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Nicholas T. Kruse

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This thesis titled

The Acute Effects of Various Stretching Modalities on Performance Across a Time Spectrum in NCAA Division I Volleyball Players

by

NICHOLAS T. KRUSE

has been approved for

the School of Applied Health Sciences and Wellness

and the College of Health Sciences and Professions by

Sharon R. Rana
Associate Professor of Applied Health Sciences and Wellness

Randy Leite
Interim Dean, College of Health Sciences and Professions
ABSTRACT

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The Acute Effects of Various Stretching Modalities on Performance Across a Time Spectrum in NCAA Division I Volleyball Players (126 pp.)

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The purpose of this investigation was to quantify the effects of a warm-up with static or dynamic stretching on various measures of performance and range of motion. Eleven female NCAA Division I varsity volleyball players participated in this investigation. Participants underwent three randomized testing sessions of either a static stretching, control, or dynamic stretching session. Performance variables of force, power output, vertical jumping ability, and range of motion were measured and analyzed at time intervals of 1, 5, 15, and 25 minutes post-stretch on a force plate using a Vertec apparatus. Significant differences were found in peak power output, relative peak power output, and vertical jumping ability. Significant differences were also determined at 1 and 5 minutes post stretch as well as between trials of static stretching vs. dynamic stretching, dynamic stretching vs. static stretching, but not static stretching vs. control. There may be a critical point in a post-stretch time period (< 25 minutes) where an athlete who engages in their typical dynamic stretching regimen has compromised performance.

Approved: _____________________________________________________________

Sharon R. Rana

Associate Professor of Applied Health Sciences and Wellness
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CHAPTER 1: INTRODUCTION

Warming-up with stretching prior to physical activity has long been a recommended and supportive measure to increase performance in all fitness populations. Stretching has consistently been included as part of the warm-up as a means to increase flexibility and potentially prevent injury, but it is unclear as to whether it increases performance. Nevertheless, the relationship between strength, power, and flexibility has been a topic of debate regarding the success of many explosive sports. Theories have been postulated concerning the notion of what favorable combination of strength and flexibility one must demonstrate to be considered “optimal” for their given sport. A further look into the components of muscular strength and power, as well as flexibility gives rise to several training theories and possibilities to potentiate performance.

Two common modes of stretching among athletes and endorsed by coaches are static stretching (SS) and dynamic stretching (DS). When deciding which stretch is best the importance lies in understanding the components and mechanism of what each stretch does to potentially enhance performance. Sport specific warm-ups, active warm-ups, or what this investigation will identify as dynamic stretching (DS), appears to be the most favorable precompetition mode, because it involves movements related to the activity. However, many athletes still use the more traditional mode of SS as part of a pre-competition warm-up (Bishop, 2003, and McMillan, Moore, Hatler, & Tayler, 2006). Therefore, it is important to compare two common stretching modalities to determine which is the most effective for a particular sport.
Static stretching was coined the “traditional” mode of stretching because it has been incorporated into warm-ups dating back to 1945 when Asmusen & Bode introduced the concept of a warm-up and its likely physiological mechanisms (Asmusen & Bode, 1945). Static stretching was originally theorized to be incorporated into warm-ups as a way to improve range of motion (ROM), reduce the risk of injuries, and enhance performance (Bishop, 2003). Concrete evidence of these effects however, has only linked SS with increases in flexibility and/or ROM (Radford, Burns, Buchbinder, Landorf, & Cook, 2006), and not injury prevention (Witvrouw, Mahieu, Danneels, & McNair, 2004) or performance (Evetovich, Neumann, Conley, & Todd, 2006; and Fowles, Sale, & MacDougall, 2000).

Research supporting SS’S effect on performance is currently unclear. The general acceptance has been that DS promotes the most significant gains in performance, particularly for explosive related athletics, and that SS may actually cause decrements in performance (Herda, Cramer, Ryan, McHugh, & Stout, 2006; McMillian, Moore, Hatler, & Taylor, 2006). Yet more recently, some investigations have shown no significant effect of SS on power related activities such as the vertical jumping ability (VJA) test or an agility test (Beedle, Rytter, Heale, & Ward, 2008; Manoel, Harris-Love, Danoff & Miller, 2008; Samuel, Holcomb, Guadagnoli, Rubley, & Wallmann, 2008; Torres et al., 2008). Additionally, it has been stated that muscle performance is dependent on the type of stretching (i.e., SS vs. DS) and muscular activity (i.e., concentric vs. eccentric muscle action) performed (ACSM, 2008). Although inconclusive, the American College of Sports Medicine (ACSM) supports the notion, based on scientific literature, that SS has a
detrimental effect on power output and jump height when compared to DS. While it
appears almost conclusively that DS enhances performance when compared to a control,
inconclusive evidence has supported the theory that SS has decrements in performance
(Unick, Kieffer, Cheesman, & Feeney, 2005; Yamaguchi & Ishii, 2005). There seems to
be a limit to the amount of flexibility one can gain without disrupting more important
performance measures of muscular power and strength. This limit to which SS may
cause decrements in physical performance is identified as “stretching-induced force
deficits” and both neural and mechanical physiological mechanisms have been
hypothesized (Ryan et al. 2008). Finally, the duration of hold and timing effects (time
between completion of the stretch and measures of performance) may play a critical role
in controlling for stretching-induced force deficits. Durational (Robbins & Sheuermann,
2008; Unick et al., 2005) and timing (Ryan et al., 2008; Yamaguchi & Ishii, 2005)
theories concerning SS and its effect on performance variables have come forth in recent
years. Ryan et al. (2008) reported that the most commonly cited study relative to the
acute effects of stretching on strength was by Fowles, Sale, and MacDougal (2000) who
demonstrated an exaggerated duration of 30 minutes passive stretching that decreased
plantar flexor strength immediately (28%), and 1 hour post stretch (9%). Even though
many investigations have referenced their study, the authors admitted to using an
exaggerated stretch duration. For this reason, the duration of SS needs to be further
examined and evaluated using a more practical duration.
Significance of the Study

Certain stretching modalities may play an advantageous or disadvantageous role in power-related sports and consequently, can determine the defining line of victory or defeat. For this reason it will be important to compare the effectiveness of a sport-specific DS compared to its SS counterpart. This investigation will provide a current state of evidence to Division I National Collegiate Athletics Association (NCAA) volleyball players and their coaches along with other applicable sports as to whether their current stretching regimen will produce optimal performance gains. To date no investigation has taken a direct approach by extrapolating an actual athletic team’s stretching regimen and made comparative measures with a traditional mode of SS. Few investigations (Church, Wiggins, Moode, & Crist, 2001; Egan, Cramer, Massey, & Marek et al., 2006; Unick et al., 2005) have been conducted using NCAA athletes as their subject population. The studies that have utilized athletes did not include a sport-specific stretching protocol involving players’ actual stretching regimen.

Furthermore, this investigation intends to explore the duration and timing effects that SS and DS may or may not have on performance measures of force production, power output, ROM, and vertical jump height. Ryan et al., (2008) investigated the effect of SS immediately, and 10, 20, and 30 minutes post-stretching on measures of isometric peak torque, percent voluntary activation, electromyography (EMG) amplitude, peak twitch torque, rate of twitch torque development and ROM. Their investigation found immediate and significant deficits in performance measures, but neglected to find any significant interactions at 10, 20, and 30 minutes post-stretch. A potential setback to their
investigation may have been due to impractical durations (2, 4, and 8 minutes of SS), muscle groups involved (plantar flexors), and the specificity of performance variables unrelated to multi-joint movements. This investigation will follow a similar timing protocol as Ryan et al. (2008), but will include a more practical duration of SS (30 seconds per stretch) of 7 specific muscle groups activated in a multi-joint movement test in a CMJ. As Ryan et al. (2008) did, this investigation will also incorporate four timing variables of: (a) immediately post SS (SS-1), (b) 5 minutes post-SS (SS-5), (c) 15 minutes post-SS (SS-15), and (d) 25 minutes (SS-25).

**Purpose**

The purpose of this investigation was two-fold:

1. To determine whether a practical duration of a SS protocol (30 seconds per each targeted muscle group) elicits as much effectiveness as a highly trained athlete’s pre-competition DS regimen on measures of ROM, ground reaction forces (GRFs), power output, and CMJ height.

2. To determine whether a dose-response relationship exists regarding the timing effects of a practical duration of both SS and DS preceding a VJA test on a force plate. An additional control trial was done where participants underwent similar procedures, but did not stretch for seven minutes.

For the purpose of this investigation highly trained athletes were defined as a specific and small population: NCAA Division 1 volleyball players who compete in a sport where anaerobic and explosive power are required. Additionally, these athletes were defined as having performed a strength and conditioning program with inclusion of
plyometrics while under supervision of a certified strength and conditioning coach for at least 3 months prior to testing.

Research Questions

1. What is the effect of a standard SS session on the VJA performance measures as compared to a DS and control session in NCAA Division I volleyball players?
2. Is performance altered at the expense of increasing ROM through SS?
3. Is there a significant interaction in timing variations of SS and DS on power output and vertical jump height?

Hypotheses

The hypotheses for this study included the following:

1. Static stretching duration of 30 seconds of the targeted muscle groups (total duration of all groups 7 minutes) will result in a significant decrease in force, power output, and countermovement jump CMJ heights when compared to a DS session of the same duration at one and five minutes post-stretch.
2. There will be no significant differences between the SS and DS sessions at 15 and 25 minutes post-stretch.
3. ROM will significantly increase at 1 and 5 minutes post-SS session.

Delimitations

The delimitations of the investigation are:

1. Participants are highly trained based on exclusively being NCAA Division I athletes currently performing a strength training and plyometric program for 3 months prior to testing.
2. Participants are all female.
Limitations

The study will be limited by the following:

1. The inability to control female subjects’ menstrual cycle and its potential influence on power output.
2. Participants’ capability to go about their typical training regimen during the course of this study.
3. The possibility of positive psychological effects attributed to the DS session, since it is most related to participants’ typical warm-up, creating a potential bias for that particular session.
4. The inability to blind participants as to whether they stretched or not.
5. The desire to give their best performance during all testing procedures.
6. The possibility that the addition of ROM measures may impact power output during the protocol.

Assumptions

1. Participants followed all instructions given to them by the principal investigator.
2. Participants will abstain from alcohol, caffeine, or any other nutritional supplementation 24 hours prior to testing days.
3. Participants will abstain from all lower body exercises 24 hours prior to testing days.
4. Participants have experience performing tests and DS protocols in this study similar to their normal pre-event warm-up.
5. Power and force were considered to be directly proportional to athletic performance.

6. Subject population for this investigation was limited to only 11 female volleyball players which can run the risk of Type II error in the statistics.

**Definition of Terms**

*Compliance:* An increase in the length of a muscle-tendon unit (MTU) due to a result of chronic stretching. This is considered a permanent change in the MTU properties.

*Countermovement jump (CMJ):* A jump where the subject uses a whole body synchronized movement to enhance the stretch shortening cycle to increase jump performance.

*Dynamic stretching (DS):* Part of a warm-up that involves specific movements that are related to the task that will be performed.

*Ground reaction forces (GRFs):* Any force exerted by the ground on the body. The ground in this investigation was a highly sensitive force plate that measured instantaneous GRFs at the moment of take off from a CMJ.

*Hoffman reflex (H-reflex):* The H-reflex is an electrically-induced reflex that utilizes the same pathway as a simple spinal cord stretch reflex.

*Length-tension relationship:* Force generating capacity increases as muscle is stretched until an optimal length, at which point further stretching, pulls sarcomeres farther apart and thus decreases tension.
**Muscle-tendon-unit (MTU):** The collective combination of the muscle, tendon, and its connective tissue properties that contribute to the elastic energy and force production during movements.

**Peak power:** The highest determined power output determined during a given time interval of a maximal performance test.

**Performance:** The collective testing measurements of force, power output, and countermovement jump height in this investigation.

**Power output:** The rate of doing work. In this investigation power output was measured from a regression equation where the participant’s weight, height, and CMJ heights were used in the equation to determine power output.

**Range of motion (ROM):** The extent to which a muscle moves about a joint for a given task or effort.

**Static stretching (SS):** A sustained stretch usually for about 15-30 seconds duration to gradually lengthen the muscle and increase ROM.

**Stretch tolerance:** The ability to feel less pain for the same force applied to a muscle.

**Stretch shortening cycle (SSC):** Series of muscle events starting with an eccentric contraction and loading of the muscle followed immediately by a concentric contraction of the loaded muscle.

**Stretch reflex:** A monosynaptic reflex initiated by stretching of muscle spindles and resulting in immediate development of muscle tension.
Timing variables: The time to which a stretch commences to performance measures. This investigation contained four timing variables of 1, 5, 15, and 25 minutes post-stretch protocol.

Vertical jumping ability test (VJA): The highest recorded height a person can obtain. This test involves both an eccentric and concentric component pertaining directly to performance sports.

Viscoelasticity: This is a property of the muscle tendon ability. It reflects the ability of the tendon to accommodate force and change length as it undergoes the transition from its resting position, through an eccentric stretch and then concentric movement. An acute bout of static stretching increases viscoelasticity and is considered a temporary change in the MTU.

Warm-up: Aerobic activity performed prior to an activity to increase core and muscle temperature and increase activity of aerobic systems.
CHAPTER 2: REVIEW OF LITERATURE

This review of literature will provide a firm base of knowledge about a general warm-up, as well as SS and DS, and the physiological mechanisms associated with each. Furthermore, this review will cover scientific evidence regarding SS and DS and the implications on performance and how duration and timing theories have carved a path for new theories and future research. Finally, this review will provide a brief explanation of gender differences and hormonal effects on connective tissue properties in performance.

Warm-Up

A warm-up can briefly be defined as a preactivity movement used to adjust the body from rest to exercise (Bishop, 2003). It can further be clarified as a standard exercise performed to prepare the body for the metabolic demands of physical activity or competition (Bishop, 2003). Upon the onset of a warm-up, viscoelasticity, which is the ability of muscle and tendon to respond to stretch, is temporarily enhanced due to both temperature (Fisher et al., 1999) and non-temperature related mechanisms (McCutcheon, George, & Hinchcliff, 1999), therefore making muscles, tendons, and connective tissue pliable (Bishop, 2003). Bishop (2003) postulated that the warm-up effects on temperature-related mechanisms include decreased muscle stiffness, increased nerve-conduction velocity, increased anaerobic energy yield, and thermoregulatory strain. Furthermore, Bishop (2003) categorized a warm-up into two specific routines prior to exercise, either a passive or an active warm-up. Young and Behm (2002) further elaborated that a warm-up has three typical components prior to activity: (a) A relatively low intensity aerobic component that is general in nature to increase core temperature,
improving neuromuscular function, (b) Some stretching of the specific muscles involved in the subsequent activity to achieve a short term increase in ROM at a joint or to induce muscle relaxation and therefore decrease the stiffness of the muscle-tendon system, (c) Rehearsal of the skill about to be performed at gradually increasing intensities, culminating in some efforts that are equal to or greater than the expected competition intensity to activate or recruit the specific muscle fibers and neural pathways required to achieve optimum neuromuscular performance.

To date warm-up methods have limited scientific evidence due to a scarcity of well-controlled studies that have included large subject populations and appropriate statistical analysis to conclude that any or all of these mechanisms have an effect on performance (Bishop, 2003). For this reason, in order to ensure that an athlete is adequately prepared for optimal performance, it may be appropriate for an athlete to include, to some extent, each of the warm-up methods noted by Bishop (2003) and Young and Behm (2002). Although similar, these studies appear to provide a firm base of scientific evidence related to a warm-up’s mechanisms to enhance performance. This investigation was designed in a similar fashion to Bishop’s, and Young and Behm’s suggestions; that is, to compare stretching (SS) to relax the muscles and decrease muscle stiffness to more sport specific movement patterns (DS) after a standardized general warm-up.
**Stretching**

The ACSM (2008) examined several key points concerning stretching that should follow a standard warm-up. These entail: (a) stretching exercise is most effective when the muscles are warm; (b) stretching should be performed before and/or after the conditioning phase; (c) stretching following exercise may be preferable for sports in which muscular strength, power, and endurance are important for performance; (d) stretching may not prevent injury (Fradkin, Gabble, & Cameron, 2006); (e) stretching should be performed at least 2-3 days per week; and, (f) static stretches should be held for 15-60 seconds (Thacker, Gilchrist, Stroup, & Kimsey, 2004).

In addition to the ACSM, the *National Strength and Conditioning Association* (NSCA, 2008) recommends that a stretch be held for 15-30 seconds to elicit significant gains in ROM. The NSCA further elaborates that acute effects of stretching on ROM are momentary and are greatest immediately after a stretching session, then decline across time. The NSCA also recommends that for improvements in flexibility, stretching should be done at least twice per week for at least 5 weeks. In reference to when an athlete should stretch for optimal benefits, the NSCA states the following: (a) static stretching should be performed within 5 to 10 minutes post-practice or competition, when muscle temperature is increased since the raised temperature increases elastic properties of collagen within muscles and tendons; (b) it may be appropriate to incorporate additional stretching sessions after a thorough warm-up if increases in flexibility are needed. These sessions may serve as a useful recovery session on the day after competition.
Several important factors need to serve as focal points when considering enhancements in performance as a result of increased flexibility after a stretching program. First, sports and activities have specific requirements for ROM. Therefore optimal levels of flexibility exist, relating to the movements within that particular sport (Thacker et al., 2004). If there are optimal ranges in flexibility for specific sports then it may be appropriate to increase or decrease the frequency, timing, and duration accordingly so that an athlete is not engaging in activities outside of his/her ROM, and thus potentially causing an increased risk for injury and/or decreased performance. Also, inflexibility and hyper-flexibility have been found to result in higher risk of injury (Thacker et al., 2004), and imbalances in flexibility can predispose athletes to an increased risk of injury (Knapik, Bauman, & Jones, 1991). Therefore, appropriate sport specific muscle stretching before and/or after competition may enhance performance and reduce the risk of injury, but needs to be further validated.

Muscle-Tendon Unit Properties

Anatomy and Physiology of Muscle and Tendons

Skeletal muscle functions as an integrated system of several properties jointly coined the muscle-tendon or musculotendinous unit (MTU) (Ishikawa & Komi, 2008). The MTU contains basic contractile and tensile elements, which contribute to plastic and elastic properties respectively. Contractile elements consist of muscle fascicles and play a critical role in the function of the entire MTU unit (Ishikawa & Komi, 2008). The elastic property of the MTU is utilized during stretch-shortening cycles (SSC), and indicates that when a small load is applied, the tissue will change shape but when the load
is removed, the tissue will immediately return to back to its original shape. Extensibility is also a component in the SSC that indicates the ability of the MTU to be stretched while elasticity indicates that the MTU will be able to return to its original length. Ultimately, extensibility and elasticity act in concert to promote the stretch shortening cycle (SSC) of the MTU. On the other hand, plastic properties of the MTU demonstrate that when a load is applied, the MTU changes shape or conformation temporarily (altering extensibility and elasticity) but returns back to its resting value over time. When applying a stretch to the MTU, the goal is to create a lengthened unit, or work on the plastic property of the tissue, but to not apply so much force that the tissues actually fail (Hall, 2007).

Muscle also contains a parallel elastic component (PEC) and a series elastic component (SEC). Both the SEC and PEC are passive tissues, whereas muscle itself is active, in that it can contract (Hall, 2007). The SEC is considered to be the tendons, in line with the muscle (not surrounding it). The SEC stores elastic energy when a muscle is stretched in an eccentric action, and this energy is released when the muscle is subsequently contracted concentrically. Adversely, the PEC surrounds the muscle as membranes, and resists a passive stretch. The PEC also helps muscle stretch and recoil, as does the SEC, although it is not believed to store as much elastic energy (Hall, 2007).

Stretch Shortening Cycle

The stretch shortening cycle (SSC) is considered to be the fundamental concept in unrestricted human locomotion consisting of a series of muscle events starting with an eccentric contraction and loading of the muscle followed immediately by a concentric contraction of the loaded muscle (Ishikawa & Komi, 2008). The primary purpose of the
SSC is to enhance the push-off phase (concentric action) when the body experiences natural movements such as walking, running, and jumping. When compared to an isolated concentric action, the SSC typically generates more force generating capacity. This is because stored energy is contained in the elastic properties, which allows for higher contractile performance at the onset of the concentric action creating greater force gains. Most human dynamic movement tasks involving the SSC contain a variable muscle activation profile, meaning that central activation as well as reflex pathways can play a contributing role of enhancement of the SSC (Komi & Golhofer, 1997). In the act of hopping, it has been shown to cause considerable differences in the activation strategy of the soleus and gastrocnemius (Moritani, Oddsson, & Thorstenson, 1997). As the muscle fascicles are controlled both by external stretch and internal activation, evidence is clear that different length changes due to different fascicle and tendon activation contribute considerably to the SSC (Ishikawa & Komi, 2008). A CMJ is a prime example of a human dynamic movement that utilizes the SSC. With the storage of elastic energy in the SEC, PEC and although unclear, to some extent, the stretch reflex, the SSC is utilized in the CMJ. As a person lowers his/her center of gravity, the PEC prevents the muscle from over-stretching which can potentially attenuate elastic energy stored via the SEC (Ishakawa & Komi, 2008). Eccentric lengthening loading the SEC and activating the stretch reflex helps to create an immediate and violent concentric contraction to facilitate maximal force generating capacity (Ishakawa & Komi, 2008).
The Stretch Reflex

The stretch reflex is an injury protective mechanism used to enhance muscle force via muscle spindles (Kjaer, 2004). When a muscle experiences a quick stretch, length monitoring intrafusal muscle fibers, embedded in muscle spindles, send afferent information to the spinal cord to be sent back to the same muscle with an excitatory reflex. This ensures that the muscle does not stretch to a point of uncontrolled damage. An example of a stretch reflex would be when a volleyball player approaches the net to spike the ball; an initial lowering movement (flexion of the hips, knees, and ankles) is made to eccentrically stretch the extensors, quickly followed by aggressive extension of the plantar flexors, knees, and hips to achieve maximal torque. This eccentric stretching may activate the stretch reflex, helping to increase the force and power of the subsequent jump.

Muscle-Tendon Behavior and Performance

Joint stability provides for the appropriate means of engaging quick powerful movements during activities (Goldie, Bach, & Evans, 1989). To the contrary joint laxity, while increasing ROM, can cause severe decrements in movement kinetics in power related activities (Holt & Lamborne, 2008; Bradley, Olsen, & Portas, 2007; Knudson & Noffal, 2005; Young & Elliot, 2005). Dynamic movements similar to natural movements (e.g., walking or running) stimulate the elastic elements both inside and outside the muscle, which causes them to be stretched and then recoil elastically, enhancing the velocity and power of the resulting movement (Lappin et al., 2006). Recent studies have shown that when muscles recoil elastically, they behave as nonlinear load-dependent
springs (Lappin et al., 2006). What this means is that as a muscle develops force
isometrically, elastic elements are strained, consequently throwing them from their
equilibrium forces. When the resisting force is decreased, the elastic elements recoil
back to their resting length. As described by Lappin et al. (2006), the nonlinear load-
dependent stiffness of muscle during active shortening also has the ability to intrinsically
self-stabilize deviations in load. An MTU is much like a rubber band, where it will
become stiffer when an external load increases and will become more compliant when
the load decreases for a given force. In other words, as the load changes unexpectedly,
the muscle itself has the ability to adjust its stiffness accordingly without initiating neural
input. These are time dependent changes of muscle and force in response to changes in
length (Rassier & Herzog, 2004)

Length-Tension and Force-Velocity Relationship

The magnitude of force a muscle can generate is dependent on the length, velocity
of contraction, and stimulation (Leiber, 2002). Muscle creates forces in response to an
externally applied load to the levers (limbs) creating sarcomere lengthening and
shortening. If sarcomeres are stretched too far, excessive force is applied to the
contractile machinery to produce effective shortening velocity. Alternately, if a muscle is
not stretched far enough, the contractile machinery becomes so ineffective that the return
velocity of muscle is depressed resulting in less power produced (Martini, Lindsley, &
Cummings, 2008). These concepts infer to the length-tension relationship of muscle.
Simply put, the length-tension relationship dictates force generating capacity at optimal
sarcomere lengths (Hall, 2007). An optimal length-tension ratio via optimal eccentric
lengthening produces tension concentrically that can be converted to the greatest amount of force applied from the muscle to the ground.

**Measurements of Vertical Jumping Ability**

Measurements of force can be viewed as ground reaction forces (GRFs) on a force plate. The force plate transfers the forces applied to four specific sensors embedded within the plate and converts it into a GRF curve plot on the computer. Since power is a product of force and velocity, and if any two components are compromised, power will be reduced. One of the most acceptable ways to experimentally measure power output is by testing vertical jump ability (VJA). The ability to perform a vertical jump is regarded by many coaches a great indicator of athletic performance, especially for those sports where vertical jumping is a priority to athletic success. Sports such as football, volleyball, basketball and certain jumping events in track and field rely on the athlete’s ability to generate a large amount of force to enhance a vertical jump. Therefore a positive correlation exists regarding VJA and explosive anaerobic type sports (Klavora, 2000; Carlock et al., 2004). When determining a VJA modality, a CMJ is a more applicable assessment in an experimental setting compared to common static or squat jump testing. This is because a CMJ is a multijoint movement that requires very similar muscle actions typical to explosive athletics. Thus an increase in power and strength through coordination and enhancement of the stretch shortening cycle (SSC) is heavily relied upon (Komi, 2003). This investigation measured GRF’s on a force plate concurrently using a Vertec apparatus to determine power output as well.
Static Stretching

Static stretching is advantageous in several ways: It is simple to learn, can be performed individually, and is effective at increasing joint ROM (Kokkonen, Nelson, and Cornwell, 1998). The most effective means of increasing ROM appears to be through gradually increasing muscle temperature by an active or passive warm-up, (e.g., warm pack or ultrasound) followed by some form of SS (Bishop, 2003). Comparatively, the amount of flexibility one can demonstrate or gain is related to the duration and frequency of an SS session. The amount of time spent stretching to increase ROM has been optimally found by Roberts and Wilson (1999). They concluded that holding a stretch (static stretching) for 15-30 seconds appears to elicit just as much lengthening as would anything longer in duration, whereas anything less in duration was found to non-significantly increase ROM. The ASCM (2008) has defined static stretching as stretching a muscle to the end point of range of motion, which is perceived as the point of mild tightness without discomfort, and holding for 15-60 seconds. This investigation followed the ACSM guidelines for statically stretching muscle groups to a point of mild tightness with the duration that Roberts and Wilson previously noted as optimal for increasing ROM, at 30 seconds per targeted muscle group.

Performance

For years it has been thought that if stretching increases flexibility, performances would be enhanced. The recent consensus among coaches and athletes reveals that SS prior to athletics may cause decrements in muscular power as a result of stretching-induced force deficits. A review article by Shrier (2004) noted that 22 of 23 articles
found that acute bouts of different stretching modalities (SS and proprioceptive neuromuscular facilitation stretching) diminished performance tests of force, torque, and/or jumping, or that there was no clinically relevant difference between the two modes of stretching when compared to a control. Additional relevant investigations have also concluded that an acute bout of SS can have negative alterations in performance pertaining to isometric and dynamic strength (Fowles et al., 2000; Kokkonen, Nelson, & Cornwell, 1998), isokinetic torque (Cramer, Housh, Coburn, Beck, & Johnson, 2006; Cramer et al., 2004; Egan et al., 2006; Marek et al., 2005), 1-RM (Kokkonen et al., 1998), and balance, reaction time, and movement (Behm, Bambury, Cahill, & Power, 2004). Furthermore, SS has been found to have detrimental effects on a variety of performance tests which include measures in force production (Egan et al., 2006; Marek et al., 2005), sprint speed (Fletcher & Jones, 2004; Nelson, Driscoll, Landin, Young, & Schexnayder, 2005) and agility (McMillan, Moore, Hatler, & Taylor, 2006). Relative to this investigation, some investigations have suggested that SS can reduce power output (Bradley, Olsen, & Portas, 2007; Holt & Lamborne, 2008; Knudson & Noffal, 2005; Young & Elliot, 2005) and VJA (Bradley, Olsen, & Portas, 2007; Robbins & Sheuermann, 2008; Young & Elliot, 2001). Although there appears to be much evidence supporting claims that SS reduces performance, conflicting evidence has revealed that SS elicits no significant reductions in power output and VJA (Danoff & Miller, 2008; Monoel et al., 2008; Knudson, Bennett, Corn, Leick, & Smith, 2001; Unick et al., 2005). Therefore, stretching-induced force deficit theories have not been fully clarified and further research must be performed.
Stretching-Induced Force Deficit Mechanisms

The proposed mechanisms to which SS may cause decrements to performance (stretching-induced force deficits) include neural factors and mechanical factors. A negative neural factor would be considered a decrease in muscle activation, whereas a negative mechanical factor would be considered an increase in compliance of the MTU.

Mechanical factors. Growing evidence has suggested that mechanical factors may play a more predominant role than neural factors regarding stretching-induced force deficits after an acute bout of SS. Wilson, Murphy and Pryor (1994) proposed that an increase in the stiffness of the MTU should result in a higher force and rate of force development. They hypothesized that a stiffer MTU would transmit force to bone more rapidly, thus creating a higher rate of force development, whereas a more compliant MTU would be unable to transmit force to the bone as rapidly, and consequently decrease rate of force development relative to its stiffer counterpart (Wilson et al., 1994). Static stretching has been shown to decrease the viscoelastic responsiveness as well as increasing MTU compliance (Avela, Kyrolainen, & Komi, 1999). Stretch tolerance is increased after each bout of SS and is defined by Shrier and Glossal (2000) as the ability to “feel” less pain for the same force applied to a muscle. The thought is that if a muscle is consistently held to its end range of motion for a considerable amount of time (30 seconds–five minutes), an increase in compliance results over the entire MTU. This concept is referred to as “increasing the slack” of the MT structures. As a result, this changes the elastic properties of the MTU, decreasing the ability to release energy which can have a detrimental effect on performance.
**Neural factors.** Speculation for a decrease in power output may be the result of decreased motor neuron excitability due to alterations of the stretch reflex. These alterations can be detected by experimental use of the Hoffman reflex (H-reflex). The H-reflex is an electrically-induced reflex that utilizes the same pathway as a simple spinal cord stretch reflex. Decreased H-reflex activity seemingly involves several neural mechanisms that are located at the presynaptic and postsynaptic locations (Guissard & Duchateau, 2006). Guissard and Duchateau (2006) determined that the H-reflex is usually depressed after a prolonged bout of stretching but recovers fairly quickly (< 5 minutes). This indicates that some type of neural inhibition is present after an acute bout of SS. The authors further elaborated that upon initiation of SS the H-reflex decreases considerably over only a short period of time yet a decrease in performance still exists (Guissard & Duchateau, 2006). This may suggest that the actual physical change in muscle length (increased compliance) disrupts GRF’s, and ultimately results in a length-tension relationship beyond optimal forces (results in the decline of the length-tension relationship).

**Static Stretching Duration and Timing Theories**

The duration and time course to which SS has a significant reduction in performance measures may play a critical role in understanding the physiological mechanisms that contribute to stretching induced force deficits. The duration of significant improvements in flexibility has been shown to range from 3 minutes (Depino, Webright, & Arnold, 2005) to 24 hours (DeWeijer, Gorniak, & Shamus, 2003).
Duration. Duration of static stretching involves the length of time it takes to stretch the muscle. The National Strength and Conditioning Association (NSCA) recommend that a SS should be held for 15-30 seconds. This is different to the ACSM’s (2008) guidelines that recommend SS for a period of 15-60 seconds. Although similar in duration, research has shown that there can be small, but significant differences in performance measures if a muscle is stretched for only 30 seconds (Robbins & Scheuermann, 2008) or less compared to stretching for 60 seconds and beyond (Young & Behm, 2003). More importantly literature suggests that when applying a more practical duration (15-60 seconds) of SS, performance variables remain unchanged compared to a control (Ogura, Miyahara, Hisashi, Shizu, & Junichiro, 2007; Robbins & Scheuermann, 2008; Zakas, 2005). This is different to studies that have involved durations of SS beyond the ACSM and NSCA guidelines where they found significant reductions in performance after a less-than-practical bout of stretching (Cramer et al., 2005; Evetovich et al., 2003; Fowles et al., 2000). This suggests that a durational application to SS can alter performance significantly and adds a critical element of knowledge for coaches and athletes when designing an effective stretching routine as part of a warm-up.

Time. The time from which a SS is applied to the measurement of performance variables has also been shown to play an important component in determining the effectiveness of the stretch (Kay & Blazovich, 2009; Ogura, Miyahara, Naito, Katamoto, & Aoki, 2007; Ryan et al., 2008). Kay and Blazевич (2009) investigated the timing effects (2 and 30 minutes post-stretch) involved with muscle and tendon mechanical properties and muscle activation of a medium duration SS (3 x 60s) of the triceps surae...
muscle and Achilles tendon. They found significant decreases in peak concentric moment after stretching, with 60% of the deficit recovering 30 minutes post-stretch which was accompanied by, and correlated with ($r = 0.81; p < 0.01$) reductions in peak triceps surae EMG amplitude. The main findings to their investigation were that the impact on mechanical properties and neuromuscular activity (EMG amplitude) was minimal at 30 minutes post-stretch.

Another study done by Ryan and colleagues (2008) involved both a duration and timing aspect to a bout of SS on performance variables. Their study involved the durational experimental conditions: a) control, b) passive stretch for 2 minutes, c) passive stretch for 4 minutes, and d) passive stretch for 8 minutes, with post-treatment timing variables of immediately, 10 minutes, 20 minutes, and 30 minutes post-treatment. All timing variables were done on the same day of post-treatment durations. Isometric peak torque, percent voluntary activation, EMG amplitude, peak twitch torque, rate of twitch torque development, and ROM of the plantar flexors were determined with five separate two-way repeated measures ANOVAs. Only significant differences were found in performance variables immediately after an acute bout of SS, and not at 10, 20, and 30 minutes post stretch in all durations. Although their results were mostly nonsignificant the authors suggested that there may be a stretching-induced force deficit through a curvilinear response which is governed by a dose-response relationship with respect to stretch durations.
Static Stretching and Highly Trained Athletes

Universal evidence exists endorsing that SS negatively affects highly trained athletes. Highly trained athletes are usually participants at the collegiate or professional level. Most of the literature, as previously covered, has evolved around subject populations ranging from sedentary-to-recreationally fit participants, but only a few studies have been done with NCAA athletes (Church, Wiggins, Moode, & Crist, 2001; Egan et al., 2006; Unick et al., 2005) and other various highly trained professional affiliations (Fletcher, & Annes, 2007; Fletcher, & Jones, 2004; Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004; Little & Williams, 2006; McMillan et al., 2006; McNeal & Sands, 2003; Siatras et al., 2003). With minimal literature involving highly trained athletes it is difficult to understand whether stretching-induced force mechanisms correlate in much the same manner as less trained individuals.

Differences in experimental designs have provided universal evidence regarding the effects of SS on performance variables. Fletcher and Jones (2004) tested rugby union players in a 20 meter sprint test with and without prior SS. They found SS to have a detrimental effect on performance compared to the control of no SS. Similarly, Fletcher and Annes (2007) completed a study involving the acute effects of a SS and DS protocol on 50 m sprint ability. Their results concluded that SS decreased 50 m sprint ability and increased time to complete the time trial. In contrast, Unick et al. (2005) found SS to elicit no effect in either a CMJ or drop jump trial in a study with NCAA-Division III basketball players. Additionally, no changes in peak torque or mean power output of the leg extensors were observed in a study of NCAA Division-I women’s basketball players.
due to SS (Egan, Cramer, Massey, & Marek, 2006). Another NCAA study done on various Division I athletes found no change in CMJ after SS, but found a significant decrease in performance after undergoing a proprioceptive neuromuscular facilitation (PNF, another form of static stretching) stretch (Church, Wiggins, Moode, & Crist, 2001).

Relative to the NCAA studies using athletes, SS has also been found to have mixed results in various highly trained or professional populations. Knudson et al. (2004) examined tennis serve speed and accuracy after SS to which no significant changes were found when compared to a control group. Additionally, Little and Williams (2006) examined the effect of SS on professional soccer players. They found that SS elicited no effect on CMJ or 10 m sprint time, but did find that SS improved performance in a flying start 20 m sprint. In perhaps one of the most extensive studies done involving the effects of stretching on performance in a highly trained population, McMillan et al. (2006) tested the U.S. Military Academy (USMA) in a 5-step jump test compared to no prior activity. The authors of this investigation found that prior SS actually increased performance.

*Regular Long Term Stretching*

There is some evidence supporting the notion that regular long term stretching increases isometric force production and velocity of contraction (Shrier, 2004). In a systematic critical review of literature detailing the effects of regular long term stretching on power output Shrier (2004) concluded that the mechanism by which regular long-term stretching improves performance is likely related to stretch-induced hypertrophy.
Stretch-induced hypertrophy is theorized to be an increase in the muscle-tendon cross-sectional area as a result of consistent day-to-day stretching over a period of several months. Mice and rabbit studies have shown that when a muscle is stretched 24 hours per day, some hypertrophy occurs even though the muscle has not been contracting (Goldspink, Cox, Smith et al., 1994). 

Theoretically, it can be assumed that applying a more applicable approach such as stretching a muscle for 30-60 seconds a day over a period of 3-4 months, one would predict an increase in force and contraction velocity. A study done by Kokkonen, Nelson, Eldridge, and Winchester (2007) investigated the influence of an intensive, chronic, lower-extremity stretching routine on strength, strength endurance, 20-m sprint, vertical jump, and standing long jump on 38 physically inactive or recreationally active students through a 10 week, 40-minute, 2 days per week stretching routine designed to stretch all the major muscle groups of the lower extremity. The stretching group compared to the non-stretching (control) group had significant average improvements ($p < .05$) for flexibility (18.1%), standing long jump (2.3%), vertical jump (6.7%), 20-m sprint (1.3%), knee flexion 1RM (15.3%), knee extension 1RM (32.0%), knee flexion endurance (30.4%) and knee extension endurance (28.5%). The control group had no improvements in the study. These results indicate that for inactive to moderately active populations a chronic stretching-only regimen can improve specific exercise performance. While these specific exercises correlate well to athletic performances, it is still unclear as to whether results would be altered if a highly fit athletic population underwent the same protocol. It is likely that the volleyball players in this investigation
have undergone stretching exercises for such a prolonged period of time that they may be immune to any chronic SS-induced performance changes.

**Dynamic Stretching**

*Physiological Mechanisms*

In recent years, DS has been promoted as a preferred mode of stretching used by many athletes and coaches. Dynamic stretching, sometimes referred to as an active warm-up, is a process of warming up specific muscle groups through an active ROM that will “prime” the muscles prior to competition. It is theorized that by targeting specific muscle groups, DS will optimally raise the temperature of muscle, a critical physiological component to successful athletic endeavors. An example of a DS would be a track sprinter incorporating fast skips, hops and lunges into a warm-up as a means to “prime” the MTU for his/her sport-specific task, sprinting at top end speed.

*Performance*

The general consensus among research is that DS increases several performance variables when compared to a control or SS protocol of the same duration (Curry, Chengalath, Crouch, Romance, & Manns, 2009; Fletcher & Ruth, 2007; Hough, Ross, & Howatson, 2009; Manoel et al., 2008; Moran, McGrath, Marshall & Wallace, 2009; Siatras et al., 2003). Bishop (2003) proposed that active warm-ups (DS) will most likely produce higher cardiovascular and metabolic changes needed to complete the exercise than would a passive warm-up (SS), which has also been found to increase cardiovascular and metabolic demands, but to a lesser extent.
A secondary warm-up is something that many athletes do prior to competition and consists of dynamic sport specific movements performed as a way to adjust the body to meet the demands of the task. Simply put, a secondary warm-up is a more specific DS routine. Dynamic stretching alone or secondary movement activity could perhaps cause postactivation potentiation, defined as a transient improvement of muscular performance after previous contractions (Sale, 2002). Postactivation potentiation is a neurological phenomenon that may enhance muscle function after either DS or a secondary sport-specific warm-up. Although inconclusive, postactivation potentiation may pose limitations in studies involving multiple consecutive jumps for data collection. This, in return, may alter results when evaluating the effect of different stretching variables on performance because postactivation potentiation may enhance subsequent jumps after the initial jump.

Pearce, Kidgel, Dawson, Zois, and Carlson (2008) underwent a highly controlled study investigating the effects of a secondary bout of activity after static and dynamic stretching on 13 university students. Each student completed three trials that included a five minute standardized warm up, followed by a vertical jump on a force platform, an intervention (SS, DS, or control), followed by a second vertical jump. Then, each participant completed a series of movements, followed by a vertical jump at 10, 20, 30, 45 and 60 minutes post secondary exercise protocol. Their findings were that a second warm-up bout increased vertical jump height following a dynamic exercise protocol, whereas the SS condition did not show any difference, thus showing that a second exercise does not reverse the effect of an acute bout of SS causing decrements in vertical
jump height. Fletcher and Jones found similar results with 97 male rugby union players. They were assigned randomly to four groups (SS, DS, active static stretch, and passive static stretch). All groups performed a standard 10-minute jog warm-up, followed by two 20-m sprints. The 20-m sprints were then repeated after subjects had performed different stretch protocols. The passive SS and active SS groups had a significant increase in sprint time ($p \leq 0.05$), while the active DS group had a significant decrease in sprint time. Their findings suggest that DS should be incorporated into a standard warm-up because rehearsal of specific movement patterns may help coordination for that particular sport.

Another unique study by Tayler, Sheppard, Lee, and Plummer (2008) evaluated the effects of a sport specific warm-up on SS and DS. When comparing only SS to DS their findings match other studies (Cornwell, Nelson, Heise & Sidaway, 2001; Young, Elias, & Power, 2006) in which SS resulted in significantly poorer performance than dynamic warm-up in vertical jump height ($-4.2\%$, $0.40$ ES) and 20m sprint time ($1.4\%$, $0.34$ ES). However, no significant difference in either performance variable was evident when a secondary movement activity was preceded by SS or DS. Their findings suggest that performance variables can be restored with the addition of some secondary skill-based activity.

**Flexibility and Gender**

Gender appears to have a noteworthy influence in flexibility. For example it has been found that males tend to be less flexible than females (Schramm, Latin, Berg, & Stuberg, 2001). Connective tissue and muscle mass in general are greater in males due to higher testosterone levels (Alter, 2004). This, in return, reduces muscle and tendon
extensibility when compared to females, whose hormonal levels of estrogen are higher, allowing for higher accumulations of fat rather than muscle, which allow them to have some flexibility advantages over males (Haywood & Getchell, 2001). When examining the effect of gender on the response of flexibility to training, both males and females appear to increase ROM homogeneously (Walter, Figoni, Andres, & Brown, 1996).

**Hormonal Effects on Connective Tissue Properties**

Hormones may affect performance measures in this study, particularly hormones during the menstrual cycle. Sarwar, Beltran and Rutherford (1996) explored the effect of different phases of the menstrual cycle on skeletal muscle strength, contractile properties and fatigability in ten young (20.7 +/- 1.4 years) relatively healthy females. They were compared to a similar group who were on the combined (non-phasic) oral contraceptive pill. Cycle phases were divided into the early and mid-follicular, mid cycle (ovulatory) and mid and late luteal phases. Participants were examined weekly through two complete cycles and measurements that included quadriceps and handgrip maximum voluntary isometric force and relaxation times, force-frequency relationship, and fatigue index of the quadriceps. Results showed that women not taking the oral contraceptive had a significant increase (11%) in quadriceps and handgrip strength at mid-cycle compared with both the follicular and luteal phases. Additionally, there was a significant slowing of relaxation and increase in fatigability at mid-cycle. Finally, no changes in any parameter were found in the women taking the oral contraceptive. The authors suggested that the changes in muscle function at mid-cycle may be due to the increase in estrogen that happens prior to ovulation.
CHAPTER 3: METHODS

Experimental Design

The objective of this design was to evaluate the effectiveness of different static stretching (SS) timing variables (SS-1 vs. SS-5 vs. SS-15 vs. SS-25) to the typical pre-competition dynamic stretching (DS) routine of a volleyball player (DS vs. SS) on range of motion (ROM), rate of force development (RFD), power output, and vertical jump ability (VJA). A total of four sessions were performed consisting first with a preliminary testing and familiarization day followed by three days of random testing or stretching protocols that involved: (a) a SS protocol followed by a VJA test on force plate 1, 5, 15, and 25 minutes post-SS, (b) a control protocol of just a general warm-up and VJA test on a force plate 1, 5, 15, and 25 minutes post-general warm-up, and (c) a volleyball player’s DS routine and VJA test on a force plate 1, 5, 15, and 25 minutes post-DS. The experimental design is summarized in Table 1.
Table 1. *Experimental Protocol*

<table>
<thead>
<tr>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 3</th>
<th>Session 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Overview of study</td>
<td>- Testing day 1</td>
<td>- Testing day 2</td>
<td>- Testing day 3</td>
</tr>
<tr>
<td>- Informed consent</td>
<td>- Randomly assigned protocol (SS, control, DS)</td>
<td>- Randomly assigned protocol (SS, control, DS)</td>
<td>- Randomly assigned protocol (SS, control, DS)</td>
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<tr>
<td>- Anthropometric data</td>
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<tr>
<td>- Familiarization: ROM, SS, and VJA procedures</td>
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</table>

**Participants**

With written and verbal permission by the coaches, 11 volunteer, female, NCAA Division I varsity volleyball players were recruited and consented to participate in this investigation in the spring quarter of the academic year. All participants completed an informed consent process approved by the Ohio University Institutional Review Board. Their demographic data are listed in Table 2.
Table 2. Participants’ Demographic Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tbody>
<tr>
<td>n = 11</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.00 ± 1.55</td>
</tr>
<tr>
<td>Body Weight (kg)</td>
<td>74.55 ± 12.18</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.78 ± 0.08</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>20.85 ± 3.70</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.41 ± 2.81</td>
</tr>
</tbody>
</table>

Note. Values reported as mean demographics ± standard deviation

Inclusion Criteria

Based on past and current training regimens from a training status questionnaire, inclusion criteria for this investigation involved a very specific population, NCAA Division I varsity volleyball players. Players were characterized as strength and power athletes, which is indicative of a rigorous weight training program working the entire body with the addition of plyometric training that involves medium-to-high impact bounding, leaping, and jumping drills. As part of the athletic and training status questionnaire process participants were asked the number of years of competitive volleyball played, and also the number of years each has been in a previous strength and conditioning program with a qualified strength and conditioning coach. Subject qualifications, in this regard, involved having each player participating on Ohio University’s varsity volleyball team under a supervised and coordinated strength and
conditioning regimen for a span of at least one year. Seniors, who completed their season in the fall, which was just prior to testing in the spring, met the pretesting questionnaire criteria, and who trained for spring volleyball, were eligible to participate in this investigation.

Participants were asked to arrive to the Exercise Physiology laboratory, Grover Center E116 wearing the same practice shoes on roughly the same time of day (2-5pm) for all testing sessions. Participants were also asked to refrain from alcohol and caffeine 24 hours prior to testing as they have been shown to decrease (Paton, Hopkins, William, & Vollebregt, 2001) and enhance (Bruce et al., 2000; Doherty, Smith, Hughes, & Davidson, 2004) anaerobic power, respectively. Nutritional supplementation was allowed during the course of this investigation with no further monitoring conducted. For descriptive purposes, participants were asked to fill out a brief questionnaire making note of their menstrual cycle status at the time each testing session began, because the luteal phase of the menstrual cycle has been shown to produce significantly higher anaerobic power outputs when compared to the follicular phase (Masterson, 1999). Finally, subjects were asked to go about their typical training regimen with their coaches, but refrain from any type of vigorous activity 24 h prior to the day of their testing session.

**Anthropometric Measures**

A stadiometer (Invicta Plastics Limited, England) was used to measure height in meters and an electronic scale (Tanita BWB-800, Tanita Corporation, Japan) was used to measure mass in kilograms. From these measures collectively, body mass index (BMI) was calculated ($\text{BMI} = \frac{\text{kg}}{\text{m}^2}$) and used for descriptive purposes. Additionally, the
density of the body was assessed using the three site skin-fold procedure (Jackson & Pollock, 1985; Pollock, Schmidt, & Jackson, 1980), as a means for estimating body composition. Briefly, a skinfold caliper (Lange, Beta Technology Incorporated, Cambridge, Maryland) was used to access the thickness of subcutaneous fat at the locations of the triceps brachii, suprailiac, and thigh. Skinfold assessments corresponded with the ACSM’s guidelines: (a) all measurements taken on the right side of the body with subject standing upright, (b) the caliper placed directly on the skin surface, 1 cm away from the thumb and finger, perpendicular to the fold, and halfway between the crest and the base of the fold, (c) the pinch maintained for 1-2 seconds while reading the caliper, (d) measurements taken in a rotational manner through all sites, (e) duplicate measures taken at each site specified above and retested if duplicate measures are not within 1 to 2 mm. From this the average of the two closest measurements were calculated and used in a gender and race specific equation that determines body density. Once the predicted body density was determined, (Jackson & Pollock, 1985; Pollock et al., 1980), percent body fat was then calculated using the Siri Equation (1956).

**Experimental Protocol**

*Session 1*

Each participant met with the primary investigator on an individual basis for each session. Session 1 involved participants entering Ohio University’s Exercise Science Laboratory to undergo procedures as delineated below.

*Questionnaires.* Participants were first asked to fill out an informed consent and health history questionnaire (see Appendix A) upon entering the laboratory during the
first session. Participants also filled out an athletic status questionnaire during this time (see Appendix B).

Resting measures. When all questionnaires were completed each participant had height, weight, and body fat % determined as described in the anthropometric measures section.

Verbal familiarization. After obtaining resting measures, the principal investigator thoroughly explained all testing sessions and procedures related to the SS routine, ROM and VJA. Since it was this study’s intent to compare SS to a volleyball player’s actual DS regimen, it was assumed that all participants understood the DS procedures and no additional familiarization was provided.

Range of Motion Procedures

ROM familiarization began with the primary investigator giving a concise overview on how to accurately perform and determine ROM. After verbal cues were given, the participant was then asked to perform the procedure to determine if she understood what to do. Ankle and hip ROM measurements were found before and after each stretching protocol to determine if any change in flexibility has occurred as a result of the stretching protocol. ROM was measured to the nearest degree with a digital inclinometer (Baseline Measurements, New York). All measurements were recorded as the difference of angles in degrees and only taken on subjects’ dominant leg with one ROM assessment taken per muscle group.

Hip flexibility. To assess hip flexibility each participant lay supine on a table with legs and arms resting comfortably to the side of the body. When the participant was
relaxed the digital inclinometer was placed on the lower thigh approximately one third the distance between the proximal border of the patella and the inguinal crease. When secured at this position the principal investigator “zeroed” the inclinometer and under his command, the participant actively flexed her hip and knee simultaneously attempting to bring their knee toward their chest. Hence, the movement was an active stretch of the gluteus maximus muscle of the measured leg where the agonistic contraction of the hip flexors can only support any advances in ROM. This means that the investigator could not assist in further stretching the muscles along with no assistance from the participant by using their hands and arms to help flex their leg further to enhance the stretch. During this maneuver, the principal investigator also momentarily ensured that the opposite leg was maintaining a straight leg posture using verbal cues to have the participant maintain an extended leg while simultaneously flexing the dominant leg. The importance to monitoring this was it did not enhance hip flexion of the measured leg, which can potentially allow for experimental error and consequently result in inconsistent and inaccurate data. When the participant could not actively flex her hip any further, the investigator obtained the reading on the inclinometer’s display screen in degrees and recorded it on a data sheet.

*Plantar flexor flexibility.* Sequentially, plantar flexor ROM followed hip flexibility assessments and began with the participant sitting upright and lengthwise on the table so that both legs were straight in front of her torso and only the feet were hanging freely over the edge. Plantar range of motion measurement was determined as the degree of angle difference spanned by maximal plantar-flexion-to-dorsiflexion. With
the subject relaxed, the investigator placed the digital inclinometer on the plantar surface of the shoe so that it was centered both longitudinally and mediolaterally. Next, the investigator asked the participant to maximally plantar flex her foot. When the participant was stabilized in this position, the investigator promptly “zeroed” the digital inclinometer and informed the participant to begin dorsiflexing her foot up as far as it could go. Once stabilization had occurred (or no movement), the investigator read and recorded the number on the inclinometer in degrees.

Vertical Jump Ability Testing

Evaluations for performance testing were done with a VJA test and conducted using a force plate (Kistler, Winterthur, Switzerland, Type 9021) and Vertec (Vertec Sports Imports, Hilliard, OH). By using a force plate, performance was subjectively measured as GRFs. Additionally, a jump and reach test with a Vertec was used to objectively determine participants’ VJA. This investigation used both aspects of VJA to determine performance measures of force, power, and maximal jump height achieved.

Vertec. A standing vertical jump assessment with a Vertec apparatus is one of the most common testing methods for determining VJA and was used to objectively determine vertical jump height in meters to the nearest 0.01 m. The jump height was measured as the highest point that the subject could reach and displace the overhead plastic vanes placed 0.0127 m apart on a telescoping aluminum adjustable pole. Jump height was performed using a countermovement jump (CMJ) where participants would maximally reach and displace the vanes with their dominant hand, much in the same
manner as volleyball player would jump at the net to spike a ball in competition (procedure described below).

*Force plate (ground reaction forces).* A Kistler force plate (type 9281B, Kistler, Winterthur, Switzerland) was used to determine GRF at the simultaneous action of the CMJ. The force plate is a flat, 0.4 m x 0.6 m (240 m²), sheath of metal embedded into a wooden gym floor, and level with the floor. GRFs (baseline and average GRF) were determined through processed vertical displacement of the force plate connected to a Kistler 8 Channel Amplifier (Type 9865B, Kistler, Winterthur, Switzerland). The signal was streamed continuously through an analog-to-digital converter to a desktop computer.

Once all equipment was set and ready for data collection, participants performed three CMJs on the force plate with a 1-minute standing rest between jumps. The 1-minute rest was used to store and save data by the investigator, prepare the equipment for the next jump, and give the participant sufficient rest to replenish ATP-PCr stores. Before initiating all jumps, participants were instructed to position themselves behind the force plate and to be immediately ready to initiate CMJs when the investigator had readied the force plate. When the equipment was activated to begin testing again, the participant stepped forward onto the force plate, feet approximately shoulder width apart and knees slightly flexed in the “ready” position. From this point no movement by the participant was allowed to allow the force plate to “zero” out. On the investigators “go” command the participant rapidly flexed at the knees, ankles, and hips, lowering their center of gravity while swinging their arms backward to enhance deceleration downward. Participants then quickly and forcefully extended from their ankles, knees, and hips to
propel themselves vertically upward. Participants were allowed to assist their jump displacement by reaching with their favored arm.

*Static Stretching Session Procedures*

The final portion of session 1 was familiarization of the SS protocol where the principal investigator described and then demonstrated proper stretching procedures. Each participant’s stretching form was evaluated to ensure that everyone understood correct stretching procedures. Muscle groups, stretching types, and correct procedures used for this investigation are explained and found in Appendix C. The order of the SS protocol was performed in the following order: (a) pretzel, (b) supine knee flex, (c) kneeling hip flexor lunge, (d) hurdler’s stretch, (e) side quadriceps stretch, (f) standing calf stretch, and (g) standing soleus stretch. For the SS protocol, the duration of each stretch was for 30 seconds of static holding on both sides of the body. The ASCM’s guidelines book prescribes that SS consists of moving each muscle to the end point of ROM that will stretch the given muscle to a point of slight discomfort. It was at this point of slight discomfort as communicated with the participants during the stretches that a digital watch (Accusplit, Pro Survivor, cum/time 601x, San Jose, California) would begin timing for 30 seconds. Each participant performed this SS protocol (1-7) under tight supervision of the principal investigator to assure each participant’s understanding to this aspect of the protocol. Additionally, it was stressed to each participant that they not waste more than 5 seconds when transitioning to the next stretch, because anything longer may take away from controlling the duration and timing variables within the experimental protocol. For this reason, these stretches were performed sitting or lying
(except for the calf and soleus stretches) on a cushioned floor mat so that there was efficient transitioning between stretches to both sides of the body.

**Testing Sessions**

Upon entering the Exercise Laboratory participants were randomly assigned to one of three protocols via the principal investigator drawing sheets of labeled paper from a box. Three sheets of paper were labeled as SS, Control, or DS and were folded and put into a box for each participant to select. The participant’s weight was then measured and recorded just prior to the start of the testing session. The remaining procedures involved in the testing session were performed in the following order: (a) a pre-session ROM measurement taken and recorded, (b) a standard warm-up on a cycle ergometer (Monark) of 60 RPM at 1 kg for five minutes, (c) a stretching protocol or control, (d) the first time period of rest at 1 minute post-stretch, (e) a second ROM assessment, and (f) a VJA test. Participants repeated steps 4-6 but at time periods post-stretch or post warm-up that cumulated to 5, 15, and 25 minutes.

Participants performed one of three experimental protocols (SS, control, DS). Each protocol was for a total duration of 7 minutes and involved all targeted muscle groups of the lower extremity specific to volleyball and vertical jumping. Once a stretching protocol was completed, and after waiting for their specific time period of rest, participants then had a second ROM assessment which was immediately followed by the performance of three CMJs on a force plate (9281b, Kistler, Winterthur, Switzerland). The two highest of three scores from the CMJ heights and GRF’s were determined from the VJA test. Values were then summed and averaged to be used in the statistical
analysis. Peak power (P_{pk}) was determined from the CMJ as the greatest power output in Watts (see equations below), and peak CMJ was determined from highest jump height accomplished and recorded in meters as previously noted.

*Sessions 2-4: Static Stretching Session*

Procedures for SS have been previously described in the familiarization section and its components are outlined in Appendix C. A standardized warm-up was then performed on a cycle ergometer followed by the SS-1 protocol. Testing for SS-1 consisted of a SS routine for a total duration of 7 minutes stretching all the major muscle groups of the lower extremity that are involved in volleyball play, as outlined in Appendix C. Stretch duration fell within the ASCM’s recommended durations (15-60) to SS, which was 30 seconds. Following the order in Appendix C, participants began with the “pretzel” stretch. Next, participants followed the procedures as listed next to its name, first stretching the right side of the body for 30 seconds, then switch, and stretching for another 30 seconds on the left leg for a total duration of 1 minute. Participants then followed the table in Appendix C finishing out stretches 2-7. Range of motion and force plate analyses immediately followed this procedure, at 1 minute post-stretch. Once ROM and VJA assessment were determined after the first time period (1 minute post-stretch), participants were then asked to be seated until the next time period had elapsed where they would begin this series of assessments again, which occurred at 5, 15, and 25 minutes post SS protocol.
Sessions 2-4: Control Session

The control session was performed in similar fashion as the SS session previously mentioned except that no stretching protocol was performed after the standard aerobic warm-up. The period of time post warm-up that would be spent stretching for the SS and DS protocols, was spent sitting in a chair for the control session (7 minutes). After 7 minutes of sitting had elapsed, an additional 1 minute of sitting was needed to stay consistent with the experimental timing protocol and the stretching sessions.

Sessions 2-4: Dynamic Stretching Session

The DS protocol (see Appendix D) involved the volleyball player’s stretching regimen as prescribed by their coaches. Each movement pattern was specific to volleyball, which is also specific to vertical jumping. Fourteen movements were conducted for 30 seconds each (7 minutes total duration) or approximately half the length of a basketball court (20 meters), then approximately a five second pause, followed by the next stretch in the following order as listed in Appendix D.

Anaerobic Power Calculations

Peak power output was determined during VJA test by using the equation developed by Johnson and Bahamonde (1996). Peak power output (P_{pk}) was considered to be the highest power output at a single moment of the push off phase during the CMJ. The calculation is represented below for P_{pk}.

\[
\text{Power peak (W)} = 78.6 \times \text{VJ (cm)} + 60.3 \times \text{mass (kg)} - 15.3 \times \text{ht (cm)} - 1308
\]

Where:

\begin{align*}
\text{VJ} & = \text{Vertical Jump} \\
\text{BM} & = \text{Body Mass} \\
\text{ht} & = \text{Height}
\end{align*}
The two highest of three recorded jumps had their GRF’s found with power output calculated and analyzed. Calculations were determined on a computer in Microsoft Excel software to determine peak power output.

**Statistical Analysis**

The purpose of this experiment was to quantify the effects of a warm-up with static or dynamic stretching on 11 female Division I varsity volleyball players using the following dependent variables: VJA, GRF’s, peak power output, and hip and ankle ROM. An alpha of 0.05 was set for all statistical analyses.

Vertical jumping ability, power, and force assessments were analyzed using a 3 x 4 way repeated measures analysis of variance (ANOVA) on a statistical package for statistical software (SPSS) version 17.0 (Windows 2007, Chicago, IL) for treatment (SS, control, DS) across time (1, 5, 15, and 25 minutes). Hip and Ankle ROM had a pretest measurement taken. Thus, a 3 x 5 way repeated measures ANOVA was run for treatment and time variables. Means and standard deviations were configured from the results to assess differences between trial and time.

If a significant interaction was found, a one way repeated measures ANOVA was run for each protocol (SS, control, and DS) at timing intervals of 1 vs. 5 vs. 15 vs. 25 minutes. Also, a one way repeated measures ANOVA was run between trials at each particular time interval. A Bonferroni post hoc test was run if applicable. If no significant interaction was found for the 3 x 4 or 3 x 5 ANOVA, then the main effects were assessed, with Bonferroni post hoc analyses if significant. A power correlation analysis was run in which all correlations were .80 and above.
CHAPTER 4: RESULTS

Peak Force (Fpk)

Peak force was analyzed with a 3 x 4 way repeated measures ANOVA for trial across time and a violation in sphericity was found. The Greenhouse Geisser adjustment was utilized and the analysis revealed no significant interaction for Fpk \( (p = .350) \). A significant main effect for time \( (p = .024) \) was found, with a significant difference between the 5th and 25th minute \( (p = .019) \) post-stretch time period, but no main effect was found for trial.

Relative Peak Force (RFpk)

Relative force was analyzed with a 3 x 4 way repeated measures ANOVA for trial across time and a violation in sphericity was found. The Greenhouse Geisser adjustment was utilized and the analysis revealed no further significant interaction. No significant main effects were found for trial and time.

Peak Power Output (Ppk)

Peak power output was analyzed with a 3 x 4 way repeated measures ANOVA for trial interaction across time. The group means and standard deviations (meters) for Ppk are presented in Table 3 and Figure 1.
Table 3

**Peak Power Output (Watts)**

<table>
<thead>
<tr>
<th></th>
<th>SS-1</th>
<th>Con-1</th>
<th>DS-1</th>
<th>SS-5</th>
<th>Con-5</th>
<th>DS-5</th>
<th>SS-15</th>
<th>Con-15</th>
<th>DS-15</th>
<th>SS-25</th>
<th>Con-25</th>
<th>DS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power Output (Watts)</td>
<td>4114.64 ± 614.66</td>
<td>4243.26 ± 624.4</td>
<td>4521.82 ± 613.36</td>
<td>4271.84 ± 636.06</td>
<td>4257.55 ± 569.79</td>
<td>4846.10 ± 685.20</td>
<td>4228.97 ± 703.06</td>
<td>4250.41 ± 568.56</td>
<td>4307.46 ± 692.00</td>
<td>4278.99 ± 626.31</td>
<td>4207.53 ± 511.02</td>
<td>4236.01 ± 632.36</td>
</tr>
</tbody>
</table>

*Note.* Values reported as mean performance ± standard deviation.

![Figure 1](image_url)

*Figure 1.* Peak power output trial interaction across time.

*Note.* (a) Denotes a significant difference ($p < .05$) from SS-1.

(b) Denotes a significant difference ($p < .05$) from DS-1 and DS-5.

(*) Denotes significant differences ($p < .05$) at DS-1 > Con-1 & DS-1 > SS-1.

(**) Denotes significant differences ($p < .05$) at DS-5 > Con-5 & DS-5 > SS-5.
The 3 x 4 way repeated measures ANOVA to assess $P_{pk}$ revealed no violation of sphericity and a significant interaction ($p < .001$). To further analyze the interaction a one way repeated measures ANOVA was performed across time for each trial condition.

For SS, a violation of sphericity ($p = .039$) was initially found so the Greenhouse-Geisser adjustment was utilized and a significant difference across time ($p = .002$) was found. The post hoc test showed significant differences between SS-1 vs. SS-5 minutes ($p < .001$) and SS-1 vs. SS-25 minutes ($p = .013$). Negative mean difference in these values indicates that there was a significant increase in $P_{pk}$ (Watts) across time in the SS group. Table 4 and Figure 2 illustrate these differences.

Table 4

*Peak Power Output across Time Static Stretching*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>SS-5</th>
<th>SS-15</th>
<th>SS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power output (watts)</td>
<td>4114.64 ± 614.66</td>
<td>4271.84 ± 636.06 *</td>
<td>4228.97 ± 703.06</td>
<td>4278.99 ± 626.31 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in $P_{pk}$ from SS-1. Values reported as mean performance ± standard deviation.
For the control session no violation of sphericity was found and no significant difference was found across time ($p = .334$).

For the DS session no violation of sphericity ($p = .088$) was found and a significant difference across time was found ($p < .001$). Post hoc analyses revealed significant differences between DS-1 vs. DS-15 ($p = .002$), DS-1 vs. DS-25 ($p < .001$), DS-5 vs. DS-15 minutes ($p < .001$), and DS-5 vs. DS-25 ($p < .001$). Positive mean values for wattage indicates that $P_{pk}$ decreased across time from 1 and 5 minutes to 15 and 25 minutes in the DS group. Table 5 and Figure 3 illustrate these differences.

*Figure 2.* Peak power output across time for static stretching. *Note.* (*) Denotes a significant difference in $P_{pk}$ from SS-1.
Table 5

*Peak Power Output across Time for Dynamic Stretching*

<table>
<thead>
<tr>
<th>Trial</th>
<th>DS-1</th>
<th>DS-5</th>
<th>DS-15</th>
<th>DS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak power output (watts)</td>
<td>4521.82 ± 613.36</td>
<td>4846.10 ± 685.20</td>
<td>4307.46 ± 692.00 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in P_{pk} from DS-1 and DS-5. Values reported as mean performance ± standard deviation.

*Figure 3.* Peak power output across time for dynamic stretching. 
*Note.* (*) Denotes a significant difference in P_{pk} from DS-1 and DS-5.
To further assess the significant interaction, a one way repeated measures ANOVA was run for $P_{pk}$ at each time point between trials.

For trial differences at one minute post stretch no violation of sphericity was found and a significant difference was found ($p < .001$) between trials. Post hoc analysis revealed that significant differences were found between SS-1 vs. DS-1 ($p < .001$) and Con-1 vs. DS-1 ($p < .001$). Negative mean difference values indicated that DS was significant greater than SS or Control. Table 6 and Figure 4 illustrate these differences.

Table 6

*Peak Power Output between Trials at 1 Minute Post Stretch.*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>Con-1</th>
<th>DS-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power output (watts)</td>
<td>4114.64 ± 614.66 *</td>
<td>4243.26 ± 621.48 *</td>
<td>4521.82 ± 613.36</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in $P_{pk}$ from DS-1. Values reported as mean performance ± standard deviation.
Figure 4. Peak power between trials at 1 minute post stretch. Note. (*) Denotes a significant difference in $P_{pk}$ from DS-1.

For the analysis at 5 minutes post-stretch, no violation of sphericity was found and a significant difference was found ($p = .001$) between trials. Post hoc analysis revealed that there was significant differences between SS-5 vs. DS-5 ($p = .014$) and between Con-5 vs. DS-5 ($p = .007$). Negative mean values at this time indicate that DS was significantly higher compared to SS and control trials. Table 7 and Figure 5 illustrate these differences.
Table 7

*Peak Power Output between Trials at 5 Minutes Post Stretch*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-5</th>
<th>Con-5</th>
<th>DS-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak power output</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(watts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4271.84 ± 636.06 *</td>
<td>4257.55 ± 569.79 *</td>
<td>4846.10 ± 685.20</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in Ppk from DS-5. Values reported as mean performance ± standard deviation.

*Figure 5.* Peak power between trials at 5 minute post-stretch.  
*Note.* (*) Denotes a significant difference in Ppk from DS-5.
For trial differences at 15 and 25 minutes post-stretch no violation of sphericity was found and no significant differences were determined at 15 minutes ($p = .491$) and 25 minutes ($p = .410$) respectively.

**Relative Peak Power Output ($\text{RP}_{pk}$)**

The 3 x 4 way repeated measures ANOVA analysis reveal no violation in sphericity and a significant interaction was found ($p = .012$). Further analysis with a one way repeated measures ANOVA was used to determine specific significant differences across time interactions for each trial condition. Table 8 and Figure 6 illustrate trial interaction across time.

Table 8

*Relative Peak Power Output*

<table>
<thead>
<tr>
<th></th>
<th>SS-1</th>
<th>56.19 ± 4.13</th>
<th>Con-1</th>
<th>57.90 ± 4.08</th>
<th>DS-1</th>
<th>61.83 ± 4.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS-5</td>
<td>58.35 ± 4.51</td>
<td>Con-5</td>
<td>58.24 ± 4.53</td>
<td>DS-5</td>
<td>61.22 ± 3.89</td>
<td></td>
</tr>
<tr>
<td>SS-15</td>
<td>57.63 ± 5.23</td>
<td>Con-15</td>
<td>58.14 ± 4.53</td>
<td>DS-15</td>
<td>58.71 ± 3.82</td>
<td></td>
</tr>
<tr>
<td>SS-25</td>
<td>58.48 ± 4.40</td>
<td>Con-25</td>
<td>57.63 ± 4.38</td>
<td>DS-25</td>
<td>57.88 ± 4.35</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Values reported as mean performance ± standard deviation.
Figure 6. Relative peak power output (trial interaction across time).

Note. (a) Denotes a significant difference ($p < .05$) from SS-1.
(b) Denotes a significant difference ($p < .05$) from DS-1 and DS-5.
(*) Denotes significant differences ($p < .05$) at DS-1 > Con-1, DS-1 > SS-1.
(**) Denotes significant differences ($p < 0.05$) at DS-5 > Con-5 & DS-5 > SS-5.

The one way repeated measures ANOVA for SS across time revealed a violation of sphericity ($p = .042$). The Greenhouse Geisser adjustment was utilized and a significant difference was found ($p = .004$) across time. The post hoc test demonstrated significant differences for SS-1 vs. SS-5 ($p < .001$), and SS-1 vs. SS-25 ($p = .015$). The negative relative mean differences indicate that RP$\text{pk}$ significantly increased in wattage across time for the SS session. Table 9 and Figure 7 illustrate timing differences for SS.
Table 9

*Relative Peak Power across Time for Static Stretching*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>SS-5</th>
<th>SS-15</th>
<th>SS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative $P_{pk}$ (watts)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56.19 ± 4.13</td>
<td>58.35 ± 4.51 *</td>
<td>57.63 ± 5.23</td>
<td>58.48 ± 4.40 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in $RP_{pk}$ from SS-1. Values reported as mean performance ± standard deviation.

*Figure 7.* Relative peak power across time for static stretching.

*Note.* (*) Denotes a significant difference in $RP_{pk}$ from SS-1.
Timing interaction for the control trial showed no violation in sphericity and no significant differences across time \((p = .520)\).

The one way repeated measures ANOVA for DS across time revealed no violation of sphericity \((p = .115)\) and significance was found \((p < .001)\). Post hoc analysis revealed significant differences at DS-1 vs. DS-15 \((p = 0.002)\), DS-1 vs. DS-25 \((p < 0.001)\), DS-5 vs. DS-15 \((p < 0.001)\), and DS-5 vs. DS-25 \((p < 0.001)\). Positive mean differences signified that \(R_{pk}\) decreased in wattage across time. Table 10 and Figure 8 illustrate timing differences for DS.

Table 10

*Relative Peak Power across Time for Dynamic Stretching*

<table>
<thead>
<tr>
<th>Trial</th>
<th>DS-1</th>
<th>DS-5</th>
<th>DS-15</th>
<th>DS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{pk}) (watts)</td>
<td>61.83 ± 4.00</td>
<td>61.22 ± 3.89</td>
<td>58.71 ± 3.82 *</td>
<td>57.88 ± 4.35*</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in \(R_{pk}\) values from DS-1 & DS-5. Values reported as mean performance ± standard deviation.
Figure 8. Relative peak power across time for dynamic stretching.  
*Note.* (*) Denotes a significant difference in RP$_{pk}$ values from DS-1 & DS-5.

To further assess the significant interaction, a one way repeated measures ANOVA was run for RP$_{pk}$ at each time point between trials.

The one-way repeated measures ANOVA for trial differences at one minute post-stretch revealed no violation of sphericity and a significant difference ($p < .001$). Post hoc analysis revealed significant differences in RP$_{pk}$ between SS-1 vs. DS-1 ($p < .001$), and Con-1 vs. DS-1 ($p = .001$). Table 11 and Figure 9 illustrate trial differences at one minute post stretch.
Table 11

Relative Peak Power Output between Trials at 1 Minute Post-Stretch

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>Con-1</th>
<th>DS-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPₚk (watts)</td>
<td>56.2 ± 4.13</td>
<td>57.9 ± 4.08</td>
<td>61.8 ± 4.00 *</td>
</tr>
</tbody>
</table>

Note. (*) Denotes a significant difference in RPₚk values from SS-1 and Con-1. Values reported as mean performance ± standard deviation.

Figure 9. Relative peak power output between trials at 1 minute post stretch.  
Note. (*) Denotes a significant difference in RPₚk values from SS-1 and Con-1.

The one way repeated measures ANOVA for trial differences at five minutes post stretch revealed no violation of sphericity and a significant difference (p = .001) between trials. Post hoc analysis showed significant differences between SS-5 vs. DS-5 (p =
.013), and Con-5 vs. DS-5 (p = .003). Table 12 and Figure 10 illustrate trial differences at five minutes post-stretch.

Table 12

*Relative Peak Power Output between Trials at 5 Minutes Post-Stretch*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-5</th>
<th>Con-5</th>
<th>DS-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPpk (watts)</td>
<td>58.4 ± 4.51</td>
<td>58.2 ± 4.53</td>
<td>61.2 ± 3.89 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in RPpk values from SS-5 and Con-5. Values reported as mean performance ± standard deviation.

Figure 10. *Relative peak power output between trials at 5 minutes post stretch.*

*Note.* (*) Denotes a significant difference in RPpk values from SS-5 and Con-5.
For trial differences at 15 minutes post stretch no violation of sphericity was found and no significant differences were found ($p = .568$).

For trial differences at 25 minutes post stretch no violation of sphericity was found and no significant differences were found ($p = .510$).

**Vertical Jumping Ability Assessments**

The group means and standard deviations (meters) for peak jump height during vertical jumping ability testing are presented in Table 13.

Table 13

*Maximal Vertical Jump Height*

<table>
<thead>
<tr>
<th></th>
<th>SS-1</th>
<th>Con-1</th>
<th>SS-5</th>
<th>Con-5</th>
<th>SS-15</th>
<th>Con-15</th>
<th>SS-25</th>
<th>Con-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>2.79 ± .13</td>
<td>2.81 ± .12</td>
<td>2.81 ± .13</td>
<td>2.81 ± .11</td>
<td>2.81 ± .13</td>
<td>2.80 ± .11</td>
<td>2.80 ± .12</td>
<td></td>
</tr>
<tr>
<td>Con</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Values reported as mean performance ± standard deviation.
Figure 11. Vertical jumping ability (trial interaction across time).

Note. (a) Denotes a significant difference \((p < .05)\) from SS-1.
(b) Denotes a significant difference \((p < .05)\) from DS-1 and DS-5.
(*) Denotes significant differences \((p < .05)\) at DS-1 > Con-1, DS-1 > SS-1.
(**) Denotes significant differences \((p < 0.05)\) at DS-5 > Con-5 & DS-5 > SS-5.

The 3 x 4 way repeated measures ANOVA to assess VJA showed no violation of sphericity and a significant interaction among trials across time \((p < .001)\). To assess the interaction a one way repeated measures ANOVA was run for VJA across time in each trial condition (SS, Con, DS). For the SS group, no violation of sphericity was found and a significant difference across time \((p < .001)\) was found. The post hoc analysis showed significant differences between SS-1 vs. SS-5 \((p < .001)\) and SS-1 vs. SS-25 \((p = .013)\). This indicated that there was a significant increase in VJA scores across time for SS. Table 14 and Figure 12 show these differences.
Table 14

Vertical Jumping Ability for Static Stretching Across Time

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>SS-5</th>
<th>SS-15</th>
<th>SS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.79 ± .13</td>
<td>2.81 ± .13 *</td>
<td>2.81 ± .13</td>
<td>2.81 ± .12 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in jump height from SS-1. Values reported as mean performance ± standard deviation.

*Figure 12.* Vertical jumping ability across time for the SS session

*Note.* (*) Denotes a significant difference in jump height from SS-1.
For the control trial no significant differences ($p = .334$) were found for any timing variable.

For the DS trial, no violation of sphericity was found and a significant difference across time ($p < .001$) was found. The post hoc analysis showed significant differences between DS-1 vs. DS-15 ($p = .002$), DS-1 vs. DS-25 ($p < .001$), DS-5 vs. DS-15 ($p < .001$) and DS-5 vs. DS-25 ($p < .001$). Positive mean difference values indicate that vertical jump height significantly decreased across time for the DS session. Table 15 and Figure 13 show these differences.

Table 15

*Vertical Jumping Ability for Dynamic Stretching across Time*

<table>
<thead>
<tr>
<th>Trial</th>
<th>DS-1</th>
<th>DS-5</th>
<th>DS-15</th>
<th>DS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (m)</td>
<td>2.84 ± .12</td>
<td>2.84 ± .12</td>
<td>2.81 ± .13 *</td>
<td>2.80 ± .12 *</td>
</tr>
</tbody>
</table>

*Note.* (*) Denotes a significant difference in jump height from DS-1 & DS-5. Values reported as mean performance ± standard deviation.
To further assess the significant interaction, a one-way repeated measures ANOVA was run for VJA at each time point across trials.

At one minute post stretch a significant difference ($p < .001$) was found between trials. Post hoc analyses revealed that significant differences were found between SS vs. DS ($p < .001$), and control vs. DS ($p = .001$) trials. Negative mean differences in both trials indicate that DS had significantly higher jump heights compared to SS and control trials respectively. This is seen in Table 16 and Figure 14.
Table 16

Vertical Jumping Ability between Trials at 1 Minute Post-Stretch

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-1</th>
<th>Con-1</th>
<th>DS-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (m)</td>
<td>2.79 ± .13 *</td>
<td>2.81 ± .12 *</td>
<td>2.84 ± .12</td>
</tr>
</tbody>
</table>

*Note. (*) Denotes a significant difference in jump heights from DS-1. Values reported as mean performance ± standard deviation.

Figure 14. Vertical jump height differences between trials at 1 minute post stretch. *Note. (*) Denotes a significant difference in jump heights from DS-1.

At 5 minutes post stretch, a significant difference ($p = .001$) was found between trials. A post hoc test revealed significant differences between SS-5 vs. DS-5 ($p = .014$) and Con-5 vs. DS-5 ($p = .007$) trials. Negative mean differences in both trials indicate
that DS had significantly higher jump heights compared to SS and control trials respectively. This is seen in Table 17 and Figure 15.

Table 17

*Vertical Jumping Ability between Trials at 5 Minutes Post-Stretch*

<table>
<thead>
<tr>
<th>Trial</th>
<th>SS-5</th>
<th>Con-5</th>
<th>DS-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (m)</td>
<td>2.81 ± .13 *</td>
<td>2.81 ± .11 *</td>
<td>2.84 ± .12</td>
</tr>
</tbody>
</table>

*Note. (*) Denotes a significant difference in jump heights from DS-5. Values reported as mean performance ± standard deviation.*

Figure 15. *Vertical jump height differences at 5 minute post-stretch.*

*Note. (*) Denotes a significant difference in jump heights from DS-5.*
At both the 15 and 25 minute post stretch time points, no significant differences at 15 minutes ($p = .582$) and 25 minutes ($p = .410$) were found between trials.

**Range of Motion Assessments**

A 3 x 5 (trials x time) repeated measures ANOVA was run to determine if there was any significant interaction among hip ROM trials. Hip ROM means and standard deviations are represented in Table 18.

<table>
<thead>
<tr>
<th></th>
<th>SS-P</th>
<th></th>
<th>Con-P</th>
<th></th>
<th>DS-P</th>
<th>121.18 ± 12.94</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS-1</td>
<td>118.36 ± 12.93</td>
<td></td>
<td>123.27 ± 11.48</td>
<td></td>
<td>123.00 ± 11.70</td>
<td>125.27 ± 12.34</td>
</tr>
<tr>
<td>SS-5</td>
<td>121.46 ± 9.75</td>
<td></td>
<td>121.46 ± 13.79</td>
<td></td>
<td>121.46 ± 9.75</td>
<td>125.46 ± 11.67</td>
</tr>
<tr>
<td>SS-15</td>
<td>120.09 ± 11.38</td>
<td></td>
<td>122.36 ± 12.82</td>
<td></td>
<td>120.09 ± 11.38</td>
<td>124.55 ± 12.83</td>
</tr>
<tr>
<td>SS-25</td>
<td>122.64 ± 14.54</td>
<td></td>
<td>121.46 ± 14.25</td>
<td></td>
<td>122.64 ± 14.54</td>
<td>122.64 ± 14.54</td>
</tr>
</tbody>
</table>

*Note.* Values reported as mean performance ± standard deviation.

No trial by time significant interaction ($p = .154$) was found for hip ROM with no main effects for trial and time determined.

A 3 x 5 (treatment x time) repeated measures ANOVA was run to determine if there was any significant interaction among ankle ROM trials. Ankle ROM means and standard deviations are represented in Table 19.
Table 19

*Range of Motion all Participants during ROM Plantar Flexion*

<table>
<thead>
<tr>
<th></th>
<th>SS-P</th>
<th>Con-P</th>
<th>DS-P</th>
<th></th>
<th>SS-1</th>
<th>Con-1</th>
<th>DS-1</th>
<th></th>
<th>SS-5</th>
<th>Con-5</th>
<th>DS-5</th>
<th></th>
<th>SS-15</th>
<th>Con-15</th>
<th>DS-15</th>
<th></th>
<th>SS-25</th>
<th>Con-25</th>
<th>DS-25</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72.27 ± 7.88</td>
<td>71.27 ± 7.06</td>
<td>73.18 ± 4.85</td>
<td></td>
<td>74.18 ± 7.93</td>
<td>72.55 ± 6.96</td>
<td>75.00 ± 6.05</td>
<td></td>
<td>72.91 ± 6.56</td>
<td>74.82 ± 9.77</td>
<td>75.27 ± 5.87</td>
<td></td>
<td>72.36 ± 6.95</td>
<td>74.27 ± 8.55</td>
<td>74.55 ± 6.49</td>
<td></td>
<td>72.73 ± 7.39</td>
<td>73.64 ± 9.32</td>
<td>73.73 ± 6.10</td>
<td></td>
</tr>
</tbody>
</table>

_Note._ Values reported as mean performance ± standard deviation.

No significant trial by time interaction ($p = .460$) was found for ankle ROM with no main effects for trial and time determined.
CHAPTER 5: DISCUSSION

Using a repeated measure design the main findings of this investigation were that the sport specific DS session produced significantly \((p < .05)\) greater jump and power output scores compared to the SS and control sessions of equal duration. Conversely, force and ROM were found to be unchanged \((p > .05)\) after a DS and SS session. To date, no study has taken a practical duration of SS and made comparative measures to an NCAA team’s DS routine and a control trial of equal duration (7 minutes) on measures of jump height, power output, force, and ROM over a post-warm-up time spectrum of 1, 5, 15, and 25 minutes. Figure 16 represents the general theme to this investigation’s design and main findings; timing interactions in SS vs. DS sessions are evident across a time spectrum from 1-25 minutes post-stretch. Based on the consistent findings concerning the VJA performance variables of CMJ height, and power output, Figure 16 was developed to show how performance returns back to baseline between the SS and DS session across a time span of 25 minutes. The bold lines indicate where performance was the highest and the lightest lines indicate where performance diminished. Therefore, contrasting views are seen regarding how performance is affected between an acute bout of SS versus an acute bout of DS.
Figure 16. Theoretical influence that a SS and DS session has on performance across a time spectrum of 25 minutes. 

*Note.* Figure compares timing effects between static and dynamic stretching and not a control.

**Stretching**

The first hypothesis of this study stated that one bout of DS would acutely (1 and 5 minutes post-stretch) elicit significant improvement in performance compared to a control and SS session of equal duration. Alternatively, this hypothesis postulated that one bout of SS would acutely elicit significant decrements in performance when compared to a control and DS session. The results match the hypotheses of this investigation for DS but not SS, at 1 and 5 minutes post-stretch, but the effects of DS were no longer evident at the 15 and 25 minute post-stretch time points.
Dynamic Stretching

In this investigation DS acutely produced significant increases above SS and control trials in CMJ height, $P_{pk}$, and $R_{pk}$ at 1 and 5 minutes post-stretch. Most research generally demonstrates that performance can be significantly improved if DS is added to a brief aerobic warm-up (Curry et al., 2009; Fletcher & Ruth, 2007; Hough et al., 2009; Monoel et al., 2008; Moran et al., 2009; Siatras et al., 2003). Many of these studies however, have used a less-than-practical stretch speed in their DS session. For example, Yamaguchi et al. integrated a stretch speed of 2 seconds per stretch for a DS protocol. Although significant differences were found when incorporating a DS protocol at such speeds, it is not practical for sport specific tasks like sprinting or jumping where the effective utilization of the stretch shortening cycle is paramount for success. To alleviate such discrepancies this investigation included a sport specific DS regimen of a volleyball team as prescribed by their coaches. The dynamic movements in this investigation consisted of jumps, skips, bounds and other quick movements that effectively utilize the stretch shortening cycle relative to vertical jumping. With that significant improvements were found as was seen in Yamaguchi et al’s investigation. Importantly, the improvements at 1- and 5-minutes post-stretch disappeared at 15- and 25-minutes post-stretch, which may consequently label this stretch as an effective mode for only a limited duration.

Dynamic stretching mechanisms. The mechanisms by which the DS session enhanced performance in this investigation are uncertain, but it does appear that both mechanical and neural factors may play a predominant role in increasing performance.
From a purely mechanical standpoint Wilson et al. (1994) hypothesized that a MTU with greater stiffness via DS as compared to greater compliance due to SS may be able to transmit force from muscle to bone more effectively. Additionally, Bishop (2003) proposed that performance enhancements may be the result of both temperature and non-temperature related mechanisms. These are considered to be aspects of postactivation potentiation (PAP) which include enhanced neuromuscular function, facilitated motor control via more specific muscle movement patterns, and increased core and/or muscle temperature. Sale (2002) proposed that enhanced neuromuscular control in fast twitch muscle fibers may be the result of more sport specific movement patterns (i.e., volleyball players DS routine) which may increase the rate of force development via PAP. Post activation potentiation, the neurological phenomenon thought to enhance muscle function and force production from the muscle’s previous activity, may have been a contributing performance enhancing mechanism in this investigation. Human muscle and its connective tissue properties are highly adaptable, and so it is possible that by incorporating the DS session, specific neural pathways were opened up that may have facilitated motor unit activation that ultimately created acute increases in VJA and power output. This is supported by other investigations which have stated that a DS session may have enhanced performance with sport specific movement patterns via facilitated motor unit control (Fletcher et al., 2004; Young et al., 2003). Other such studies have also supported these claims in that PAP increases the efficiency of muscular contraction by lowering the threshold of motor unit recruitment and by increasing the rate of cross bridge formation (Faigenbaum et al., 2006; Hamada et al., 2000).
Temperature mechanisms may have also caused significant improvements due to the DS session. Bishop (2003) proposed that warm up effects in temperature-related mechanisms are increased nerve-conduction velocity, increased energy yield, and thermoregulatory strain. Collectively, the temperature-related mechanisms may have optimally prepared the volleyball players for the specific metabolic demands of the activity (jumping), which may have correlated to subsequent increases in jump height and power output.

*Static Stretching*

The SS session had opposing conclusions to the DS session of this investigation in that acute, significant reductions in CMJ, Ppk, and RPpk were found for minutes 1 and 5 as compared to minutes 15 and 25, but that the SS session did not differ from the control trial at any time period. Unlike DS, there appears to be universal evidence suggesting a SS session actually creates significant reduction in performance. Relative to this investigation previous research has found reductions in jump height (Behm et al., 2006; Bradley et al., 2007; Robbins & Sheuermann, 2008; Young & Elliot, 2001) and power output (Bradley et al., 2007; Holt & Lamborne, 2008; Knudson & Noffal, 2005; Young & Elliot, 2005) due to an acute bout of SS. Yet, there are a number of investigations that have demonstrated no significant reductions in performance due to a SS (Church et al., 2001; Egan et al., 2006; Power et al., 2004; Unick et al., 2005).

*Static stretching mechanisms.* The exact mechanisms responsible for reductions in performance as a result of SS are currently unclear. In the current investigation altered performance due to the SS session may be the result of an increase in MTU compliance
(Hunter et al., 2004; Kubo et al., 2001; Wilson et al., 1994) and/or reduction in neural activation (Adam et al., 2003; Hunter et al., 2004). An increase in compliance of the MTU is believed to be the result of an acute bout of SS because it causes a reduction in active and/or passive tension (Kubo et al., 2001; Wilson et al., 1994). In the current investigation the physical deformation that was created through SS may have altered the way that the MTU functions during a CMJ, thus creating a less-than-optimal length-tension relationship.

The second likely cause to a decrease in performance may be related to neural mechanisms. Hunter et al. (2004) revealed that neural inhibition may contribute to reductions in excitatory inputs. Some evidence suggests that reductions in pre-synaptic neural input to the motor neuron pool is the result to a moderate bout of SS, and with more intense stretching (stretching the muscle further) post-synaptic reduction in the excitability of the alpha motor neurons may play a larger role in stretch-induced force deficits (Guissard & Duchateau, 2006). Furthermore, the research by Adam et al. (2003) addressed that a decrease in excitation is compensated for by the increasing recruitment of new motor units, with the initial and the subsequent motor units complying with specific and unchangeable patterns.

Stretching implications. Given the somewhat convincing scientific evidence supporting SS reductions in performance, athletic teams still incorporate some form of a SS into preparticipation warm-ups. Personal preference is certainly a non-scientific explanation to this, but there is some scientific evidence supporting claims that SS does not alter performance, and for that reason it remains under critical review. For instance,
Egan et al. (2006) found no changes in peak torque or mean power output after an application of a SS protocol compared to a control. Similarly, Unick et al. (2005) found that SS did not alter performance in a CMJ or drop jump in NCAA-Division II basketball players, while Church et al. (2001) found no change in CMJ after SS in NCAA Division I athletes when compared to a control. This investigation found similar results to these investigations in that significant decreases were found in the SS session when compared across time to the DS session, but it was never found to be significantly different than the control trial when compared between trials. Additionally, the negative effect of SS seemed to dissipate quickly, which means that when using a practical duration of SS, performance will return to baseline within 5-15 minutes after performing SS. On the other hand, DS creates performance increases within 1-5 minutes post-DS, but these benefits could dissipate the longer the athlete waits to perform or compete.

**Timing Applications to Performance**

The second hypothesis in this investigation was supported by the results (with the exception of force) in that there would be significant differences in performance immediately after a bout of SS and/or DS after which these changes would return back to baseline across a time spectrum of 25 minutes. The effect of time on performance between the SS and DS session is represented above in Figure 16.

There is only a select amount of research that has been conducted dealing with post-stretch performance variables at different timing intervals. To date no study has extrapolated a DS regimen from a specific varsity college team and made comparative measures on performance variables across time using a more practical duration of SS.
The few studies that have investigated the timing effects of stretching on performance measurements have done so only with an acute bout of SS (Curry et al., 2009; Ogura et al., 2007; Robbins & Sheuermann, 2008; Zakas, 2005), but not DS. Therefore, the other novel aspect of this investigation was to determine how an acute bout of DS would affect performance variables across time.

The investigation conducted by Ryan and colleagues (2008) determined that a practical duration (2, 4, and 8 minutes static stretching) of SS did not alter muscular strength at post-stretch time intervals of 10, 20, and 30 minutes. Their investigation more than likely incorporated a more than practical duration of stretching that may have significantly contributed to the outcome of the results. More notably, their post-stretch timeline starting at 10 minutes post-stretch on performance variables was probably too lengthy to see any acute effects that SS typically creates. Using a similar protocol to Ryan et al.’s study, but with a more practical duration of SS (30s) per targeted muscle group, as well as a more practical time interval assessment (1, 5, 15, and 25 minutes post-stretch), this investigation revealed that such an application did in fact have significant differences, although not different from a control trial.

This investigation produced similar results for CMJ, Ppk and RPpk in which an acute bout of DS was more beneficial than the SS or control trials in improving performance within a short period of time (1 and 5 minutes post-stretch), whereas SS was not significantly different from the control trial at any time post-stretch. It does appear however, that the performance measures for DS drop off by 25 minutes and, while nonsignificant, SS begins to increase. There is some evidence that supports this notion.
Ryan et al.’s study found non-significant increases in peak torque of the plantar flexors at 20 and 30 minutes post-stretch after 2 minutes of SS. Further investigations should examine longer time intervals beyond this investigation’s 25 minute time period along with a similar practical duration of stretching in 30 seconds of the major muscle groups to determine if these trends continue, and to what point would these trends begin to plateau or become significantly different from each other in the opposing direction (SS greater than DS in performance measures).

*Timing and Performance Mechanisms*

To help explain the results seen over time, one can examine two different physiological mechanisms, both of which require further examination. Firstly, DS of the major muscle groups increases core body and muscle temperature, and, in doing so the body begins to compensate for such increases by vasodilation and sweating. This form of negative feedback causes the body and muscle to cool down at a much faster rate than would after a light-to-moderate bout of SS or sitting. Consequently, this may have correlated to a steeper decrease in jump heights and power outputs across time compared to the SS session. Secondly, the SS session created a viscoelastic deformity of the muscle that elicited to immediate reductions in the rate at which the force is applied to the ground, thereby causing reductions in VJA. But, due to the phenomenon of PAP from consecutive jumps (3 jumps for each time interval at 1, 5, 15, and 25 minutes, 3 x 4 = 12 jumps per session) VJA may have gradually increased across this time spectrum. In light to the previous mechanisms, it should again be noted that at no time was the SS session different from the control trial, but that only the DS session produced significantly higher
performance measures. When separating the trials and examining each individual, the initial performance decrease for SS appeared.

Specific Performance Variables of Vertical Jumping Ability

Force

In the current investigation there was no significant interaction for peak force ($p = .350$) or relative peak force ($p = .411$), and a significant main effect was only found for peak force between 5 and 25 minutes post-stretch. Previous research has shown that an acute bout of SS can create significant reductions in force production (Alskaya & Koceja, 2007). It seems reasonable to assume that a higher force output applied onto a force plate would correlate to a higher maximal CMJ, but the results in this investigation contest this assumption. A possible reason for this is that force is an objective measure; a value that is measured at some time instant rather than throughout time. The rate at which a body applies a force is a more applicable measure. Thus, measurements of impulse and power output are more important and subjective in defining athletic performance. Because of this, power output and CMJ was an additional performance variable measured and analyzed in this study.

Power Output

The current investigation found several significant power output interactions in all trials across time. This parallels other investigation in that significant interactions in power output were found (Bradley et al., 2007; Holt & Lamborne, 2008; Knudson & Noffal, 2005; Young & Behm, 2003; Young & Elliot, 2005) between both SS and DS groups. Conversely, some research has shown that SS and DS does no significantly
contribute to power output results (Knudson et al., 2001; Monoel et al., 2008; Samuel et al., 2008; Unick et al., 2005). Discrepancies in these investigations can be attributed to muscle groups involved, the types of stretches done, and the duration of each stretch to specific targeted muscle. Some research will only focus on stretching one specific muscle group such as the plantar flexors (Fowles et al., 2000), but in an athletic setting it takes the collective synchronization of multiple muscle groups to contract to effectively achieve a task. This investigation wanted to alleviate these discrepancies, and so all major muscle groups involved in jumping performance were stretched. The findings in this investigation matched previous research when stretching all the major muscle groups used for performance variables (Marek et al., 2005; Power et al., 2004; Yamaguchi et al., 2006). Future research may want to focus on the practicality of stretching protocols to further validate current research.

*Vertical Jumping Ability*

Vertical jumping ability was the primary and most important performance variable measured and analyzed in this study. The results of this investigation coincide with other investigations in that SS produced significant reductions in VJA when compared to DS (Bradley et al., 2007; Brill, 2005; Robbins & Sheuerman, 2008; Young & Elliot, 2001), and DS significantly improved performance when compared to a control and SS (Curry et al., 2009; Fletcher & Ruth, 2007; Holt & Lamborne, 2008; Siatras et al., 2003; Vetter, 2007). Brill (2005) reported that SS of the hamstrings, quadriceps, and calves for 4.5 minutes (3 sets of 30 seconds) reduced vertical jump performance in male soccer players compared to a control group. Referencing DS, Holt and Lamborne
conducted testing on four protocols: (a) General warm-up only, (b) General warm-up + SS, (c) General warm-up + DS, and (d) General warm-plus dynamic flexibility. Their finding demonstrated that compared to the general warm-up + SS, all groups elicited significantly higher CMJ’s.

**Range of Motion**

Results for ROM did not support this investigation’s final hypothesis in that ROM would be significantly increased after the SS session. In the current investigation stretching sessions did not significantly alter ROM for hip flexibility ($p = .154$) and ankle flexibility ($p = .460$). Previous research supports the claim that an acute bout of SS (Ogura et al., 2007; Robbins & Sheuermann, 2008; Siatras et al., 2003) increases ROM. However, many of these investigations did not incorporate a practical duration of SS into their warm-up, as was done in the current investigation. Therefore, this may have potentially affected the outcome of the results.

**Performance Mechanisms as a Result of ROM**

Although it did not occur in this investigation, supported literature indicates that the time intervals where viscoelasticity would have been most affected would have been at 1 and 5 minutes post-stretch. The mechanisms that potentially contribute to these enhancements in joint flexibility are often temperature related and correlate to the mechanical and neural properties of the MTU. It is well known that viscoelasticity is enhanced after an acute bout of SS (Wilson, Wood & Elliot, 1991) and DS (Woolstenhulme, Grifiths, Woolstenhulme, & Darcel, 2006). A warmer MTU renders a more compliant structure capable of being stretched to a greater ROM, whereas a cooler
muscle is less compliant than its counterpart. For that reason it cannot be stretched as far to increase joint flexibility. Nevertheless, viscoelasticity is related to how a muscle exhibits change and then rebounds back to its normal length. Therefore, SS, where a stretch is held for a certain length of time, should temporarily change the viscoelastic properties of the MTU and ultimately increase ROM. Again, the practicality of the stretching protocol in this investigation may not have elicited enough gains in changing the viscoelasticity of the MTU.

The other mechanism that may have likely contributed to non-significant increases in ROM in this investigation was the inability to decrease neural activation via a prolonged, moderately intense stretch. Guissard and Duchateau (2006) suggested that an acute bout of stretching lasting 30 seconds or more is sufficient enough to cause alpha motor neurons’ deactivation to allow for a further stretch. Consequently, this would enhance both passive and dynamic flexibility. In the current investigation no differences in ROM were determined after a practical duration of stretching.

*Duration and Timing*

The results for ROM in this investigation do not match previous research in that an acute bout of stretching leads to acute ROM increases. One thought is that the practical duration (30s per muscle group) did not produce sufficient time to cause any physical or neural changes in the MTU properties. Ogura et al. (2007) compared two durations (30s and 60s) of SS to a control group and found that there were significant differences at 30 and 60 seconds with the addition of being significantly different between timing (30s vs. 60s) durations as well. Subsequently, Siatras et al. (2003)
showed that knee joint flexibility was significantly increased after stretching for 30 and 60 seconds but not at 10 and 20 seconds. Their study involved stretching the targeted muscle groups to a point of pain, and not to what the ACSM recommends; to a point of slight-to-mild discomfort. Accordingly, the intensity of the stretch may have also directly contributed to the significant increases at 30 and 60 seconds. Relative to this investigation the intensity of the stretch, which was in accordance to the ACSM standards, may have caused non-significant differences. Future research should continue to apply the 30 second stretching duration application as was done in this investigation as well as the others previously mentioned to determine if this practical dose of stretching does in fact increase ROM.

**Psychological Implications**

There may have been a psychological advantage to the volleyball players and their DS regimen in this investigation. Previous literature has reported that athletes who simply “imagined” a warm-up had an enhanced physiological performance (Malareki, 1954). A psychological advantage may have been present to the volleyball players in this investigation of just knowing that their DS session has produced prior success in competitions. For this reason the psychological advantage concerning the DS session on performance may have significantly altered performance variables compared to the SS session. At present the psychological effects are an unyielding area of research with respect to pre-competition stretching on performance and are not a clearly understood mechanism in performance enhancements. Future research may want to cover the
psychological advantages involved in an athletic team’s warm-up compared to a warm-up that is still traditionally done (i.e., static stretching).

**Practical Applications**

The ultimate goal of any stretching program is to increase flexibility. Because certain sports require a specific ROM a comprehensive stretching program still appears to have its place in pre-competitive sports; but to what extent and what type? It is possible that even though flexibility needs to be enhanced to accomplish a sport specific task, it may be simultaneously compromising performance as well. For example, it seems reasonable to assume that for a runner to increases his/her hip ROM a longer and more efficient stride can be gained. However, there is decisive evidence indicating that runners who exhibit less hip flexibility than their counterparts are actually more economical and thus making them an overall faster runner (Craib et al., 1996; Gleim et al., 1990; Jones, 2002). For this reason SS may not be needed prior to activity. On the other hand, SS may still be desirable in its association to the neuromuscular mechanism associated with the stretch reflex. It may be appropriate to SS the antagonist muscles prior to activity, because this may allow for a progressive increase in the agonist muscles to contract better. With current research providing insight that prolonged SS inhibits neural and mechanical mechanisms associated with the stretch reflex, it may be to the advantage of the athlete engaging in explosive athletics to SS their antagonist muscles before competition. Additionally, SS may still be needed at the onset of an activity as a means to increase MTU compliance back to its original ROM as well as a way to relax the body after competition.
Lastly, to a coach or competitive athlete changes in force and power output due to a stretching program are less important than performance outcomes reflected in maximal jump height achieved. In this investigation the outcomes for $P_{pk}$ and $RP_{pk}$ reflected the significant changes found in a CMJ which added to the validity of the results. When designing an effective stretching program athletes and coaches should follow what the most current and decisive research states concerning warm-up and stretching modalities to provoke the most successful performance gains; that is, to warm-up prior to DS or sport specific movements and SS in the cool down period (Faigenbaum et al., 2006; Fletcher et al., 2005; Young & Behm, 2002).

**Future Considerations**

The present investigation contained several limitations that may have contributed to the outcome of the study. Firstly, the population sample in this investigation was small ($n = 11$) which lowered the statistical significance and overall power. Anytime a sport-specific population is chosen for a study, the population will more than likely be minimal. Future considerations relative to this investigation may need to combine similar sports, meaning that it may be appropriate to use a combination of basketball players, track and field high jumpers, and volleyball players collectively to increase population sample size. Secondly, all testing sessions were done at approximately the same time of day, which was in the early evening hours. This was to ensure consistency in data collection especially with ROM measurements. Flexibility is known to be enhanced later on in the day compared to morning hours (Manire, Adams, Swank, Kipp, & Stamford, 2004). Knowing this and that ROM did not produce any significant differences in this
investigation, it is possible that the time of day may have affected the outcome of ROM measurements. Future research may want to determine if there is any correlation between VJA and ROM assessments in the morning versus in the evening hours. Thirdly, fatigue may have been a possible outcome in any of the performance variables that were measured in this investigation. Delayed onset muscle soreness can last well over 24 hours (Paulsen et al., 2010), contributing to performance decrements. All testing sessions ensured that a 24 hour window of no physical activity be accompanied prior to all testing sessions. Twenty four hours may not have been a sufficient rest period for the participants. It may be more appropriate for future investigations to allow for a 48 hour window or more of rest before conducting testing sessions to ensure that participants are fully recovered. Lastly, the participant’s menstrual cycle may have partially affected performance results. It was the original intent of this investigation to document menstrual cycle phases (luteal or follicular) for the descriptive purposes; however, a few athletes were unsure of the phase they were in at the time of some of the testing sessions. Therefore, menstrual cycle status could not be accurately documented and was not accounted for in the statistics. It may however, be more practical to not account for the menstrual cycle in athletic populations, because it is unable to be controlled for when an athlete is actually competing.

There were a few uncontrollable factors in this experimental design that may have also contributed to the outcome of the results. Perhaps the most important limitation was that this investigation was not done in a competitive setting. It is neither possible nor ethical to obtain measurements during an actual competition. Therefore, a “true” effort
may not have been given during VJA testing. Another uncontrollable factor to this investigation was that the intensity of the stretch was relative to the perceived pain threshold that each individual was experiencing. Controlling for intensity cannot be done because it is a relative measure of a pain threshold. Additionally, ROM was an active flexibility test, which was a perceived ability self stretch. This may have also been subject to discrepancies of measurements in this investigation. Future research may need to control for ROM by using more standardized flexibility tests.

Aside from the current limitations and uncontrollable factors in this investigation future research may want to consider the timing, dosage, body joints assessed, and fitness of the sample population for stretching sessions in order to distinctly define these variables. It has been previously mentioned that an increase in temperature due to DS is a paramount mechanism to increase performance. To date no research has verified temperature difference in a SS vs. DS group. This may serve as a focal point in both performance and ROM applications in a stretching program. More importantly, when could temperature-related mechanisms begin to significantly affect performance? A specific ROM dependent on temperature and time would be an area that future research may want to verify. Additionally, the findings in this investigation strictly relate only to a highly trained population in NCAA Division I volleyball players, but may pertain to other highly anaerobically trained individuals. It may be useful to involve a homogenous subject population of various fitness levels to determine if these effects could be evident in less fit populations. Additionally, it may also be beneficial for future research when working with an NCAA team, that their actual pre-competition warm-up serve as the DS
variable when comparing to a SS routine. Lastly, increasing ROM prior to activity appears to not have as significant of an effect in enhancing performance. For this reason it may be more beneficial for future research to set up a design where it concentrates on maintaining pre-activity ROM through a comprehensive post-activity SS protocol and control, and then determine whether this maintenance on ROM improves subsequent performance measures.

**Conclusions**

The findings of this investigation coinciding with previous research reveals that designing an effective warm-up routine appears to favor a general brief aerobic warm-up followed by some sport specific dynamic movements to enhance overall performance. The contrasting view to this is that SS resulted in acute significant reductions in performance, yet to coaches and athletes this still appears to be the preferred mode of stretching prior to competition. Performance decrements as a result to the SS session in this investigation are contributed to a number of physiological and non-physiological mechanisms that can result in the phenomenon known as “stretching induced force deficits.” The novel finding in this investigation was that the time spent post-stretch in combination with a practical duration of SS may be an appropriate warm-up design for athletes engaging in a competition at least 15 minutes after SS. Therefore, SS should not be completely ruled out as an ineffective routine because there is a lack of supporting evidence regarding its place before or after competition. The timing aspects to stretching may reveal additional conclusions on the effects of these two common stretching modalities.
References


Bishop, D. (2003). Warm up II: Performance changes following active warm up and how to structure the warm up. *Sports Medicine, 33*(7), 483-498.


Malareki, I. (1954). Investigation on physiological justification of so-called ‘warming up.’


*Medicine and Science in Sports and Exercise, 42*(1), 75-85.


APPENDIX A: CONSENT FORM

Ohio University Consent Form

Title of Research: The acute affects of two stretching protocols on performance in NCAA Division I volleyball players

Researchers: Nicholas Kruse

You are being asked to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

EXPLANATION OF STUDY

This study is being done because limited research has been done involving highly trained athletes. This study is also being done to gain a better understanding of the effects of two different stretching protocols (dynamic stretching vs. static stretching) on performance measures of vertical jump height, rate of force development and range of motion. Static stretching has been found to decrease performance when longer (less practical) durations of stretching are applied. Therefore, another reason this study is being done is to apply a more practical duration of static stretching and make comparative measures to a dynamic stretching regimen of equal duration with different timing intervals on performance measures to find out if static stretching affirmatively causes decreases in performance and if dynamic stretching is, in fact the best pre-activity warm-up to increase performance.

If you agree to participate, you will be asked to be involved in a total of five sessions. You will be asked to abstain from alcohol, tobacco, and caffeine products at least 24h prior to testing. The first session will last roughly 45 minutes and will be a familiarization day in which you will come to the laboratory (Grover E116) and get a good sense of what will
be going on in this study. You will also get simple measurements of height, weight, and body fat by a brief skin-fold test. Additionally, you will have baseline force samples done with a force plate and vertical jump height measured. Once familiarized with the experiment and control sample is finished, you will then show up to the lab another two different times that will be separated by at least 24 hours and no longer than 72 hours between sessions. For the two testing sessions each test will be randomly selected consisting of either your current dynamic stretching exercises or a static stretching protocol. These stretching sessions will last approximately 30-45 minutes depending on the test chosen. These stretches are designed to work all of your major muscle groups in your lower extremity that will have a direct impact on the vertical jump testing. You will also have range of motion examined of your hip flexors and ankle flexors/extensors before and after each stretching session to see if the stretches you have performed (dynamic or static stretches), produced any significant changes. Finally, you will conduct a vertical jump test on a force plate to assess your movements.

You should not participate in this study if:
- you have any lower body injuries
- you are unaware of how to perform the varsity volleyball teams dynamic stretching routine
- you are not doing your volleyball specific strength and conditioning program with the addition of plyometric drills
- you are not currently under a supervised program with team and strength and conditioning coaches
- you have not participated in NCAA division I volleyball athletics for at least 1 season

Your participation in the study will last about two weeks

Risks and Discomforts

Risks or discomforts that you might experience are mostly related to the static stretching or dynamic stretching protocols but may involve other places during experimental testing. All testing sessions have been formatted and controlled to alleviate any potential risks of injuries occurring by following the American College of Sports Medicine (ACSM) *Guidelines to Exercise Testing and Prescription* 8th edition. The static stretching protocol will involve certain stretches that you may not be used to, but are meaningful to this study. The stretches are designed to minimally affect any type of severe discomfort because they will only be held to a point of slight discomfort, for a duration of 30 seconds as stated in the ACSM handbook. Other injuries that may occur during testing are impact-related injuries.
Since vertical jumping is considered to be a moderate-to-high impact movement, their poses the risk that muscle, tendon, or ligament strains or sprains could occur in the feet, ankles, knees, and hips. Although slight, there also poses the risk that you may be injured during your dynamic stretching procedures. Some of these movements can disorient the body in such a way that could cause muscle, tendon, or ligament injuries of the feet, ankles, knees, and hips. For this reason at least one certified First Aid and CPR person will be available at the time of all testing sessions. If at any time you feel like you cannot complete and of these protocols due to any discomforts or pains feel free to stop.

Benefits

This study is important to science/society because it will give athletes and coaches a better understanding to the effectiveness of various stretching programs through effective testing. The study is also important in determining if a more practical duration of static stretching is just as effective to your dynamic program. Finally, this study is designed to leave athletes and coaches the question of whether an optimal amount of time between static stretching and vertical jumping exists.

Individually, you may benefit from this experiment by finding a sound base of knowledge of different stretching protocols and the timing variables involved that may affect your own personal performances on the volleyball court.

Confidentiality and Records

Your study information will be kept confidential by using a code number for each qualified participant. Your code number will be secure by storing it in a password file on a computer and a back up USB port.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;
Contact Information

If you have any questions regarding this study, please contact [Nicholas Kruse, phone: (419)-966-2797 or email: nk283208@ohio.edu /Dr. Sharon Rana, phone: (740)593-9494 or email: rana@ohio.edu.]

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:
- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature_________________________ Date__________

Printed Name______________________________  

Version Date: [insert mm/dd/yy]
APPENDIX B: HEALTH HISTORY/VOLLEYBALL TRAINING
QUESTIONNAIRE

American Heart Association/American College of Sports Medicine Health/Fitness Facility Pre-participation Screening Questionnaire

Assess your health status by marking all true statements

**History**
You have had:
__ a heart attack
__ heart surgery
__ cardiac catheterization
__ coronary angioplasty
__ pacemaker/implantable cardiac
__ defibrillatory/rhythm disturbance
__ heart valve disease
__ heart failure
__ heart transplant

If you marked any of these statements in this section, consult your physician or other health care provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

__ congenital heart disease
other

**Symptoms**

__ chest discomfort with exertion
__ unreasonable breathlessness
__ dizziness, fainting, blackouts
__ you take heart medication

**Other health issues**
__ you have diabetes
__ you have asthma or other lung disease
__ you have burning or cramping in your lower legs when walking short distance
__ you have musculoskeletal problems that limit Your physical activity
__ you have concern about the safety of exercise
__ you take prescription medications

Please list:
___ you are pregnant

**Cardiovascular risk factors**

___ you are a man older than 45 years
___ you are a woman older than 55 years, have
   had a hysterectomy, or are postmenopausal
___ you smoke or quit smoking within the
   previous 6 months
___ your blood pressure is >140/90mmHg
___ you do not know your blood pressure
   might
___ you take blood pressure medication
___ your cholesterol is > 200mg/dL
___ you have a close blood relative who had
   a heart attack or heart surgery before age 55
   (father or brother) or age 65 (mother or sister)
___ you are physically inactive (you get < 30
   minutes of physical activity on at least 3 days
   per week
___ you are > 20 pounds overweight

___ None of the above

You should be able to exercise safely
without consulting your physician or
other health care provider in a self-guided
program or almost any facility that
meets your exercise needs.

**Joint-Muscle Status** (Check areas where you currently have problems)

<table>
<thead>
<tr>
<th>Joint Areas</th>
<th>Muscle areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ) Wrists</td>
<td>( ) Arms</td>
</tr>
<tr>
<td>( ) Elbows</td>
<td>( ) Shoulders</td>
</tr>
<tr>
<td>( ) Shoulders</td>
<td>( ) Chest</td>
</tr>
<tr>
<td>( ) Upper Spine and Neck</td>
<td>( ) Upper Back and Neck</td>
</tr>
<tr>
<td>( ) Lower Spine</td>
<td>( ) Abdominal Regions</td>
</tr>
</tbody>
</table>
( ) Hips                  ( ) Lower Back
( ) Knees                  ( ) Buttocks
( ) Ankles                  ( ) Thighs
( ) Feets                  ( ) Lower Leg
( ) Other_________________ ( ) Feet
( ) Other_________________ ( ) Other______________

Please expand on problem:
________________________________________________________________________
________________________________________________________________________

When did this injury/problem occur:
________________________________________

Have you been cleared by your primary care physician to participate in exercise:  YES
NO

Are you currently able to exercise without pain/discomfort:  YES
NO

Physical Activity Status for Varsity Volleyball  (Check any of the following if they are characteristic of your current habits)
Within the past 3 months have you:
( ) participated in Ohio University’s Volleyball training program?
( ) been in a strength & conditioning program under the direct supervision of a qualified coach (NSCA or ACSM certified)?
( ) engaged in a plyometrics program specific to volleyball?
### APPENDIX C: STATIC STRETCHING PROCEDURES

<table>
<thead>
<tr>
<th>Stretch</th>
<th>Procedures</th>
<th>Muscles affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Pretzel</td>
<td>Sit with legs straight and upper body nearly vertical. Bend right leg and cross right foot over to the left side of the knee. Push right leg knee toward left leg for a more rigorous stretch.</td>
<td>Gluteus muscles and illitotibial band</td>
</tr>
<tr>
<td>2) Supine Knee Flex</td>
<td>Lie on back with legs straight. Flex right knee and hip; bring the thigh toward the chest. Position hand behind the knee and continue to pull further towards chest.</td>
<td>Hip extensors (gluteus maximus and hamstrings)</td>
</tr>
<tr>
<td>3) Kneeling Hip Flexor Lunge</td>
<td>Begin with by kneeling on both knees. Bring left thigh forward and settle in front of the torso at 90 degrees hip and knee flexion. Placing hands on torso and maintain upright posture pull hips from underneath to that tension is placed on the right hip flexors.</td>
<td>Hip flexors (iliopsoas, rectus femoris, sartorius, and tensor fasciae latae)</td>
</tr>
<tr>
<td>4) Hurdler's Stretch (Figure Four)</td>
<td>Sit with upper body nearly vertical and legs straight. Place the sole of the foot on the inner side of the right knee with the outer side of the leg resting on the floor. Lean forward using hip flexion keeping torso straight and reaching with right hand towards the tip of the shoes.</td>
<td>Gastrocnemius, hamstrings, erector spinae</td>
</tr>
<tr>
<td>5) Side Quadricep Pull</td>
<td>Lie on the side with both legs straight. Place the left forearm flat on the floor and the upper arm perpendicular to the floor. Place the left forearm at a 45 degree</td>
<td>Quadriceps and iliopsoas.</td>
</tr>
</tbody>
</table>
angle to the torso. Flex the right leg (knee), with the heel of the right foot moving toward the buttocks. Grasp the front of the ankle with the right hand and pull toward the buttocks.

| 6) **Standing Calf Stretch (Wall Stretch)** | Stand facing the wall with feet shoulder width apart and approximately 2 feet from the wall. Bring right leg directly back while leaning with hands placed against the wall. Keep back leg straight and lower heel to the floor while flexing knees to approximately 45 degree bend to apply stretch. | Quadriceps and iliopsoas. |
| 7) **Soleus Stretch** | Same procedures as the calf stretch except to slightly bend the extended leg at the knees to isolate the soleus muscle. | Same procedures as the calf stretch except to slightly bend the extended leg at the knees to isolate the soleus muscle. |
# APPENDIX D: DYNAMIC STRETCHING PROCEDURES

<table>
<thead>
<tr>
<th>Name of stretch</th>
<th>Procedures</th>
<th>Muscles affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying leg cross-overs</td>
<td>Lying supine then prone legs are swung mediolaterally ten times per leg on both sides</td>
<td>Gluteals, groin, hamstring</td>
</tr>
<tr>
<td>High knees pull</td>
<td>A walk pulling every other leg up towards the chest with the hands and simultaneously dorsiflexing.</td>
<td>Gluteals, hamstrings, gastrocnemius</td>
</tr>
<tr>
<td>High lunge pull</td>
<td>Same procedures as the high knees pull but after the pull the participant lunges.</td>
<td>Gluteals, hamstrings, gastrocnemius</td>
</tr>
<tr>
<td>High knees to chest</td>
<td>Exaggerated running motion actively pulling the knees up to the chest.</td>
<td>Gluteals, hamstrings, gastrocnemius</td>
</tr>
<tr>
<td>Quad pull</td>
<td>A walking exercise where every other leg is continuously pulled with the aid of the hands</td>
<td>Quadriceps</td>
</tr>
<tr>
<td>Hip cradle</td>
<td>Walking exercise where every other leg is actively stretched by pulling the ankle medially up to the groin</td>
<td>Gluteal groups</td>
</tr>
<tr>
<td>Lunge with twist</td>
<td>Each lunge on both legs concludes with a twist opposite to the side leg in front of the body</td>
<td>Gluteals, hamstrings, quadriceps, and hip flexors</td>
</tr>
<tr>
<td>Reverse kick</td>
<td>Medium impact movement where the players skips and kicks forward then backward for every other leg</td>
<td>Gastrocnemius, soleus, hip flexors, gluteals, and quadriceps</td>
</tr>
<tr>
<td>High kicks with reach</td>
<td>Walk with flexions at the hips and full extension of the leg and thigh with the opposite hand reaching to touch the toe</td>
<td>Hamstrings and gastrocnemius</td>
</tr>
<tr>
<td>Spiderman</td>
<td>Exaggerated floor crawl; sequential hip flexion and extension movement</td>
<td>Hips flexors, gluteals, quadriceps, gastrocnemius, soleus</td>
</tr>
<tr>
<td>Skip hop</td>
<td>Light-to-medium intensity</td>
<td>Hip flexors, quadriceps,</td>
</tr>
<tr>
<td>Exercise</td>
<td>Description</td>
<td>Primaries</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Exaggerated back pedal</td>
<td>Exaggerated backward running with</td>
<td></td>
</tr>
<tr>
<td>Medium impact high kicks</td>
<td>Same as the high kicks with reach but with an exaggerated skipping with full extension of the legs and thighs</td>
<td>Gluteals, hamstrings, and gastrocnemius</td>
</tr>
</tbody>
</table>
### APPENDIX E: SUMMARY TABLE OF THE ACUTE EFFECTS OF STATIC STRETCHING ON PERFORMANCE

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Interventions</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siatras et al. (2003)</td>
<td>11 competitive male gymnasts Mean 9.8 yrs</td>
<td>1 x 30 (30s) 2 lower body stretches</td>
<td>Decreased vault approach speed</td>
</tr>
<tr>
<td>Fletcher and Jones (2004)</td>
<td>97 male rugby Mean 23 yrs</td>
<td>1 x 20s (20s)</td>
<td>Decreased performance in 20m sprint</td>
</tr>
<tr>
<td>Knudson et al. (2004)</td>
<td>83 tennis players Various skill levels</td>
<td>2 x 15s (30s) 7 upper/lower body stretches</td>
<td>No change in serve speed or accuracy</td>
</tr>
<tr>
<td>Unick et al. (2005)</td>
<td>16 NCAA D-III female basketball players Mean 19.2 yrs</td>
<td>3 x 15s (45s) 4 lower body stretches</td>
<td>No change in CMJ height, No change in drop jump height</td>
</tr>
<tr>
<td>McMillan et al. (2006)</td>
<td>30 USMA cadets rugby, lacrosse, strength/conditioning 16 male, 14 females Mean 20.2, 20.4 yrs</td>
<td>1 x 20-30s 8 stretches including upper and lower body</td>
<td>No change in T-drill speed (agility), No change in medicine ball throw, Increase distance in 5 step jump</td>
</tr>
<tr>
<td>Egan et al. (2006)</td>
<td>11 NCAA D-1 female basketball players Mean 20 yrs</td>
<td>4 x 30s (120s) 4 leg extensor stretches</td>
<td>No change in peak torque or mean power</td>
</tr>
<tr>
<td>Little and Williams (2006)</td>
<td>18 pro male soccer players</td>
<td>1 x 30s (30s) 4 lower body stretches</td>
<td>No change in CMJ height, No change in 10m sprint time (stationary start), Decreased 20m sprint time (flying start), No change in zig-zag drill time (agility)</td>
</tr>
<tr>
<td>Study</td>
<td>Participants</td>
<td>Protocol Details</td>
<td>Findings</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Evetovich et al. (2008)</td>
<td>15 D-II female basketball and volleyball players</td>
<td>4 x 30s (120s) 4 quadriceps femoris stretches</td>
<td>Decreased torque and EMG amplitude No change in MMG during isokinetic concentric movements</td>
</tr>
<tr>
<td>Donovan et al. (2008)</td>
<td>15 male football players</td>
<td>1 x 20 and 30s 2 tricep and chest stretches</td>
<td>No change in 1RM</td>
</tr>
<tr>
<td>Winchester et al. (2008)</td>
<td>11 males, 11 female NCAA D-I track athletes</td>
<td>Dynamic warm up followed by 3 x 30s (90s) static stretch 4 stretches of calf and thigh muscles</td>
<td>Decreased 40m sprint performance (3%)</td>
</tr>
<tr>
<td>Sayers et al. (2008)</td>
<td>20 elite female soccer players</td>
<td>1 x 30s (30s) Leg extensors and flexors</td>
<td>Decreased performance in acceleration, max velocity sprint time, and overall 30m sprint time</td>
</tr>
<tr>
<td>Gerglely (2009)</td>
<td>15 male competitive golfers</td>
<td>20 minutes of passive static stretching warm up protocol</td>
<td>Decreased club head speed (-4.19%) Decreased distance (-5.62%) Decreased accuracy (-31.04%) Decreased consistent ball contact (-16.34%)</td>
</tr>
</tbody>
</table>