193	9.066	.738
	Huynh-Feldt	64589.542	2.000	32294.771	4.533	.017	.193	9.066	.738
	Lower-bound	64589.542	2.000	32294.771	4.533	.017	.193	9.066	.738
Error(test)	Sphericity Assumed	270714.226	38	7124.059					
	Greenhouse-Geisser	270714.226	38.000	7124.059					
	Huynh-Feldt	270714.226	38.000	7124.059					
	Lower-bound	270714.226	38.000	7124.059					

Figure 29. Within Subjects Effects Max Peak Power.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	2381058950.260	1	2381058950.260	1980.111	.000	.981	1980.111	1.000
Treatment	852368.047	2	426184.023	.354	.704	.018	.709	.103
Error	45694518.935	38	1202487.340					

Figure 30. Between Subjects Effects Max Peak Power.

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	maxjht1 - maxjht2	-.08467	2.17159	.56070	-1.28725	1.11792	-.151	14	.882
Static	Pair 1	maxjht1 - maxjht2	-1.36071	2.14049	.57207	-2.59660	-.12483	-2.379	13	.033
Dynamic	Pair 1	maxjht1 - maxjht2	-2.32833	1.51564	.43753	-3.29132	-1.36534	-5.322	11	.000

Figure 31. Paired Samples T-test Max Jump Height.

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	PPmax1 - PPmax2	-5.34200	131.68166	34.00006	-78.26487	67.58087	-.157	14	.877
Static	Pair 1	PPmax1 - PPmax2	-90.35500	125.72769	33.60214	-162.94801	-17.76199	-2.689	13	.019
Dynamic	Pair 1	PPmax1 - PPmax2	-141.53250	92.03297	26.56763	-200.00746	-83.05754	-5.327	11	.000

Figure 32. Paired Samples T-test Peak Power.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	27.760	1	27.760	5.043	.031	.123	5.043	.589
	Greenhouse-Geisser	27.760	1.000	27.760	5.043	.031	.123	5.043	.589
	Huynh-Feldt	27.760	1.000	27.760	5.043	.031	.123	5.043	.589
	Lower-bound	27.760	1.000	27.760	5.043	.031	.123	5.043	.589
test * Treatment	Sphericity Assumed	12.077	2	6.038	1.097	.345	.057	2.194	.227
	Greenhouse-Geisser	12.077	2.000	6.038	1.097	.345	.057	2.194	.227
	Huynh-Feldt	12.077	2.000	6.038	1.097	.345	.057	2.194	.227
	Lower-bound	12.077	2.000	6.038	1.097	.345	.057	2.194	.227
Error(test)	Sphericity Assumed	198.187	36	5.505					
	Greenhouse-Geisser	198.187	36.000	5.505					
	Huynh-Feldt	198.187	36.000	5.505					
	Lower-bound	198.187	36.000	5.505					

Figure 33. With-in Subjects Effect for Knee Range of Motion.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	1389890.351	1	1389890.351	22473.720	.000	.998	22473.720	1.000
Treatment	95.183	2	47.592	.770	.471	.041	1.539	.171
Error	2226.425	36	61.845					

Figure 34. Between Subjects Effect for Knee Range of Motion.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	154.294	1	154.294	7.054	.012	.164	7.054	.734
	Greenhouse-Geisser	154.294	1.000	154.294	7.054	.012	.164	7.054	.734
	Huynh-Feldt	154.294	1.000	154.294	7.054	.012	.164	7.054	.734
	Lower-bound	154.294	1.000	154.294	7.054	.012	.164	7.054	.734
test * Treatment	Sphericity Assumed	24.879	2	12.439	.569	.571	.031	1.137	.137
	Greenhouse-Geisser	24.879	2.000	12.439	.569	.571	.031	1.137	.137
	Huynh-Feldt	24.879	2.000	12.439	.569	.571	.031	1.137	.137
	Lower-bound	24.879	2.000	12.439	.569	.571	.031	1.137	.137
Error(test)	Sphericity Assumed	787.451	36	21.874					
	Greenhouse-Geisser	787.451	36.000	21.874					
	Huynh-Feldt	787.451	36.000	21.874					
	Lower-bound	787.451	36.000	21.874					

Figure 35. With-in Subjects Effect for Hip Range of Motion.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	356793.589	1	356793.589	3328.007	.000	.989	3328.007	1.000
Treatment	9.070	2	4.535	.042	.959	.002	.085	.056
Error	3859.538	36	107.209					

Figure 36. Between Subjects Effect for Hip Range of Motion.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
test	Sphericity Assumed	45.396	1	45.396	21.111	.000	.351	21.111	.994
	Greenhouse-Geisser	45.396	1.000	45.396	21.111	.000	.351	21.111	.994
	Huynh-Feldt	45.396	1.000	45.396	21.111	.000	.351	21.111	.994
	Lower-bound	45.396	1.000	45.396	21.111	.000	.351	21.111	.994
test * Treatment	Sphericity Assumed	20.378	2	10.189	4.738	.014	.195	9.476	.759
	Greenhouse-Geisser	20.378	2.000	10.189	4.738	.014	.195	9.476	.759
	Huynh-Feldt	20.378	2.000	10.189	4.738	.014	.195	9.476	.759
	Lower-bound	20.378	2.000	10.189	4.738	.014	.195	9.476	.759
Error(test)	Sphericity Assumed	83.863	39	2.150					
	Greenhouse-Geisser	83.863	39.000	2.150					
	Huynh-Feldt	83.863	39.000	2.150					
	Lower-bound	83.863	39.000	2.150					

Figure 37. With-in Subjects Effect for Sit and Reach.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Intercept	51512.408	1	51512.408	247.292	.000	.864	247.292	1.000
Treatment	4.085	2	2.042	.010	.990	.001	.020	.051
Error	8123.918	39	208.306					

Figure 38. Between Subjects Effect for Sit and Reach.

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	ROMknee.1 - ROMknee.2	-1.10000	3.89970	1.04224	-3.35162	1.15162	-1.055	13	.310
Static	Pair 1	ROMknee.1 - ROMknee.2	-2.22500	2.47428	.71426	-3.79708	-.65292	-3.115	11	.010
Dynamic	Pair 1	ROMknee.1 - ROMknee.2	-.26154	3.30821	.91753	-2.26067	1.73759	-.285	12	.780

Figure 39. Paired Samples T-test Knee ROM

			Paired Differences						df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
Treatment			Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t	Std. Deviation	Std. Error Mean
Control	Pair 1	ROMhip.1 - ROMhip.2	-1.32857	6.02743	1.61090	-4.80870	2.15156	-.825	13	.424
Static	Pair 1	ROMhip.1 - ROMhip.2	-3.15000	8.26290	2.38529	-8.39999	2.09999	-1.321	11	.213
Dynamic	Pair 1	ROMhip.1 - ROMhip.2	-3.97692	5.41282	1.50125	-7.24786	-.70599	-2.649	12	.021

Figure 40. Paired Samples T-test Hip ROM

Treatment			Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Upper	Lower	t	df Std. Deviation	Sig. (2-tailed) Std. Error Mean
Control	Pair 1	Sreach.1 - Sreach.2	-.12000	1.49855	.38692	-.94987	.70987	-.310	14	.761
Static	Pair 1	Sreach.1 - Sreach.2	-2.32143	2.28950	.61189	-3.64335	-.99951	-3.794	13	.002
Dynamic	Pair 1	Sreach.1 - Sreach.2	-1.97692	2.38298	.66092	-3.41694	-.53690	-2.991	12	.011

Figure 41. Paired Samples T-test Sit and Reach

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