A Comparison of a Standard Warm-Up Model and a Dynamic Warm-Up Model on Flexibility, Strength, Vertical Jump Height, and Vertical Jump Power

By
Alain J. Aguilar

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Approved by

Advisor: Darin A. Padua, PhD, ATC
Reader: Kevin Guskiewicz, PhD, ATC
Reader: Cathy Brown, MA, ATC
Reader: Daniel Herman, BS

ABSTRACT

ALAIN J. AGUILAR: A Comparison of a Standard Warm-Up Model and a Dynamic Warm-Up Model on Flexibility, Strength, Vertical Jump Height, and Vertical Jump Power
(Under the direction of Dr. Darin A. Padua)

Objective: To compare the acute effects of a dynamic warm up and standard warm up on hamstring, quadriceps, and hip flexor flexibility, quadriceps and hamstring strength, and vertical jump height and power. **Design and Setting:** An experimental research design was used to compare a standard warm up (n=15), a dynamic warm up (n=15), and a control group (n=15) on acute changes after a single bout of warm up. **Subjects:** Forty-five physically active recreational soccer players (age = 22.13 ± 2.77 years, ht = 68.47 ± 3.77 in, wt = 73.59 ± 14.53 kg) volunteered to participate. **Measurements:** Flexibility, strength, vertical jump height, and vertical jump power were evaluated. A mixed model analysis of variance was used for statistical analyses. **Results:** The dynamic warm up significantly increased hamstring flexibility from pre test measures ($p < 0.0001$) and significantly increased eccentric quadriceps peak torque ($p = 0.012$). Furthermore, a trend indicated that the dynamic warm up increased concentric quadriceps peak torque from pre to post-test measures. No other variables were significantly impacted by any warm up group. **Conclusion:** Our results suggest that an acute bout of a dynamic warm up improves hamstring flexibility and eccentric quadriceps strength. Future research should investigate the effects of a dynamic warm up on reducing muscular injury rates. **Key Words:** Dynamic warm up, hamstring flexibility, quadriceps strength, reciprocal inhibition.

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ABBREVIATIONS

1. Standard Warm Up…………………………...……………………………….….…….SWU

2. Dynamic Warm Up…….……………………………………….……………….….DWU

3. Control Group………...………………….………………………………………..…CON

CHAPTER 1 – INTRODUCTION

Introduction

Warming up prior to physical activity is a commonly accepted and widely encouraged practice within the athletic and physically active populations. Although type, sequence, and duration of the warm-up vary greatly, the goals are similar: to prepare the body for the demands of physical activity. The rationale for incorporating warm-up protocols began anecdotally as coaches and athletes observed an increase in performance and a decrease in injury when using a warm-up. One major type of injury that a warm-up is thought to prevent is a lower extremity muscular strain, particularly of the hamstring, hip flexor and hip adductor groups (Shellock and Prentice 1985; Safran, Seaber and Garrett 1989). The goal of a warm-up is to positively alter the musculoskeletal and neuromuscular system to increase performance and decrease injury risk factors (Bishop 2003).

Two commonly reported risk factors for muscle strain injury are a lack of flexibility (Gabbe, Finch et al. 2005, Witvrouw, Danneels et al. 2003) and strength deficits (Parkkari 2001, Christensen and Wiserman 1971). An increase in flexibility acutely or over time is generally thought to reduce the incidence of injury (Evans, Knight et al. 2002). Stretching is a widely accepted method of increasing muscle and tissue extensibility, thereby allowing an increased amount of stretching to occur before the onset of muscle and tendon damage (Evans, Knight et al. 2002). The literature also highlights both strength imbalances and eccentric strength deficits as risk factors (Parkkari 2001). Furthermore, Clark et al. links flexibility and strength together via reciprocal inhibition. This suggests that antagonist muscle group inflexibility will reduce the net force production of agonist muscles, which may lead to injury (Clark and Russell 2001). In theory, these injury risk factors will be ameliorated through the incorporation of a warm up.

One (standard) model consists of a brief period of an active warm-up (jogging), followed by a bout of static stretching. Proposed effects of the standard warm up may benefit performance as well as reduce the injury risk. Performance is enhanced due to the active warm up which increases metabolic, hemodynamic, neuromuscular, and musculoskeletal properties (Bishop 2003). In theory, the active warm-up period will increase the ultimate strength of the musculoskeletal tissue as well as increase muscle pliability (Bishop 2003). The static stretching phase is thought to allow an increased amount of stretching of the muscle and tendon to occur before the onset of tissue damage (Evans, Knight, Draper and Parcell 2002).

However, there is some evidence to suggest that the standard warm-up (SWU) is not the most efficient method. Current studies have revealed limitations with a standard warm up's ability to prevent muscle strain injury and enhance performance. First, muscle strain injury rates did not differ when comparing static stretching and no stretching prior to physical activity (Pope, Herbert, Kirwan and Graham 2000; Herbert and Gabriel 2002; Thacker, Gilchrist, Stroup and Kimsey 2004). Second, the current literature shows that static stretching prior to activity can negatively affect performance via a reduced force output (Church, Wiggins, Moode and Crist 2001; Cramer, Housh, Johnson, Miller, Coburn and Beck 2004). Performance measures affected by static stretching include decreased strength

(Kokkonen, Nelson and Cornwell 1998; Nelson, Allen, Cornwell and Kokkonen 2001; Cramer, Housh et al. 2004), power (Nelson, Cornwell and Heise 1996; Church, Wiggins et al. 2001; Young and Elliott 2001), balance, reaction and movement time (Behm, Bambury, Cahill and Power 2004), and vertical jump (Church, Wiggings et al. 2001). Thirdly, any positive effects on the neuromuscular system due to increases in body temperature would be attenuated as the body temperature returns to resting levels during the static stretching phase of the warm-up within 15-20 minutes (Bishop 2003). Finally, static stretching beyond normal range of motion may do little to decrease muscular injury since most muscular injuries occur during the eccentric contraction within a normal range of motion (Thacker, Gilchrist et al. 2004). Due to these limitations, some have ignored the standard warm-up model in search of a more effective method of warming up.

The dynamic warm up (DWU) is a contemporary alternative to the standard model. The DWU combines an active warm-up with dynamic flexibility. Whereas static stretching involves holding a stretch for a single muscle group, dynamic flexibility involves multi-planar movement, the use of muscle force production, and use of the body's momentum to take a joint through the full available range of motion (Clark and Russell 2001). The DWU is a progressive method as it involves gradual transitions from warming up isolated muscle groups to functional multi-planar muscle groups. Several benefits exist with a dynamic warm-up. First, the dynamic flexibility exercises acutely increase active flexibility as well as motor neuron excitability (Schilling and Stone 2000). Second, the progressive increase in body temperature throughout the warm-up period improves nerve conduction speed and central nervous system function; these improvements benefit sport activities that demand high levels of reaction speed and complex body movements (Bishop 2003). Third, the incorporation of functional exercises primes the neuromuscular components in a manner that may increase strength potential and peak power (Bishop 2003; Yamaguchi and Ishii 2005). These positive benefits provide evidence that a DWU may improve performance and decrease muscular injury risk, perhaps more than a SWU.

To our knowledge, no study has compared the effects of a dynamic versus a standard warm-up on muscular injury risk factors, such as muscle strength and flexibility, or on performance factors including vertical jump height and power. This information may provide clinicians and athletes with an evidentiary basis on which to create a warm-up protocol that more effectively minimizes injury risk and has a positive effect on performance.

Statement of Purpose

The purpose of this study was to compare the acute effects of a dynamic warm up and standard warm up on hamstring, quadriceps and hip flexor flexibility, quadriceps and hamstring strength, and vertical jump height and power in club and intramural soccer athletes.

Dependant Variables:

1. Flexibility of the dominant leg as measured by a digital inclinometer.
    a. Maximum hamstrings flexibility
    b. Maximum quadriceps flexibility
    c. Maximum hip flexor flexibility
2. Strength of the dominant leg as measured by a Biodex isokinetic dynamometer.
    a. Concentric knee extension peak torque

b. Eccentric knee extension peak torque
c. Concentric knee flexion peak torque
d. Eccentric knee flexion peak torque
e. Concentric knee flexion to concentric knee extension ratio
f. Eccentric knee flexion to concentric knee extension ratio

3. Vertical Jump Variables from a counter movement jump (CMJ) as measured by a force plate.
    a. Maximum Vertical Jump Height
    b. Maximum Vertical Jump Power.

Independent Variables:

1. Group – Control group, standard warm-up (SWU) group, or the dynamic warm-up (DWU) group.
2. Time of testing – Prior to the warm-up treatment or immediately after completion of the warm-up.

Research Questions

1. Were there significant changes in hamstrings, quadriceps, and hip flexor flexibility from pre to post warm-up testing in the SWU, DWU, and control group in the college recreational male and female soccer athlete?
2. Were there significant changes in quadriceps and hamstrings peak torque from pre to post warm-up testing in the SWU, DWU, and control group in the college recreational male and female soccer athlete?

3. Were there significant changes in hamstrings to quadriceps peak torque ratios from pre to post warm-up testing in the SWU, DWU, and control group in the college recreational male and female soccer athlete?
4. Were there significant changes in vertical jump height and power from pre to post warm-up testing in the SWU, DWU and control group in the college recreational male and female soccer athlete?

Null Hypotheses

1. H_o: There was no significant interaction or main effect of hamstrings, quadriceps, and hip flexor flexibility between treatment time (pre versus post) and treatment type (SWU, DWU, control) in the college recreational male and female soccer athlete as measured by an inclinometer.
2. H_o: There was no significant interaction or main effect of concentric and eccentric peak torque of the hamstrings and quadriceps muscles between treatment time and treatment type in the college recreational male and female soccer athlete as measured by the Biodex isokinetic dynamometer.
3. H_o: There was no significant interaction or main effect in the hamstrings to quadriceps ratio between treatment time and treatment type in the college recreational male and female soccer athletes as measured by the Biodex isokinetic dynamometer.
4. H_o: There was no significant interaction or main effect in vertical jump height or power between treatment time and treatment type in the college recreational male and female soccer athlete calculated by a formula using the subject's body mass and the impulse from a force plate.

Research Hypotheses

1. H_A: There was a significant increase in hamstrings, quadriceps, and hip flexor flexibility for the SWU and DWU, from pre to post treatment testing in the college recreational male and female soccer athlete as measured by an inclinometer.
2. H_A: There was a significant increase in hamstrings and quadriceps concentric and eccentric peak torque in the DWU group when compared to the SWU group at post-test in the college recreational male and female soccer athlete as measured by a Biodex isokinetic dynamometer.
3. H_A: There was a significant increase in hamstrings to quadriceps peak torque ratio in the DWU group when compared to the SWU group at post-test in the college recreational male and female soccer athlete.
4. H_{A1}: There was a significant increase in vertical jump height and power in the DWU group when compared to the SWU group at post-treatment testing in the college recreational male and female soccer athlete as measured by impulse generated from the jump off a force plate.

   H_{A2}: There will be a significant decrease in vertical jump height and power in the SWU from pre to post –treatment measurements in the college recreational male and female soccer athlete as measured by a formula using body mass and impulse generated off a force plate.

Definition of Terms

1. Dynamic warm-up: Consisted of 5 minutes of cycling on an Airdyne Ergometer at 25% of the subjects perceived maximal effort, followed by 10 minutes of the dynamic warm up protocol. The DWU protocol consisted of 10 yards of a "walking" dynamic lower extremity flexibility exercise followed by 10 yards of progressive running, then followed by jogging back to the starting point.
2. Dynamic flexibility: Utilized agonists and synergists muscles, as well as body momentum to actively move a limb through its full available range of motion while the functional antagonists were stretched. These exercises were performed while the athlete was moving forward. See dynamic warm-up protocol for sequence (Appendix D,E)
3. Standard warm-up: Consisted of 5 minutes of cycling on an Airdyne Ergometer at 25% of the subject's perceived maximal effort, followed by 10 minutes of static stretching. Static stretching exercises mimicked common protocols for soccer teams. See standard warm-up protocol. (Appendix D,E)
4. Static stretching: Common stretches of the lower extremity muscle groups used for pre-activity warming up. The subject lengthened a muscle group to its end range of motion until they felt a mild "stretch", then they statically held the position for 20 seconds. Subjects performed the stretch twice for each muscle group and for both legs.
5. Physically active soccer athletes: Males and females who played at least one year of varsity soccer at the high school level, and who currently plays soccer in a league.

They are also engaged in physical activity three times a week for at least thirty minutes per session around the time of testing.

Operational Definitions

1. Healthy Subject: No history of current injury or illness that prevented them from participating in soccer activities.
2. Dominant leg: The leg with which they would kick a soccer ball for maximal distance. This leg was used for all testing.
3. Flexibility: Active range of motion to end range for the hamstrings, quadriceps, and hip flexor muscle groups of the dominant leg. A digital inclinometer (an angular measurement tool) was used to measure flexibility.
4. Peak Torque Strength: The middle three data sets of five maximal concentric/eccentric contractions for knee extension was measured to determine the maximal peak torque for concentric knee extension and eccentric knee extension. For knee flexion, the middle three data sets of five maximal concentric/eccentric contractions for knee flexion were evaluated to determine the maximal peak torque for concentric knee flexion and eccentric knee flexion. The isokinetic dynamometer was set at 60 degrees per second.
5. Strength Ratio: The peak torque values were taken from the previous concentric knee extension and flexion testing. These numbers will provide a ratio of knee flexion (hamstrings) to knee extension (quadriceps) strength.
6. Isokinetic dynamometer: Biodex Medical Systems, System 3 Model 900-850 measured peak torque. The speed was set at 60 degrees per second.

7. Vertical Jump Height: A double leg standing counter movement jump (CMJ) with subject's hands on their hips. Height was calculated by using the subjects body mass and the impulse to determine velocity of the subjects body (V = I/M). Then velocity is placed into this equation: height (in meters) = (V)^2 / (2*g) (Aragon-Vargas 2000) Gravity (g) is 9.81 M/s^2 Impulse was computed by a Bertec force plate (Model 14060 A).
8. Vertical Jump Power: Determined by using a prediction equation, using the subject's mass and their vertical jump height. Power (W) = 61.9 x jump height (cm) + 36.0 x mass (Kg) – 1822 (Canavan and Vescovi 2004).
9. Force plates: Used in vertical jump measurement. Bertec systems model number 4060-08A, Bertec Corp., Columbus OH).

Assumptions

1. Subjects provided accurate and truthful responses to the questionnaire.
2. Tools used in evaluation of subjects (inclinometer, isokinetic dynamometer, and force plate) provided reliable and valid measurements.
3. Subjects in all treatment groups put forth their best effort in tasks required: during flexibility testing, strength evaluation, vertical jump assessment and the warm up treatments.
4. The vertical force produced by a CMJ was an accurate indirect estimate of lower body power.
5. Activity levels of all subjects were similar.
6. Subjects were properly nourished and hydrated.

7. Subjects adhered to the 24-hour pre-test exercise restriction.

Delimitations

1. The subjects were men and women between the ages of 18 and 30, with at least one year of varsity soccer experience at the high school level, who performed some form of exercise 3 times a week for 30 minutes.
2. Subjects were instructed to refrain from physical activity at least 24 hours prior to testing.
3. Subjects that had any injury or illness at the time of testing, which prevented them from giving their best effort were excluded from the study.
4. The same investigator performed all measurements.
5. Post treatment testing occurred within the window of temperature increase benefit (15-20 minutes) after the warm-up (Bishop 2003).
6. Treatment times for the control, dynamic, and standard warm-up were similar in duration.
7. Subjects in the DWU group underwent two training/familiarization sessions of a dynamic warm-up prior to testing.

Limitations

1. Treatment and measurements only apply to college club and intramural recreational athletes. Findings may only be applied to this population.
2. Activity levels of the athletes may differ due to the “club” nature of the soccer team.

3. For the standard warm up protocol there may not be enough time to create noted changes in flexibility, strength, and vertical jump as in previous studies.
4. Differences may not be seen due to the lower intensity of the standard warm-up as compared to the dynamic warm-up.

Significance of the Study

Despite a lack of proven efficacy, the dynamic warm up has received much attention in fitness and coaching magazines. This study compared the acute effects of a dynamic warm up and a standard warm up on select risk factors for lower extremity muscular injury, and on select athletic performance variables. If the dynamic warm up can positively affect these injury risk factors while avoiding negative effects on performance, the dynamic warm up would be a superior option compared to the standard warm up. These findings would scientifically validate the dynamic warm up, may convince more athletic teams to choose a dynamic warm up over a standard warm up, and may lower muscular injury rates.

CHAPTER 2 – REVIEW OF THE LITERATURE

Introduction

Warming-up prior to activity is postulated to decrease injury risk as well as improve performance. Performance improves secondary to the body's physiologic changes. Common methods of evaluating and predicting performance include strength and vertical jump testing. Moreover, muscle strain is a frequent athletic injury that a warm-up is supposed to reduce. Risk factors for muscle injury include inflexibility, strength deficits, and an inadequate warm-up. A warm-up is aimed to improve these injury risk factors and decrease the risk of injury. A common warm-up method includes a period of active warming-up followed by a period of static stretching; however newer protocols have been used that include active warming-up with dynamic flexibility. This contemporary method is referred to as a dynamic warm-up.

Physiology of Muscle Strain Injury

A strain is classified as a stretch or tear in the muscle or adjacent tissue such as the fascia or muscle tendons (Arnheim and Prentice 2000). The severity of the injury may range from a small separation of connective tissue and muscle fibers to a complete muscle rupture, and is graded on a scale from mild to severe. It has been theorized that at the cellular level, the initial event causes the sacromeres to lengthen non-uniformly (Morgan 1990). This occurs in the muscle after the optimal length of active tension, in the region of sacromere instability (Gordon, Huxley and Julian 1966). On a macroscopic scale, some muscle groups are more prone and get injured due to the excess of dynamic loads they sustain during a specific activity.

Mechanism of Muscle Strain Injury

There is a common activity, or mechanism, that causes strain for each muscles in the lower limb. Gastrocnemius strains often occur during the single-leg support phase during push-off movements with the body weight far in front of the calf (Orchard 2002). The exact moment of hamstring strains is not known, but video evidence demonstrates that hamstring strains occur due to over-striding at fast speeds, possibly when the body is leaning forward to gain or maintain speed (Orchard 2002). The rectus femoris muscle is the most commonly injured quadriceps muscle and is strained due to under striding or braking, as well as during the swing phase of a kicking motion while running as in Australian football. Under-striding causes the body to lean backward and the legs to extend further than normal, which can cause stress on the rectus femoris (Orchard 2002). Just as the mechanisms for injury are different for each muscle group, the rates of injury are also different.

Rates of Muscle Strain Injury

Muscular strain injury is a common occurrence in athletics, and commonly seen in sports which involve sprinting. According to the NCAA surveillance system's injury tracking data, thigh muscular strains comprise 8.7% of all injuries in men's soccer competition and 13% of all injuries during practice, with the average time loss being 10 days of activity (NCAA

2004-2005). For women during competition thigh muscle strains comprise 2.8% of all injuries, where in practice they comprise 14.6% of all injuries sustained. (NCAA 2004-2005). This trend is also seen in professional soccer with the majority of muscle strain injuries occurring to the quadriceps and hamstring muscle groups (Ekstrand and Gilliquist 1982; Morgan and Oberlander 2001; Volpi, Melegati, Tornese and Bandi 2004). In other field sports which involve sprinting and kicking, as in Australian rules football, hamstring injuries caused as much as 16% of all time missed from competition, with a re-injury rate of 34% (Seward, Orchard, Hazard and Collinson 1993). Ekstrand noted that the majority of muscular injury in soccer athletes was in the dominant leg, probably due to the dynamic motion of kicking (Ekstrand and Gilliquist 1982). Overall, muscular injury rates are as high as 41% of all injuries sustained (Hawkins and Fuller 1999; Volpi, Melegati et al. 2004). Because of the high prevalence of this injury, theories have be researched and investigated to identify risk factors for muscle strain injury.

Risk Factors of Muscle Strain Injury

Risk factors are commonly classified into intrinsic (person-related) or extrinsic (environment-related). A previous injury of muscle injury is perhaps the largest intrinsic risk factor identified (Orchard 2001). Unfortunately this is considered a risk factor that cannot be changed, and thus considered to be “non-modifiable”. Therefore, a lot of research has been aimed at evaluating “modifiable” risk factors that can be changed acutely or over time. One of the most commonly reported modifiable extrinsic risk factors is an absence or insufficient warm-up prior to activity (Worrell 1994; Garrett 1996; Hawkins and Fuller 1999). Other extrinsic risk factors include fatigue (Garrett 1996), inadequate fitness level, (Hawkins and

Fuller 1999; Heidt, Sweeterman, Carlonas, Traub and Tekulve 2000), and abrupt changes in activity (Almeida, Williams, Shaffer and Brodine 1999). Intrinsic risk factors include increased age (Croisier 2004), decreased flexibility (Witvrouw, Danneels, Asselman, D'Have and Cambier 2003; Gabbe, Finch, Bennell and Wajswelner 2005) flexibility imbalance (Knapik, Bauman, Jones, Harris and Vaughan 1991), strength deficits (Christensen and Wiserman 1972; Parkkari, Kujala and Kannus 2001), and strength imbalance (Taimela, Kujala and Osterman 1990; Aagaard, Simonsen, Trolle and al. 1995; Croisier 2004), including concentric quadriceps to hamstrings strength ratio (Soderman, Alfredson, Pietila and Werner 2001).

Decreased Flexibility

Inflexibility is perhaps one of the most commonly noted modifiable risk factors for muscle injury. A decrease in flexibility of the hamstrings and quadriceps was shown to significantly predispose soccer athletes to strains of those muscles (Knapik, Bauman et al. 1991; Witvrouw, Danneels et al. 2003). Furthermore, inflexibility in the antagonist muscle group has been shown to increase muscle injury risk (Gabbe, Finch et al. 2005). However, in that same study, they did not find that a decrease in flexibility of the hamstrings muscle group predisposed Australian rules football players to hamstring injuries (Gabbe, Finch et al. 2005), however the subject population was small and the data collection timeline was only weeks long. Finally, evidence exists that athletes that are hyper and hypo flexible can sustain significantly more muscular injuries than athletes who have a normal range of flexibility (Jones 1999). Besides inflexibility, the literature has also highlights strength deficits as an intrinsic risk factor.

Strength Deficits

Strength deficits are reported to predispose an athlete to muscle strain injury (Christensen and Wiserman 1972; Orchard, Marsden, Lord and Garlick 1997; Parkkari, Kujala et al. 2001). Multiple studies which investigated isometric strength found that a 10% hamstring strength deficit when compared bilaterally would predispose an athlete to injury (Christensen and Wiserman 1972). With regards to peak torque of the hamstring muscles, there is evidence to suggest that lower hamstring strength values when compared bilaterally will also predispose an athlete to injury (Orchard, Marsden et al. 1997). Along with deficits, a decreased strength ratio has also been proposed to increase injury risk.

The most noted ratio of the lower body is the hamstrings to quadriceps ratio. Normal hamstring to quadriceps ratio is somewhat difficult to define and is between 50% and 80%, with higher ratios at faster isokinetic speeds (Rosene, Fogarty and Mahaffey 2001). Also, there appears to be no difference in hamstrings to quadriceps ratio between the sports of volleyball, soccer, softball, and basketball, or between limb dominance (Rosene, Fogarty et al. 2001). Prospective studies investigating this ratio have revealed that a decreased ratio, as measured with isometrics and isokinetics, will predispose track and Australian football athletes to hamstring injury (Yamamoto 1993; Orchard, Marsden et al. 1997). Furthermore, a study of professional women's soccer in Sweden revealed that lower extremity injuries occurred in women who had a statistically significant lower hamstring to quadriceps ratio, however the clinical difference appears to be insignificant as the standard error is larger than the reported difference (Soderman, Alfredson et al. 2001). Other than maximal strength and ratios, researchers also hypothesize that the angle in which maximum resistance is exerted is also a consideration for injury risk.

The optimum length of active tension, otherwise known as angle of peak torque, is hypothesized to be a factor in predisposing an athlete to hamstring injury (Proske, Morgan, Brockett and Percival 2004). The shorter the optimum length of active tension, the more susceptible the athlete is to eccentric damage and then strain. This hypothesis was tested in a study which compared the optimum length of previously injured hamstrings to uninjured hamstrings. The results revealed a much sooner angle of peak torque in previously injured hamstrings than in uninjured hamstrings (Brockett, Morgan and Proske 2004).

Performance

Aside from muscular injury risk factors, performance has been at the heart of many research articles for many years, since athletic success depends on it. Studies focus on different types of performance and include short term, intermediate term, and long term performance (Bishop 2003). Short term performance involves tasks that last shorter than ten seconds in duration. Intermediate performance includes tasks that last longer than ten seconds, but not longer than five seconds. Long term performance is classified as tasks that take longer than five minutes or until fatigue. Short term performance measures reported in the literature frequently include vertical jump height and maximal strength.

Vertical Jump

Jump height has been shown to be related to maximum strength and muscular power of the leg extensors (Young, MacDonald and Flowers 2001). Timing and sequence of multiple joint segments, speed and amplitude of the countermovement, as well as a decreased amoritization phase can contribute to increasing performance on a vertical jump test (Young, MacDonald et al. 2001). Due to its complex nature, some researchers disagree vertical jump is a valid test for only leg extensor strength and power, however when used as a performance measure as a whole, most researchers view the vertical jump as a predictor of hip and leg muscle power (Young, MacDonald et al. 2001). Some researchers suggest eliminating shoulder movement from the test, since arm swing and trunk flexion came close to significantly altering the outcome on jump height measurements. Furthermore, the use of an overhead goal during jumping and grabbing with both hands from a drop jump significantly increases vertical height in males and females (Ford, Myer, Smith, Byrnes, Dopirak and Hewett 2005). Many different jump methods and measurements have been developed to measure jumping ability.

The most common types of vertical jump include the squat jump, drop jump, and countermovement jump. The squat jump includes a concentric action as the subject begins in a squatted position and then extends the knees and hips (Kokkonen, Nelson et al. 1998). A drop jump requires a subject to jump down from a box of a certain height, land, then jump in place as high as possible. With this jump, the elastic component of the leg muscles are utilized to produce an efficient jump. Finally, the countermovement jump involves a subject to be in a standing position, then lower their body at a self selected speed and distance, then propel it upward as high as possible. Some research states that the squat jump yields better power performance than countermovement due to variability in countermovement jumping (Sayers, Harackiewicz, Everett, Frykman and Rosenstein 1999). However, both tests are said to be reliable and valid for the estimation of power in the lower limbs (Markovic, Dizdar, Jukic and Cardinale 2004). Just as there are multiple methods of jumping, there are also multiple methods of measuring jump height.

Methods to measure jump height include using marked increments on a wall, a tape measure, a standing device with moveable fingers, and force plates. The sergeant jump is a jump and reach test in which the jump height is determined by subtracting the standing reach height from the jumping reach height on a wall. Another test, the Abakalow jump test uses a tape measure affixed to the waist of the jumping subject to measure vertical jump height. The Vertec system (Sports Imports, Hilliard, OH) is a popular method of measuring vertical jump (Church, Wiggins, Moode and Crist 2001). This system includes elevating a series of plastic fingers that measure in fractions of an inch. The subject is instructed to jump as high as they can and displace the highest finger they can reach, which is taken as their maximal vertical jump height. The use of force plates is another method to measuring vertical jump height. These plates include simple systems such as the Just Jump System (Probotics, Huntsville, AL) which calculates the time the subjects are in the air and height they jump, as well as more complex force plates that measure forces in all planes. An example of a more complex force plate is a Bertec strain-gauge force plate (model number 4060-08A, Bertec Corp.,Columbus, OH). Besides vertical jump height, strength is also a common measure of performance.

Strength – biodex

Maximal strength, endurance, and power have been both used to measure performance. Many methods have been used to measure these including one repetition maximum with an isotonic exercise (Kokkonen, Nelson et al. 1998), isometric maximal voluntary contraction with a hand-held dynamometer (Nelson, Allen et al. 2001), and peak torque with isokinetic devices (Laur, Anderson, Geddes, Crandall and Pincivero 2003; Cramer, Housh et al. 2004). With regards to isokinetic devices, subjects are able to produce more torque at slower velocities (Cramer, Housh et al. 2004). Improving these performance factors and reducing risk factors are the primary goals of a warm-up.

Active and Passive Warm-Up Methods

The warm-up is a general term used to describe a method of preparing the body for work preceding physical activity or athletic competition (Shellock and Prentice 1985). Current warm-up methods include increasing core and muscular body temperature and flexibility exercises. Increasing body temperature is accomplished by active or passive methods. A passive warm-up uses external means to elevate a body's temperature, such as saunas, hot showers or baths, diathermy, and heating pads (Bishop 2003). The benefit of a passive warm-up is that the athlete doesn't expend his own energy, however it is not practical for most athletes (Bishop 2003). More commonly seen in athletic settings is the use of an active warm-up to increase body temperature. These are activities such as cycling, jogging, calisthenics, swimming, jogging and sprinting, and stepping. An active warm-up uses exercise and causes greater metabolic and cardiovascular changes than a passive warm-up (Bishop 2003). Therefore, active is preferred over passive for practicality and efficiency purposes.

The Physiological Effects of an Active Warm-Up

One major physiological effect of an active warm-up is an increase in body temperature. This increase has a positive effect on the neuromuscular system and causes increases in nerve impulse transmission speed as well as central nervous system function (Bishop 2003). This benefits performance in a number of sports, especially those sports which require high levels of reaction speed and complex body movement (Bishop 2003). Also, an increase in muscle and body temperature has musculoskeletal effects including a general decrease in muscular resistance and an increase in muscle pliability. The decrease in resistance occurs in both contractile and non-contractile tissue (Bishop 2003). Due to these effects, active warming up may prevent muscular strain injury.

Active Warm-up to Prevent Muscular Strain Injury

The active warm-up has been postulated to decrease the risk of injury through various mechanisms. We found no research examining the direct effects of an active warm-up on injury rates; however the literature does discuss various mechanisms which may affect muscular injury rates. One mechanism, a decrease in musculotendinous (MTU) stiffness and extensibility means that there is an increase in max strain a muscle can resist before injury (Safran, Seaber et al. 1989; Garrett 1996). Other researchers have concluded that a decrease in MTU stiffness isn't due to stretching as commonly thought, but due to increased temperature via an active warm-up (Rosenbaum and Hennig 1995). Several programs that combine warm-up, strength, and balance training with stretching have demonstrated effectiveness in the prevention of knee and ankle injuries (Thacker, Gilchrist, Dona and Kimsey 2004). Besides potentially reducing the risk of muscle injury, an active warm-up is reported to enhance performance.

Active warm-up effects on performance

Research examining active warm-up effects on performance indicates increases in vertical jump height (Pacheco 1957; Goodwin 2002), decreased 55m sprint time (Grodjinovsky and Magel 1970), and increased peak power on a cycle ergometer (Dolan and Sergent 1984; McKenna, Green and Shaw 1987; Sargeant and Dolan 1987). The warm up for these studies include jogging, cycling, swimming, stepping, and sprinting. Some findings contradict these findings of improved vertical jump performance in vertical jump (Pyke 1968) and cycling peak power (Margaria, di Prampero and Aghemo 1971; Sargeant and Dolan 1987). However, no changes may have been observed due to an inadequate warm up from only three practice jumps before vertical jump performance testing (Pyke 1968) or fatigue from an intense warm-up protocol such as an eight minute incremental warm-up on untrained subjects (Margaria, di Prampero et al. 1971; Sargeant and Dolan 1987). From this data, it appears that the shortest amount of a warm up time for optimal short-term performance tasks is a 3-5 minute bout of moderate intensity exercise (Bishop 2003). Furthermore, increases in cycle ergometer performance can be seen more in the afternoon than in the morning, and after an active warm up at 50% of their VO2 max than nothing, however no significant difference were seen for time of day combined with an active warm-up (Racinais, Blonc and Hue 2005). From this data, time of day of testing will not significantly influence results when it comes to warm-up experiments. Therefore, both muscular injury prevention and performance enhancement may be achieved by an active warm-up. Besides an active warm-up, flexibility exercises are commonly implemented in pre-activity warming up.

Flexibility Exercises

Flexibility is defined as "the range of motion available in a joint or a group of joints that is influenced by muscles, tendons, ligaments, and bones (Anderson and Burke 1991). Types of flexibility exercises include: ballistic, proprioceptive neuromuscular facilitation, static, and dynamic stretching. Ballistic stretching is perhaps the oldest method of stretching which involves repetitive bouncing motions at the end range of motion. Although shown to be effective, most people avoid ballistic stretching because the repetitive pulling could be greater than the extensibility of the tissue, which could cause injury (Shellock and Prentice 1985). Proprioceptive neuromuscular facilitation involves acutely increasing flexibility through a series of alternating contraction and relaxation of an agonist and antagonist muscle group. This method requires a partner who understands the technique. The most widely used method of increasing flexibility is static stretching, because it doesn’t require a partner for stretching, it is a simple technique (Shellock and Prentice 1985), it requires less energy, and it’s unlikely to exceed the tissue extensibility limits (Bandy and Irion 1994). Static stretching is a method which the muscle is slowly elongated to tolerance, and the position is held with the muscle in the greatest length (Bandy and Irion 1994). A more contemporary method is called dynamic flexibility, which involves the use of agonists and synergists muscles, as well as body momentum to actively move a limb to its end range while the functional antagonists are being stretched (Clark and Russell 2001).

These methods have been proven to cause acute increases in flexibility. One bout of static stretching for the hamstrings can significantly increase flexibility from baseline to three minutes, and return to baseline by six minutes (DePino, Webright and Arnold 2000). When static stretching is compared to active warming-up, both groups had as significant increase in hamstring flexibility immediately post treatment, however they were not different from each other. This difference only lasted 15 minutes as hamstring length significantly decreased from the initial post treatment gains. Interestingly, at 24 hours post stretching a significant increase was seen again (de Weijer, Gorniak and Shamus 2003). Furthermore, both static stretching and PNF stretching with soft tissue mobilization produced significant increases acutely after six minutes of treatment (Godges, MacRae, Longdon, Tinberg and MacRae

1989). Flexibility alone can acutely increase range of motion, however many warm-ups combine flexibility with active warming-up.

When comparing the acute effects of an active warm-up with static stretching versus an active warm-up only, the results are conflicted. Some studies show that static stretching plus active warm-up group significantly increased lower extremity range of motion including hip flexion, hip extension, hip abduction, knee flexion, and ankle dorsi flexion versus the active warm-up only group (Zakas, Vergou, M.G., Zakas, Sentelidis and Vamvakoudis 2003). This finding is both supported and contradicted in another study which revealed that both fifteen minutes of static stretching and fifteen minutes of a cycling active warm-up both significantly increased hip flexion and extension range of motion without being significantly different from each other (Hubley, Kozey and Stanish 1984). The discrepancy may be from the method of active warming-up, where the former study performed intermittent sports specific warm-up exercises and the latter study performed continuous activity at light-moderate intensity. Besides the acute changes in flexibility, research has also highlighted changes in range of motion over time.

Flexibility training over time has consistently produced data which reveals increases in range of motion. PNF and static stretching over a four week period of time significantly increased the flexibility of the hamstring muscles (Davis, Ashby, McCale, McQuain and Wine 2005). Moreover, the least amount of time and frequency needed to increase hamstring flexibility is one session of a thirty second static stretch five times a week for six weeks (Bandy and Irion 1994). Interestingly, an increase in duration of stretching to sixty seconds did not produce more of a significant change from the thirty second treatment (Bandy and Irion 1994). Another flexibility training study comparing dynamic stretching with static stretching five times per week for six weeks reported significant increases for both groups, however the increases in the static group more than doubled the increases in the dynamic stretching group (Bandy, Irion and Briggler 1998). The dynamic stretching consisted of six active knee extensions with a five second hold at the end range during each treatment. Similarly, another study also reported increases in flexibility for both passive and active methods of stretching (Winters, Blake, Trost, Marcello-Brinker, Lowe, Garber and Wainner 2004). Finally, eccentric training has also been shown to increase hamstring flexibility and have an added benefit of increased hamstring eccentric strength. Significant changes in flexibility have ranged from 4% to 29%. However the discrepancy may be due to the testing population, method of measurement, as well as instrumentation. The phenomenon of increasing flexibility both acutely and chronically are attributed to specific physiologic changes in the body.

Range of Motion Assessment

There are various ways to measure range of motion in clinical studies. In most studies the use of a goniometer is used. This consists of a plastic measurement device which measures angles of the joint. The clinician must align the stationary and movement arms with the proximal and distal parts of the body segments.

Another instrument used measure range of motion is an inclinometer. It is a digital device that electronically measures the angle of which the device is placed. It is zeroed on a flat surface, and then measures the incline of the limb as it is moved toward the end range. One study which used this device displayed an intraclass correlation coefficient value of 0.90 for ankle dorsiflexion, 0.66 for hip extension, 0.69 for hip flexion, and 0.94 for knee flexion (Stewart and Sleivert 1998). This indicates a reasonable to strong test-retest reliability.

Physiological Basis of Stretching

Increases in ROM are attained by mechanical and neural processes. Stretching theoretically reduces the risk of injury by mechanically increasing compliance in a muscle which is composed of both contractile and non contractile tissues. The ability of a muscle to absorb energy (compliance) is dependant on those two factors (Safran, Seaber et al. 1989). In a highly compliant muscle the tendon can absorb more force and spare the muscle fibers from tearing. In a lowly compliant muscle, little energy is absorbed by the tendon and the majority of it goes to the muscle. This provides a mechanism of the association between flexibility and muscular injury (Witvrouw, Mahieu, Danneels and McNair 2004). Flexibility is also proposed to increase through neural processes. In this, the golgi tendons override the stretch reflex and cause a neuromuscular inhibition, which allows the joint more motion at the end range (Shellock and Prentice 1985). Because of these physiologic changes, static stretching has been incorporated in pre activity warming-up.

Static Stretching on Muscular Injury Prevention

Static stretching has been used prior to activity as part of a warm-up in order to combat the injury risk factor of inflexibility, however not much evidence exists to support this practice (Pope, Herbert, Kirwan and Graham 2000; Herbert and Gabriel 2002). In fact, there are studies which show no reduction in the rate of muscle strain injuries. A prospective study of military recruits who were given a static stretching intervention before activity every day, showed no significant difference between the control and intervention group (Pope, Herbert et al. 2000). A study of the effect of a health intervention including information/education and performance of a standardized warm-up, cool down, and stretching exercises showed no significant decrease in injury (van Mechlen 1993). Others agree that stretching before exercise does not prevent muscle soreness or injury and that there is insufficient evidence to assess effect on performance (Herbert and Gabriel 2002). Little evidence associates increased flexibility with muscular injury prevention (Knapik et al., 1991, 1992; Van Mechelen, 1996). Although recent studies demonstrate that static stretching prior to activity does not decrease injury rates, a couple of studies hint toward a benefit of static stretching.

Some research has shown that a pre-activity intervention, which included static stretching, is effective at reducing injury. An intervention study comparing a control group and an intervention group which consisted of warm-up and stretching routine, leg guards, special shoes, ankle taping, controlled rehabilitation, education and close supervision and correction by doctors and physiotherapists revealed that the treatment group received 75% less injuries than the control group (Ekstrand and Gilliquist 1982). However, this study was confounded by multiple treatment variables and short periods of time. It is difficult to definitively state that the flexibility program was the major contributor to a reduction of injuries. Also, another study was done with a high school football team, where a warm-up and stretching routine was implemented at half time and reduced the incidence of third-quarter sprains and strains injuries, but not overall injuries (Bixler and Jones 1992). The study lasted one season. There is stronger evidence to demonstrate that pre activity static stretching does not decrease injury rates and some evidence exists to show that it may hinder performance.

Stretching Impact on Strength Performance

Static stretching's impact on performance immediately post intervention reveals some negative effects. Prior to strength testing, a decrease in peak torque, maximal voluntary contraction, and one repetition max may be seen. With regard to peak torque, static stretching produces significant decreases in the static stretch group when compared to the non-static stretch group (Nelson, Allen et al. 2001; Cramer, Housh et al. 2004). These studies found that the stretch group produced a significantly lower peak torque at slower speeds, (60 degrees per second) in both non dominant and dominant legs. Besides isokinetic strength testing, isometric testing has also produced the same type of results.

Decreases in isometric strength have also been seen. Deficits were seen in the plantar flexors (Avela, Kyrolainen and Komi 1999; Fowles, Sale and MacDougall 2000), however, this may be due to the protocol of a prolonged stretch treatment of 30 minutes to 1 hour on the gastrocnemius and soleus muscle group, with isometric testing measured immediately after the stretching protocol**.** In studies that used more practical static stretching treatments, decreases were still found after 135 seconds of passive and active static stretching of the quads, hamstrings, and gastrocnemius and soleus complex; however it was not significantly different from the control group (Behm, Bambury, Cahill and Power 2004)**.** Significant decreases have been reported to be between 8-12% (Behm, Button and Butt 2001; Nelson, Allen et al. 2001). Furthermore, there is no relationship when testing the acute effects of flexibility on isometric strength between one time of static stretching and 4 weeks of flexibility training (Behm, Bradbury, Haynes, Hodder, Leonard and Paddock 2006). Also, isometric deficits can bee seen at a certain joint angle (Nelson, Allen et al. 2001). Just as isometric strength is reduced, so is isotonic activity.

One repetition maximal performance following static stretching revealed a significant decrease in muscle power after acute stretching bout (Kokkonen, Nelson et al. 1998). This study demonstrated a significant decrease in one repetition maximum (1RM) of knee flexion and extension (7.3% with knee flexion and 8.1% with knee extension) when compared to non-stretch group after a combination of five active and passive static stretching of multiple muscles which cross the knee joint. Each stretch was held for 15 seconds and performed three times for a total of 20 minutes. Therefore is appears that static stretching produces strength deficits immediately afterwards, and similar effects can be seen in vertical jump performance.

Static Stretching on Vertical Jump Performance

Overall, most of the literature shows that stretching before vertical jump performance statistically decreased vertical jump performance measured by a squat jump (Nelson, Cornwell and Heise 1996; Young and Elliott 2001; McNeal and Sands 2003) a drop jump , and a counter movement jump (Nelson, Cornwell et al. 1996; Young and Elliott 2001). However, some studies show that there are non-significant (4.5-9%) decreases in squat and countermovement jumping after a series of static stretching for the lower extremity (Power, Behm, Cahill, Carroll and Young 2004). One study showed that drop jump and squat jump height was decreased after a warm up consisting of sub maximal running and static stretching, however that decrease was not quantified. Instead, the study focused on the significant height increases (3-4%) from sub maximal running and practice jumps (Young and Behm 2003). Also, another study showed that three sets of thirty seconds of stretching for both gastrocnemius muscles significantly decreased vertical jump height by 5.6 % thirty seconds after stretching (Wallmann, Mercer and McWhorter 2005). This decrease was not due to inhibition of neural activity in the gastrocnemius muscles as the EMG activity of those muscles actually increased (Wallmann, Mercer et al. 2005). Furthermore, in a study comparing different warming up for vertical jump performance, no significant difference was seen when static stretching was used for about 5 minutes prior to jumping, however a significant increase was seen when using weighted jumping as a warm-up (Burkett, Phillips and Ziuraitis 2005).

Standard Warm-Up

In order to combine the benefits of active warming-up and counter the effects of inflexibility, most warm up protocols involve a brief period of active warming-up followed by a bout of static stretching. This method has become the "standard". The bout of static stretching normally follows a set routine and lasts for 5-10 minutes. Static stretching is most often used since it can be performed safely by the athlete without external equipment (Shellock and Prentice 1985).

Dynamic Warm-Up

A dynamic warm-up involves continuous active warming-up with dynamic flexibility and agilities interspersed. Dynamic flexibility is a technique which allows a muscle to be lengthened naturally by the contraction of its antagonist via the reciprocal inhibition mechanism (Clark and Russell 2001). Therefore the joint that the muscle crosses is moved through a full available range of motion in a slow and controlled manner.

Several arguments have been made to suggest that a dynamic ROM is better than static stretching. First, DROM can increase muscle temperature (Marten, Robinson, Wiegman and Aulick 1975) which increases muscle compliance and nerve conductivity**.** Second, a dynamic stretch after exercise would increase circulation and possibly remove lactic acid from the area and possibly reduce delayed onset muscle soreness (Murphy 1994)**.** Third, while static stretching is most popular, it has not been proven to improve athletic performance (Murphy 1994).

Dynamic Warm-Up on Injury Prevention

There is only one study that compares static stretching and dynamic stretching for injury prevention in a collegiate athletic population (Mann 1999). Injury rates were not different, however the dynamic stretching group had significantly fewer days lost when compared to the static stretch group. Furthermore, the dynamic stretch group reported lower levels of muscular soreness as the season progressed, while the static stretch group had the highest levels (Mann 1999). Of course, over an 8 week period of time, injury rates would be difficult to assess. Besides injury prevention, dynamic flexibility has been the topic of performance studies.

Dynamic Warm-Up on Performance

The evidence looks promising as dynamic stretching seems to improve performance. With regards to 20 meter sprint speed, one study in male pre-pubescent gymnasts showed no difference between the control group and a dynamic warm up group, however the dynamic warm-up consisted of stationary dynamic flexibility exercises (Siatras, Papadopoulos, Mameletzi, Gerodimos and Kellis 2003). Conversely, a study with male rugby players showed significant decreases in 20 meter sprint times with a dynamic warm-up, but not with static stretching (Fletcher and Jones 2004)Besides sprint time, dynamic flexibility has also affected power performance.

A dynamic warm-up may significantly increase lower extremity power over a stretching (Yamaguchi and Ishii 2005). This study compared a practical timeline for static stretching and dynamic flexibility. They found no change in power when subjects statically stretched, however there was a significant increase in power when the subjects stretched dynamically. They attribute increases to an elevation of muscle temperature from the active and rhythmic contractions of the muscle, and post activation potentiation, which causes a transient improvement of muscular performance after previous contractions.

Summary

Non-contact muscular injury is prevalent in athletics. Risk factors include both extrinsic and intrinsic factors. Improper warm-up and inflexibility have been identified as common risk factors for muscular injury. Attempts to improve the warm-up have been made through research. The standard warm up has traditionally included static stretching; however research reveals no effects of static stretching on injury and deleterious effects on performance. The dynamic warm-up is a newer method of warming up and is being researched. This contemporary warm-up has not been shown to decrease injury rates, however the studies are few. Moreover, there is evidence to suggest that a dynamic warm-up may acutely increase lower leg power. The dynamic warm up appears to be a superior model than static stretching with regard to performance. More research needs to be done in order to investigate the effect of a standard warm up and a dynamic warm up on injury rates.

CHAPTER 3 – METHODS

Experimental Design

To investigate the effects of a standard warm-up (SWU) and dynamic warm-up (DWU) on flexibility, strength, and vertical jump measures, we used a mixed model design with one between factor (control, SWU, or DWU) and one within factor (pre-test or post-test). We matched gender and counterbalanced subjects into three groups: control, SWU or DWU. Data was collected once before and once after the warm-up treatment during a single testing session.

Subjects

45 physically active male and female recreational soccer players from the club and intramural teams at UNC-CH, were recruited for the study (control = 15, Standard warm-up = 15, Dynamic warm-up = 15). Gender was matched for each group. At the time of testing, the subjects stated they had no current injuries or illnesses. Injury was defined as any orthopedic or head injury, and illness was defined as any non-musculoskeletal condition that prevented them from playing soccer at the time of testing. All subjects had previous playing experience of at least one year at the varsity level in high school. An *a priori* statistical power analysis was performed based on previously published data comparing flexibility measurements (Nelson, Allen et al. 2001). The study revealed that a 7.5% change in pre-stretch to post-stretch flexibility was significant. Consequently, we hypothesized that this

represented a clinically significant change. The data from this study indicated that a sample size of 15 subjects per group would provide a power of .80 to detect a 7.5% change in flexibility. Prior to the initiation of testing, all subjects signed an informed consent form approved by the University of North Carolina-Chapel Hill Biomedical Institutional Review Board and filled out a healthy subject questionnaire (Appendix D).

Procedures

All subjects reported to the Sports Medicine Research Laboratory in Fetzer Gymnasium on the campus of the University of North Carolina-Chapel Hill for testing. Subjects were required to wear athletic clothing, including shorts, a tee shirt, and sneakers. Subjects were counter balanced into the control (n=15), standard warm up (n=15), and dynamic warm up (n=15) groups based on their gender and the order in which they contacted the principal investigator to volunteer for the study. For example, the first subject of each gender was assigned into the control group, the second was assigned into the standard warm up group, and the third was assigned into the dynamic warm up group. This cycle repeated as the participants reported.

All groups reported for a single testing session lasting 90 minutes. However, subjects assigned to the DWU group reported for two familiarization sessions (20 minutes each) prior to the testing session. These sessions were on separate days, and were separated by no less than 24 hours and no more than a week. These familiarization sessions were necessary in order to acquaint the subjects with the DWU protocol for increasing subject safety, warm up effectiveness, and testing time efficiency. Up to five DWU subjects were scheduled for each familiarization session. Both sessions consisted of watching a video that demonstrated the dynamic flexibility exercises and practicing the DWU protocol. No familiarization sessions were held for the SWU group as the stretching exercises are common in the general athletic population.

The pre-test data collection order began with ROM measurements and was followed by counterbalanced strength and vertical jump testing. A two minute rest was given between all three tests. Only the dominant leg was measured, which was defined as the leg the subjects would use to kick a ball for maximal distance. After pre-testing, subjects sat quietly in a chair for fifteen minutes (cool down period) so that increased body temperature from pre-testing would not add to the effects of the warm up treatments.

Subjects then underwent the warm-up treatment to which they were assigned (Control, SWU, or DWU). Each treatment began with a five minute cycling warm-up on an Air-dyne ergometer (Schwinn Bicycle Company, Chicago, IL) at 25% of their self-estimated maximum speed. Three minutes into the cycling warm-up, participants rated their perceived exertion on a 20 pt RPE scale (McArdle, Katch and Katch 2001). They were then instructed to either increase, decrease, or maintain their effort in order to score an 11 or 12 by the end of the 5 minute cycle warm-up. Following the cycle warm-up, the control group sat quietly for 10 minutes, the SWU group performed a series of static stretches, and the DWU group performed the DWU protocol in the hallway behind the Fetzer Athletic Training Room.

After the warm up treatment, the post-test order began with ROM measurements and was followed by counter balanced strength and vertical jump testing. The subject's dominant leg was again used for all post-testing evaluations.

Data Collection

Range of Motion Assessment

Hamstrings, hip flexor, and two quadriceps muscle flexibility were assessed using a digital inclinometer (Saunders Group Inc, Chaska MN**,** USA) set to measure in degrees. Prior to testing, the subject randomly selected the order of ROM testing by drawing numbers. The subject drew numbers twice once for pre test order and once for post-test order. Subjects performed three trials of each ROM assessment with the average taken as the final measurement. Before pre- and post-testing, the inclinometer was zeroed on the flat surface of a laboratory cart. Marks were made on the subject around the inclinometer so that placement of the inclinometer was the same from pre to post testing. All ICC testing was accomplished during pilot testing and calculated using three trials for three subjects. Pictures of each ROM assessment are included in Appendix B.

<u>Active Knee Extension (AKE) Hamstring flexibility (DePino, Webright et al. 2000)</u> (Fig 6)

Subjects lay supine on a table with their dominant hip flexed to 90 degrees, while their non-dominant leg remained straight and relaxed. Subjects supported their dominant thigh with one hand, and with the other hand held a 90 degree T-bar that helped keep their dominant thigh perpendicular to the table. The subjects were instructed to "keep their thigh perpendicular to the table, and then use the front of their thigh to straighten their leg as far as possible, without moving their thigh from its perpendicular position." The digital inclinometer was placed along the medial tibial shaft, just distal to the tibial tuberosity. Participants who achieved full extension during pre-testing were excused from the study, since that eliminated any chance of observing differences between sessions. ICC $_{(2,1)}$ = 0.94 (SEM = 0.568).

Active Knee Flexion: Quadriceps flexibility (Norkin and White 1985) (Figure 7)

Subjects lied prone with their hip in 0 degrees of extension, abduction, adduction, and rotation. They were instructed to "pull their heel to their butt as far as they can, then hold it without elevating or moving their hip." The digital inclinometer was placed along the medial tibial shaft just distal to the tibial tuberosity. Participants who reached full flexion (140 degrees) during pre-testing were excused from the study since that eliminated the ability to observe differences between sessions. ICC $_{(2,1)}$ = 0.98 (SEM = 0.369).

Thomas Test: Rectus Femoris flexibility (Figure 9)

Subjects sat with their gluteal folds at the edge of the table and their dominant hip against the wall, against which the table was positioned. The subjects leaned back until they lied supine and then pulled their knees to their chest, before releasing their dominant leg to drop to the ground until the end range of motion was reached. Having subjects perform the test against the wall prevented hip abduction so that the pre and post-testing positions were similar. The subjects were then instructed to "completely relax their leg, pull their non-dominant knee all the way to their chest, and to not arch their back." The digital inclinometer was placed on the medial shaft of the tibia just distal to the tibial tuberosity. ICC $_{(2,1)}$ = 0.98 (SEM = 0.353).

Active Hip Extension: Hip Flexor flexibility (Norkin and White 1985) (Figure 8)

Subjects lied prone, with their hip in 0 degrees of abduction, adduction, and rotation. The subjects were instructed to "keep their leg straight and lift their heel up as far as possible without elevating or moving their hip from its position." The digital inclinometer was placed medial to the hamstring tendons and proximal to the popliteal crease so that it lay on the posterior thigh. The inclinometer was then re-zeroed. ICC $_{(2,1)}$ = 0.99 (SEM = 0.239).

Muscular Strength Assessment

The Biodex 3 Isokinetic dynamometer (Biodex Medical System, Inc., Shirley, NY) was used to measure quadriceps and hamstrings peak torque strength in foot · pounds. Velocity was set at 60 degrees per second and knee motion was set from 0 to 90 degrees (Nelson, Allen et al. 2001). The isokinetic dynamometer was calibrated two months prior to data collection. Data conversion/reduction was performed by the Biodex Advantage Software version 3.2 and Matlab 12 (The Math Works, Inc.).

This isokinetic dynamometer measured a knee extension concentric/eccentric contraction and a knee flexion eccentric/concentric contraction for quadriceps and hamstrings peak torque, respectively. Each test consisted of one set of five repetitions at maximal effort with data taken from the middle three trials. The first repetition was eliminated for a learning effect and the fifth repetition was eliminated for possible fatigue. Prior to testing, subjects randomly selected the order of testing by drawing numbers for pre and post testing separately in order to eliminate order effects. $ICC_{(2,1)}$ values for the concentric/eccentric knee extension and the eccentric/concentric knee flexion tests were 0.98 (SEM = 0.353) and 0.98 (SEM = 0.353) respectively. This was determined using three subjects with three trials each. Subject positioning was identical for pre and post testing as well as both contractions.

Subjects were positioned sitting upright and were secured using torso, pelvic, thigh, and shin stabilization straps. The input shaft of the dynamometer was aligned with the axis of rotation of the subject's knee, considered to be the point at the center of a line that passes transversely through the femoral condyles. The shin pad attachment was placed 1-2 cm proximal to the subject's lateral malleolus. With the exception of positioning, the testing procedure was also identical for all subjects.

The strength testing began with familiarization (warm-up) repetitions. Each subject performed three sub-maximal attempts (50% capacity), followed by three maximal contractions of both concentric/eccentric knee extension and eccentric/concentric knee flexion (Kaminski, Buckley, Powers, Hubbard and Ortiz 2003). A one minute rest was provided at the end of the practice session. Instructions and verbal encouragement was similar for all subjects. For the concentric/eccentric knee extension test, subjects were instructed to "kick as hard as they can against the resistance until their knee is straight, and then resist the machine as it pulls their leg back as quick and as hard as possible." During the test, subjects received constant verbal encouragement to "kick out" during the concentric phase and "resist" during the eccentric phase. For the eccentric/concentric knee flexion test, subjects were instructed to "resist the machine as it pulls their heel away and then pull their heel toward them as quick and as hard as possible." During the test they received verbal encouragement to "resist" during the eccentric phase and "pull back" during the concentric phase. After each test, the subjects were asked to rate their effort according to the Borg 15-category scale (McArdle, Katch et al. 2001) for the rating of perceived exertion (RPE). A perceived "very hard" exertion was considered a successful trial (Egan 2003). This equates to a score of 17 or higher on the Borg 15 category scale. Subjects who score 16 or less two times in a row were excused from the study, in order to minimize the effects of fatigue.

Vertical Jump Height and Power

Vertical jump height was tested using a double leg countermovement vertical jump (CMJ) while the subject's hands were on their hips. The subjects impulse from the jump were recorded by the Bertec strain gauge force plate (model number 4060-08A, Bertec Corp., Columbus OH). Height was calculated using a formula that imputed velocity (V=I/M - impulse created during take off/subject mass) into this equation: height (in meters) = (V)^2 / (2*g) (Aragon-Vargas 2000) Gravity (g) = 9.81 M/s^2. Vertical jump power was estimated using Harman's equation: Power (W) = 61.9 x jump height (cm) + 36.0 x mass (Kg) – 1822, which has been found to be highly reliable during repeated measures testing (Canavan and Vescovi 2004). Data was measured at a sampling rate of 1000 Hz. The analog signals from the force plate were amplified by a Bertec amplifier (AM-6701) and collected by the PEAK Performance Motus analog-to-digital interface unit (Englewood, CO). Matlab 12 (The Math Works, Inc.) used the digital data to calculate impulse and vertical jump height. Calibration occurred prior to the start of each trial. Subjects performed three pre-test and post-test trials with 30 seconds rest in between. The data from the maximal vertical jump height from the three pre-test trials and three post-test trials were analyzed.

Prior to the pre-test trials, subjects underwent three practice trials and the overhead goal was set up. Subjects were instructed to "keep your hands on your hips" in order to eliminate upper body force production, and to "jump as high as you can and try to head the soccer ball (overhead goal)." At that time, a soccer ball was suspended over the force plate at a position slightly higher than subject's maximal practice CMJ. The purpose of the overhead goal was to ensure maximal performance (Ford, Myer et al. 2005). During pilot testing reliability values were calculated for six subjects with five trials each. ICC $_{(2,1)}$ values for vertical jump height and power were 0.92 (SEM = 0.657) and 0.98 (SEM = 0.365) respectively.

Warm-Up Procedures

Standard Warm-Up

The subjects first performed a five-minute general warm-up on the Airdyne ergometer as described above (II. Procedures). The subjects then performed a 10 minute static stretching sequence for the lower extremity muscle groups including the gastrocnemius, hip adductor, gluteal, hip flexor, hamstrings, and quadriceps muscles. Stretches were held for 20 seconds. For each muscle group, the right side was always stretched twice before stretching the left side twice. After the muscle group was stretched on both sides, the subject continued to the next muscle group in the sequence. Subjects were instructed to elongate the appropriate muscle until the point of "mild stretch" and not "pain" was felt, and then hold. The subjects were given a short break (2-5 seconds) between each stretch. This sequence was the consistent between all subjects in the SWU group in order to represent a clinically relevant standard model of stretching a soccer team may use for a warm up. Pictures of each exercise are shown (figure 4)

1. Standing Gastrocnemius stretch: Subjects extended their arms and leaned against a wall while having one leg extended backward with the heel on the ground. The subjects self adjusted the distance of their back heel to the wall to feel a stretch.
2. Standing Adductor stretch: Subjects were in standing position with their feet spread apart. They leaned to one side and kept the opposite leg straight in order to stretch the hip adductor on that side.

3. Gluteus Stretch: Subjects lay supine and placed the lateral aspect of one foot/ankle on their opposite flexed knee. They pulled their flexed knee to their chest, which stretched the opposite leg's gluteal area.
4. Hip Flexor stretch: Subjects performed a kneeling lunge with one knee on the ground and the other leg flexed at the hip and knee. They held and pulled their back ankle/foot slowly toward their gluteal area while leaning forward until a stretch in the anterior hip of the kneeling leg was felt.
5. Standing Hamstring stretch: Subjects stood on one leg and placed their other leg's heel on a treatment table while keeping that knee extended. The subjects kept their hands on their hips and bent forward at the waist until a stretch in the posterior thigh of the leg on the table was felt. They were monitored for lumbar or thoracic flexion compensations.
6. Standing Quadriceps stretch: Subjects stood on one leg, flexed their opposite knee, and place the anterior part of their ankle on a table. The subjects slowly sat back until a stretch was felt in the anterior thigh of the flexed leg.

Dynamic Warm-Up

The DWU may be divided into three phases: an active warming phase, a functional dynamic flexibility phase, and a neural activation phase. The active warming phase was accomplished through the 5 minute cycling warm-up as described in the above procedures. The final two phases, dynamic flexibility and neural activation phase, took 10 minutes to perform in the hallway behind the Fetzer Athletic Training Room. The dynamic flexibility phase was performed over a ten-yard distance and gradually progressed into more complex and intense flexibility and agility exercises by using body weight, momentum, and antagonistic muscle groups to allow muscle elongation. Each leg was alternated five times for each flexibility exercises. On each alternation, the leg was brought to the point of mild stretch and then quickly released. The subjects also bounced three times, as if jumping rope, between each flexibility repetition. The final phase, neural activation, occurred over the next ten yards where the subject performed a percentage of their maximal sprint which increased as the warm-up progressed. After the final phase, the subjects jogged back to begin the next dynamic flexibility exercise in the sequence. The sequence remained the same for each participant in the DWU group since the DWU was designed to be progressive. Each item in the sequence was only performed once. A picture of each exercise is provided in figure 6. The sequence of dynamic flexibility exercises was as follows:

1. <u>Heel Toe Walks:</u> (Neural activation phase is at a jogging pace) Subjects walked "on their heels" with their knees fully extended and eccentrically contracted their anterior tibialis muscle, which reciprocally inhibited their gastrocnemius muscles.
2. <u>Walking Gastrocnemius</u>: Subjects stepped forward with one leg while keeping their back heel flat on the ground and their back knee flexed. Next, they contracted their quadriceps and tibialis anterior muscles to extend back knee, while shifting their weight forward and felt a mild stretch on the gastrocnemius muscle before releasing.
3. <u>Forward Run</u>: Subjects ran straight ahead at a jogging pace.
4. <u>Backward Run</u>: Subjects "backpedaled" for the first 10 yards.
5. <u>Russian Walk</u>: (Increase Neural activation phase to 50% of max speed) Subjects lifted one of their knees upward while extending the same lower leg, which mildly stretching the lifted limb's hamstrings muscle.

6. Walking quad stretch: Subjects flexed a knee and pulled that ankle to their gluteal area with both hands until the point of mild stretch.
7. Low amplitude butt kick (heel kicks): Subjects performed "butt kicks," by quickly bringing their heel to their gluteal area and alternating legs while moving backward. They turned after the first 10 yards.
8. Walking hamstring stretch: Subjects first crossed their arms over each other, then they placed one heel forward on the ground while keeping the knee extended. Next they flexed their hips forward until a mild stretch was felt in the forward leg's posterior thigh while they kept their lumbar and thoracic spine in a neutral position.
9. High knee pull: Subjects flexed their hip and knee to their chest while balancing on the contra lateral limb. They grasped and pulled their knee closer to their chest until a mild stretch was felt in the upper posterior thigh and gluteal area.
10. Carioca with high knee drive: Subjects performed a carioca maneuver, while flexing and bringing the trail leg's knee as close to their chest as possible. This was repeated in the opposite direction.
11. Walking Lunge with Transverse Reach: (Increase Neural activation phase to 75% of max speed) Subjects lunged forward on with their body erect until a mild stretch was felt in their trail leg hip flexor muscle. As they lunge forward, they rotated their arms and trunk to toward the side of their forward knee.
12. Balanced Gluteal stretch: Subjects placed one ankle on opposite knee while standing and then squat down on the standing limb until a mild stretch was felt in the gluteal area of the crossed over leg.

13. Prancing: Subjects kept both knees extended at all times. Then the subjects leaped forward and flexed one hip as in "reaching." Once the forward limb made contact with the ground that leg moved from hip flexion to extension and propelled the body forward. This exercise is similar to straight-leg-skipping.
14. High Skip**:** Subjects propelled themselves forward with one leg, while the opposite knee and hip were forward and flexed. Once they landed, they repeated the action with the opposite legs. Subjects were instructed to skip and jump as high as possible.
15. Rear Leg swing**:** Subjects balanced on one leg and leaned forward at the waist, while they swung their opposite leg backward and slightly flexed their knee. The subjects were instructed to control and "swing" their leg backwards until they felt a mild stretch in the anterior thigh of the swinging leg.
16. Backwards Run: (Increase Neural activation phase to 90% of max speed) Subjects backpedaled as fast as possible for the first 10 yards and then turned.
17. Shuffle for Speed: Subjects laterally shuffled without crossing their feet and leading with their dominant leg for the first 10 yards, and then turned. This will be done once.
18. Run with a 360 degree turn: Subjects ran at 75% of their max speed for the first 10 yards, and then stopped and quickly turned one complete revolution to the right. This was repeated with a turn to the left**.**
19. Acceleration to Sprint: Subjects gradually accelerated their speed so that they achieved top speed by the beginning of the neural activation phase, and then maintained that speed for 10 yards.

Data Analysis

A mixed model 2x3 analysis of variance (ANOVA) was used to investigate possible main effects and interaction between warm up time and type for each dependent variable. A Tukey HSD post-hoc analysis was used to determine where differences occur in any interaction effect. An alpha level of .05 will be set a priori. SPSS 10 for windows was used to analyze all data.

CHAPTER 4 – RESULTS

All 45 subjects counterbalanced into the control group (n=15), the standard warm-up group (n=15), and the dynamic warm-up group (n=15), none of them were retained throughout the study. Thus, no data were excluded from the analyses. Subject demographics are presented in Table 1.

Hamstrings Flexibility

Means, standard deviations, and effect sizes for hamstring flexibility are presented in Table 2. There was a significant group x time interaction [$F_{(2,42)} = 12.00$, $p < 0.0001$] for hamstring flexibility (Figure 1). A Tukey honestly significant difference (HSD) post-hoc analysis demonstrated that the hamstring flexibility within the DWU group was significantly greater at post-test than at pre-test. Also, the pre-test DWU measure was significantly greater than the CON and SWU pre-test measures. There was no significant main effect for group [$F_{(2,42)} = 0.15$, $p = .860$, $1\text{-}\beta = 0.072$]. However, there was a significant main effect for time [$F_{(1,42)} = 22.60$, $p < 0.0001$, $1\text{-}\beta = 0.996$] demonstrating greater hamstring flexibility in the post-test.

Eccentric Knee Extension Peak Torque

Means, standard deviations, and effect sizes for eccentric knee extension peak torque are presented in Table 3. The results revealed a significant group x time interaction [$F_{(2,44)} =$

4.930, $p = 0.012$] for eccentric knee extension peak torque (Figure 2). A Tukey post-hoc analysis revealed a significant increase in the DWU group from pre-test to post-test measures. Furthermore, there was no significant difference between the pre-test measures for all three groups. There was no significant group main effect [$F_{(2,42)} = 0.164$, $p = 0.849$, $1\text{-}ß = 0.074$]. However there was a significant main effect for time [$F_{(1,42)} = 4.546$, $p = 0.039$, $1\text{-}ß=0.549$], which indicated a greater knee extension peak torque at post-test than at pre-test.

Concentric Knee Extension Peak Torque

Means, standard deviations, and effect sizes for concentric knee extension peak torque are presented in Table 4. There was a significant group x time interaction [$F_{(2,42)} = 3.671$, $p = 0.034$] for concentric knee extension peak torque (Figure 3). A Tukey post-hoc analysis indicated no significant differences between the three groups at pre-test measurement. Furthermore, no group demonstrated a significant difference from pre-test to post-test measures. The only significant finding was that the DWU at post-test had significantly greater concentric knee extension peak torque than the CON and SWU at post-test. Although the DWU group did show an increase from pre-test to post-test measures (8.99 ft•lbs) it was not significant as the minimum significant difference (MSD) was 10.25 ft•lbs. There was no significant group main effect [$F_{(2,42)} = 0.163$, $p = 0.85$, $1\text{-}ß=0.074$], or time main effect [$F_{(1,42)} = 1.307$, $p = 0.259$, $1\text{-}ß = 0.201$].

Quadriceps Flexibility

Means, standard deviations, and effect sizes for quadriceps flexibility are presented in Table 5. There was no significant group x time interaction [$F_{(2,42)}= 0.735$, $p = 0.485$, ES =

0.08, 1-ß = 0.166]. Thus, quadriceps flexibility does not appear to be influenced by the type of warm up. There was no significant main effect for group [$F_{(2,42)}$ = 0.619, p = 0.543, 1-ß = 0.146], nor was there a significant main effect for time [$F_{(1,42)}$ = 1.194, p = 0.281, 1-ß = 0.187].

Hip Flexor Flexibility

Means, standard deviations, and effect size for hip flexor flexibility are presented in Table 6. There was no significant group x time interaction [$F_{(2,42)}$ = 8.538, p = 0.408, ES = 0.27, 1-ß= 0.198]. Thus, hip flexor flexibility does not appear to be influenced by different warm-ups. There was no significant group main effect [$F_{(2,42)}$=0.848, p = 0.435, 1-ß = 0.186], nor was there a significant main effect for time [$F_{(1,42)}$ = 1.972, p = 0.168, 1-ß = 0.168].

Rectus Femoris Flexibility

Means, standard deviations, and effect size for rectus femoris flexibility are presented in Table 7. There was no significant group x time interaction [$F_{(2,44)}$ = 2.602, p = 0.086, ES = 0.25, 1-ß=0.49]. Thus, rectus femoris flexibility does not appear to be influenced by the type of warm up. There was no significant main effect for group [$F_{(2,42)}$ = 0.859, p = 0.431, 1-ß = 0.188], nor was there a significant main effect for time [$F_{(1,42)}$ = 1.155, p = 0.289, 1-ß = 0.183].

Concentric Knee Flexion Peak Torque

Means, standard deviations, and effect size for concentric knee flexion peak torque are presented in Table 8. Furthermore, There was no significant group x time interaction [$F_{(2,42)}$ =

1.091, p = 0.345, ES = 0.22, 1-ß=0.229]. Thus concentric knee flexion peak torque does not appear to be influenced by the type of warm up. There was no significant main effect for group [$F_{(2,42)}$ = 0.380, p = 0.686, 1-ß = 0.107], nor was there a significant main effect for time [$F_{(1,42)}$ = 2.143, p = 0.151, 1-ß = 0.299].

Eccentric Knee Flexion Peak Torque

Means, standard deviations, and effect size for eccentric knee flexion peak torque are presented in Table 9. There was no significant group x time interaction [$F_{(2,42)}$ = 0.358, P=0.701, ES = 0.13, 1-ß = 0.104]. Thus, eccentric knee flexion peak torque does not appear to be influenced by the different warm ups. There was no significant group main effect [$F_{(2,42)}$ = 0.404, p = 0.670, 1-ß = 0.111], nor was there a significant main effect for time [$F_{(1,42)}$ = 0.595, p = 0.445, 1-ß=0.117].

Concentric Hamstrings to Concentric Quadriceps Ratio

Means, standard deviations, and effect size for concentric hamstrings to concentric quadriceps ratio are presented in Table 10. There was no significant group x time interaction [$F_{(2,42)}$ = 0.426, p = 0.656, ES = 0.002, 1-ß = 0.115]. Thus, concentric hamstrings to concentric quadriceps ratio does not appear to be influenced by the different warm ups. There was no significant group main effect [$F_{(2,42)}$ = 0.638, p = 0.533, 1-ß = 0.150], nor was there a significant main effect for time [$F_{(1,42)}$ = 0.655, p = 0.423, 1-ß = 0.124].

Eccentric Hamstrings to Concentric Quadriceps Ratio

Means, standard deviations, and effect size for eccentric hamstrings to concentric quadriceps ratio are presented in Table 11. Furthermore, there was no significant group x time interaction [$F_{(2,42)} = 1.573$, $p = 0.219$, ES = 0.24, 1-ß=0.315]. Thus, eccentric hamstrings to concentric quadriceps ratio does not appear to be influenced by the different warm ups. There was no significant group main effect [$F_{(2,42)} = 0.126$, $p=.880$, 1-ß = 0.068], nor was there a significant time main effect [$F_{(1,42)} = 0.021$, $p = 0.886$, 1-ß = 0.052].

Vertical Jump Height

Means, standard deviations, and effect size for vertical jump height are presented in Table 12. There was no significant group x time interaction [$F_{(2,42)} = 2.230$, $p = 0.120$, ES = 0.10, 1-ß = 0.429]. Thus, vertical jump height does not appear to be influenced by the different warm ups. There was no significant group main effect [$F_{(2,42)} = 0.252$, $p = 0.779$, 1-ß = 0.087], nor was there a significant main effect for time [$F_{(1,42)} = 0.026$, $p = 0.873$, 1-ß = 0.053].

Vertical Jump Power

Means and standard deviation for vertical jump power are presented in Table 13. There was a significant group main effect [$F_{(2,42)} = 0.729$, $p = 0.488$, 1-ß = 0.165], nor was there a significant main effect for time [$F_{(1,42)} = 0.026$, $p = 0.873$, 1-ß = 0.053]. There was no significant group x time interaction [$F_{(2,42)} = 2.230$, $p = 0.120$, ES = 0.06, 1-ß = 0.429]. Thus, vertical jump power does not appear to be influenced by different warm ups.

CHAPTER 5 – DISCUSSION

Our findings revealed that a single bout of the dynamic warm up protocol resulted in greater quadriceps eccentric strength and hamstring flexibility, and a trend towards increasing concentric quadriceps strength. However, no changes were observed after the DWU in quadriceps and hip flexor flexibility, concentric and eccentric hamstring strength, hamstrings to quadriceps ratios, and vertical jump height. Also, our findings indicate that an acute bout of static stretching (SWU) does not significantly affect any of the dependent variables in this study and that warm ups don't seem to affect most of these variables.

Eccentric Quadriceps Peak Torque

Perhaps the most important finding in this study is that the DWU acutely increased eccentric quadriceps strength significantly more than the control or SWU from pre to post testing. Furthermore the values of all three groups were equivalent at pre-test, emphasizing the effects of the warm up. This appears to be the first research study to investigate the effects of a DWU on eccentric quadriceps peak torque. Furthermore, this also appears to be the first study that investigates the effects of a static stretching on eccentric strength, as most previous studies have focused on concentric strength. (Nelson, Guillory, Cornwell and Kokkonen 2001; Cramer, Housh et al. 2004; Cramer, Housh, Weir, Johnson, Coburn and Beck 2005).

The acute increase in eccentric quadriceps strength was possibly a result of increased neural activity and motor unit recruitment. A general active warm up, which increases muscle and core temperature, has been shown to acutely increase motor unit recruitment and neural activity (Bishop 2003). This would explain the significant increase reported for the DWU, and why an increase was not observed in the standard warm up or control groups, since by nature the DWU group performed a longer active warm up. Furthermore, a recent study provides evidence that a longer active warm up may be beneficial for increasing lower extremity muscle performance. (Racinais, Blonc et al. 2005). Therefore the active warm up inherent in the DWU may have caused a strength increase in quadriceps eccentric peak torque.

The dynamic stretching component of the DWU could also explain the increase in eccentric quadriceps strength. A previous study demonstrated a significant increase in leg extensor power following a series of dynamic flexibility exercises (Yamaguchi and Ishii 2005). Dynamic flexibility could cause short-duration performance increases through increasing temperature (Bishop 2003), as well as post-activation potentiation (Sale 2002) due to the active contractions associated with dynamic stretching. Increasing muscle temperature has been shown to benefit performance through increasing blood flow and neurological efficiency (Bishop 2003). Furthermore, post-activation potentiation has been noted to increase performance in activities involving speed and power (Hodgson, Docherty and Robbins 2005). Previous contractions of a muscle cause an increase in calcium and drives more cross bridges between the actin and myosin which produces more force. The previous contractions also cause changes in the neurological system, which is reflected by changes in the H-reflex (Hodgson, Docherty et al. 2005). Therefore, if the previous contraction had a fast rate of force development and acceleration then the post-activation potentiation could increase peak velocity and power during the performance of dynamic muscle contractions (Hodgson, Docherty et al. 2005).

Also, various actions of the DWU protocol could contribute to the increase in eccentric strength by increasing the functional efficiency of the actin and myosin. For eccentric contractions, the external load exceeds the force produced by the cross bridges between the actin and myosin. This causes the actin and myosin to reattach and pull apart which causes a greater tension than a concentric contraction (Perrin 1993). In this study, as the subject decelerated at the end of the run phase, they activated their quadriceps eccentrically to control this motion. The eccentric force to decelerate the body increased as the run phase reached a maximal sprint. Therefore the increased external resistance from slowing body momentum caused increased force and tension development. Since this occurred at high speeds, the quadriceps would have the ability to produce more force against a slower contraction, such as the testing speed used in this study (60 degrees/second)

Finally, the theory of reciprocal inhibition may explain the acute eccentric strength increases. Applying this theory, if the hamstring muscles are tight, then that tightness may result in inhibition of the antagonist muscles, the quadriceps. Thus the reverse would also be true. If the hamstring length increases, then the quadriceps muscle would be less inhibited and have the potential to produce more force (Clark and Russell 2001). In the current study, an increase in hamstring flexibility was observed, which may explain the mechanism for improvement in quadriceps strength.

Aside from the performance gains, the ability of the body to increase eccentric quadriceps strength could also be protective measures against quadriceps muscle injury. Most quadriceps muscle strains occur during deceleration or "braking" (Orchard 2002), as the muscle eccentrically contracts to slow the body's velocity while the body leans backward. This movement places an increased stretch on the rectus femoris muscle, which is the most commonly strained muscle of the quadriceps group. Increasing eccentric strength may possibly provide an ability to absorb more force and reduce the risk of injury.

Hamstring Flexibility

Another interesting finding of this study was that the DWU group acutely increased hamstring flexibility more than the SWU or CON groups from pre to post-test. However, at pre-test the DWU pre-test value was significantly less than the CON or SWU. Therefore it is possible that the DWU group had more limited hamstring flexibility prior to the DWU, causing a greater potential for change. This initial difference between groups may confound results. However, the difference in hamstring flexibility from pre to post testing in the DWU group (9.6º) is much greater than the CON (0.09º) or SWU (3.2º). Thus, the DWU could be more effective at acutely increasing hamstring flexibility regardless of flexibility starting point and is clinically relevant. We believe this is the first study to observe the acute effects of a DWU on hamstring flexibility. There is one study which investigates the training effects of dynamic range of motion (DROM) and static stretching on hamstring flexibility (Bandy, Irion et al. 1998), however the DROM exercise was a simple knee extension, not whole body movements, and the study observed a training effect over six weeks. In the previous study, both groups displayed an increase in flexibility, however the static stretching group more than doubled the increases of the DROM group (Bandy, Irion et al. 1998). These findings contradict our study's findings, and may be explained by the different methods of dynamic motion. In the previous study the DROM training group performed active knee extensions from a 90-90 position, whereas this current study's DWU group used momentum, body weight, and multi-muscle groups to bring a series of joints through a full range of motion. Practically, the DWU is more clinically relevant as a complete warm up, therefore this current study applies clinically more than the former study.

Surprisingly, an acute bout of static stretching in the SWU group produced no significant increase in hamstring flexibility. This contradicts previous studies, which reported static stretching increases ROM in the hip joint (Godges, MacRae et al. 1989; DePino, Webright et al. 2000; de Weijer, Gorniak et al. 2003). The contradicting results is most likely due to the differences of hamstring stretching duration. In the previous studies, total stretching lasted between one and a half to 10 minutes (DePino, Webright et al. 2000; de Weijer, Gorniak et al. 2003). This current study only stretched the hamstring muscles for a total of 40 seconds, which may not have been enough to cause changes in hamstring length. Furthermore, hamstring length was measured in the previous studies by passive flexibility, whereas the current study used the quadriceps muscle to extend the knee actively, from a 90-90 position.

The increase in hamstring length observed in DWU group is possibly due to the active warm up and active contractions. The DWU spent 15 minutes actively warming up, and the SWU only performed an active warm up for 5 minutes. The extended time could increase muscle temperature and improve viscoelasticity and pliability of the musculotendinous unit. Furthermore, an active contraction of the quadriceps muscle to extend the knee was used to measure hamstring flexibility. Since the DWU showed increases in concentric quadriceps peak torque, an increased efficiency of the muscle to contract could cause the quadriceps to pull the leg into further extension and display a greater hamstring length increase. Therefore, the DWU acutely increases hamstring flexibility more efficiently than a SWU protocol or no warm up at all. Since hamstring inflexibility is a risk factor for muscle injury, this warm up may reduce injury risk, assuming that acutely increasing hamstring flexibility has preventative measures.

Concentric Quadriceps Peak Torque

Although a significant interaction was found, it was not between pre and post testing for any of the groups. Therefore, the individual warm ups did not significantly change from pre to post testing. However, a trend toward significance was observed in the DWU group as it appeared to have larger increases in concentric peak torque than the SWU or CON from pre to post-testing. Although we believe this to be the only study that observed the acute effects of a DWU on concentric quadriceps peak torque, there have been multiple studies which observed the acute effects of static stretching on concentric quadriceps peak torque (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2004; Cramer, Housh et al. 2005). In our current study the SWU did not elicit significant decreases in concentric quadriceps peak torque, which differs from previous studies that demonstrate significant decreases in quadriceps peak torque. This was possibly a result of our study's more clinical relevant static stretching time frames. The previous studies state neural inhibition was the mechanism for the strength decreases (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2005). It is important to note that in previous studies the purpose was to examine the effects of prolonged stretching on peak torque in order to provide some foundational evidence. This information was extrapolated to the clinical realm, however our study which investigated a clinically relevant static stretching protocol revealed no significant decrease. A possible explanation for the non significant finding may be because autogenic inhibition may not have occurred, as evidenced by no significant increase in quadriceps flexibility for the SWU.

A trend towards a significant increase in concentric quadriceps peak torque after a DWU could be due to the same benefits of an active warm up and active contractions that were mentioned previously for the increase in eccentric quadriceps strength. Also, this finding could provide more evidence toward reciprocal inhibition, since both concentric and eccentric strength were improved as hamstring length increased.

Quadriceps, Hip Flexor, and Rectus Femoris Flexibility

With regard to quadriceps, hip flexor, and rectus femoris flexibility, no significant changes were seen after any of the warm up treatments. We have not find other studies which observed the acute effects of a DWU on quadriceps, hip flexor, and rectus femoris flexibility. One study which investigated quadriceps and hip flexor flexibility following an acute bout of static stretching (Young, Clothier, Otago, Bruce and Liddell 2004). This study revealed that 4.5 minutes of static stretching did not significantly increase quadriceps flexibility or hip flexor flexibility as measured by the Thomas Test, which supports our study, despite the differences in stretching protocol. Another study investigated the training effects of a static stretching and active range of motion on passive hip extension, as measured by the Thomas Test, over a six week period of time (Winters, Blake et al. 2004). This study revealed that both active and passive stretching increased hip flexor flexibility. There are a number of differences between these protocols. First, the subject population in the previous study included subjects with limited hip flexor flexibility. In the current study, the lack of change following stretching migh have occurred because our subjects did not have restrictions in the hip flexors. Second, differences may be due to shorter time of stretching in the SWU protocol when compared to the previous study, which stretched the hip flexors for 240 seconds. Finally, differences may not have been observed due to the method of measurement, as in the previous study the Thomas Test was used to measure hip extension, and in the current study an active straight leg hip extension test was used.

Hamstring Peak Torque

Concentric and eccentric hamstring peak torques as well as the hamstring to quadriceps ratio was not significantly impacted by the acute warm up treatments. To our knowledge this is the first study that investigates hamstrings concentric and eccentric peak torque following an acute bout of a DWU. Furthermore, although much research has investigated the effect of stretching on quadriceps strength, this is the first study to investigate the acute effects of static stretching on hamstring strength.

This finding is interesting in light of the no change in hamstring flexibility in the SWU group after static stretching. It is thought that gains in ROM from static stretching are achieved through a process called autogenic inhibition (Shellock and Prentice 1985). Since no significant increase in hamstring flexibility was demonstrated after the SWU, autogenic inhibition may not have occurred and thus hamstring strength did not change. It is possible that if the stretching time for the hamstring increased in the SWU group, autogenic inhibition may occur and decrease hamstring strength as it has for gastrocnemius strength (Fowles, Sale et al. 2000) and quadriceps strength (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2004; Cramer, Housh et al. 2005). Interestingly, the current study showed that the DWU increased hamstring flexibility but did not change hamstring concentric and eccentric peak torque.

This is important as it may suggest that DWU increased hamstring flexibility while maintaining the strength of the muscles that were elongated, which vastly differs from the static stretching literature. Perhaps the mechanism of flexibility for the DWU is more temperature related, where as the increase due to static stretching is based on autogenic inhibition. Thus, the DWU would provide protective measures against muscular injury risk by increasing hamstring flexibility and maintaining hamstring strength.

Reasons also exist which may explain why the DWU did not significantly increase hamstring strength. First, the DWU does not include exercises which specifically isolate and target the hamstring muscles and thus prime them to have an acute increase in peak torque. Additionally, reciprocal inhibition states that a flexibility increase in the agonist will increase antagonist strength. Since no increase in quadriceps flexibility was seen, it seems logical that hamstring peak toque would not be affected.

Hamstrings to Quadriceps Peak Torque Ratio

Concentric hamstrings to concentric quadriceps and eccentric hamstrings to concentric quadriceps ratios did not change after the DWU or SWU treatments. To our knowledge, this was the first attempt to observe the acute effects of a warm up protocol on hamstrings to quadriceps ratios**.** As we observed no changes in concentric or eccentric hamstring or concentric quadriceps peak torque, we expected to find no difference in ratios. Although no changes were seen, all the ratio's were within "normal" range already, therefore theoretically it did not predispose them to injury (Rosene, Fogarty et al. 2001).

Vertical Jump Height and Power

Finally, no significant difference in VJ height was noted following the DWU, SWU, or CON. A previous study investigated the effects of an acute bout of a DWU and static stretching on vertical jump height (Faigenbaum, Bellucci, Bernieri, Bakker and Hoorens 2005). Our DWU results support the lack of change in vertical jump, but do not support the SWU decrease in vertical jump height (Faigenbaum, Bellucci et al. 2005). These differences may be attributed to the varying methods of the studies. The former study did not include a pre-test for all variables, therefore, it is difficult to definitively state that the static stretching group produced significantly larger decreases than the dynamic group. Also, the testing session followed the same testing procedure for all conditions, with vertical jump being the first one tested resulting in a possible order effect. In our study, vertical jump was either the second or third of three variables tested during post test. The difference in order may have minimized any temporary deficits in jumping performance. Furthermore, a study that investigated the acute effects of ballistic stretching on vertical jump performance (Unick, Kieffer, Cheesman and Feeney 2005) revealed similar results to ours in that an acute bout of ballistic or static stretching produced no significant change in vertical jump height.

In contrast to our findings, many other studies reported significant decreases in vertical jump performance following an acute bout of static stretching (Nelson, Cornwell et al. 1996; Cornwell, Nelson and Sidaway 2002; Young and Behm 2003; Faigenbaum, Bellucci et al. 2005; Wallmann, Mercer et al. 2005). Many of these studies often had static stretching protocols that were much longer than static stretching methods used clinically. One study did follow practical timelines and still had reported decreases in vertical jump (Faigenbaum, Bellucci et al. 2005). For the most part, when static stretching protocols were shorter and within the time frame of actual clinical practice, significant decreases were not seen (Church, Wiggins et al. 2001; Young and Elliott 2001; Power, Behm et al. 2004).

Initially, we hypothesized that the DWU would cause an acute increase in strength, while the SWU group would cause a decrease in strength; and the difference between the SWU and DWU would possibly be significant. Since no changes in concentric quadriceps peak torque following the DWU or concentric quadriceps peak torque following the SWU were observed, then leg extensor power may not have been changed. If leg extensor power was not changed, then it makes sense that vertical jump height and power would also not be changed.

Limitations

A limitation of the study is a small magnitude of power (0.104 to 0.42) for most of the dependent variables. A larger sample size would have increased power. However, the effect sizes for the non significant dependent variables were also very small (0.002 to 0.27). Therefore, the differences were small to begin with and may not be found to be clinically significant even if more subjects are included in the study.

The ability to generalize these findings is also limited since, we only evaluating soccer players. More specifically, the findings of this study only apply to recreational soccer players between the ages of 18 and 30 years old. We utilized a single sport because warm up methods are very sports specific and this DWU sequence was designed for soccer players. Even though the applications are limited, there are many athletes who fall under this category that would benefit from the DWU. Furthermore, these findings may also apply to all field sports which are similar to soccer and involve sprinting, cutting, and jumping.

Another possible limitation involves the difference in body temperature and VO_2 levels between the DWU and the SWU. Although this was not directly measured, subjectively it appeared that subjects in the DWU group had a higher body temperature, displayed by more perspiration, and possibly higher VO2 increase, observed by heavier breathing, than the SWU group. However, the DWU and the SWU treatments were designed to closely resemble common warm up protocols of athletic teams. Therefore, even though temperature was not controlled for the laboratory setting the results of this study apply directly to the athletic setting, which is arguable more important.

These findings only apply to this specific sequence of a DWU. Other sequences which include different exercises or time durations may produce other results. However, the current study did follow a pattern that defines the DWU, which is using a progressive series of tasks to gradually prepare the body for activity. Therefore, these findings may also apply to different DWU sequences that are also progressive in nature.

Finally, it is difficult to say which part of the DWU was largest contributor in increasing hamstring flexibility and quadriceps strength. It could have been the dynamic flexibility or the continuous active warm up which produced these benefits. Although it would be interesting to find out which part of the DWU most influenced these variables, it is not a crucial point, since all of these components comprise the DWU in clinical practice.

Future Research

A randomized, prospective study using the DWU and the SWU and measuring subsequent injury rates would be ideal to provide evidence that one warm up is better or no different at reducing injury rates. Based on the results of this study it is possible to speculate that the DWU could reduce hamstring and possibly rectus femoris muscle strain injury rates. Second, whether or not the training effects of the DWU occurred with flexibility, strength, speed, agility, and balance should be investigated. Since the DWU displayed an acute increase in hamstring flexibility, it is logical to say that this flexibility would be increased over training period. Strength would probably not increase since body weight would not be enough stimulus to cause overload and thus hypertrophy adaptation. There is evidence that dynamic flexibility acutely increases sprint speed, therefore it is possible that the DWU would have a training effect of increased speed. Third, the DWU could benefit other short term performance measures including balance and reaction time, as well as long term performance as in a mile run. Thus, its applicability to other tasks should be investigated. Fourth, it would be interesting to see if adding a DWU protocol in the rehabilitation plan for a muscle injury would produce quicker results and lower re-injury rates. Since this warm up is progressive and contains all the components of a muscle strain rehabilitation program, it would allow the clinician to condense the components of the rehabilitation and bring an athlete to their highest intensity below the threshold of re-injury in a controlled setting.

Summary

Overall, the results of this study indicate that performing a DWU can acutely increase hamstring flexibility and improve quadriceps eccentric strength. Inflexibility of the hamstring muscles is commonly reported in the literature as a risk factor for hamstring injury. The increases in hamstring flexibility from the DWU may provide protection against hamstring strain injury more than the SWU. Furthermore, an increase in eccentric quadriceps strength is very important for performance, as eccentric contractions control the body during athletic movement. Finally, this study provides evidence toward the theory of reciprocal inhibition, since quadriceps strength increased when hamstrings flexibility increased.

Appendix A: Tables

Table 1: Subject Demographics; Mean(SD)

Group	Gender	Age (yr)	Height (in)	Weight (kg)
CON	7M 8F	22.73 ± 2.55	67.47 ± 3.34	69.63 ± 16.04
SWU	8M 7F	21.00 ± 2.07	68.73 ± 3.92	75.53 ± 9.50
DWU	8M 7F	22.67 ± 3.27	69.20 ± 4.41	75.60 ± 16.95
Total	23M 22F	22.13 ± 2.77	68.47 ± 3.77	73.59 ± 14.53

CON = Control

SWU = Standard Warm Up

DWU = Dynamic Warm Up

Table 2: Hamstring Flexibility (Degrees from full extension)

Group	Pre-Test *Means ± SD*	Post-Test *Means ± SD*	*Effect Size*
CON	19.5111 ± 10.83*	19.4222 ± 11.96*	0.01
SWU	21.4667 ± 10.45*†	19.2889 ± 11.39*	0.19
DWU	26.4444 ± 13.50	16.8889 ± 9.369*	0.71

$p < .0001$ for group by test interaction
MSD = 4.29
$1\text{-}\beta = 0.996$

* denotes significant difference from dynamic warm up Pre-Test Measure
† denotes significant difference relative to the dynamic warm up Post-Test Measure

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 3: Eccentric Quadriceps Peak Torque (Ft·lbs)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	151.9467 ± 70.07	156.6244 ± 65.62*	0.07
SWU	144.8511 ± 48.94	140.6556 ± 59.49†	0.07
DWU	136.7044 ± 46.14	155.5467 ± 51.25*	0.37

$p = 0.012$ for group by test interaction

MSD = 15.65

$1\text{-}\beta = 0.779$

* denotes significant difference from DWU Pre-Test Measure

† denotes significant difference from the CON Post-Test Measure

CON = Control

SWU = Standard Warm Up

DWU = Dynamic Warm Up

Table 4: Concentric Quadriceps Peak Torque (Ft·lbs)

Group	Pre-test *Means ± SD*	Post-Test *Means ± SD*	*Effect Size*
CON	125.8467 ± 46.14	127.7667 ± 51.57*	0.04
SWU	128.2067 ± 34.46	124.0800 ± 31.25*	0.12
DWU	129.1933 ± 37.86	138.1889 ± 38.38	0.23

$p = 0.034$ for group by test interaction
MSD = 10.25
$1-\beta = 0.644$

* denotes significant difference from the DWU Post-Test Measure

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 5: Quadriceps Flexibility (Degrees)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	129.5778 ± 9.27	127.7556 ± 8.31	0.20
SWU	127.7333 ± 6.95	127.9333 ± 7.41	0.03
DWU	126.0667 ± 7.96	125.4444 ± 6.48	0.08

$p = 0.485$ for group by test interaction
$1\text{-}\beta = 0.166$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 6: Hip Flexor Flexibility (Degrees)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	26.3778 ± 4.55	26.7333 ± 3.81	0.08
SWU	25.7111 ± 8.19	26.9333 ± 6.86	0.15
DWU	28.0667 ± 7.84	30.2000 ± 5.49	0.27

$p = 0.408$ for group by test interaction
$1-\beta = 0.198$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 7: Thomas Test Flexibility (Degrees)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	67.9333 ± 10.09	66.4000 ± 6.53	0.15
SWU	71.4222 ± 11.53	72.5333 ± 11.53	0.10
DWU	68.9111 ± 12.22	72.0222 ± 10.99	0.25

$p = 0.086$ for group by test interaction

$1\text{-}\beta = 0.49$

CON = Control

SWU = Standard Warm Up

DWU = Dynamic Warm Up

Table 8: Concentric Hamstrings Peak Torque (Ft·lbs)

Group	Pre-Test *Means ± SD*	Post-Test *Means ± SD*	*Effect Size*
CON	65.3933 ± 24.61	67.0778 ± 21.53	0.07
SWU	71.7311 ± 18.59	71.4445 ± 24.57	0.01
DWU	70.1978 ± 21.84	74.8978 ± 19.35	0.22

$p = 0.345$ for group by test interaction
$1-\beta = 0.229$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 9: Eccentrc Hamstrings Peak Torque (Ft·lbs)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	111.6089 ± 40.27	112.1622 ± 37.78	0.01
SWU	117.9955 ± 31.65	118.0711 ± 35.40	0.002
DWU	120.9400 ± 27.23	124.4022 ± 26.30	0.13

$p = 0.701$ for group by test interaction
$1\text{-}\beta = 0.104$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 10: Concentric Hamstrings to Concentric Quadriceps Peak Torque Ratio

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	0.5225 ± 0.07	0.5506 ± 0.09	0.31
SWU	0.5691 ± 0.11	0.5716 ± 0.12	0.02
DWU	0.5463 ± 0.09	0.5479 ± 0.96	0.002

$p = 0.656$ for group by test interaction
$1\text{-}\beta = 0.115$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 11: Eccentric Hamstrings to Concentric Quadriceps Peak Torque Ratio

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	0.9032 ± 0.15	0.9339 ± 0.23	0.13
SWU	0.9371 ± 0.20	0.9488 ± 0.15	0.06
DWU	0.9715 ± 0.21	0.9207 ± 0.10	0.24

p = 0.219 for group by test interaction
1-β = 0.315

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 12: Vertical Jump Height (m)

Group	Pre-Test *Means ± SD*	Post-Test *Means ± SD*	*Effect Size*
CON	0.2492 ± 0.05374	0.2382 ± 0.05267	0.20
SWU	0.2479 ± 0.09034	0.2496 ± 0.07931	0.02
DWU	0.2577 ± 0.07353	0.2652 ± 0.06881	0.10

$p = 0.120$ for group by test interaction
$1-\beta = 0.429$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 13: Vertical Jump Power (watts)

Group	Pre-Test	Post-Test	
	Means ± SD	*Means ± SD*	*Effect Size*
CON	2227.0178 ± 796.19	2159.1111 ± 787.25	0.09
SWU	2250.4453 ± 791.53	2260.9600 ± 726.35	0.01
DWU	2494.9600 ± 810.27	2541.4489 ± 829.00	0.06

$p = 0.120$ for group by test interaction
$1\text{-}\beta = 0.429$

CON = Control
SWU = Standard Warm Up
DWU = Dynamic Warm Up

Table 14: Statistical Results

	Group	Time	Group x Time Interaction
Hamstring Flexibility	[$F_{(2,42)}$ = 0.151, p =.860, 1-β=0.072]	[$F_{(1,42)}$ = 22.608, p < 0.0001, 1-β=0.996]	[$F_{(2,42)}$ = 12.004, p < 0.0001, ES = 0.71, 1-ß=0.996]
Quadricps Flexibility	[$F_{(2,42)}$ = 0.619, p = 0.543, 1-ß=0.146]	[$F_{(1,42)}$ = 1.194, p = 0.281, 1-ß=0.187]	[$F_{(2,42)}$= 0.735, p = 0.485, ES = 0.08, 1-ß=0.166]
Rectus Femoris Flexibilty	[$F_{(2,42)}$ = 0.859, p = 0.431, 1-ß=0.188]	[$F_{(1,42)}$ = 1.155, p = 0.289, 1-ß=0.183]	[$F_{(2,44)}$ = 2.602, p = 0.086, ES = 0.25, 1-ß=0.49]
Hip Flexor Flexibility	[$F_{(2,42)}$=0.848, p = 0.435, 1-ß=0.186]	[$F_{(1,42)}$ = 1.972, p = 0.168, 1-ß=0.168]	[$F_{(2,42)}$ = 8.538, p = 0.408, ES = 0.27, 1-ß=0.198]
Concentric Quadriceps Peak Torque	[$F_{(2,42)}$ = 0.163, p = 0.85, 1-ß=0.074]	[$F_{(1,42)}$ = 1.307, p = 0.259, 1-ß=0.201]	[$F_{(2,42)}$ = 3.671, p = 0.034, ES = 0.23, 1-ß=0.644]
Eccentric Quadriceps Peak Torque	[$F_{(2,42)}$ = 0.164, p = 0.849, 1-ß=0.074]	[$F_{(1,42)}$ = 4.546, p = 0.039, 1-ß=0.549]	[$F_{(2,44)}$ = 4.930, p = 0.012, ES = 0.37, 1-ß=0.779]
Concentric Hamstring Peak Torque	[$F_{(2,42)}$ = 0.380, p = 0.686, 1-ß=0.107]	[$F_{(1,42)}$ = 2.143, p = 0.151, 1-ß=0.299]	[$F_{(2,42)}$ = 1.091, p = 0.345, ES = 0.22, 1-ß=0.229]
Eccentric Hamstring Peak Torque	[$F_{(2,42)}$ = 0.404, p = 0.670, 1-ß=0.111]	[$F_{(1,42)}$ = 0.595, p = 0.445, 1-ß=0.117]	[$F_{(2,42)}$ = 0.358, P=0.701, ES = 0.13, 1-ß=0.104]
Con Hamstring to Con quadriceps ratio	[$F_{(2,42)}$ = 0.638, p = 0.533, 1-ß=0.150]	[$F_{(1,42)}$ = 0.655, p = 0.423, 1-ß=0.124]	[$F_{(2,42)}$ = 0.426, p = 0.656, ES = 0.002, 1-ß=0.115]
Ecc Hamstring to Con Quadriceps ratio	[$F_{(2,42)}$ = 0.126, p=.880, 1-ß=0.068]	[$F_{(1,42)}$ = 0.021, p = 0.886, 1-ß=0.052]	[$F_{(2,42)}$ = 1.573, p = 0.219, ES = 0.24, 1-ß=0.315]
Vertical Jump Height	[$F_{(2,42)}$ = 0.252, p = 0.779, 1-ß=0.087]	[$F_{(1,42)}$ = 0.026, p = 0.873, 1-ß=0.053]	[$F_{(2,42)}$ = 2.230, p = 0.120, ES = 0.10, 1-ß=0.429]
Vertical Jump Power	[$F_{(2,42)}$ = 0.729, p = 0.488, 1-ß=0.165]	[$F_{(1,42)}$ = 0.026, p = 0.873, 1-ß=0.053]	[$F_{(2,42)}$ = 2.230, p = 0.120, ES = 0.06, 1-ß=0.429]

Appendix B: Figures

Figure 1: Hamstring Flexibility (Degrees)

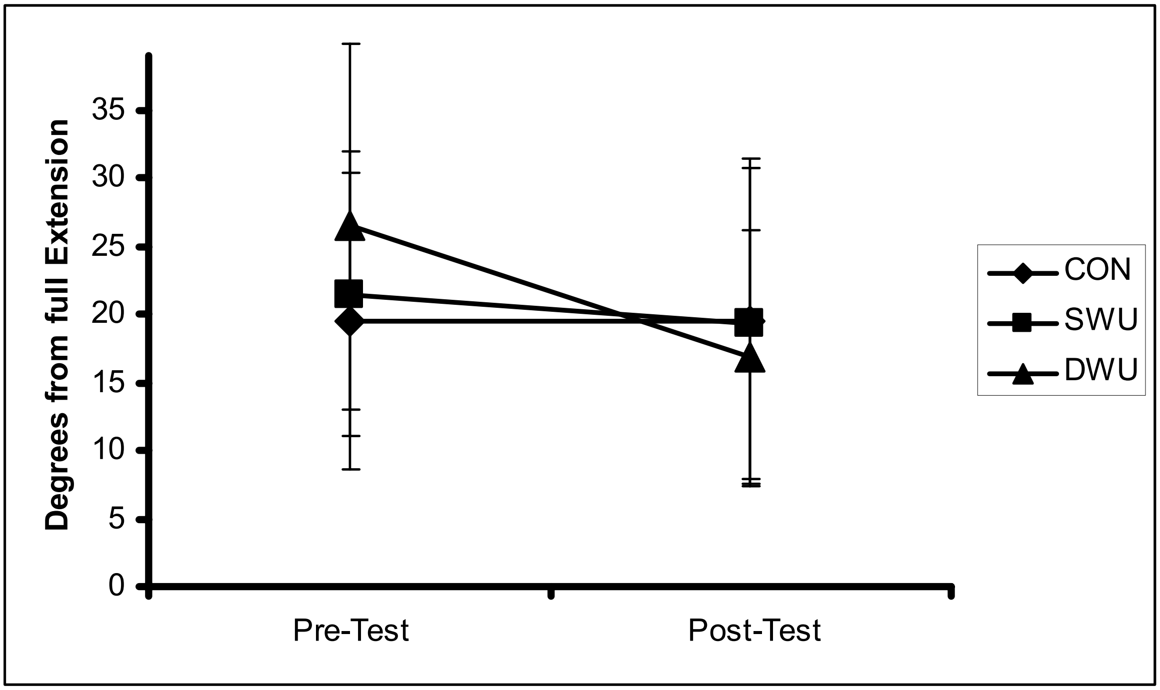


Figure 2: Eccentric Quadriceps Peak Torque (Ft·lbs)

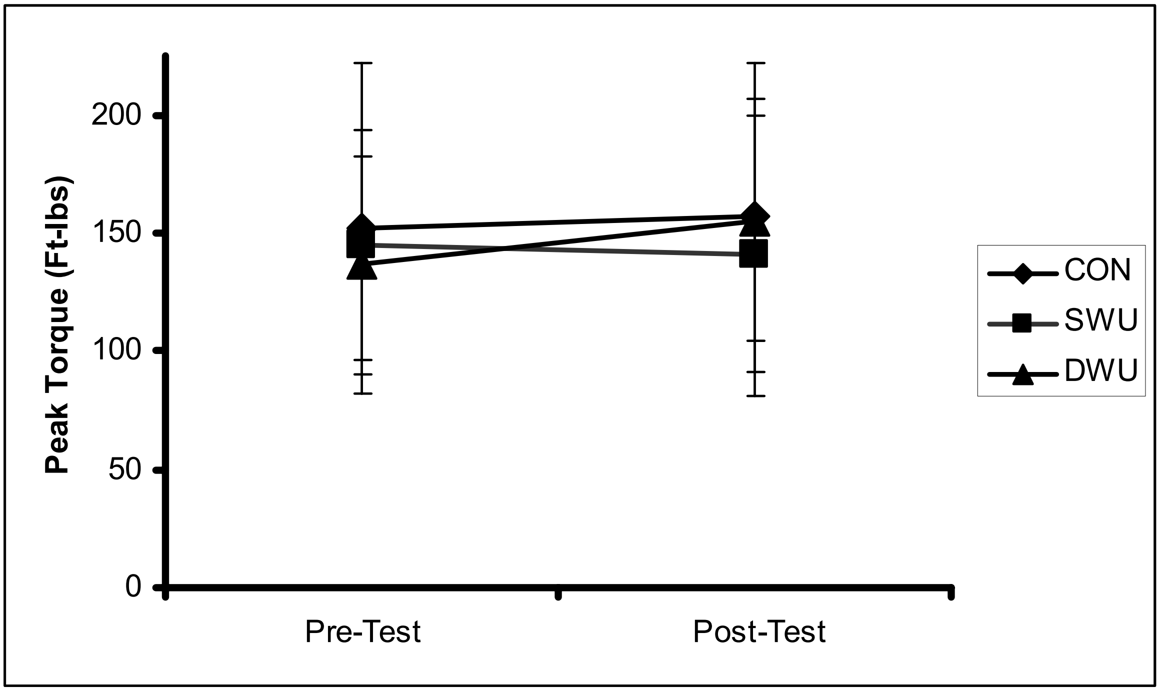


Figure 3: Concentric Quadriceps Peak Torque (Ft·lbs)

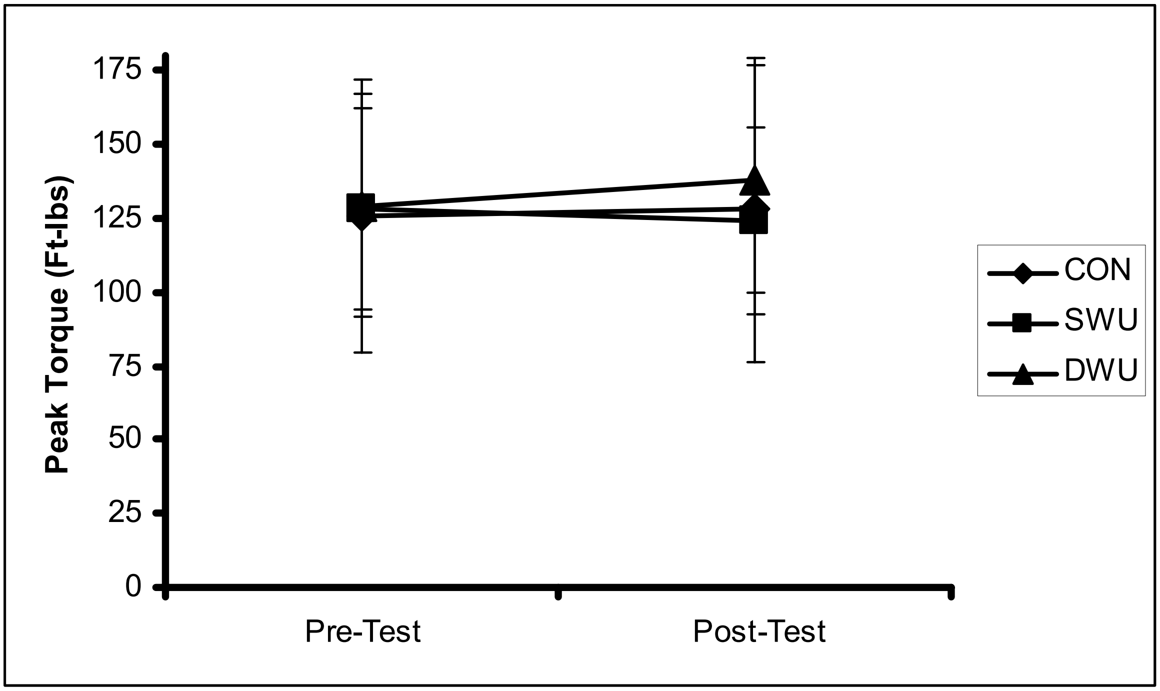


Figure 4: Static Stretching Protocol

Standing Gastrocnemius Stretch

Hamstrings Stretch

Standing Quadriceps Stretch

Gluteus Stretch

Hip Flexor Stretch

Figure 5: Dynamic Warm-Up Flexibility Exercises


Heel Toe Walks


Walking Gastrocnemius


Russian Walks


Walking Quadriceps


Low Amp Butt Kicks
(Backwards Butt Kicks)


Walking Hamstrings

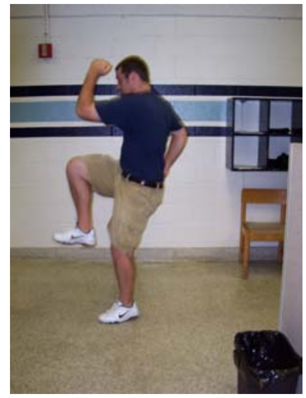

High Knee Pull


Carioca with High Knee Drive


Lunge with Transverse Reach


Balanced Gluteal

Prancing


High Skip


Rear Leg Swing

Figure 6: Hamstring Flexibility Assessment Positioning

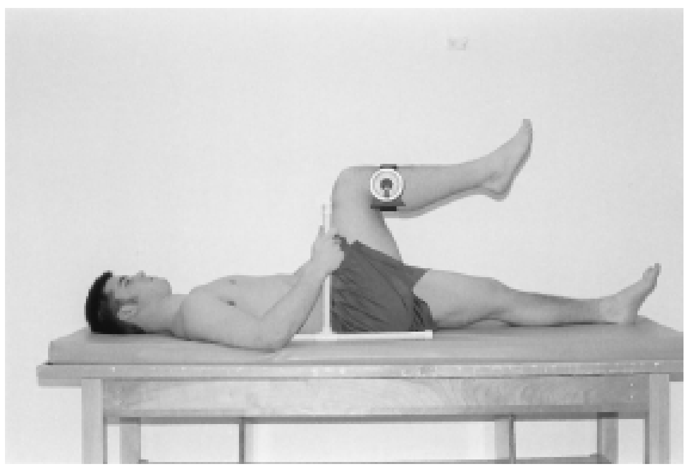


Figure 7: Quadriceps Flexibility Assessment Positioning

Figure 8: Hip Flexor Assessment Positioning

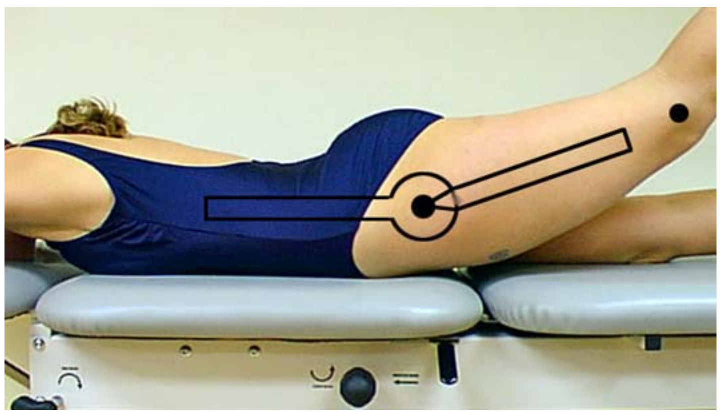


Figure 9: Rectus Femoris Assessment Positioning

Appendix C: Manuscript

A Dynamic Warm-Up Model Increases Quadriceps Strength and Hamstring Flexibility More than a Standard Warm-Up

Alain J. Aguilar*; Darin A. Padua*; Kevin Guskiewicz*; Cathy N. Brown*; Dan Herman*; Lindsay J. Strickland*; John Cone†

*University of North Carolina, Chapel Hill, NC; †Kansas City Wizards, Kansas City, MO

Alain J. Aguilar, MA, ATC, PES and Darin A. Padua PhD, ATC contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Kevin Guskiewicz, PhD, ATC, Cathy N. Brown, PhD, ATC, Dan Herman BS, and Lindsay J. Strickland, MA, ATC contributed to conception and design; and critical revision and final approval of the article. John Cone, MA, contributed to conception and design.

Address correspondence to Darin A. Padua, PhD, ATC, University of North Carolina, Chapel Hill, Department of Exercise and Sport Science, CB #8700, Chapel Hill, NC 27713-8700. Address e-mail to dpauda@email.unc.edu

A Dynamic Warm-Up Model Increases Quadriceps Strength and Hamstring Flexibility More than a Standard Warm-Up

Context: Limited evidence exists about the contemporary dynamic warm-up.

Objective: To compare the acute effects of a dynamic warm up and standard warm up on hamstring, quadriceps, and hip flexor flexibility, quadriceps and hamstring strength, and vertical jump height and power.

Design: A pre test – post test experimental research design was used to compare a dynamic warm up (DWU), a standard warm-up (SWU), and a control group (CON).

Setting: Sports Medicine Research Laboratory

Participants: Forty-five physically active recreational soccer players (23 males [age = 22 ± 3 years, height = 181 ± 7 cm, mass = 80 ± 7 kg] and 22 females [age = 21 ± 2 years, height = 166 ± 6 cm, mass = 63 ± 11 kg]) without lower extremity injury. Subjects were counterbalanced and assigned into the different warm-up groups: DWU = 15, SWU = 15, CON = 15.

Intervention(s): Three different clinical methods of pre activity warm-up.

Main Outcome Measure(s): Flexibility, strength, vertical jump height, and vertical jump power were evaluated. A mixed model analysis of variance tested for differences between and within groups.

Results: The DWU significantly increased hamstring flexibility *($p < 0.0001$)* and eccentric quadriceps peak torque *($p = 0.012$)* from pre to post-test. Furthermore, the DWU a revealed trends in increasing concentric quadriceps peak torque from pre to post-test measures. No other variables were significantly impacted by any warm up group.

Conclusion: An acute bout of a DWU improved hamstring flexibility and eccentric quadriceps strength more than a standard warm up.

Key Words: Dynamic warm up, hamstring flexibility, quadriceps strength, reciprocal inhibition.

INTRODUCTION

Warming up prior to physical activity is a commonly accepted and widely encouraged practice within the athletic and physically active populations. Although type, sequence, and duration of the warm up vary greatly, the goals are similar: to prepare the body for the demands of physical activity by reducing the risk of injury and enhancing performance. One common type of injury that a warm up is thought to prevent is a lower extremity muscular strain, particularly of the hamstring, hip flexor and hip adductor groups (Shellock and Prentice 1985; Safran, Seaber et al. 1989). Overall, muscular injury rates during physical activity are as high as 41% of all injuries sustained (Hawkins and Fuller 1999; Volpi, Melegati et al. 2004). Therefore efforts have been focused on finding ways to reduce the injury rates through preventative measures. Two commonly reported risk factors for muscle strain injury are a lack of flexibility (Gabbe, Finch et al. 2005, Witvrouw, Danneels et al. 2003) and strength deficits (Parkkari 2001, Christensen and Wiserman 1971). Warm up routines that improve flexibility while maintaining or improving strength are considered beneficial and may help to reduce the risk of muscle strain injury resulting from physical activity.

One (standard) model of warm up (SWU) consists of a brief period of active warming up (jogging), followed by a bout of static stretching. This method has been proposed to reduce injury risk as well as benefit performance (Shellock and Prentice 1985). Performance is enhanced through the period of an active warm up (jogging) by increasing metabolic, hemodynamic, neuromuscular, and musculoskeletal effects (Bishop 2003) and is noted to improve vertical jump height (Pacheco 1957; Goodwin 2002). In theory, the active warm up will reduce injury risk by increasing the ultimate strength as well as the pliability of the musculoskeletal tissue (Bishop 2003). Furthermore, the static stretching phase is thought to reduce muscular injury rates by allowing an increased amount of stretching of the muscle and tendon to occur before the onset of tissue damage (Evans, Knight et al. 2002).

However, there is some evidence to suggest that the (SWU) is not the most efficient method. First, muscle strain injury rates did not differ when comparing individuals who performed static stretching prior to physical activity to those who did not stretch (Pope, Herbert et al. 2000; Herbert and Gabriel 2002; Thacker, Gilchrist et al. 2004). Second, the current literature demonstrates that static stretching prior to activity can negatively 1RM and concentric isokinetic peak torque (Kokkonen, Nelson et al. 1998; Nelson, Allen et al. 2001; Cramer, Housh et al. 2004), power (Nelson, Cornwell et al. 1996; Church, Wiggins et al. 2001; Young and Elliott 2001), balance, reaction and movement time (Behm, Bambury et al. 2004), and vertical jump height (Church, Wiggings et al. 2001). Third, any positive effects on the neuromuscular system due to increases in body temperature would be attenuated within the 15-20 minutes of the static stretching phase of the warm up (Bishop 2003). Finally, static stretching beyond normal range of motion may do little to decrease muscular injury since most muscular injuries occur during the eccentric contraction within a normal range of motion (Thacker, Gilchrist et al. 2004).

Due to the lack of evidence supporting the standard warm up model (active warm up followed by static stretching) there is increased interest in determining a more effective warm up model that positively influences flexibility, strength, power, and functional performance in preparation for physical activity. The dynamic warm-up (DWU) is a contemporary alternative to the standard model. The DWU combines an active warm-up with dynamic flexibility. Whereas static stretching involves holding a stretch for a single muscle group, dynamic flexibility involves multi-planar movement, the use of muscle force production and the use of body's momentum to take a joint through the full available range of motion (Clark and Russell 2001). The DWU is also a progressive method as it builds on gradual transitions from warming-up isolated muscle groups to functional multi-planar movements.

Several benefits are proposed to exist with the DWU model. First, the dynamic flexibility exercises acutely increase active flexibility as well as motor neuron excitability (Schilling and Stone 2000). Second, the progressive increase in body temperature throughout the warm up period is believed to improve nerve conduction speed and central nervous system function; these improvements are thought to benefit sport activities that demand high levels of reaction speed and complex body movements (Bishop 2003). Third, the incorporation of functional exercises primes the neuromuscular components in a manner that may increase strength (Bishop 2003; Yamaguchi and Ishii 2005). Recent studies have shown that the DWU significantly improved lower extremity power (Yamaguchi and Ishii 2005) and 20 meter sprint time more than a static stretching warm up (Fletcher and Jones 2004). These improvements provide some evidence that a DWU may be more effective in improving flexibility, strength, power, and functional performance in comparison to a standard warm up that focuses on static stretching.

To our knowledge, no study has compared the effects of a dynamic versus a standard warm-up on muscular injury risk factors, such as muscle strength and flexibility, or on performance factors including vertical jump height and power. This information may provide clinicians and athletes with an evidentiary basis on which to create a warm-up protocol that more effectively minimizes injury risk and has a positive effect on performance. If the DWU facilitates greater improvements in these parameters compared to standard warm up, then the DWU may be considered a more effective method. These findings would validate the DWU, and may convince more athletic teams to utilize the DWU over a SWU. Additionally, adopting a DWU may lower muscular injury rates. Therefore, the purpose of this study was to compare the acute effects of a dynamic warm up versus a standard warm up on hamstring, quadriceps and hip flexor flexibility, quadriceps and hamstring strength, and vertical jump height and power in recreational soccer athletes.

METHODS

Subjects

Forty-five physically active male (n=23) and female (n=22) recreational soccer players from the club and intramural teams at the University of North Carolina at Chapel Hill were recruited for the study, and were assigned and counterbalanced into one of these groups control = 15, Standard warm-up = 15, Dynamic warm-up = 15). Gender was matched between groups. Subject demographics are presented in Table 1. Inclusion criteria included that subjects exercise at least three days per week for at least 30 minutes, and played at least one year of varsity soccer in high school. Exclusion criteria included currently symptomatic injuries or illnesses such as any orthopedic, head injury, or illness that prevented them from playing soccer at the time of testing. Furthermore, subjects were excluded if they demonstrated full knee extension during flexibility testing, or if they had to repeat the strength test protocols more than twice. Prior to testing, all subjects signed an informed consent form approved by the Biomedical Institutional Review Board and completed a healthy subject questionnaire. The questionnaire contained questions about current injury or illness as well as physical activity performed during the week, and was used to ensure inclusion or exclusion.

Procedures

All subjects reported to the Sports Medicine Research Laboratory on the campus of the University of North Carolina at Chapel Hill for testing. Subjects were required to wear athletic clothing, including shorts, a tee shirt, and sneakers. Subjects were assigned in a counter-balanced fashion (matching for gender) into either the control (n=15), standard warm up (n=15), and dynamic warm up (n=15) groups.

All subjects reported for a single testing session lasting 90 minutes. The subjects in the DWU group reported for two familiarization sessions (20 minutes each) prior to the testing session. The familiarization sessions were on separate days, and were separated by no less than 24 hours and no more than a week. These familiarization sessions were necessary in order to acquaint the subjects with the DWU protocol for increasing subject safety, warm up effectiveness, and avoiding learning and practice effects. Both familiarization sessions consisted of watching a video that demonstrated the dynamic flexibility exercises and then practicing the DWU protocol. No familiarization sessions were held for the SWU group as the stretching exercises are common in the general athletic population.

Testing order consisted of flexibility measurements followed by counterbalanced strength and vertical jump assessment. Flexibility was the most important variable of interest, therefore flexibility was measured first during pre and post testing to ensure that the other testing procedures would not influence its outcome. Subjects rested for 2-minutes between each of the assessment conditions. After pre-testing was completed the subjects sat quietly in a chair for fifteen minutes (cool down period) so that increased body temperature from pre-testing would not add to the effects of the warm up treatments (Bishop 2003). The dominant leg was used for all testing and was defined as the leg that subjects would use to kick a ball for maximal distance.

Following the cool down period subjects performed the specific warm-up protocol based on the group to which they were assigned (Control, SWU, or DWU). Each warm up protocol began with five–minutes of cycling on an Air-dyne ergometer (Schwinn Bicycle Company, Chicago, IL). To ensure that subjects performed a "light" warm-up, they were then instructed to either increase, decrease, or maintain their effort in order to score an 11 or 12 on a 15 pt RPE scale (McArdle, Katch et al. 2001), by the end of the 5 minute cycle warm-up. Following the cycle warm up, the control group sat quietly for 10 minutes and the SWU and DWU group subjects performed their specified warm up exercises. The SWU group performed a series of static stretches (Table 3) and the DWU group performed the DWU protocol (Table 3) in a hallway adjacent to the laboratory.

Immediately following completion of the warm up protocols, the subjects repeated the testing protocol. The post-test assessment order was flexibility measurements then was counterbalanced strength and vertical jump testing performed in a counter-balanced order. Strength and vertical jump were counterbalanced in order to eliminate the possibility of an order effect. The subject's dominant leg was again used for all post-testing evaluations.

Data Collection

Range of Motion Assessment

Hamstrings, hip flexor, and quadriceps flexibility were assessed using a digital inclinometer (Saunders Group Inc, Chaska MN, USA) set to measure in degrees. Prior to testing, the subject randomly selected the order of pre and post flexibility testing by drawing numbers. Three trials of each flexibility assessment were taken and the average of the three trials was used for analysis. The inclinometer was zeroed on a flat and level surface before pre and post testing. Marks were made on the subject around the inclinometer so that pre and post testing placement of the inclinometer was consistent.

<u>Active Knee Extension (AKE) Hamstring flexibility</u>

Subjects lay supine on a table with their dominant hip flexed to 90 degrees, while their non-dominant leg remained straight and relaxed on the table (DePino, Webright et al. 2000). Subjects supported their dominant thigh with one hand, and with the other hand held a 90 degree T-bar that helped keep their dominant thigh perpendicular to the table (Figure 6). The subjects were instructed to "keep their thigh perpendicular to the table, and then use the front of their thigh to straighten their leg as far as possible, without moving their thigh from its perpendicular position." The digital inclinometer was placed along the medial tibial shaft, just distal to the tibial tuberosity. Participants who achieved full extension during pre-testing were excused from the study, since that eliminated any chance of observing differences between sessions. $ICC_{(2,1)} = 0.94$ (SEM = 0.568).

<u>Active Knee Flexion: Quadriceps flexibility</u>

Subjects lay prone with their hip in 0 degrees of extension, abduction, adduction, and rotation (Norkin and White 1985). They were instructed to "pull their heel to their butt as far as they can, then hold it without elevating or moving their hip" (Figure 7). The digital inclinometer was placed along the medial tibial shaft just distal to the tibial tuberosity. ICC $_{(2,1)}$ = 0.98 (SEM = 0.369).

Thomas Test: Rectus Femoris flexibility

Subjects sat with their gluteal folds at the edge of the table and the lateral side of their dominant hip against the wall, against which the table was positioned (Norkin and White 1985). The subjects leaned back until they were supine and then pulled their knees to their chest, before releasing their dominant leg to drop to the ground until the end range of motion was reached (Figure 9). Having subjects perform the test against the wall prevented hip abduction so that the pre and post-testing positions were similar. The subjects were then instructed to "completely relax their leg, pull their non-dominant knee all the way to their chest, and do not arch the back." The digital inclinometer was placed on the medial shaft of the tibia just distal to the tibial tuberosity. ICC $_{(2,1)}$ = 0.98 (SEM = 0.353).

Active Hip Extension: Hip Flexor flexibility

Subjects lay prone, with their hip in 0 degrees of abduction, adduction, and rotation (Norkin and White 1985). The subjects were instructed to "keep their leg straight and lift their heel up as far as possible without elevating or moving their hip from its position" (Figure 8). The digital inclinometer was placed medial to the hamstring tendons and proximal to the popliteal crease so that it lay on the posterior thigh. The inclinometer was then re-zeroed to accommodate for the resting position of the leg. ICC $_{(2,1)}$ = 0.99 (SEM = 0.239).

Muscular Strength Assessment

The Biodex 3 Isokinetic dynamometer (Biodex Medical System, Inc., Shirley, NY) was used to measure concentric and eccentric quadriceps and hamstrings peak torque in foot pounds. Prior to testing, subjects randomly selected the order of testing by drawing numbers for pre and post testing separately in order to eliminate order effects. Subjects were positioned sitting upright and were secured using torso, pelvic, thigh, and shin stabilization straps (Cramer 2004). The input shaft of the dynamometer was aligned with the axis of rotation of the subject's knee, considered to be the point at the center of a line that passes transversely through the femoral condyles. The shin pad attachment was placed 1-2 cm proximal to the subject's lateral malleolus. With the exception of positioning, the testing procedure was also identical for all subjects.

For quadriceps testing, the concentric motion was tested first as the knee extended, followed by an eccentric motion as the knee was flexed against resistance. For hamstring testing, the eccentric motion was tested first with the knee forced into extension as the hamstrings resisted, followed by a concentric motion as the hamstrings pulled the knee into flexion. Velocity was set at 60 degrees per second and knee motion range of motion was set from 0 (flexion) to 85 (extension) degrees (Nelson, Allen et al. 2001). ICC $_{(2,1)}$ = 0.98 (SEM = 0.353) and 0.98 (SEM = 0.353) for knee extension and flexion respectively. Data conversion/reduction was performed by the Biodex Advantage Software version 3.2 and Matlab 12 (The Math Works, Inc. Natick, RI). The average from the peak torque values were used to calculate concentric hamstrings to concentric quadriceps ratio as well as the eccentric hamstrings to concentric quadriceps ratio.

The strength testing began with familiarization (warm-up) repetitions. Each subject performed three sub-maximal attempts (50% capacity), followed by three maximal contractions of both concentric/eccentric knee extension and eccentric/concentric knee flexion (Kaminski, Buckley et al. 2003). A one minute rest was provided at the end of the practice session. Instructions and verbal encouragement were similar for all subjects. Each test consisted of one set of five repetitions at maximal effort with data taken from the middle three trials. The first repetition was eliminated for a learning effect and the fifth repetition was eliminated for possible fatigue. After each test, the subjects were asked to rate their effort according to the Borg 15-category scale (McArdle, Katch et al. 2001) for the rating of perceived exertion (RPE). A perceived "very hard" exertion was considered a successful trial (Egan 2003). This equates to a score of 17 or higher on the Borg 15 category scale. Subjects who score 16 or less two times in a row were excused from the study, in order to minimize the effects of fatigue.

Vertical Jump Height and Power

Vertical jump height was tested using a double leg countermovement vertical jump (CMJ) while the subject's hands were on their hips. An overhead goal was positioned just above the subjects maximal practice trial to ensure maximal performance (Ford, Myer et al. 2005). The subjects performed three pre-test trials and three post-test trials with 30 seconds of rest between. The average of the three tests was analyzed. Subjects were instructed to "keep your hands on your hips" in order to eliminate upper body force production, and to "jump as high as you can and try to head the soccer ball (overhead goal)." The subjects' impulse from the jump was recorded by the Bertec strain gauge force plate (model number 4060-08A, Bertec Corp., Columbus OH). Height was calculated using a formula that imputed velocity (V=I/M - impulse created during take off/subject mass) into this equation: height (in meters) = (V)^2 / (2*g) (Aragon-Vargas 2000) Gravity (g) = 9.81 M/s^2. Vertical jump power was estimated using Harman's equation: Power (W) = 61.9 x jump height (cm)

+ 36.0 x mass (Kg) – 1822, which has been found to be highly reliable during repeated measures testing (Canavan and Vescovi 2004). Data was measured at a sampling rate of 1000 Hz. Matlab 12 (The Math Works, Inc., Natick RI) used the digital data to calculate impulse and vertical jump height. Calibration occurred prior to the start of each trial. $ICC_{(2,1)}$ = 0.92 (SEM = 0.657) and 0.98 (SEM = 0.365) for vertical jump height and power respectively.

Data Analysis

A mixed model 2x3 analysis of variance (ANOVA) was used to investigate possible interactions and main effects between warm up time and type for each dependent variable. The between subjects factor was group (3 levels: DWU, SWU, Control), and the within subjects factor was time (2 levels: pre-test, post-test). A Tukey HSD post-hoc analysis was used to determine where differences occur in any interaction effect. An alpha level of .05 was set a priori. Statistical Program for the Social Sciences (SPSS 13.0, Chicago, IL) was used to analyze all data.

RESULTS

All subjects of the 45 original subjects were retained. Subject demographics are presented in Table 1.

Flexibility

Means, standard deviations, and effect size are presented for hamstring flexibility (Table 2), quadriceps flexibility (Table 5), hip flexor flexibility (Table 6), and rectus femoris flexibility as measured by the Thomas Test (Table 7). There was a significant group x time interaction for hamstring flexibility [$F_{(2,42)} = 12.004$, $P < 0.0001$] (Figure 1). Minimum significant difference (MSD) = 4.29 degrees. A Tukey post-hoc analysis demonstrated that the hamstring flexibility in the DWU group was significantly greater at post-test than at pre-test. There was no main effect for group (Table 14) however, there was a main effect for time (Table 14) with post test being significantly greater than pre-test values. Thus the DWU appears to increase hamstring flexibility more than the SWU or no warm up at all.

There were no significant main effects or interactions involving group for quadriceps, hip flexor, and rectus femoris flexibility as shown in Table 14 ($P > 0.05$). Furthermore, neither the SWU, DWU nor CON acutely changed quadriceps, hip flexor, and rectus femoris flexibility. Therefore it appears that quadriceps, hip flexor, and rectus femoris flexibility is not changed by a SWU or a DWU. Power for these variables are indicated in Table 14.

Quadriceps and Hamstrings Peak Torque

Means, standard deviations, and effect size are presented for eccentric quadriceps peak torque (Table 3), concentric quadriceps peak torque (Table 4), concentric hamstring peak torque (Table 8), eccentric hamstring peak torque (Table 9), concentric hamstrings to concentric quadriceps ratio (Table 10), and eccentric hamstrings to concentric quadriceps ratio (Table 11). Statistical results are presented in Table 14.

There was a significant group x time interaction for eccentric quadriceps peak torque, [$F_{(2,42)} = 4.930$, $P = 0.012$] (Figure 2). MSD = 15.65 foot pounds. A Tukey post-hoc analysis revealed a significant increase in the DWU group from pre-test to post-test measures. There was no significant difference for the pre-test measures, and the other groups did not significantly change.

Furthermore, concentric quadriceps peak torque demonstrated a significant group x time interaction [$F_{(2,42)} = 3.671$, $P = 0.034$] (Figure 3). MSD = 10.25 foot pounds. A Tukey post-hoc analysis indicated no significant differences for all three groups at pre-test measurement. Furthermore, no group demonstrated a significant difference from pre-test to post-test measures. The only significant finding was that DWU at post-test was significantly greater than the CON and SWU at post-test. Although the DWU group demonstrated an increase from pre-test to post-test measures (8.99 ft•lbs) it was not significantly significant (MSD = 10.25 ft•lbs). Thus the DWU significantly increased eccentric quadriceps strength when compared to the SWU or no warm groups, and it also appears to produce a trend of increase in concentric quadriceps strength.

No significant differences were observed for concentric hamstring peak torque [$F_{(2,42)} = 1.091$, $P = 0.345$, ES = 0.22, 1-ß=0.229], eccentric hamstring peak torque [$F_{(2,42)} = 0.358$, $P=0.701$, ES = 0.13, 1-ß = 0.104], concentric hamstrings to concentric quadriceps ratio [$F_{(2,42)} = 0.426$, $P = 0.656$, ES = 0.002, 1-ß = 0.115], or eccentric hamstrings to concentric quadriceps ratio [$F_{(2,42)} = 1.573$, $P = 0.219$, ES = 0.24, 1-ß=0.315]. Furthermore, both hamstring to quadriceps ratio variables did not demonstrate any significant main effect or interaction ($P > 0.05$). Therefore, it appears that none of the warm up groups significantly changed in these measures.

Vertical Jump

Means, standard deviations and effect size are listed for vertical jump height (Table 12) and vertical jump power (Table 13). Furthermore, statistics are presented in Table 14. No significant difference was observed for vertical jump height [$F_{(2,42)} = 2.230$, $P = 0.120$, ES = 0.10, 1-ß = 0.429], or vertical jump power [$F_{(2,42)} = 2.230$, $P = 0.120$, ES = 0.06, 1-ß =

0.429]. Thus it appears that none of the warm up groups significantly changed vertical jump performance.

DISCUSSION

Our findings revealed that a single bout of the dynamic warm up protocol resulted in greater quadriceps eccentric strength and hamstring flexibility, and a trend towards increasing concentric quadriceps strength. However, no changes were observed after the DWU in quadriceps and hip flexor flexibility, concentric and eccentric hamstring strength, hamstrings to quadriceps ratios, and vertical jump height. Also, our findings indicate that an acute bout of static stretching (SWU) does not significantly affect any of the dependent variables in this study and that warm ups don't seem to affect most of these variables.

Eccentric Quadriceps Peak Torque

Perhaps the most important finding in this study is that the DWU acutely increased eccentric quadriceps strength significantly more than the control or SWU from pre to post testing. This appears to be the first research study that investigates the effects of a DWU on eccentric quadriceps peak torque. Furthermore, this also appears to be the first study that investigates the effects of a static stretching on eccentric strength, as most previous studies have focused on concentric strength. (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2004; Cramer, Housh et al. 2005).

We believe that the acute increase in eccentric quadriceps strength is a result of increased neural activity and motor unit recruitment following the DWU. A general active warm up, which increases muscle and core temperature, has been shown to acutely increase motor unit recruitment and neural activity (Bishop 2003), which improves the rate and coordination of motor unit firing and produces more strength. This would explain the significant increase reported for the DWU and why an increase was not observed in the SWU or CON groups, since by nature the DWU group performed a longer active warm up. Furthermore, a recent study provides evidence that a longer active warm up may be beneficial for increasing lower extremity muscle performance (Racinais, Blonc et al. 2005). Therefore the active warm up inherent in the DWU may have caused a strength increase in quadriceps eccentric peak torque.

Dynamic stretching could be another explanation for the DWU group's increase in eccentric quadriceps strength. . A previous study demonstrated a significant increase in leg extensor power following a series of dynamic flexibility exercises (Yamaguchi and Ishii 2005). Dynamic flexibility could cause short-duration performance increases through increasing temperature (Bishop 2003), as well as post-activation potentiation (Sale 2002) due to the active contractions associated with dynamic stretching. Increasing muscle temperature has been shown to benefit performance through increasing blood flow and neurological efficiency (Bishop 2003). Furthermore, post-activation potentiation has been noted to increase performance in activities involving speed and power (Hodgson, Docherty and Robbins 2005). Previous contractions of a muscle cause an increase in calcium and drives more cross bridges between the actin and myosin which produces more force. The previous contractions also cause changes in the neurological system, which is reflected by changes in the H-reflex (Hodgson, Docherty et al. 2005). Therefore, if the previous contraction had a fast rate of force development and acceleration then the post-activation potentiation could increase peak velocity and power during the performance of dynamic muscle contractions (Hodgson, Docherty et al. 2005).

The DWU protocol could prime the quadriceps muscles to perform better eccentrically by increasing the functional efficiency of the actin and myosin. For eccentric contractions, the external load exceeds the force produced by the cross bridges between the actin and myosin. This causes the actin and myosin to reattach and pull apart which causes a greater tension than a concentric contraction (Perrin 1993). In this study, as the subject decelerated at the end of the run phase, they activated their quadriceps eccentrically to control this motion. The eccentric force to decelerate the body increased as the run phase reached a maximal sprint. Therefore the increased external resistance from slowing body momentum caused increased force and tension development. Since this occurred at high speeds, the quadriceps would have the ability to produce more force against a slower contraction, such as the testing speed used in this study (60 degrees/second)

Finally, the theory of reciprocal inhibition may explain the acute eccentric strength increases. Applying this theory, if the hamstring muscles are tight, then that tightness may result in inhibition of the antagonist muscles, the quadriceps. Thus the reverse would also be true. If the hamstring length increases following dynamic stretching, then the quadriceps muscle would be less inhibited and have the potential to produce more force (Clark and Russell 2001). In the current study, an increase in hamstring flexibility was observed, which may explain the mechanism for improvement in quadriceps strength

Aside from the performance gains, the ability of the body to increase eccentric quadriceps strength could also produce protective measures against quadriceps muscle injury. Most quadriceps muscle strains occur during deceleration or “braking” (Orchard 2002), as the muscle eccentrically contracts to slow the body's velocity while the body leans backward. This movement places an increased stretch on the rectus femoris muscle, which is the most commonly strained muscle of the quadriceps group. Increasing eccentric strength may possibly provide an ability to absorb more force and reduce the risk of injury.

Hamstring Flexibility

Another interesting finding was that the DWU acutely produced a greater increase in hamstring flexibility than the SWU or CON groups. However, the DWU pre-test value was significantly less than the CON or SWU group at pre-test. Therefore it is possible that the DWU group had more limited hamstring flexibility prior to the DWU, causing a greater potential for change. However, the difference in hamstring flexibility from pre to post testing in the DWU group (9.6º) is much greater than the CON (0.09º) or SWU (3.2º). Thus, the DWU could be more effective at acutely increasing hamstring flexibility regardless of flexibility starting point.

This appears to be the first study to observe the acute effects of a DWU on hamstring flexibility, although there is one study which investigates the training effects of dynamic range of motion (DROM) and static stretching on hamstring flexibility over six weeks (Bandy, Irion et al. 1998). Although comparing the two studies is difficult due to the different protocols in the studies, an argument could be made that the training results were a reflection of the daily acute gains from the treatment groups. The results of this current study contradict the results of the previous study in that the DWU group had significant increases from the static stretching (SWU) group. In the previous study, the static stretching group more than doubled the increases of the DROM group (Bandy, Irion et al. 1998). Differences between the studies treatment protocols may explain the contradictions. In the DROM training group, the subjects performed active knee extensions from a 90-90 position, whereas this current study's DWU group used momentum, body weight, and multi-muscle groups to bring a series of joints through a full range of motion.

In our current study, the acute bout of static stretching in the SWU group produced no significant increase in hamstring flexibility. This contradicts previous studies (Godges, MacRae et al. 1989; DePino, Webright et al. 2000; de Weijer, Gorniak et al. 2003). The reason for the disagreement is most likely due to the differences in duration of hamstring stretching. In the previous studies, total stretching lasted between one and a half minutes (DePino, Webright et al. 2000) and 10 minutes (de Weijer, Gorniak et al. 2003). Subjects in our study only stretched the hamstring muscles for 40 seconds total, which may not have been enough to cause increases in hamstring length. Furthermore, the method of hamstring length measurement in the previous studies included passive flexibility, whereas the current study used the quadriceps muscle to extend the knee actively.

The increase in hamstring length observed in DWU group is possibly due to the active warm up and active contractions. The DWU spent 15 minutes of an active warm up, and the SWU only performed an active warm up for 5 minutes. The extended time could increase muscle temperature and improve viscoelasticity and pliability of the musculotendinous unit. Furthermore, an active contraction of the quadriceps muscle to extend the knee was used to measure hamstring flexibility. Since the DWU frequently used the quadriceps muscles, an increased efficiency of the muscle to contract could cause the quadriceps to pull the leg into further extension and display more of an increase in hamstring length than the SWU group which did not use active quadriceps contractions. Therefore, the DWU acutely increases hamstring flexibility more efficiently than a SWU protocol or no warm up at all. Since hamstring inflexibility is a risk factor for muscle injury, this warm up may reduce injury risk, assuming that acutely increasing hamstring flexibility has preventative measures.

Concentric Quadriceps Peak Torque

Although a significant interaction was found, it was not between pre and post testing for any of the groups. Therefore, none of the individual warm ups caused significant changes from pre to post testing. However, a trend toward significance was found with the DWU group as it appeared to have larger increases than the SWU or CON from pre to post testing. Although we believe this to be the only study which observed the acute effects of a DWU on concentric quadriceps peak torque, there have been multiple studies which observe the acute effects of static stretching on concentric quadriceps peak torque (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2004; Cramer, Housh et al. 2005). The findings in this study contradict those of the previous studies. In this current study the SWU did not show significant decreases in concentric quadriceps peak torque, but in the previous studies significant decreases in quadriceps peak torque were consistently noted. This could be explained by the shortened static stretching time in the SWU when compared to the previous studies. In the current study, the quadriceps received only 40 seconds of static stretching, whereas in the previous studies the quadriceps received multiple minutes of static stretching. Those previous studies state neural inhibition was the mechanism for the strength decreases (Nelson, Guillory et al. 2001; Cramer, Housh et al. 2005). Since this study reported no significant changes in quadriceps flexibility, the autogenic inhibition phenomenon may not have occurred, and thus concentric quadriceps peak torque did not decrease. Finally, in this current study, we did not have enough subjects to produce adequate power to reject a true null hypothesis.

A trend towards a significant increase in concentric quadriceps peak torque after a DWU could be due to the same benefits of an active warm up and active contractions that were mentioned previously for the increase in eccentric quadriceps strength. Also, this finding could provide more evidence toward reciprocal inhibition, since both concentric and eccentric strength was improved as hamstring length increased.

Quadriceps, Hip Flexor, and Rectus Femoris Flexibility

With regard to quadriceps, hip flexor, and rectus femoris flexibility, no significant changes were seen after any of the warm up treatments. We did not find other studies which observed the acute effects of a DWU on quadriceps and hip flexor, and rectus femoris flexibility. One study investigated quadriceps and hip flexor flexibility following an acute bout of static stretching (Young, Clothier et al. 2004). This study revealed that 4.5 minutes of static stretching did not significantly increase quadriceps flexibility or hip flexor flexibility as measured by the Thomas Test from baseline measurements, which supports our results. Another study investigated the training effects of a static stretching and active range of motion on passive hip extension, as measured by the Thomas Test, over a six week period of time (Winters, Blake et al. 2004). This study revealed that both active and passive stretching increased hip flexor flexibility. Several differences between this study and our study should be noted. First, the subject population in the previous study included subjects whom displayed a loss of hip flexor flexibility initially. In the current study, no differences may have been seen since our subjects did not have limited hip flexor flexibility. Second, differences may be due to the reduced time of stretching in the SWU protocol when compared to the previous study, as the previous study stretched the hip flexors for 240 seconds and the current study stretched the hip flexor for only 40 seconds. Finally, differences may not have been observed due to the method of measurement, as in the previous study the Thomas Test was used to measure hip extension, and in the current study an active straight leg hip extension test was used.

Hamstring Peak Torque

Concentric and eccentric hamstring peak torques as well as the hamstring to quadriceps ratio was not significantly impacted by the acute warm up treatments. To our knowledge this is the first study that investigates hamstrings concentric and eccentric peak torque following an acute bout of a DWU. Furthermore, although much research has investigated the effect of stretching on quadriceps strength, this is the first study to investigate the acute effects of static stretching on hamstring strength.

This finding is interesting in light of this current study's result in hamstring flexibility. The current study found no change in hamstring flexibility after an acute bout of static stretching (SWU). It is thought that gains in ROM from static stretching are achieved through a process called autogenic inhibition (Shellock and Prentice 1985). Since this study showed no significant increases in hamstring flexibility due to the SWU, autogenic inhibition may not have occurred and thus hamstring strength did not decrease. It is possible that if the stretching time for the hamstring increased in the SWU group, then autogenic inhibition may possibly occur, and decrease hamstring strength as it has for gastrocnemius strength (Fowles, Sale et al. 2000) and quadriceps strength (Nelson, Guillory et al. 2001; Cramer, Housh et al.

2004; Cramer, Housh et al. 2005). Interestingly, the current study showed that the DWU increases hamstring flexibility but has no change in concentric and eccentric peak torque. This is important and may suggest that DWU increased hamstring flexibility while maintaining its strength of the muscles that were elongated, which vastly differs from the static stretching literature. Perhaps the mechanism of flexibility for the DWU is more temperature related, where as the increase due to static stretching is based on autogenic inhibition. Thus the DWU would provide protective measures against muscular injury risk by increasing hamstring flexibility and maintaining hamstring strength.

Reasons also exist which may explain why the DWU did not significantly increase hamstring strength. First of all, the DWU doesn't include exercises which specifically isolate and target the hamstring muscles and thus prime them to have an acute increase in peak torque. Another reason could be due reciprocal inhibition. Reciprocal inhibition states that a flexibility increase in the agonist will increase antagonist strength. Since no increase in quadriceps flexibility was seen, it would make sense that hamstring peak toque would not be affected.

Hamstrings to Quadriceps Peak Torque Ratio

Both concentric hamstrings to concentric quadriceps and eccentric hamstrings to concentric quadriceps ratios were not significantly different after the DWU or SWU treatments. To our knowledge this was the first attempt to observe the acute effects of a warm up protocol on hamstrings to quadriceps ratios. This finding makes sense since no significant difference in concentric or eccentric hamstring, or concentric quadriceps peak torque was found. Therefore the ratios were based upon data that showed no significant changes from pre to post warm up treatments. Although no changes were seen, all the ratio's were within "normal" range already, therefore theoretically it did not predispose them to injury (Rosene, Fogarty et al. 2001).

Vertical Jump Height and Power

Finally, no significant difference in VJ height was noted following the DWU or the SWU. To our knowledge one study has investigated the effects of an acute bout of a DWU and static stretching on vertical jump height (Faigenbaum, Bellucci et al. 2005). Our results both agree and disagree with these findings. They agree because the DWU in both studies found no significant increase in vertical jump and disagree because the static stretching group revealed a significant decrease in vertical jump height in the former study (Faigenbaum, Bellucci et al. 2005). This difference may have occurred due to the methods of the studies. In the former study, the methods did not include a pre-test for all their variables. Therefore, it is difficult to definitively state that the static stretching group produced significantly larger decreases than the dynamic group. Also, the testing session followed the same testing procedure for all conditions, with vertical jump being the first one tested resulting in a possible order effect. In our study, vertical jump was either the second or third of three variables tested during post test. The difference in order may have minimized any temporary deficits in jumping performance. Furthermore, a study that investigated the acute effects of ballistic stretching on vertical jump performance (Unick, Kieffer et al. 2005) revealed similar results in that an acute bout of ballistic or static stretching had no significant increase or decrease in vertical jump height.

In contrast to our findings, many other studies show significant decreases in vertical jump performance following an acute bout of static stretching (Nelson, Cornwell et al. 1996; Cornwell, Nelson et al. 2002; Young and Behm 2003; Faigenbaum, Bellucci et al. 2005; Wallmann, Mercer et al. 2005). Many of these past studies often had unrealistic static stretching protocols that were much longer than most realistic static stretching methods; except for one study which followed practical timelines and still had decreases (Faigenbaum, Bellucci et al. 2005). For the most part, when static stretching protocols were shorter and within the time frame of actual clinical practice, significant decreases were not seen (Church, Wiggins et al. 2001; Young and Elliott 2001; Power, Behm et al. 2004).

Initially, we hypothesized that the DWU would cause an acute increase in strength, while the SWU group would cause a decrease in strength; and the difference between the two would possibly be significant. Since no significant increases in concentric quadriceps peak torque following the DWU or significant decreases in concentric quadriceps peak torque following the SWU were observed, then leg extensor power may not have been changed. If leg extensor power was not changed, then it makes sense that vertical jump height and power would be unchanged.

Limitations

A limitation of the study is limited power (0.104 to 0.42) for most of the dependent variables. A larger sample size would have increased power. However, the effect sizes for the non significant dependent variables were also very small (0.002 to 0.27). Therefore, the differences were small to begin with and may not be found to be clinically significant even if more subjects are included in the study.

The ability to generalize these findings is also limited since, we only evaluating soccer players. More specifically, the findings of this study only apply to recreational soccer players between the ages of 18 and 30 years old. We utilized a single sport because warm up methods are very sports specific and this DWU sequence was designed for soccer players. Even though the applications are limited, there are many athletes who fall under this category that would benefit from the DWU. Furthermore, these findings may also apply to all field sports which are similar to soccer and involve sprinting, cutting, and jumping.

Another possible limitation involves the difference in body temperature and VO_2 levels between the DWU and the SWU. Although this was not directly measured, subjectively it appeared that subjects in the DWU group had a higher body temperature, displayed by more perspiration, and possibly higher VO2 increase, observed by heavier breathing, than the SWU group. However, the DWU and the SWU treatments were designed to closely resemble common warm up protocols of athletic teams. Therefore, even though temperature was not controlled for the laboratory setting the results of this study apply directly to the athletic setting, which is arguable more important.

These findings only apply to this specific sequence of a DWU. Other sequences which include different exercises or time durations may produce other results. However, the current study did follow a pattern that defines the DWU, which is using a progressive series of tasks to gradually prepare the body for activity. Therefore, these findings may also apply to different DWU sequences that are also progressive in nature.

Finally, it is difficult to say which part of the DWU was largest contributor in increasing hamstring flexibility and quadriceps strength. It could have been the dynamic flexibility or the continuous active warm up which produced these benefits. Although it would be interesting to find out which part of the DWU most influenced these variables, it is not a crucial point, since all of these components comprise the DWU in clinical practice.

A larger sample size per group would have increased power. However, the effect sizes for the small powered dependent variables were also very small (0.002 to 0.27). Therefore, the differences were small to begin with and may not be found to be significant even if more subjects are included in the study. Furthermore, the findings of this study only apply to recreational soccer players between the ages of 18 and 30 years old. These parameters were established because warm-up methods are very specific to sport and this DWU sequence was originally designed for soccer players. Also, there is still a very large population who fall under this category. Furthermore, these findings may also apply to all field sports which involve similar movements to soccer and involve sprinting, cutting, and jumping.

Another possible limitation involves the difference in body temperature and VO_2 levels between the DWU and the SWU. Although this wasn't directly measured, it appeared that subjects in the DWU group had a higher body temperature displayed by more perspiration, and possibly higher VO2 increase observed by heavier breathing than the SWU group. However, the DWU and the SWU treatments were designed to closely resemble common warm up protocols of athletic teams. Temperature was not controlled in order to make the study more externally valid and applicable to the athletic setting.

Furthermore, these findings only apply to this specific sequence of a DWU. Other sequences which include different exercises or time durations may have produced other results. However, the current study did follow a pattern that defines the DWU, which includes a progressive nature to gradually prepare the body for activity. Therefore these findings may also apply to different DWU sequences that are also progressive in nature.

Future Research

A randomized, prospective study using the DWU and the SWU and measuring subsequent injury rates would be ideal to provide evidence that one warm up is better or no different at reducing injury rates. Based on the results of this study it is possible to speculate that the DWU could reduce hamstring and possibly rectus femoris muscle strain injury rates. Second, whether or not the training effects of the DWU occurred with flexibility, strength, speed, agility, and balance should be investigated. Since the DWU displayed an acute increase in hamstring flexibility, it is logical to say that this flexibility would be increased over training period. Strength would probably not increase since body weight would not be enough stimulus to cause overload and thus hypertrophy adaptation. There is evidence that dynamic flexibility acutely increases sprint speed, therefore it is possible that the DWU would have a training effect of increased speed. Third, the DWU could benefit other short term performance measures including balance and reaction time, as well as long term performance as in a mile run. Thus, its applicability to other tasks should be investigated. Fourth, it would be interesting to see if adding a DWU protocol in the rehabilitation plan for a muscle injury would produce quicker results and lower re-injury rates. Since this warm up is progressive and contains all the components of a muscle strain rehabilitation program, it would allow the clinician to condense the components of the rehabilitation and bring an athlete to their highest intensity below the threshold of re-injury in a controlled setting.

Clinical Significance

Overall, the results of this study indicate that performing a DWU will acutely increase hamstring flexibility and eccentric quadriceps strength. Hamstring strain injury is commonly reported as one of the most frequent injured lower extremity muscles. Furthermore, inflexibility is reported as a risk factor for hamstring muscle strain injury. Since the DWU increased hamstring flexibility more than the SWU it is possible that the DWU is better than the SWU at protecting against hamstring strain injury. Furthermore, the DWU improved eccentric quadriceps strength acutely which benefits performance since eccentric contractions are necessary to control the body during athletic movements. Finally, these findings provide evidence to support the theory of reciprocal inhibition, as quadriceps strength increased when hamstrings flexibility improved.

To our knowledge, no study has compared the effects of a dynamic versus a standard warm-up on muscular injury risk factors, such as muscle strength and flexibility, or on performance factors including vertical jump height and power. This information provides clinicians and athletes with evidence that the DWU is possibly a better choice pre-activity than the SWU.

Appendix D: IRB Materials

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Subjects
Biomedical Form

IRB Study #_05-EXSS-697__
Consent Form Version Date: _November 18, 2005_

Title of Study: A Comparison of a Standard Warm-Up Model and a Dynamic Warm Up Model on Flexibility, Strength, Vertical Jump Height, and Vertical Jump Power

Principal Investigator: Alain J. Aguilar, BS
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 919-962-7187
Email Address: alaguila@email.unc.edu
Co-Investigators: Darin Padua, PhD, ATC, Kevin Guskiewicz PhD, ATC, Cathy Brown MA, ATC, Dan Herman PhD student
Faculty Advisor: Darin Padua, PhD, ATC

Study Contact telephone number: 475-9785
Study Contact email: alaguila@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
The purpose of this research study is to compare the effects of a standard warm-up (i.e. jogging and static stretching) to a dynamic warm-up on flexibility, strength, and vertical jump height and power in male and female soccer athletes.

Are there any reasons you should not be in this study?
You should not be in this study if you have been withheld from participation due to a lower extremity muscle strain injury in the past six months or if you are currently undergoing treatment or are symptomatic due to a lower extremity injury. Also, you should not participate in this study if you have any other injury which may be worsened or hinder your ability to warm-up.

How many people will take part in this study?
If you decide to be in this study, you will be one of approximately 45 people (males and females) in this research study.

How long will your part in this study last?
Your participation in this study will last between 90-130 minutes. If you are in the standard warm-up or control group, your participation in this study will last one session of approximately 90 minutes. If you are in the dynamic warm-up group, your participation in this study will last three sessions, consisting of two familiarization sessions that last 20 minutes each and one testing session lasting approximately 90 minutes, for a total of 130 minutes.

What will happen if you take part in the study?
During the course of this study, the following will occur:

You will be asked to report to the Sports Medicine Research Laboratory in Fetzer Gymnasium, wearing a t-shirt, athletic shorts and shoes. Upon arrival, you will be asked to fill out a general fitness and lower extremity history questionnaire. You will be randomly assigned into one of three testing groups: the control group, the standard warm-up group, or the dynamic warm-up group. Your assignment will be based upon drawing numbers out of a hat, which correspond with a certain warm-up group. The difference between the groups is the type of warm-up you will perform during the testing session and the number of times you will be asked to report to the Sports Medicine Research Laboratory. If you are assigned to the control or standard warm-up group, you will report for only one session. If you're in the Dynamic Warm-up group you will be asked to participate in two training sessions on separate days, no sooner than twenty-four hours and no later than one week apart. Then you will be asked to schedule your testing session, no sooner than twenty-four hours and no later than one week. During the familiarization sessions, you will watch an instructional video and perform the dynamic warm-up to become familiarized with the procedures. After watching the video, you may ask any questions about the nature of the dynamic warm-up.

At the time of testing, you will be seated on a machine that tests thigh muscle strength. You will have two tasks: to straighten your knee against resistance, then resist the machine as it bends your knee, and then you will resist the machine as it straightens your knee, then bend your knee against resistance. You will be given some practice, and then be asked to perform three trials of each task at maximal effort. Then, you will stand on a force plate and be asked to perform three vertical jumps as high as you can, with your arms on your hips. You will have one minute to rest between vertical jumps. After that, you will be asked to lie on a table, and will be assessed on angles of knee and hip motion. Following that, you will begin the warm up treatment, depending on what group you are in.

- If you're in the control group you will sit in a chair for fifteen minutes

- If you're in the Standard Warm-up group you will be asked to cycle on a stationary bike at a low intensity for five minutes. Then you will be asked to perform a series of leg stretches, including the calf, thighs, and "butt" muscles for 10 minutes.
- If you're in the Dynamic Warm-up group you will be asked to cycle on a stationary bike at a low intensity for five minutes. You and the primary investigator will then go to an empty, open gym space in Fetzer Gymnasium to perform the dynamic warm-up that you were previously familiarized with.

After the warm-up treatment, you again be tested on the same three tests as before. The flexibility assessment will be first, followed by either the vertical jump or strength test.

What are the possible benefits from being in this study?
Research is designed to benefit society by gaining new knowledge. The knowledge gained will provide clinicians with more evidence at to which method of warming-up is most efficient at gaining flexibility, vertical jump height and power, as well as strength right before physical activity. The benefits to you from being in this study may be gaining knowledge of a different type of warm-up which you may use as an alternative or in addition to your current methods of warming-up

What are the possible risks or discomforts involved with being in this study?
This study will involve the same risks as would accompany any non-contact physical activity warm up or match play, including muscle strains and soreness. In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

What if we learn about new findings or information during the study?
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?
No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. All participants will be assigned an identification number and the identification number will be used to identify the subject throughout all testing trials. Only the principal and co-investigators will have access to the identification numbers. All records will be stored in a locked filing cabinet in the Sports Medicine Research Laboratory. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?
All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance

company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?
You can withdraw from this study at any time, without penalty. You may refuse to participate, or may withdraw your consent to participate at any time, and for any reason. The investigators also have the right to stop your participation at any time. This could be because the entire study you have had an unexpected reaction, or because the entire study has been stopped.

Will you receive anything for being in this study?
You will be receiving an instructional video tape of a dynamic warm-up for taking part in this study. No monetary compensation is provided.

Will it cost you anything to be in this study?
There will be no costs to you for participating in this study.

What if you are a UNC student?
You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

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Title: A Comparison of a Standard Warm-Up Model and a Dynamic Warm Up Model on Flexibility, Strength, Vertical Jump Height, and Vertical Jump Power

Principal Investigator: Alain J. Aguilar
IRB Study # 05-EXSS-697

Subject's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

____ __________________
Signature of Research Subject Date

____
Printed Name of Research Subject

____ __________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

Healthy Participant Questionnaire
Subject ID ______

A Comparison of a Standard Warm-Up Model and a Dynamic Warm Up Model on Flexibility, Strength, Vertical Jump Height, and Vertical Jump Power

Please answer the following questions:

1. Do you currently have a lower extremity injury (i.e. muscle strains, and ligament sprains)? YES NO

   If Yes explain: ____

   ____

2. Have you had a muscle strain in your lower extremity in the past six months? YES NO

   If yes explain: ____

   ____

3. Do you regularly engage in physical activity for at least 30 minutes, three times per week? YES NO

   If no explain: ____

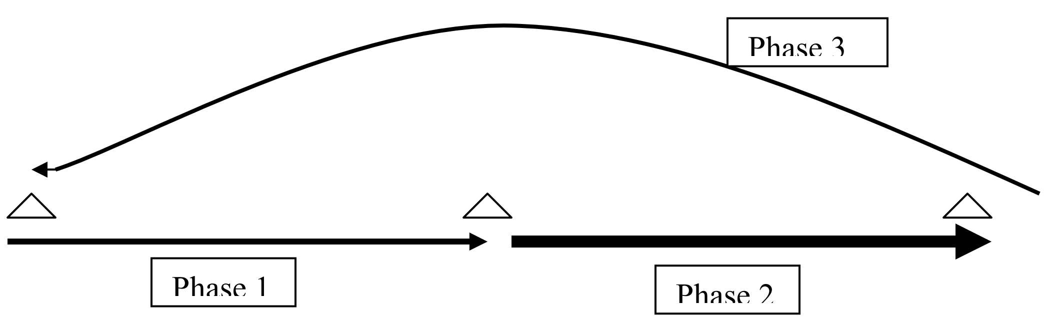
   ____

Static Stretching Description and Sequence:

1. Standing gastrocnemius stretch (twice): participants will place their fully extended arms on and lean against a wall, while having one leg extended backward with the heel on the ground, they adjust the distance of their back heel to the wall in order to feel a stretch.
2. Standing Hamstring stretch: participants will stand while placing their heel on a table the same height as their iliac crests. The participants will place their hands on their hips and flex forward from the hips until they are at the point of "stretch". They will be monitored for any compensations of lumbar or thoracic forward flexion.
3. Standing Quadriceps stretch (twice): participants will adjust a table to match their hip height. Then they will be instructed to flex their knee, and place their anterior ankle on the table. Slowly they will flex their knee to the point of stretching. After that point is reached, they will hold that position for the time previously established.
4. Standing Hamstring stretch: see above
5. Gluteus Stretch: participants will lie supine and will place one foot/ankle on their opposite flexed knee. They will be instructed to pull their knee to their chest, which will stretch the opposite leg's gluteus maximus.
6. Hip Flexor Stretch: participants will perform a kneeling lunge, facing a wall. Their back knee will be on the ground, while their front leg will be flexed at the hip and knee. They will be instructed to flex their back knee and hold their ankle anteriorly. They will then slowly pull their ankle to their gluteal area, while leaning forward toward the wall until a stretch is felt. Participants will place opposite hand against the wall for balance support.
7. Gluteus Stretch: see above
8. Hip Flexor Stretch: see above

A Dynamic Warm-Up Model (Three Phases):

1. Active/Dynamic Flexibility Phase: A 10 yd area, where the athlete performs the "walking" flexibility exercises.
2. Progressive Run: A 10 yd area (immediately following phase 1) where the athlete runs a percentage of their "max" sprint. This percentage progresses from 50 to 75 to 90% as time elapses in the DWU
3. Active Recovery: The athlete jogs back to the starting point immediately following phase 2.



Dynamic Warm-Up Flexibility Description:

20. Heel Toe Walks – **Progressive run phase is at a jogging pace:** Participants will walk "on their heels" with their knees fully extended to eccentrically contract their anterior tibialis muscle – getting reciprocal inhibition of the gastrocnemius. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
21. Walking Gastrocnemius: Participants will step forward with one leg, and keep their back heel flat on the ground while their knee is flexed. Then they will contract their quadriceps and

tibialis anterior muscles to extend back knee. At the same time, participants will be instructed to move forward to the point of mild stretch on the back gastrocnemius muscle and then immediately release. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.

22. Forward Run: Forward run at a jogging pace.
23. Backward Run: "backpedal" for the first 10 yards, turn, and jog.
24. Russian Walk – **Increase progressive run phase to 50% of max speed**: Participants will lift one of their knees forward, while extending that limb's lower leg, mildly stretching the lifted limb's hamstring muscles. They will immediately lower the leg after a mild stretch is felt, and then they will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
25. Walking quad stretch: Participants will flex their knee to their gleuteal area and will assist the stretch with both hands until the point of mild stretch, and then the ankle will be released. They will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
26. Low amplitude butt kick (heel kicks): Participants will perform "butt kicks", by quickly bringing their heel to their gluteal area and alternating legs without stopping. This will be done moving backward for the first 10 yards, then they will turn and run at 50% of max speed.
27. Walking hamstring stretch: Participants will place one leg forward, while keeping the knee extended, and put the heel of that leg on the ground. Participants will forwardly flex their hips while keeping their lumbar and thoracic spine in a neutral position. The participants will lean forward until mild stretch is felt, then release. Their arms will be crossed over each other. They will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
28. High knee pull: Participants will actively flex their hip and knee to their chest while balancing on the contra lateral limb. They will grasp their knee and stretch their hip extensors to the point of mild stretch, then release. They will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
29. Carioca with high knee drive: Participants will perform a carioca maneuver, which is lateral movement while crossing their legs. As they cross their trail leg forward, they will be instructed to flex their hip and knee and bring it as close to their chest as possible. This will be done for the first 10 yards, and then they will turn and run at 50% of their max speed. This will be performed one time each direction.
30. Walking Lunge with Transverse Reach – **Increase progressive run phase to 75% of max speed.**: Participants will lunge forward on one leg with their knee flexed and with their body erect until a mild stretch is felt in their trail leg hip flexor muscle. As they lunge forward, they will be instructed to control their body and rotate their arms and trunk to toward the side of their forward knee. They will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase..
31. Balanced Gluteal stretch: Participants will place one heel on opposite knee while standing, then squat down with the standing limb until a mild stretch is felt in the contralateral gluteal area and then release. They will bounce in between stretching the alternate limb as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
32. Prancing: Participants will leap forward and "reach" with one leg as to mildly stretch the hamstring muscles, while keeping the knee extended. Once the forward limb makes contact with the ground, momentum will carry the subject forward while forward limb moves into hip extension and propels the body forward. In the hip extension position, the hip flexor is

mildly stretched. The legs alternate and exercise will be performed three times each, until the end of the 10 yards, then the subject runs at 75% of their max speed.

33. High Skip**:** Participants will leap off of one leg with the opposite knee and hip flexed. When they land, they will immediately perform the same for the opposite leg. Participants will be instructed to skip and "jump" as high as they can. This will be performed three times each, until the end of the 10 yards, then the subject will run at 75% of their max speed.
34. Rear Leg swing**:** Participants balance on one leg, lean forward from waist and kick opposite leg backward in the sagittal plane, while slightly flexing their knee. The participants will be instructed to control their hip and "swing" their leg backwards until the point of mild stretch on their hip flexor muscles, and then release the stretch. They will bounce in between stretching alternate limbs as if jumping rope three times. Five repetitions for each leg will be performed within the 10 yard dynamic flexibility phase.
35. Backwards Run – **Increase Progressive run phase to 90% of max speed**: participants will be instructed to backpedal as quickly as possible for the first 10 yards, then turn and run at 90% of the participants max speed.
36. Shuffle for Speed: Participants will laterally shuffle without crossing their feet, leading with their dominant leg for the first 10 yards, and then turn and run at 90% of their max speed. This will be done once.
37. Run with a 360 degree turn: Participants will run at 75% of their max speed for the first 10 yards, and then stop and quickly turn one complete revolution to the right. The participants will then run at 90% of their max speed.
38. Run with a 360 degree turn: Participants will run at 75% of their max speed for the first 10 yards, and then stop and quickly turn one complete revolution to the left. The participants will then run at 90% of their max speed.
39. Acceleration to Sprint: Participants will gradually accelerate their speed so that they achieve their top speed after 10 yards, then they will run at their top speed for the progressive run phase

Club and Intramural Soccer Players needed to participate in a Dynamic Warm-Up research study!

Study will measure:

- Vertical jump height and power
- Knee strength
- Knee and hip flexibility

Study will require:

- One 90 minute testing session
- Two training/familiarization sessions of 20 minutes each if you are assigned into the dynamic warm-up group

You may not participate in the study if you have sustained a hip, thigh, knee, or ankle injury within the past 6 months.

Please contact Alan Aguilar at 919-475-9785 or alaguila@email.unc.edu if interested

Recruiting Script

My Name is Alain Aguilar. I'm a certified athletic trainer and a graduate student here at UNC.

I'm doing my thesis study on a dynamic warm-up which is a newer method of warming-up. It's the same warm-up that the UNC varsity men's soccer team uses before practice and games.

I'm looking to see whether a DWU can change flexibility, strength, and vertical jump immediately after the warm-up

Then I'll compare it to a regular warm-up – similar to jogging and static stretching to see which warm up does a better job at preparing the body for activity

If you decide to participate in the study, testing will only be done once and will last about an hour for most people. If you end up being in the DWU group you'll be asked to come in two times prior to learn and familiarize yourself with the DWU.

Unfortunately, you will not be paid for your participation, but you will receive a video of the "dynamic warm-up".

If you are interested or have questions, please hang around so that I can give you my contact information.

Thanks coach and thank you for your time.

Subject: INFORMATIONAL: Dynamic Warm-Up Study

Hello! We're looking for subjects to participate in a study comparing different warm-ups for soccer athletes. You will receive a copy of the UNC Varsity Men's Soccer Team dynamic warm-up upon completion of your testing session.

We need both males and females who play soccer (outdoor or indoor) on a team or league, and who participate in physical activity 2-3 times per week. Participants must not have a current injury or illness that prevents them from playing soccer. All participants must be at least 18 years of age.

If you are eligible and willing to participate, you will come to the Sports Medicine Research Lab in Fetzer Gym (06-F) on the campus of UNC-CH. Testing consists of the pre warm-up measurements (flexibility, strength, and vertical jump height), followed by the warm-up protocol, and finally the post warm-up measurements (same as pre warm-up). Testing will last no longer than 1 ½ hours.

If you meet the requirements, and are interested in participating, please contact Alain Aguilar at alaguila@email.unc.edu. We will be happy to answer any questions or concerns that you may have.

Approved by Biomedical Institutional Review Board on November 18, 2005. Study number: 05-EXSS-697

Appendix E: Data Collection Materials

A comparison between a dynamic warm up model and a standard warm up model on flexibility, strength, vertical jump height, and vertical jump power.

PI: Alain Aguilar Fall 05 Name:_________________ E-mail ___________________
Subject #__________ Group/#______/___ Gender______
Mass in KG: _________ Height________ Date_________
Testing Order________Age________ R L Dominant

_____ (5 min) Start Time for Introductions
_____ (5 min) Informed Consent Signature and Forms
_____ (5 min) ROM testing
Hamstring ROM t1_______ t2_________ t3_________
Knee flex ROM t1_______ t2_________ t3_________
Hip Flexor ROMt1_______ t2_________ t3_________
Thomas Test Rom _______ t2_________ t3_________
_____ (2 min) VJ target set up
_____ (5 min) VJ test

_____ (8 min) Isokinetic set up
_____ (3 min) Isokinetic practice trials
_____ (1 min) Rest
_____ (5 min) Isokinetic Testing Knee ext/flex
_____ ***RPE***
_____ (1-2 min rest)
_____ (3 min) Isokinetic practice
_____ (1 min rest)
_____ (5 min) Isokinetic Testing Knee ext/flex
_____ ***RPE***

_____ **(15 min) REST**
_____ (5 min) Stationary Bike ***RPE***_____
_____ (10 min) CON or SWU or DWU

_____ (5 min) ROM testing
Hamstring ROM t1_______ t2_________ t3_________
Knee flex ROM t1_______ t2_________ t3_________
Hip FlexorROM t1_______ t2_________ t3_________
Thomas Test Rom _______ t2_________ t3_________
_____ **(2 min) REST**
_____ (5 min) VJ test

_____ (1 min) Rest
_____ (5 min) Isokinetic Testing Knee ext/flex
_____ ***RPE***
_____ (1-2 min rest)
_____ (5 min) Isokinetic Testing Knee ext/flex
_____ ***RPE***

Standard Warm-Up Sequnce

R calf	0:00-0:20	3 s rest
R calf	0:23-0:43	3 s rest
L calf	0:46-1:06	3 s rest
L calf	1:09-1:29	4 s rest
R add	1:33-1:53	3 s rest
R add	1:56-2:16	3 s rest
L add	2:19-2:39	3 s rest
L add	2:42-3:02	5 s rest
R glut	3:07-3:27	3 s rest
R glut	3:30-3:50	3 s rest
L glut	3:53-4:13	3 s rest
L glut	4:16-4:36	6 s rest
R hip	4:42-5:02	3 s rest
R hip	5:05-5:25	5 s rest
L hip	5:30-5:50	3 s rest
L hip	5:53-6:13	5 s rest
R ham	6:18-6:38	3 s rest
R ham	6:41-7:01	3 s rest
L ham	7:04-7:24	3 s rest
L ham	7:27-7:47	6 s rest
R quad	7:53-8:13	3 s rest
R quad	8:16-8:36	3 s rest
L quad	8:39-8:59	3 s rest
L quad	9:02-9:22	

Dynamic Flexiblilty Sequence

1. Heel-toe walks
2. Walking gastroc
3. forward run
4. backward run
5. Russian walk – increase to 50%
6. Walking quad stretch
7. Low amplitude butt kick (heel kicks)
8. Walking hamstring stretch
9. High knee pull
10. Carioca with high knee drive
11. Walking Lunge with Transverse Reach
12. Balanced Glute stretch
13. Dynamic Skip or Prancing – increase to 75%
14. High Skip
15. Rear Leg swing
16. Backward Run – increase to 90%
17. Shuffle for speed
18. Run with a 360 turn
19. Repeat with turn opposite direction
20. acceleration of run to sprint

6 no exertion at all
7 extremely light
8
9 very light
10
11 light
12
13 somewhat hard
14
15 hard (heavy)
16
17 very hard
18
19 extremely hard
20 maximal exertion

Appendix F: Raw Data

Sub		Group	hspre1	hspre2	hspre3	hspreav	hspos1	hspos2	hspos2	hsposav	qpre1
1	♀	1	1	2	2	1.7	2	3	6	3.7	127
2	♂	1	33	32	31	32.0	33	33	33	33.0	124
3	♀	2	8	8	8	8.0	8	7	10	8.3	136
4	♀	3	2	2	1	1.7	0	0	-1	-0.3	141
5	♀	1	8	8	8	8.0	9	8	9	8.7	125
6	♀	2	15	14	15	14.7	7	6	8	7.0	131
7	♀	3	23	22	20	21.7	13	12	12	12.3	141
8	♂	2	20	15	13	16.0	13	12	13	12.7	132
9	♂	3	33	31	32	32.0	31	27	26	28.0	118
10	♀	1	19	14	14	15.7	18	17	19	18.0	142
11	♀	2	29	26	27	27.3	35	36	30	33.7	128
12	♂	1	31	33	31	31.7	24	26	27	25.7	130
13	♂	2	12	10	12	11.3	14	12	11	12.3	137
14	♀	3	13	15	16	14.7	11	9	11	10.3	129
15	♀	1	12	12	11	11.7	7	9	9	8.3	135
16	♂	3	12	11	13	12.0	9	7	7	7.7	121
17	♂	1	34	37	37	36.0	46	45	43	44.7	121
18	♂	2	39	41	41	40.3	38	36	38	37.3	126
19	♂	3	37	37	38	37.3	27	25	24	25.3	121
20	♂	1	19	18	18	18.3	32	32	32	32.0	146
21	♂	2	26	24	25	25.0	23	24	25	24.0	111
22	♀	2	32	30	29	30.3	22	20	17	19.7	131
23	♂	3	35	36	37	36.0	19	20	15	18.0	134
24	♂	1	23	27	23	24.3	28	28	30	28.7	114
25	♀	3	29	27	28	28.0	17	16	14	15.7	119
26	♂	2	37	35	36	36.0	33	33	29	31.7	130
27	♂	3	31	30	26	29.0	18	18	15	17.0	120
28	♂	1	36	34	35	35.0	24	27	24	25.0	124
29	♂	2	25	29	28	27.3	36	34	33	34.3	118
30	♂	3	45	44	44	44.3	30	28	27	28.3	125
31	♂	1	7	6	5	6.0	4	4	2	3.3	115
32	♀	1	17	14	14	15.0	17	19	16	17.3	138
34	♂	2	22	21	18	20.3	8	11	11	10.0	125
35	♂	3	57	47	52	52.0	33	38	34	35.0	120
36	♀	3	28	23	20	23.7	23	17	18	19.3	127
37	♀	1	24	28	24	25.3	18	18	22	19.3	125
38	♀	2	23	23	27	24.3	20	22	24	22.0	131
39	♀	1	18	12	10	13.3	15	12	9	12.0	142
40	♀	3	27	26	26	26.3	17	16	17	16.7	132
41	♀	2	1	2	1	1.3	-2	-1	-1	-1.3	125
42	♀	1	20	17	19	18.7	14	10	11	11.7	130
43	♂	3	9	8	8	8.3	5	1	3	3.0	119
44	♂	2	23	23	23	23.0	21	17	18	18.7	118
45	♀	3	30	30	29	29.7	18	17	16	17.0	125
46	♀	2	16	17	17	16.7	19	19	19	19.0	132

qpre2	qpre3	qpreav	qpos1	qpos2	qpos3	qposav	hfpre1	hfpre2	hfpre3	hfpreav	hfpos1	hfpos2
128	126	127	125	125	126	125.3	36	35	35	35.3	32	31
125	123	124	126	126	127	126.3	27	28	27	27.3	27	28
135	135	135.33	133	132	131	132.0	34	35	33	34.0	35	34
139	141	140.33	138	140	139	139.0	38	39	38	38.3	38	39
124	123	124	126	124	123	124.3	24	22	25	23.7	24	23
131	131	131	131	131	132	131.3	16	17	17	16.7	16	17
138	139	139.33	141	140	139	140.0	27	25	24	25.3	28	29
133	133	132.67	131	133	133	132.3	30	30	28	29.3	24	24
118	119	118.33	121	121	120	120.7	22	24	25	23.7	22	25
143	141	142	141	144	142	142.3	26	25	26	25.7	22	22
129	129	128.67	133	130	130	131.0	28	29	31	29.3	36	35
130	129	129.67	134	134	132	133.3	26	21	30	25.7	30	29
136	136	136.33	134	137	136	135.7	29	27	29	28.3	23	25
126	125	126.67	121	122	122	121.7	33	30	30	31.0	28	25
135	134	134.67	129	129	128	128.7	33	33	35	33.7	32	32
123	122	122	118	120	123	120.3	22	22	23	22.3	26	28
121	120	120.67	119	121	121	120.3	22	22	23	22.3	21	21
128	125	126.33	128	130	131	129.7	17	18	18	17.7	23	21
122	121	121.33	124	124	123	123.7	26	24	25	25.0	30	39
145	144	145	123	123	122	122.7	32	32	31	31.7	30	29
111	112	111.33	109	112	109	110.0	13	14	14	13.7	30	28
131	130	130.67	134	133	132	133.0	31	30	33	31.3	32	30
136	137	135.67	131	129	129	129.7	45	44	43	44.0	43	40
117	111	114	113	114	115	114.0	25	26	27	26.0	27	29
117	118	118	126	120	120	122.0	20	19	20	19.7	24	25
130	131	130.33	135	134	135	134.7	31	30	28	29.7	28	28
118	122	120	123	121	122	122.0	34	35	35	34.7	32	34
126	126	125.33	129	131	132	130.7	27	30	26	27.7	25	27
118	117	117.67	118	116	116	116.7	26	30	29	28.3	26	27
125	126	125.33	126	125	120	123.7	15	17	17	16.3	28	27
119	119	117.67	119	118	117	118.0	29	28	27	28.0	32	32
138	138	138	139	138	137	138.0	18	20	20	19.3	25	23
123	123	123.67	130	129	130	129.7	33	29	30	30.7	31	37
121	123	121.33	120	121	120	120.3	22	21	21	21.3	24	24
125	123	125	120	120	121	120.3	24	25	26	25.0	27	29
130	128	127.67	122	118	121	120.3	27	27	25	26.3	26	26
131	131	131	127	126	128	127.0	28	27	29	28.0	26	28
142	142	142	139	142	139	140.0	21	22	24	22.3	23	26
135	134	133.67	131	130	130	130.3	33	30	31	31.3	33	30
126	126	125.67	125	121	121	122.3	28	29	31	29.3	20	20
134	132	132	131	133	132	132.0	18	21	23	20.7	22	23
117	119	118.33	128	122	124	124.7	25	27	23	25.0	29	27
122	123	121	120	120	120	120.0	12	12	12	12.0	15	15
127	125	125.67	123	122	125	123.3	38	38	38	38.0	40	39
136	135	134.33	133	133	135	133.7	40	43	44	42.3	33	38

hfpos3	hfposav	ttpre1	ttpre2	ttpre4	ttpreav	ttpos1	ttpos2	ttpos3	ttposav	conqpre1	conqpre2
34	32.3	45	47	45	45.7	56	58	59	57.7	126.2	117.7
28	27.7	64	60	61	61.7	65	63	66	64.7	159.7	178.7
37	35.3	77	77	78	77.3	77	81	78	78.7	89.7	79.4
38	38.3	94	94	105	97.7	102	100	99	100.3	98.9	91.9
24	23.7	60	59	61	60.0	56	56	55	55.7	101.9	99.1
18	17.0	57	60	61	59.3	64	65	66	65.0	104.7	96.3
32	29.7	39	41	48	42.7	54	57	58	56.3	73.2	74
24	24.0	72	74	71	72.3	56	59	55	56.7	141.8	147
27	24.7	64	65	64	64.3	67	68	69	68.0	164.2	175.9
23	22.3	73	75	72	73.3	71	72	72	71.7	73.1	74.5
33	34.7	76	78	83	79.0	77	78	74	76.3	116.3	110.7
30	29.7	66	68	73	69.0	70	70	66	68.7	133.6	145.4
28	25.3	79	78	79	78.7	81	82	82	81.7	174.3	168.4
26	26.3	74	73	77	74.7	72	69	67	69.3	108.5	101.6
33	32.3	76	79	80	78.3	65	66	72	67.7	80.5	76.7
29	27.7	66	63	62	63.7	66	63	61	63.3	193.8	179.6
24	22.0	74	76	78	76.0	62	65	66	64.3	180	166.8
20	21.3	60	65	61	62.0	59	61	63	61.0	133.4	131.8
28	32.3	62	62	62	62.0	63	69	67	66.3	92.3	106.3
31	30.0	70	69	63	67.3	66	68	68	67.3	185.3	220.1
31	29.7	60	65	64	63.0	61	67	68	65.3	178.1	164.3
29	30.3	48	49	46	47.7	55	59	51	55.0	110.4	102.5
42	41.7	74	75	75	74.7	73	77	75	75.0	161.5	145.8
27	27.7	54	63	59	58.7	66	63	63	64.0	180.5	172.8
26	25.0	78	74	74	75.3	73	71	72	72.0	92.5	85.1
27	27.7	60	58	60	59.3	60	57	60	59.0	159.2	143.6
32	32.7	70	69	73	70.7	70	69	71	70.0	173.1	185.2
25	25.7	76	76	75	75.7	75	76	76	75.7	131.4	112.3
25	26.0	65	63	65	64.3	67	69	70	68.7	216.3	201.8
22	25.7	71	71	75	72.3	78	79	80	79.0	186.2	175
32	32.0	61	61	61	61.0	61	62	64	62.3	207.5	204.4
21	23.0	76	77	77	76.7	75	75	78	76.0	91.1	76
36	34.7	75	77	78	76.7	85	83	83	83.7	143.1	155.9
24	24.0	82	79	82	81.0	90	87	86	87.7	160.9	151.9
27	27.7	66	67	71	68.0	62	65	71	66.0	163.2	158.7
26	26.0	72	76	73	73.7	66	66	67	66.3	108.6	96.1
28	27.3	88	88	90	88.7	88	89	92	89.7	100.2	98.4
24	24.3	58	58	60	58.7	54	59	61	58.0	66.5	82.5
29	30.7	68	70	70	69.3	77	79	80	78.7	119.5	98
19	19.7	81	79	81	80.3	79	80	89	82.7	105.5	94.3
22	22.3	87	85	78	83.3	79	72	77	76.0	98.7	91
29	28.3	58	58	57	57.7	65	64	60	63.0	116.3	112.8
13	14.3	76	76	77	76.3	80	79	80	79.7	115.3	94.5
36	38.3	58	60	61	59.7	62	67	67	65.3	109.4	95.3
39	36.7	92	85	82	86.3	87	81	87	85.0	120.3	113.5

conqpre3	conqpreav	conqpos1	conqpos2	conqpos3	conqposav	eccqpre1	eccqpre2	eccqpre3
111.3	118.40	127.3	121.5	109.8	119.53	149.4	161.3	154.6
175.3	171.23	216.1	172.4	193.7	194.07	239.1	265.2	257.4
84.4	84.50	96.1	94.3	95	95.13	100.9	101.2	107.1
81	90.60	93.5	85.4	83	87.30	128.2	157.2	168
97.5	99.50	107.8	101.7	98.9	102.80	102.1	98.3	94.6
85.6	95.53	91.4	88.2	79.6	86.40	99.2	84.8	87.5
68.3	71.83	72.9	77.1	62.4	70.80	91.3	73.2	86.4
141.4	143.40	130.7	123.6	124.6	126.30	143.9	133.2	140.8
163	167.70	163.5	172.3	163.8	166.53	158	154.1	131.5
60.9	69.50	82.5	63.7	53.8	66.67	78.9	78.1	89.1
102.7	109.90	125.1	116.3	102.2	114.53	95.1	130.8	111.4
138	139.00	162.7	159.5	145.3	155.83	213.2	204.1	218.7
166.4	169.70	148.4	148.8	149.4	148.87	163.3	182.6	147.4
94.9	101.67	104.1	103.4	103.4	103.63	139.9	120.7	135.3
75.1	77.43	80.8	79.3	76.8	78.97	113	98.6	84.9
178.3	183.90	181.4	193.2	202.8	192.47	145.4	169.5	163
163.3	170.03	195.5	193.9	179.7	189.70	262.1	249.3	242.7
124.7	129.97	139.2	140.3	135.9	138.47	136.2	155.3	131.8
141.6	113.40	136	157.7	157.5	150.40	183.9	192.6	189.6
205.8	203.73	196.3	204.4	188.5	196.40	248.9	254.8	211.9
152.6	165.00	169.3	129.4	130.1	142.93	213.7	220.5	206.6
96.4	103.10	106.7	94.4	98.3	99.80	114.8	101.6	117
138.5	148.60	152.8	147.9	149.1	149.93	153.4	193.2	180.1
152	168.43	166.2	151.1	142.4	153.23	255.2	246.2	247.1
75	84.20	108.1	115.9	102.8	108.93	91.2	45	85.9
139.9	147.57	155.5	150.8	155.6	153.97	182.5	184.3	128.2
192	183.43	194.9	195	180.8	190.23	200.1	201	189.2
110.3	118.00	112.6	131.5	118.8	120.97	144.9	136.6	142.6
201.4	206.50	202.7	206.1	201.4	203.40	159.7	237.9	238.2
153.2	171.47	186.9	186.6	183.2	185.57	169	175.2	166.2
190	200.63	201.8	206.1	209.4	205.77	156.3	139.6	153.6
79.1	82.07	71.7	76.1	72.6	73.47	86	79.8	74.2
144.9	147.97	116.9	129.3	116.8	121.00	139.2	132.3	133.4
143.9	152.23	132.8	156.7	148.7	146.07	133.3	125.8	127.4
130.1	150.67	163.1	164.1	166.5	164.57	200.9	199.8	185.1
99.7	101.47	110.1	103.2	99.8	104.37	104.7	80.1	84.4
97.7	98.77	106.4	94.1	98.6	99.70	95.1	102.3	96.8
75.1	74.70	47.8	54.9	51.6	51.43	99.6	69.7	65.2
99.3	105.60	98.1	113.2	105.6	105.63	93.9	101.2	116.8
81.9	93.90	101.3	101.2	78.1	93.53	150.1	88.3	133.3
91	93.57	110.2	106.9	92.8	103.30	95.4	102.7	103.4
108.7	112.60	140.3	134.3	139.2	137.93	55.4	58.4	67.5
123.8	111.20	170.8	111.2	132.7	138.23	277.9	240.9	250.2
95.3	100.00	114.2	115.5	108.8	112.83	82.4	90.1	76.4
114.5	116.10	102.6	97.5	96.7	98.93	122.1	90.9	108

eccqpreav	eccqpos1	eccqpos2	eccqpos3	eccposav	conhpre1	conhpre2	conhpre3
155.10	175	166.6	160	167.2	-60.2	-60.9	-57.4
253.90	273.7	244.1	263.8	260.5	-73.1	-70.5	-72
103.07	93.4	76.9	44	71.4	-48.5	-48.6	-49.1
151.13	124.3	88	137.2	116.5	-52.6	-53	-43.6
98.33	102.2	104.3	112.2	106.2	-53.9	-54.2	-50
90.50	86.4	97.7	61.3	81.8	-53.3	-50.8	-53.2
83.63	83.6	75.8	82.5	80.6	-28.2	-28.9	-29.2
139.30	123.6	122.1	113.5	119.7	-79.4	-81.6	-72.1
147.87	202.3	188.1	209.4	199.9	-96.3	-99	-104.4
82.03	85	80.1	90.4	85.2	-32.7	-41.5	-37.2
112.43	114.5	129.2	84.4	109.4	-57.8	-63.3	-58.4
212.00	205.9	210.8	210.1	208.9	-66.4	-60.2	-62.3
164.43	186.7	195.9	169.5	184.0	-70.4	-71.4	-52.6
131.97	117.2	110.7	96.6	108.2	-60.8	-56.8	-59.4
98.83	105.7	108.6	89.3	101.2	-54.5	-50.8	-48
159.30	168.2	183.6	209.4	187.1	-111.9	-111.2	-105
251.37	262.1	254.1	252.3	256.2	-100.2	-91.6	-84.2
141.10	119.8	113.6	101.3	111.6	-67.4	-73.7	-66.1
188.70	189.6	194.1	196	193.2	-65.3	-76.7	-68.6
238.53	232.3	205.5	192.3	210.0	-107	-122.3	-119.2
213.60	200.8	234.6	218.4	217.9	-103.1	-100.9	-98.9
111.13	73	100.4	121.2	98.2	-51.9	-51.6	-44.7
175.57	193.8	208.2	218.1	206.7	-58	-57.3	-55.9
249.50	246.9	238.4	221.6	235.6	-96.3	-104.9	-84.4
74.03	93.7	87	101	93.9	-62.4	-62.9	-55.6
165.00	181.7	182.5	177.4	180.5	-78	-100.4	-95
196.77	227.6	230.9	229.2	229.2	-102.7	-97.6	-99.9
141.37	148.5	151.9	160.6	153.7	-66.8	-71.5	-68.4
211.93	176.8	232.2	198.8	202.6	-102.7	-79.6	-108.8
170.13	179.4	213.6	221.9	205.0	-93.3	-77.9	-60.5
149.83	164	188.3	197.9	183.4	-95	-87.6	-103.3
80.00	75.1	86.9	74.9	79.0	-35.8	-37.9	-41.2
134.97	97.9	59.1	106.6	87.9	-84	-82.3	-93.8
128.83	158.8	154.7	126	146.5	-82.5	-77.4	-80.1
195.27	208.1	214.8	211	211.3	-82.1	-79.8	-75.5
89.73	90.5	125.4	123.3	113.1	-66.8	-61.2	-55.2
98.07	115	101.7	95	103.9	-85.5	-69.7	-70.5
78.17	92.4	79.5	60.9	77.6	-33.1	-33.5	-37.6
103.97	133.2	156.8	138.2	142.7	-66	-69.1	-58.5
123.90	138.8	145.3	144.5	142.9	-50.9	-48.9	-50
100.50	108.5	113.5	112.7	111.6	-50.3	-41	-40.6
60.43	86.8	106.1	78.6	90.5	-66.6	-74.4	-73.6
256.33	279.7	282.2	276.9	279.6	-93.9	-89.1	-97.5
82.97	122.7	112	130.8	121.8	-42	-42.5	-53.9
107.00	116	119.4	119.8	118.4	-60.2	-60.9	-57.4

conhpreav	conhpos1	conhpos2	conhpos3	conhposav	ecchpre1	ecchpre2	ecchpre3	ecchpreav
-59.50	-64	-52.9	-54.3	-57.07	-116.3	-109.8	-96.4	-107.50
-71.87	-88.9	-82	-96.3	-89.07	-138.9	-140.4	-123.4	-134.23
-48.73	-51.2	-48.6	-44.2	-48.00	-70.7	-76.3	-86.3	-77.77
-49.73	-49.1	-47.5	-46.5	-47.70	-88.7	-88.2	-80.3	-85.73
-52.70	-56.7	-55.6	-51.8	-54.70	-76.9	-73.6	-71.5	-74.00
-52.43	-51.9	-56.9	-56.8	-55.20	-89.2	-69.8	-87.5	-82.17
-28.77	-37.8	-35.3	-39.1	-37.40	-73	-77.2	-73.6	-74.60
-77.70	-56.7	-68.1	-62.7	-62.50	-86.7	-96.5	-107.9	-97.03
-99.90	-96.1	-99.7	-99.2	-98.33	-143.2	-139.6	-150.1	-144.30
-37.13	-43.3	-44.8	-46	-44.70	-76.7	-74.5	-71	-74.07
-59.83	-63.1	-64	-63.6	-63.57	-128.2	-119.1	-119.1	-122.13
-62.97	-80.1	-73.3	-73.3	-75.57	-135.6	-131.1	-137.2	-134.63
-64.80	-65.6	-82.1	-72.1	-73.27	-140.1	-132.7	-135.9	-136.23
-59.00	-52.9	-58.3	-50.6	-53.93	-107.3	-90.2	-108.8	-102.10
-51.10	-49.3	-52.2	-52.6	-51.37	-100.7	-84.4	-83.4	-89.50
-109.37	-101.7	-97.4	-100.1	-99.73	-170.3	-169.8	-185.3	-175.13
-92.00	-93.8	-81.6	-71.7	-82.37	-136.9	-120.3	-106.6	-121.27
-69.07	-74.1	-66.8	-66.8	-69.23	-137.4	-111.2	-99.4	-116.00
-70.20	-88.7	-80.4	-75.2	-81.43	-175.3	-154.2	-149.1	-159.53
-116.17	-101.1	-101.4	-93.1	-98.53	-190.7	-188	-197.1	-191.93
-100.97	-114	-114.3	-112.6	-113.63	-154	-148	-131.7	-144.57
-49.40	-52.8	-46.8	-49.8	-49.80	-98.8	-107.3	-94.5	-100.20
-57.07	-62.6	-53.9	-72.7	-63.07	-116.7	-108	-126.5	-117.07
-95.20	-98.8	-109.4	-100.9	-103.03	-188	-184.3	-180.6	-184.30
-60.30	-71.4	-75.4	-72.4	-73.07	-115.1	-116.4	-124	-118.50
-91.13	-78.8	-83.1	-86.9	-82.93	-152	-152.1	-153.2	-152.43
-100.07	-100	-93.9	-95.7	-96.53	-120.6	-136.6	-108.5	-121.90
-68.90	-73.6	-71.3	-64.8	-69.90	-117.2	-128.7	-124.2	-123.37
-97.03	-114.1	-113.2	-103.9	-110.40	-174.2	-175.2	-194.5	-181.30
-77.23	-89.1	-93.6	-84.4	-89.03	-133	-119.9	-136.9	-129.93
-95.30	-85.6	-83	-94.2	-87.60	-150.7	-129.9	-140.5	-140.37
-38.30	-42.7	-39.2	-40.5	-40.80	-73.1	-58.1	-71.3	-67.50
-86.70	-100.1	-97.8	-91.5	-96.47	-110.7	-106.8	-129.2	-115.57
-80.00	-75.3	-88.7	-90.2	-84.73	-138.4	-139.7	-136.2	-138.10
-79.13	-88.4	-81.1	-73.6	-81.03	-147.3	-130.5	-135.6	-137.80
-61.07	-63.7	-70.8	-66.8	-67.10	-87.6	-75.6	-72.9	-78.70
-75.23	-55.8	-57.6	-58.9	-57.43	-123.8	-111.1	-116	-116.97
-34.73	-40	-34.7	-35.4	-36.70	-67.7	-78.9	-72.5	-73.03
-64.53	-69.5	-65.4	-66.9	-67.27	-113.4	-108.9	-101.5	-107.93
-49.93	-45.6	-45.9	-43.2	-44.90	-89.8	-90	-94.2	-91.33
-43.97	-53.6	-43.5	-45.9	-47.67	-81.1	-79.6	-78.5	-79.73
-71.53	-88.3	-88.1	-93.5	-89.97	-89.9	-104.2	-105.7	-99.93
-93.50	-104.2	-109	-99.6	-104.27	-156	-158.6	-163.3	-159.30
-46.13	-67.3	-55.6	-57.8	-60.23	-104.2	-100.4	-100	-101.53
-59.50	-39.9	-39.4	-40.9	-40.07	-80.9	-76.2	-73.7	-76.93

ecchpos1	ecchpos2	ecchpos3	ecchposav	ch:cq pre	ch:cq pos	eh:cq pre	eh:cq pos	vjhpre1
-105.8	-118.2	-108	-110.67	0.503	0.477	0.908	0.926	0.191
-151.2	-145.4	-147.1	-147.90	0.420	0.459	0.784	0.762	0.236
-88.1	-77.8	-76	-80.63	0.577	0.505	0.920	0.848	0.216
-82.2	-89.1	-84.4	-85.23	0.549	0.546	0.946	0.976	0.208
-82	-72.8	-75.4	-76.73	0.530	0.532	0.744	0.746	0.238
-71.7	-77.9	-75.5	-75.03	0.549	0.639	0.860	0.868	0.105
-73.4	-76.5	-78.4	-76.10	0.400	0.528	1.039	1.075	0.206
-91.9	-99.8	-84.4	-92.03	0.542	0.495	0.677	0.729	0.017
-144.2	-148.7	-153.7	-148.87	0.596	0.590	0.860	0.894	0.264
-83.1	-89.9	-91.3	-88.10	0.534	0.671	1.066	1.322	0.270
-125.3	-131.7	-128.8	-128.60	0.544	0.555	1.111	1.123	0.168
-140.6	-141.1	-133.5	-138.40	0.453	0.485	0.969	0.888	0.357
-119.7	-125.1	-117.1	-120.63	0.382	0.492	0.803	0.810	0.368
-91.3	-109.3	-95.1	-98.57	0.580	0.520	1.004	0.951	0.124
-99.1	-88.8	-92.5	-93.47	0.660	0.650	1.156	1.184	0.207
-162.7	-151.6	-166.3	-160.20	0.595	0.518	0.952	0.832	0.310
-122.2	-120.9	-108.1	-117.07	0.541	0.434	0.713	0.617	0.292
-126.8	-121.1	-113.9	-120.60	0.531	0.500	0.893	0.871	0.215
-153.1	-153.6	-140.8	-149.17	0.619	0.541	1.407	0.992	0.327
-176.2	-184.1	-182.6	-180.97	0.570	0.502	0.942	0.921	0.320
-150.6	-139.7	-146.6	-145.63	0.612	0.795	0.876	1.019	0.331
-95.3	-97.5	-101.6	-98.13	0.479	0.499	0.972	0.983	0.194
-135.7	-112.5	-134.6	-127.60	0.384	0.421	0.788	0.851	0.351
-190.9	-180.5	-191.9	-187.77	0.565	0.672	1.094	1.225	0.266
-110.2	-114.6	-103.4	-109.40	0.716	0.671	1.407	1.004	0.161
-159.7	-163.7	-148.3	-157.23	0.618	0.539	1.033	1.021	0.281
-157.1	-164.8	-162.4	-161.43	0.546	0.507	0.665	0.849	0.311
-120.9	-107.7	-126.3	-118.30	0.584	0.578	1.045	0.978	0.208
-183.4	-193	-177	-184.47	0.470	0.543	0.878	0.907	0.386
-128.6	-162.2	-156.8	-149.20	0.450	0.480	0.758	0.804	0.281
-113.1	-96.8	-126.6	-112.17	0.475	0.426	0.700	0.545	0.228
-69.5	-67.8	-68.7	-68.67	0.467	0.555	0.823	0.935	0.211
-118.2	-119.8	-128.3	-122.10	0.586	0.797	0.781	1.009	0.313
-113.6	-144.8	-140.7	-133.03	0.526	0.580	0.907	0.911	0.361
-128.8	-116.8	-117.1	-120.90	0.525	0.492	0.915	0.735	0.154
-97.9	-94.1	-89.3	-93.77	0.602	0.643	0.776	0.898	0.249
-112	-111.8	-110.7	-111.50	0.762	0.576	1.184	1.118	0.231
-65.8	-60.4	-65.4	-63.87	0.465	0.714	0.978	1.242	0.186
-109	-106.2	-110.6	-108.60	0.611	0.637	1.022	1.028	0.225
-90.9	-85.4	-73.9	-83.40	0.532	0.480	0.973	0.892	0.219
-91.2	-86.6	-76	-84.60	0.470	0.461	0.852	0.819	0.205
-120.7	-124	-125.3	-123.33	0.635	0.652	0.888	0.894	0.348
-181	-169	-176.9	-175.63	0.841	0.754	1.433	1.271	0.357
-111.7	-114.2	-117.3	-114.40	0.461	0.534	1.015	1.014	0.231
-75.6	-76.1	-74.6	-75.43	0.512	0.405	0.663	0.762	0.192

vjhpre2	vjhpre3	vjhpreav	vjhpos1	vjhpos2	vjhpos3	vjhposav	vjppre1	vjppre2	vjppre3	vjppreav
0.201	0.188	0.193	0.195	0.175	0.174	0.181	1612.1	1678.7	1593.5	1628.1
0.254	0.249	0.246	0.257	0.273	0.282	0.271	2960.1	3070.1	3037.2	3022.5
0.210	0.214	0.213	0.184	0.209	0.210	0.201	1513.6	1479.9	1501.9	1498.5
0.194	0.207	0.203	0.209	0.200	0.186	0.198	1371.4	1289.6	1366.5	1342.5
0.217	0.223	0.226	0.187	0.182	0.185	0.184	1657.4	1526.9	1566.6	1583.6
0.116	0.112	0.111	0.107	0.099	0.095	0.100	1575.7	1649.0	1624.2	1616.3
0.199	0.214	0.206	0.208	0.196	0.220	0.208	1499.5	1455.3	1547.1	1500.6
0.016	0.310	0.114	0.249	0.246	0.250	0.248	609.7	605.4	2421.9	1212.3
0.261	0.280	0.268	0.274	0.282	0.283	0.280	3738.3	3720.4	3833.2	3764.0
0.260	0.273	0.268	0.236	0.243	0.262	0.247	1826.6	1765.9	1850.4	1814.3
0.174	0.166	0.169	0.167	0.157	0.166	0.163	1836.8	1876.0	1825.7	1846.2
0.380	0.386	0.374	0.337	0.368	0.375	0.360	2830.3	2969.5	3009.8	2936.5
0.340	0.379	0.363	0.338	0.322	0.334	0.331	2993.0	2820.0	3057.9	2957.0
0.138	0.135	0.132	0.151	0.146	0.134	0.144	1031.0	1117.4	1100.7	1083.0
0.215	0.213	0.212	0.196	0.200	0.202	0.199	1312.1	1357.8	1344.7	1338.2
0.313	0.258	0.294	0.306	0.310	0.323	0.313	3418.8	3432.8	3092.2	3314.6
0.312	0.305	0.303	0.278	0.305	0.292	0.291	2915.9	3042.0	2996.4	2984.8
0.229	0.229	0.225	0.212	0.231	0.246	0.229	2088.1	2175.3	2175.7	2146.4
0.331	0.327	0.328	0.339	0.341	0.335	0.338	2622.5	2644.7	2621.2	2629.5
0.336	0.342	0.333	0.301	0.298	0.320	0.306	3514.6	3612.3	3647.9	3591.6
0.357	0.362	0.350	0.318	0.331	0.344	0.331	3043.6	3202.0	3232.8	3159.5
0.214	0.195	0.201	0.187	0.181	0.180	0.182	1633.2	1756.8	1635.8	1675.3
0.331	0.337	0.340	0.343	0.350	0.349	0.347	2902.3	2773.3	2811.0	2828.9
0.281	0.289	0.278	0.253	0.247	0.264	0.255	2723.9	2820.4	2865.6	2803.3
0.177	0.176	0.171	0.186	0.173	0.173	0.177	2003.5	2104.2	2096.8	2068.2
0.285	0.293	0.286	0.288	0.286	0.277	0.283	2385.2	2413.0	2461.6	2419.9
0.302	0.308	0.307	0.330	0.330	0.329	0.330	3117.1	3061.9	3099.9	3093.0
0.214	0.215	0.212	0.222	0.212	0.224	0.219	2214.3	2251.5	2259.0	2241.6
0.389	0.395	0.390	0.370	0.382	0.376	0.376	3468.1	3490.6	3522.2	3493.6
0.301	0.305	0.296	0.299	0.284	0.283	0.289	3372.8	3495.7	3522.5	3463.7
0.225	0.252	0.235	0.229	0.226	0.241	0.232	3123.4	3105.9	3272.5	3167.3
0.213	0.203	0.209	0.196	0.206	0.197	0.200	1526.9	1541.4	1478.4	1515.6
0.325	0.323	0.320	0.307	0.310	0.329	0.315	2692.1	2766.3	2754.9	2737.8
0.351	0.347	0.353	0.367	0.360	0.391	0.373	3201.6	3136.9	3114.2	3150.9
0.154	0.139	0.149	0.162	0.176	0.153	0.164	2644.4	2643.8	2551.9	2613.4
0.243	0.267	0.253	0.248	0.258	0.250	0.252	1721.3	1682.2	1834.0	1745.8
0.233	0.234	0.232	0.228	0.237	0.231	0.232	1795.9	1806.1	1814.1	1805.4
0.189	0.196	0.190	0.180	0.169	0.176	0.175	1571.5	1587.2	1628.5	1595.7
0.240	0.241	0.235	0.238	0.254	0.246	0.246	1830.0	1921.6	1930.0	1893.9
0.211	0.184	0.205	0.222	0.219	0.207	0.216	1993.8	1948.6	1778.6	1907.0
0.211	0.200	0.205	0.203	0.197	0.202	0.200	1436.5	1468.9	1403.7	1436.4
0.351	0.343	0.347	0.316	0.334	0.327	0.326	2605.1	2623.7	2574.4	2601.1
0.335	0.368	0.354	0.354	0.365	0.338	0.352	3771.5	3638.4	3841.6	3750.5
0.227	0.252	0.237	0.239	0.250	0.249	0.246	2043.4	2014.4	2174.2	2077.3
0.191	0.174	0.186	0.188	0.183	0.180	0.183	1569.7	1562.7	1461.0	1531.1

vjppos1	vjppos2	vjppos3	vjpposav
1636.1	1513.4	1508.7	1552.7
3086.5	3188.1	3240.5	3171.7
1320.7	1474.4	1478.9	1424.7
1378.8	1321.7	1239.2	1313.2
1343.4	1311.7	1329.7	1328.3
1587.6	1542.1	1517.8	1549.2
1508.1	1438.4	1583.6	1510.0
2042.6	2025.7	2048.5	2038.9
3800.4	3848.3	3854.6	3834.4
1616.7	1659.1	1778.8	1684.9
1833.8	1768.3	1826.4	1809.5
2703.3	2894.7	2940.3	2846.1
2805.4	2704.0	2780.5	2763.3
1198.8	1167.8	1097.7	1154.8
1242.1	1267.3	1276.6	1262.0
3394.3	3414.7	3498.0	3435.7
2826.6	2994.0	2915.3	2912.0
2065.0	2185.9	2277.3	2176.1
2695.1	2708.9	2669.9	2691.3
3398.5	3378.4	3511.3	3429.4
2961.5	3039.8	3121.7	3041.0
1589.0	1550.9	1543.0	1561.0
2850.5	2892.8	2888.5	2877.3
2644.1	2610.3	2715.8	2656.7
2155.9	2077.2	2078.3	2103.8
2428.0	2416.4	2362.8	2402.4
3236.1	3238.9	3234.1	3236.4
2302.7	2242.6	2314.0	2286.4
3370.7	3441.9	3408.1	3406.9
3485.8	3390.6	3388.6	3421.7
3131.2	3114.6	3203.9	3149.9
1434.3	1500.8	1442.8	1459.3
2653.6	2673.5	2794.0	2707.0
3237.2	3195.6	3385.5	3272.8
2695.9	2783.7	2639.0	2706.2
1716.9	1778.8	1726.2	1740.6
1780.7	1831.3	1794.1	1802.0
1531.9	1463.3	1507.6	1500.9
1912.2	2008.5	1964.5	1961.7
2011.7	1993.0	1920.4	1975.0
1421.1	1381.8	1414.2	1405.7
2409.8	2522.1	2477.6	2469.8
3750.7	3820.7	3651.3	3740.9
2090.0	2157.2	2150.8	2132.7
1542.6	1511.6	1495.3	1516.5

Appendix G – SPSS Outputs

Hamstring Flexibility

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	19.5111	10.83342	15
	SWU	21.4667	10.44547	15
	DWU	26.4444	13.50407	15
	Total	22.4741	11.78115	45
AVEPOST	CON	19.4222	11.96056	15
	SWU	19.2889	11.39191	15
	DWU	16.8889	9.63926	15
	Total	18.5333	10.85171	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	349.412	1	349.412	22.608	.000	.350	22.608	.996
	Greenhouse-Geisser	349.412	1.000	349.412	22.608	.000	.350	22.608	.996
	Huynh-Feldt	349.412	1.000	349.412	22.608	.000	.350	22.608	.996
	Lower-bound	349.412	1.000	349.412	22.608	.000	.350	22.608	.996
time * Group	Sphericity Assumed	371.032	2	185.516	12.004	.000	.364	24.007	.992
	Greenhouse-Geisser	371.032	2.000	185.516	12.004	.000	.364	24.007	.992
	Huynh-Feldt	371.032	2.000	185.516	12.004	.000	.364	24.007	.992
	Lower-bound	371.032	2.000	185.516	12.004	.000	.364	24.007	.992
Error(time)	Sphericity Assumed	649.111	42	15.455					
	Greenhouse-Geisser	649.111	42.000	15.455					
	Huynh-Feldt	649.111	42.000	15.455					
	Lower-bound	649.111	42.000	15.455					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	37836.168	1	37836.168	155.873	.000	.788	155.873	1.000
Group	73.314	2	36.657	.151	.860	.007	.302	.072
Error	10194.963	42	242.737					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
20.504	1.642	17.189	23.818

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	19.467	2.845	13.726	25.207
SWU	20.378	2.845	14.637	26.118
DWU	21.667	2.845	15.926	27.407

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	22.474	1.740	18.962	25.986
2	18.533	1.646	15.212	21.855

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	19.511	3.014	13.428	25.594
	2	19.422	2.851	13.669	25.176
SWU	1	21.467	3.014	15.384	27.549
	2	19.289	2.851	13.536	25.042
DWU	1	26.444	3.014	20.362	32.527
	2	16.889	2.851	11.136	22.642

Quadriceps Flexibility

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	129.5778	9.27231	15
	SWU	127.7333	6.94674	15
	DWU	126.0667	7.62744	15
	Total	127.7926	7.95768	45
AVEPOST	CON	127.7556	8.30611	15
	SWU	127.9333	7.41748	15
	DWU	125.4444	6.48033	15
	Total	127.0444	7.35760	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	12.594	1	12.594	1.194	.281	.028	1.194	.187
	Greenhouse-Geisser	12.594	1.000	12.594	1.194	.281	.028	1.194	.187
	Huynh-Feldt	12.594	1.000	12.594	1.194	.281	.028	1.194	.187
	Lower-bound	12.594	1.000	12.594	1.194	.281	.028	1.194	.187
time * Group	Sphericity Assumed	15.514	2	7.757	.735	.485	.034	1.471	.166
	Greenhouse-Geisser	15.514	2.000	7.757	.735	.485	.034	1.471	.166
	Huynh-Feldt	15.514	2.000	7.757	.735	.485	.034	1.471	.166
	Lower-bound	15.514	2.000	7.757	.735	.485	.034	1.471	.166
Error(time)	Sphericity Assumed	442.948	42	10.546					
	Greenhouse-Geisser	442.948	42.000	10.546					
	Huynh-Feldt	442.948	42.000	10.546					
	Lower-bound	442.948	42.000	10.546					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1461193.098	1	1461193.098	13414.601	.000	.997	13414.601	1.000
Group	134.862	2	67.431	.619	.543	.029	1.238	.146
Error	4574.874	42	108.926					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
127.419	1.100	125.198	129.639

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	128.667	1.905	124.821	132.512
SWU	127.833	1.905	123.988	131.679
DWU	125.756	1.905	121.910	129.601

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	127.793	1.194	125.383	130.202
2	127.044	1.109	124.807	129.282

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	129.578	2.068	125.405	133.751
	2	127.756	1.921	123.879	131.632
SWU	1	127.733	2.068	123.560	131.906
	2	127.933	1.921	124.057	131.809
DWU	1	126.067	2.068	121.894	130.240
	2	125.444	1.921	121.568	129.321

Hip Flexor Flexibility

Within-Subjects Factors

Measure: MEASURE_1

trial	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	26.3778	4.55106	15
	SWU	26.7111	8.19298	15
	DWU	28.0667	7.84796	15
	Total	27.0519	6.93474	45
AVEPOST	CON	26.7333	3.81143	15
	SWU	26.9333	6.85704	15
	DWU	30.2000	5.49574	15
	Total	27.9556	5.63700	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
trial	Sphericity Assumed	18.375	1	18.375	1.972	.168	.045	1.972	.279
	Greenhouse-Geisser	18.375	1.000	18.375	1.972	.168	.045	1.972	.279
	Huynh-Feldt	18.375	1.000	18.375	1.972	.168	.045	1.972	.279
	Lower-bound	18.375	1.000	18.375	1.972	.168	.045	1.972	.279
trial * Group	Sphericity Assumed	17.077	2	8.538	.916	.408	.042	1.832	.198
	Greenhouse-Geisser	17.077	2.000	8.538	.916	.408	.042	1.832	.198
	Huynh-Feldt	17.077	2.000	8.538	.916	.408	.042	1.832	.198
	Lower-bound	17.077	2.000	8.538	.916	.408	.042	1.832	.198
Error(trial)	Sphericity Assumed	391.437	42	9.320					
	Greenhouse-Geisser	391.437	42.000	9.320					
	Huynh-Feldt	391.437	42.000	9.320					
	Lower-bound	391.437	42.000	9.320					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	68080.835	1	68080.835	957.909	.000	.958	957.909	1.000
Group	120.573	2	60.286	.848	.435	.039	1.696	.186
Error	2985.037	42	71.072					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
27.504	.889	25.710	29.297

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	26.556	1.539	23.449	29.662
SWU	26.822	1.539	23.716	29.928
DWU	29.133	1.539	26.027	32.240

3. trial

Measure: MEASURE_1

trial	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	27.052	1.052	24.929	29.175
2	27.956	.824	26.292	29.619

4. Group * trial

Measure: MEASURE_1

Group	trial	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	26.378	1.822	22.700	30.055
	2	26.733	1.428	23.852	29.615
SWU	1	26.711	1.822	23.034	30.389
	2	26.933	1.428	24.052	29.815
DWU	1	28.067	1.822	24.389	31.744
	2	30.200	1.428	27.318	33.082

Rectus Femoris Flexibility

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	PREAVE
2	POSTAVE

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
PREAVE	CON	67.9333	10.09888	15
	SWU	71.4222	11.53564	15
	DWU	68.9111	12.22765	15
	Total	69.4222	11.16122	45
POSTAVE	CON	66.4000	6.53100	15
	SWU	72.5333	11.52898	15
	DWU	72.0222	10.99312	15
	Total	70.3185	10.10999	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	18.075	1	18.075	1.155	.289	.027	1.155	.183
	Greenhouse-Geisser	18.075	1.000	18.075	1.155	.289	.027	1.155	.183
	Huynh-Feldt	18.075	1.000	18.075	1.155	.289	.027	1.155	.183
	Lower-bound	18.075	1.000	18.075	1.155	.289	.027	1.155	.183
time * Group	Sphericity Assumed	81.410	2	40.705	2.602	.086	.110	5.204	.490
	Greenhouse-Geisser	81.410	2.000	40.705	2.602	.086	.110	5.204	.490
	Huynh-Feldt	81.410	2.000	40.705	2.602	.086	.110	5.204	.490
	Lower-bound	81.410	2.000	40.705	2.602	.086	.110	5.204	.490
Error(time)	Sphericity Assumed	657.015	42	15.643					
	Greenhouse-Geisser	657.015	42.000	15.643					
	Huynh-Feldt	657.015	42.000	15.643					
	Lower-bound	657.015	42.000	15.643					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	439368.179	1	439368.179	2078.819	.000	.980	2078.819	1.000
Group	363.202	2	181.601	.859	.431	.039	1.718	.188
Error	8876.896	42	211.355					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
69.870	1.532	66.778	72.963

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	67.167	2.654	61.810	72.523
SWU	71.978	2.654	66.621	77.334
DWU	70.467	2.654	65.110	75.823

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	69.422	1.688	66.016	72.828
2	70.319	1.482	67.328	73.309

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	67.933	2.923	62.034	73.833
	2	66.400	2.567	61.221	71.579
SWU	1	71.422	2.923	65.523	77.322
	2	72.533	2.567	67.354	77.713
DWU	1	68.911	2.923	63.012	74.811
	2	72.022	2.567	66.843	77.202

Concentric Quadriceps Peak Torque

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	PREAVE
2	POSTAVE

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
PREAVE	CON	125.8467	46.41232	15
	SWU	128.2067	34.46246	15
	DWU	129.1933	37.86117	15
	Total	127.7489	39.00524	45
POSTAVE	CON	127.7667	51.57222	15
	SWU	124.0800	31.25311	15
	DWU	138.1889	38.38843	15
	Total	130.0119	40.77323	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	115.223	1	115.223	1.307	.259	.030	1.307	.201
	Greenhouse-Geisser	115.223	1.000	115.223	1.307	.259	.030	1.307	.201
	Huynh-Feldt	115.223	1.000	115.223	1.307	.259	.030	1.307	.201
	Lower-bound	115.223	1.000	115.223	1.307	.259	.030	1.307	.201
time * Group	Sphericity Assumed	647.046	2	323.523	3.671	.034	.149	7.342	.644
	Greenhouse-Geisser	647.046	2.000	323.523	3.671	.034	.149	7.342	.644
	Huynh-Feldt	647.046	2.000	323.523	3.671	.034	.149	7.342	.644
	Lower-bound	647.046	2.000	323.523	3.671	.034	.149	7.342	.644
Error(time)	Sphericity Assumed	3701.262	42	88.125					
	Greenhouse-Geisser	3701.262	42.000	88.125					
	Huynh-Feldt	3701.262	42.000	88.125					
	Lower-bound	3701.262	42.000	88.125					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1494913.488	1	1494913.488	466.142	.000	.917	466.142	1.000
Group	1048.045	2	524.023	.163	.850	.008	.327	.074
Error	134693.697	42	3206.993					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
128.880	5.969	116.834	140.927

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	126.807	10.339	105.941	147.672
SWU	126.143	10.339	105.278	147.009
DWU	133.691	10.339	112.826	154.557

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	127.749	5.947	115.746	139.751
2	130.012	6.152	117.596	142.428

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	125.847	10.301	105.058	146.635
	2	127.767	10.656	106.261	149.272
SWU	1	128.207	10.301	107.418	148.995
	2	124.080	10.656	102.575	145.585
DWU	1	129.193	10.301	108.405	149.982
	2	138.189	10.656	116.683	159.694

Eccentric Quadriceps Peak Torque

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	PREAVE
2	POSTAVE

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
PREAVE	CON	151.9467	70.07436	15
	SWU	144.8511	48.94237	15
	DWU	136.7044	46.14965	15
	Total	144.5007	55.15331	45
POSTAVE	CON	156.6244	65.62599	15
	SWU	140.6556	59.48907	15
	DWU	155.5467	51.25332	15
	Total	150.9422	58.19370	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	933.585	1	933.585	4.546	.039	.098	4.546	.549
	Greenhouse-Geisser	933.585	1.000	933.585	4.546	.039	.098	4.546	.549
	Huynh-Feldt	933.585	1.000	933.585	4.546	.039	.098	4.546	.549
	Lower-bound	933.585	1.000	933.585	4.546	.039	.098	4.546	.549
time * Group	Sphericity Assumed	2025.267	2	1012.633	4.930	.012	.190	9.861	.779
	Greenhouse-Geisser	2025.267	2.000	1012.633	4.930	.012	.190	9.861	.779
	Huynh-Feldt	2025.267	2.000	1012.633	4.930	.012	.190	9.861	.779
	Lower-bound	2025.267	2.000	1012.633	4.930	.012	.190	9.861	.779
Error(time)	Sphericity Assumed	8626.097	42	205.383					
	Greenhouse-Geisser	8626.097	42.000	205.383					
	Huynh-Feldt	8626.097	42.000	205.383					
	Lower-bound	8626.097	42.000	205.383					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1963947.248	1	1963947.248	305.403	.000	.879	305.403	1.000
Group	2109.496	2	1054.748	.164	.849	.008	.328	.074
Error	270088.489	42	6430.678					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
147.721	8.453	130.663	164.780

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	154.286	14.641	124.739	183.832
SWU	142.753	14.641	113.207	172.300
DWU	146.126	14.641	116.579	175.672

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	144.501	8.360	127.629	161.372
2	150.942	8.808	133.168	168.717

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	151.947	14.480	122.724	181.169
	2	156.624	15.255	125.838	187.411
SWU	1	144.851	14.480	115.629	174.074
	2	140.656	15.255	109.869	171.442
DWU	1	136.704	14.480	107.482	165.927
	2	155.547	15.255	124.760	186.333

Concentric Hamstrings Peak Torque

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	-65.3933	24.61049	15
	SWU	-71.7311	18.59077	15
	DWU	-70.1978	21.84046	15
	Total	-69.1074	21.49217	45
AVEPOST	CON	-67.0778	21.53380	15
	SWU	-71.4445	24.56854	15
	DWU	-74.8978	19.34652	15
	Total	-71.1400	21.66019	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	92.958	1	92.958	2.143	.151	.049	2.143	.299
	Greenhouse-Geisser	92.958	1.000	92.958	2.143	.151	.049	2.143	.299
	Huynh-Feldt	92.958	1.000	92.958	2.143	.151	.049	2.143	.299
	Lower-bound	92.958	1.000	92.958	2.143	.151	.049	2.143	.299
time * Group	Sphericity Assumed	94.613	2	47.307	1.091	.345	.049	2.181	.229
	Greenhouse-Geisser	94.613	2.000	47.307	1.091	.345	.049	2.181	.229
	Huynh-Feldt	94.613	2.000	47.307	1.091	.345	.049	2.181	.229
	Lower-bound	94.613	2.000	47.307	1.091	.345	.049	2.181	.229
Error(time)	Sphericity Assumed	1821.699	42	43.374					
	Greenhouse-Geisser	1821.699	42.000	43.374					
	Huynh-Feldt	1821.699	42.000	43.374					
	Lower-bound	1821.699	42.000	43.374					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	442560.091	1	442560.091	484.593	.000	.920	484.593	1.000
Group	694.121	2	347.061	.380	.686	.018	.760	.107
Error	38356.953	42	913.261					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
-70.124	3.185	-76.552	-63.695

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	-66.236	5.517	-77.370	-55.101
SWU	-71.588	5.517	-82.722	-60.453
DWU	-72.548	5.517	-83.682	-61.413

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-69.107	3.253	-75.672	-62.543
2	-71.140	3.268	-77.735	-64.545

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	-65.393	5.634	-76.763	-54.024
	2	-67.078	5.660	-78.500	-55.655
SWU	1	-71.731	5.634	-83.101	-60.362
	2	-71.444	5.660	-82.867	-60.022
DWU	1	-70.198	5.634	-81.567	-58.828
	2	-74.898	5.660	-86.320	-63.475

Eccentric Hamstrings Peak Torque

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	-111.6089	40.26588	15
	SWU	-117.9955	31.64688	15
	DWU	-120.9400	27.23241	15
	Total	-116.8481	32.95494	45
AVEPOST	CON	-112.1622	37.78300	15
	SWU	-118.0711	35.40357	15
	DWU	-124.4022	26.30485	15
	Total	-118.2118	33.14735	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	41.843	1	41.843	.595	.445	.014	.595	.117
	Greenhouse-Geisser	41.843	1.000	41.843	.595	.445	.014	.595	.117
	Huynh-Feldt	41.843	1.000	41.843	.595	.445	.014	.595	.117
	Lower-bound	41.843	1.000	41.843	.595	.445	.014	.595	.117
time * Group	Sphericity Assumed	50.399	2	25.199	.358	.701	.017	.717	.104
	Greenhouse-Geisser	50.399	2.000	25.199	.358	.701	.017	.717	.104
	Huynh-Feldt	50.399	2.000	25.199	.358	.701	.017	.717	.104
	Lower-bound	50.399	2.000	25.199	.358	.701	.017	.717	.104
Error(time)	Sphericity Assumed	2953.007	42	70.310					
	Greenhouse-Geisser	2953.007	42.000	70.310					
	Huynh-Feldt	2953.007	42.000	70.310					
	Lower-bound	2953.007	42.000	70.310					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1243196.924	1	1243196.924	571.457	.000	.932	571.457	1.000
Group	1756.323	2	878.161	.404	.670	.019	.807	.111
Error	91370.364	42	2175.485					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
-117.530	4.917	-127.452	-107.608

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CON	-111.886	8.516	-129.071	-94.700
SWU	-118.033	8.516	-135.219	-100.848
DWU	-122.671	8.516	-139.856	-105.486

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	-116.848	4.992	-126.923	-106.773
2	-118.212	4.998	-128.299	-108.125

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CON	1	-111.609	8.647	-129.059	-94.159
	2	-112.162	8.658	-129.634	-94.691
SWU	1	-117.996	8.647	-135.445	-100.546
	2	-118.071	8.658	-135.543	-100.599
DWU	1	-120.940	8.647	-138.390	-103.490
	2	-124.402	8.658	-141.874	-106.931

Concentric Hamstrings to Concentric Quadriceps Ratio

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	.5225	.06592	15
	SWU	.5691	.11220	15
	DWU	.5463	.09146	15
	Total	.5460	.09176	45
AVEPOST	CON	.5506	.09744	15
	SWU	.5716	.12076	15
	DWU	.5479	.06790	15
	Total	.5567	.09614	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.003	1	.003	.655	.423	.015	.655	.124
	Greenhouse-Geisser	.003	1.000	.003	.655	.423	.015	.655	.124
	Huynh-Feldt	.003	1.000	.003	.655	.423	.015	.655	.124
	Lower-bound	.003	1.000	.003	.655	.423	.015	.655	.124
time * Group	Sphericity Assumed	.003	2	.002	.426	.656	.020	.852	.115
	Greenhouse-Geisser	.003	2.000	.002	.426	.656	.020	.852	.115
	Huynh-Feldt	.003	2.000	.002	.426	.656	.020	.852	.115
	Lower-bound	.003	2.000	.002	.426	.656	.020	.852	.115
Error(time)	Sphericity Assumed	.167	42	.004					
	Greenhouse-Geisser	.167	42.000	.004					
	Huynh-Feldt	.167	42.000	.004					
	Lower-bound	.167	42.000	.004					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	27.357	1	27.357	1951.769	.000	.979	1951.769	1.000
Group	.018	2	.009	.638	.533	.030	1.277	.150
Error	.589	42	.014					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.551	.012	.526	.577

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	.537	.022	.493	.580
SWU	.570	.022	.527	.614
DWU	.547	.022	.503	.591

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.546	.014	.518	.574
2	.557	.015	.527	.586

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	.523	.024	.475	.570
	2	.551	.025	.500	.602
SWU	1	.569	.024	.521	.617
	2	.572	.025	.521	.623
DWU	1	.546	.024	.498	.594
	2	.548	.025	.497	.599

Eccentric Hamstrings to Concentric Quadriceps Ratio

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	PREAVE
2	POSTAVE

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
PREAVE	CON	.9032	.14661	15
	SWU	.9371	.19812	15
	DWU	.9715	.20545	15
	Total	.9373	.18318	45
POSTAVE	CON	.9339	.22791	15
	SWU	.9488	.14824	15
	DWU	.9207	.09548	15
	Total	.9344	.16296	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	1	.000	.021	.886	.000	.021	.052
	Greenhouse-Geisser	.000	1.000	.000	.021	.886	.000	.021	.052
	Huynh-Feldt	.000	1.000	.000	.021	.886	.000	.021	.052
	Lower-bound	.000	1.000	.000	.021	.886	.000	.021	.052
time * Group	Sphericity Assumed	.027	2	.014	1.573	.219	.070	3.145	.315
	Greenhouse-Geisser	.027	2.000	.014	1.573	.219	.070	3.145	.315
	Huynh-Feldt	.027	2.000	.014	1.573	.219	.070	3.145	.315
	Lower-bound	.027	2.000	.014	1.573	.219	.070	3.145	.315
Error(time)	Sphericity Assumed	.365	42	.009					
	Greenhouse-Geisser	.365	42.000	.009					
	Huynh-Feldt	.365	42.000	.009					
	Lower-bound	.365	42.000	.009					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	78.823	1	78.823	1478.469	.000	.972	1478.469	1.000
Group	.014	2	.007	.128	.880	.006	.255	.068
Error	2.239	42	.053					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.936	.024	.887	.985

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	.919	.042	.833	1.004
SWU	.943	.042	.858	1.028
DWU	.946	.042	.861	1.031

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.937	.028	.882	.993
2	.934	.025	.884	.984

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	.903	.048	.807	1.000
	2	.934	.043	.847	1.021
SWU	1	.937	.048	.841	1.034
	2	.949	.043	.862	1.035
DWU	1	.972	.048	.875	1.068
	2	.921	.043	.834	1.007

Vertical Jump Height

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	.2492	.05374	15
	SWU	.2479	.09034	15
	DWU	.2577	.07353	15
	Total	.2516	.07250	45
AVEPOST	CON	.2382	.05264	15
	SWU	.2496	.07931	15
	DWU	.2652	.07365	15
	Total	.2510	.06881	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	7.75E-006	1	7.75E-006	.026	.873	.001	.026	.053
	Greenhouse-Geisse	7.75E-006	1.000	7.75E-006	.026	.873	.001	.026	.053
	Huynh-Feldt	7.75E-006	1.000	7.75E-006	.026	.873	.001	.026	.053
	Lower-bound	7.75E-006	1.000	7.75E-006	.026	.873	.001	.026	.053
time * Group	Sphericity Assumed	.001	2	.001	2.230	.120	.096	4.459	.429
	Greenhouse-Geisse	.001	2.000	.001	2.230	.120	.096	4.459	.429
	Huynh-Feldt	.001	2.000	.001	2.230	.120	.096	4.459	.429
	Lower-bound	.001	2.000	.001	2.230	.120	.096	4.459	.429
Error(time)	Sphericity Assumed	.013	42	.000					
	Greenhouse-Geisse	.013	42.000	.000					
	Huynh-Feldt	.013	42.000	.000					
	Lower-bound	.013	42.000	.000					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	5.685	1	5.685	567.694	.000	.931	567.694	1.000
Group	.005	2	.003	.252	.779	.012	.503	.087
Error	.421	42	.010					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.251	.011	.230	.273

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CON	.244	.018	.207	.281
SWU	.249	.018	.212	.286
DWU	.261	.018	.225	.298

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.252	.011	.229	.274
2	.251	.010	.230	.272

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CON	1	.249	.019	.211	.288
	2	.238	.018	.202	.274
SWU	1	.248	.019	.209	.287
	2	.250	.018	.213	.286
DWU	1	.258	.019	.219	.296
	2	.265	.018	.229	.301

Vertical Jump Power

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	AVEPRE
2	AVEPOST

Between-Subjects Factors

		Value Label	N
Group	1.00	CON	15
	2.00	SWU	15
	3.00	DWU	15

Descriptive Statistics

	Group	Mean	Std. Deviation	N
AVEPRE	CON	2227.0178	769.18930	15
	SWU	2250.4453	791.52680	15
	DWU	2494.9600	810.27236	15
	Total	2324.1410	781.99280	45
AVEPOST	CON	2159.1111	787.24724	15
	SWU	2260.9600	726.34750	15
	DWU	2541.4489	829.00040	15
	Total	2320.5067	781.31990	45

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	297.195	1	297.195	.026	.873	.001	.026	.053
	Greenhouse-Geisser	297.195	1.000	297.195	.026	.873	.001	.026	.053
	Huynh-Feldt	297.195	1.000	297.195	.026	.873	.001	.026	.053
	Lower-bound	297.195	1.000	297.195	.026	.873	.001	.026	.053
time * Group	Sphericity Assumed	51325.983	2	25662.992	2.230	.120	.096	4.460	.429
	Greenhouse-Geisser	51325.983	2.000	25662.992	2.230	.120	.096	4.460	.429
	Huynh-Feldt	51325.983	2.000	25662.992	2.230	.120	.096	4.460	.429
	Lower-bound	51325.983	2.000	25662.992	2.230	.120	.096	4.460	.429
Error(time)	Sphericity Assumed	483382.036	42	11509.096					
	Greenhouse-Geisser	483382.036	42.000	11509.096					
	Huynh-Feldt	483382.036	42.000	11509.096					
	Lower-bound	483382.036	42.000	11509.096					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	485386927	1	485386926.6	396.260	.000	.904	396.260	1.000
Group	1785467.499	2	892733.750	.729	.488	.034	1.458	.165
Error	51446660.2	42	1224920.480					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
2322.324	116.663	2086.889	2557.759

2. Group

Measure: MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CON	2193.064	202.066	1785.279	2600.850
SWU	2255.703	202.066	1847.917	2663.488
DWU	2518.204	202.066	2110.419	2925.990

3. time

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2324.141	117.842	2086.326	2561.956
2	2320.507	116.574	2085.251	2555.762

4. Group * time

Measure: MEASURE_1

Group	time	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CON	1	2227.018	204.108	1815.111	2638.925
	2	2159.111	201.912	1751.636	2566.586
SWU	1	2250.445	204.108	1838.538	2662.352
	2	2260.960	201.912	1853.485	2668.435
DWU	1	2494.960	204.108	2083.053	2906.867
	2	2541.449	201.912	2133.974	2948.924

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