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THE EFFECTS OF STATIC STRETCHING SETS IN WARM-UP ON MAXIMUM VERTICAL JUMP PERFORMANCE

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ABSTRACT

The Effects of Static Stretching Sets in Warm-up on Maximum Vertical Jump Performance

by

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The purpose of the study was to determine whether changing the number of static stretching sets during the warm-up changes maximum vertical jump (MVJ) performance. Twenty-five healthy male and female subjects between the ages of 18-40 volunteered to be in the study. The data was statistically treated using a two (pre-test, post-test) by three (NS, 1SS, and 3SS) ANOVA with repeated measures. The dependent variable was MVJ. The independent variables were test and static stretching sets. The analysis revealed that there were no significant differences between pre-test MVJ scores, but a significant difference between post-test scores for all treatments. MVJ was significantly lower when comparing MVJ scores from 3SS to NS and from 3SS to 1SS. By increasing the number of static stretching sets performance was significantly effected. Possible explanations of the mechanisms to explain the effects of acute stretching on performance are changes in musculotendinous stiffness and neuromuscular suppression.

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CHAPTER 1

INTRODUCTION

Significance of the Study

One of the accepted principles of exercisers and athletes is that a warm-up is necessary before exercising in order for a performance to be successful and safe (Knudson, 1999). Stretching is widely accepted as an important part of the warm-up. Acute stretching (which is done just prior to physical activity) has been accepted as a way to increase performance (Gleim & McHugh, 1997). However, whether acute stretching can increase performance has been questioned (Knudson, 1999; Smith, 1994; Wilkinson, 1992). Past research on stretching has focused on the comparisons of the different stretching techniques and their effectiveness at increasing ROM, as well as what the optimal times of stretching are for maximizing increases in ROM. Recently, studies have investigated the acute affects that stretching has on performance. Some studies have concluded that acute stretching neither helps or inhibits performance (Godges, MacRae, Longdon, Tinberg, & MacRae, 1989; Knudson, Bennett, Corn, Leick, & Smith, 2001;). While most of the acute stretching and performance studies have resulted in negative performance effects (Cornwell, Nelson, & Sidaway, 1999; Fowles & Sale, 1997; Guillary, Nelson, Cornwell, & Kokkonen, 1998; Kokkonen & Nelson, 1996;

Kokkonen, Nelson, & Cornwell, 1998; Lieber, Woodburn, & Friden, 1991; Nelson, Allen, Cornwell, & Kokkonen, 2001; Nelson, Cornwell, & Heise, 1996).

Purpose of the Study

Many coaches, athletes, and trainers have accepted and applied static stretching into their workouts and training without the support of conclusive scientific evidence (Knudson, 1998). Most of the research available on pre-activity or acute stretching indicates that stretching may decrease performance (Kokkonen et al, 1998; Kokkonen & Nelson, 1996; Nelson et al, 1996; Nelson, Allen, et al, 2001). Performance decrements after acute stretching have been observed in the vertical jump (Nelson et al, 1996; Cornwell at al, 1999). The effect that static stretching has on performance needs to be further investigated. One of the distinguishing differences between the studies was the total time the stretches were performed (see Table 1). All the studies that had a total stretch time of one minute or longer resulted in an observable decrease in performance (Cornwell et al, 1999; Guillary et al, 1998; Kokkonen & Nelson, 1994; Kokkonen et al, 1998; Nelson et al, 1996; Nelson, Allen, et al 2001; Nelson, Guillary et al, 2001). While the two studies that had a total stretch time of 45 seconds or less resulted in no effect on performance (Bender et al, 2000; Knudson et al, 2001). The total stretching time was a combination of stretch duration and the number of stretches performed (sets). Time of stretching, therefore, may be an important element in identifying the effect that acute stretching could have on performance. It is therefore, hypothesized that if stretching affects performance, then greater stretch time would augment the stretch effect and performance decrement. By increasing the number of stretching sets, total stretching time

can be increased. The purpose of this study was to determine the effect of stretch time on maximum vertical jump (MVJ) performance. More specifically, the purpose was to determine whether changing the number of static stretching sets during the warm-up would also change MVJ performance.

Table 1: Summary of results of studies using stretching on performance.

Group	# of Stretches	Sets	Time (per stretch)	Total Time (min)	Effect
Bender et al (2000)	4	1	30-40 sec	2-3 min	No significant difference in 200m speed
Cornwell et al (1999)	N/A	N/A	N/A	N/A	Decrease squat jump and countermovement jump height
Guillary et al (1998)	N/A	4	N/A	15-min	Decrease max torque production at 1.05rad/s and 1.57rad/s
Kokkonen & Nelson (1994)	3	N/A	20-min	20-min	Decrease 1RM knee extension and flexion
Kokkonen et al (1998)	5	6	15-sec	6-min	Decrease 1RM knee extension and flexion
Knudson et al (2001)	3	3	15-sec	About 4min	No significant changes in kinematic variable of CMJ
Nelson et al, (1996)	2	N/A	15-sec	6-min	Decrease squat jump and countermovement jump height
Nelson, Allen et al (2001)	3	2	30-sec	3 min	Decrease isometric torque at 160° knee extension only
Nelson, Guillary et al (2001)	1	4	30-sec	2-min	Decrease max torque production at 1.05rad/s and 1.57rad/s

CHAPTER 2

REVIEW OF RELATED LITERATURE

Flexibility

Flexibility describes the available range of motion in a joint or group of joints (Smith, 1994). It is not known when flexibility training programs began; however, in ancient Greece, it was recorded that athletes used a type of flexibility training to help in performing acrobatic stunts, dancing, and wrestling (Alter, 1996). Today, flexibility is considered a vital part of physical fitness, along with cardiorespiratory endurance and muscular strength. Many flexibility training programs are planned and carried out with a regular program of stretching exercises that can progressively increase the usable range of motion in a joint (Aten & Knight, 1978).

One of the reasons for the use of flexibility exercises originates from the benefits attributed to increased flexibility. For a growing number of individuals, the benefit of flexibility training is to help unify the body, mind, and spirit. Iyengar (1996) explains that this type of flexibility training is used in yoga, a word derived from "yuj," which means to bind, attach, or yoke. In yoga, the belief is that muscles under chronic tension become less strong, less supple, and not as capable of absorbing the shock and stress of various

types of movements. Therefore stretching is implemented in Yoga to facilitate muscular relaxation, thereby promoting the release of stress and muscular tension. Others may find self-discipline through stretching, by challenging one's anatomical limits. As a part of health, flexibility training may help keep good posture and joint mobility (Smith, 1994). Farfan (1978) presented evidence for the benefit of trunk mobility that gives a mechanical advantage for function and efficiency of human movement. In physical recreation and sport, one of the purposes of stretching is to stop cramps, a painful involuntary muscle contractions (McGee, 1990). However, the most common reasons for stretching are for (1) the prevention of muscle injury (Pope, Herbert, Kirwan, & Graham, 1999), (2) to lessen delayed onset of muscular soreness (Armstrong, 1984; Buroker & Schwane, 1989; High, Howley, & Franks, 1989; Smith, Brunetz, Chenier, McCammon, Houmard, Franklin, & Israel, 1993), (3) and to increase human physical activity performance (Etnyre & Lee, 1988; Gleim, & McHugh, 1997; Prentice, 1983; Wallin, Ekblom, Grahn, & Nordenborg, 1985).

Types of Stretching

When a muscle is subjected to a tensile (pulling) force transient deformation occurs. Deformation is a change in the muscle's shape. The muscle and associated connective tissues that transmit the force exerted by muscle fibers to the bone (skeleton) are called the musculotendinous unit (Enoka, 1994). "Stretch" refers to the actual elongation of the musculotendinous unit (Alter, 1996). There are four commonly used types of stretches. These are static, ballistic, dynamic, and proprioceptive neuromuscular facilitation (PNF).

Static stretching

Static stretches are the most common form of stretching (Knudson, 1998). Static stretching is a technique that is used to increase the range of motion in a joint by sustaining a muscle stretch. The muscle is stretched to the end range of motion and then held for several seconds before releasing. Sapega, Quedenfeld, Moyer, and Butler (1981) recommended that the muscle be stretched slowly and with a low force. In static stretching, force can be applied, either externally or internally. When the force is applied externally, for example with a partner or using gravity, the stretch is called a passive static stretch. If the force is produced by the opposing muscular action then the stretch is called active static stretch. The type of static stretch employed is one of choice, or occasionally the availability of a partner. An example is the sitting toe touch stretch. In this example, the individual is sitting with the legs extended in front, and the trunk and hips flexed forward with the arms straight and hands reaching toward the toes. If this were done as an active static stretch, the subject would lean forward using the hip and trunk flexors until the end range of motion is reached. The stretch would be in the lower back and hamstrings, and would be held for several seconds. If the same sit and reach stretch was done as a passive static stretch, then the subject would relax and have a partner press against the back until the end range of motion is reached and then hold that position. In most warm-up programs, static stretches are primarily active static stretches, using gravity to assist the stretch (Holcomb, 2000).

Ballistic stretching

The second type of stretching is ballistic stretching. The muscle is stretched by momentum created from the movement of the body segments. The body's mass applies

the tensile force used for the stretch. When the end range of motion is reached, the muscle is rebounded out of the stretched opposition by it's own contraction. This is done in a cyclical bouncing motion, repeated several times (Knudson, 1998). In ballistic stretching, a person would perform a sit and toe touch stretch from a standing position with the feet close together and the knees extended. The trunk and hips would flex with the arms reaching toward the toes. Gravity would pull the person down to the end range of motion. The trunk and hip extensors would raise the upper body slightly and then relax to perform the bouncing movement. This would be done several times, and with each bounce, the range of motion might be slightly increased.

Dynamic stretching

The third type of stretching is dynamic stretching. In this type of stretching, a muscle is stretched by the muscular contraction, which increases or decreases the joint angle where the muscle crosses, and elongates the musculotendinous unit as the end range of motion is obtained (Bandy, Irion, & Briggler, 1998; Hardy & Jones, 1986). Dynamic stretching uses activity specific movements, making it a specific warm-up because it prepares the muscles by stretching them through the movements used in sport. For example, sprinter would walk using long strides, which emphasizes hip flexion and extension. This movement stretches the muscles used by the sprinter, namely the hip flexors and extensors.

Proprioceptive neuromuscular facilitation

The fourth technique to increase range of motion is proprioceptive neuromuscular facilitation (PNF). Originally, PNF was designed to increase neuromuscular relaxation and has been used by physical therapists in neuromuscular rehabilitation programs for the

past 50 years (Etnyre & Lee, 1987). PNF is now commonly used in athletics to increase range of motion. There are three basic techniques of PNF: hold-relax, hold-relax with agonist contraction, and contract-relax. All three of these PNF techniques can be described in three phases. The first phase incorporates a passive static stretch to the end range of motion. The second and third phases require different muscle actions, and the action of the third phase identifies the type of PNF and is reflected in its name.

During PNF, both isometric and isotonic muscle action are used. An isometric muscle contraction occurs when the muscle torque is equal to the resistive torque and as a consequence whole muscle length does not change. In PNF, isometric contractions are referred to as the hold. An isotonic muscle contraction is a condition where the muscle shortens and does work against a constant load. In PNF, isotonic contractions are referred to as contract. When the isotonic contraction of the agonist is used, it is called agonist contraction. Within the technique of PNF, there are combinations of passive and active static stretches that are referred to as relax (Holcomb, 2000).

In the hold-relax technique of the hamstrings, a subject would lie supine on the floor and a partner would lift the leg up (hip flexion) with the knee locked and ankle in dorsiflexion. This life would continue to the point where the individual would feel mild discomfort in the hamstrings. After holding the stretch for ten seconds, the partner begins pushing the leg into further hip flexion and the subject is instructed to resist the force. After six seconds, the resistance is released and the partner is able to further the stretch without more discomfort.

In the hold-relax with agonist contraction technique of the hamstrings, a subject would again lie supine on the floor while a partner lifts the leg up (hip flexion) with the

knee locked and ankle in dorsiflexion to the point where the hamstrings stretched feels mild discomfort. However, instead of resisting the hip flexion force like in the hold-relax technique explained above, the subject stretched contributes to the force by flexing the hips and further increasing the range of motion.

In the contract-relax technique of the hamstrings, again the person lies supine the floor and a partner lifts the leg up (hip flexion) with the knee extended and ankle in dorsiflexion to the point of mild discomfort for several seconds. The subject then extends the hip and the partner resists the hip extension movement, but allows the hip to go to full hip extension (leg on floor). The partner reapplies the passive stretch into hip flexion and holds for several seconds.

Stretching comparison

It has been well documented that static stretching, ballistic stretching, dynamic stretching, and PNF techniques increase range of motion (De Vries, 1961; Gibble, Guskiewicz, Prentice, & Shields, 1999; Godges et al, 1989; Lucas & Koslow, 1984; Prentice, 1983). The question may be, which stretching technique increases flexibility most effectively? Etnyre and Lee, (1987) reviewed stretching studies and found contradicting evidence as to which method was most effective. Hardy (1985) stated that most of the differences between studies could be explained by variations in training methods, measuring instruments, and the control of confounding variables.

When comparing static and ballistic stretching against PNF, the majority of studies indicate that PNF is more effective at producing greater ranges of motion (Cornelius & Hinson, 1980; Etnyre & Lee, 1987; Prentice, 1983; Sady, Wortman, & Blanke, 1982). When comparing static stretching against ballistic stretching, there is

commonly no significant difference in increased flexibility (De Vries, 1961; Hartly-O'Brian, 1980). Little research has been compiled on dynamic stretching, but the existing research indicates that it may produce equal or less flexibility gains than static and ballistic stretching (Bandy et al, 1998; Hartly-O'Brian, 1980; Lucas & Koslow, 1984).

Although PNF is agreed to be the best method to increase range of motion, it may not be the most practical method to use. PNF requires a partner or more skill than the other stretching methods. Partners are not always available and the knowledge required to do PNF is not always understood. PNF is not widely used with exercising adults. Static stretching is the most popular form of stretching because it needs no partner and can be performed in large groups where resources and time are limited (Knudson, 1998). Although ballistic stretching has been shown to be as good as static stretching at increasing flexibility, ballistic stretches are often not used because of the potential muscle injury from abrupt stretching (Alter, 1996; Etnyre & Lee, 1987). For the above reasons, static stretching has been recommended and widely implemented in most flexibility programs.

Flexibility Limitations and Stretching Effects

Since a goal of flexibility programs is to increase range of motion, factors that contribute to range of motion need to be understood. The four main factors that limit range of motion are bone structure, age, neurological activation, and connective tissue.

Bone structure

The structure of the joint directly determines the degree of freedom within anatomical planes (Marshall, Johanson, Wickiewicz, Tishler, Koslin, Zeno & Myers,

1980). Range of motion is the degree of movement within a joint's possible degrees of freedom, but will not be any larger (Alter, 1996). Ball-and-socket joints, like the shoulder and hip, move in all anatomical planes and will produce the greatest degrees of freedom (Holcomb, 2000). Other joints, such as the wrist are ellipsoidal and only allow movement in the sagittal and frontal planes. The knee and elbow have even less degrees of freedom, since being hinge joints, they can only move in the sagittal plane. Therefore, when considering range of motion and flexibility, the type of joint has a major impact.

Age

Age also affects flexibility. It has been stated that younger individuals are more flexible than older individuals (Alter, 1996). Some decrease in flexibility is due to fibrosis, a condition where fibrous connective tissue replaces degenerative muscle. Most often, the loss of flexibility with age is due to physical inactivity (Holcomb, 2000). Reductions in flexibility with age have also been shown in active older people. McHugh, Magnusson, and Gleim (1993) performed a cross-sectional study of soccer players and found that younger soccer players were more flexible in lumbar flexion and hip rotation than older soccer players.

Neuromuscular activation

A neurological component called active resistance, also limits increases in flexibility. This active component of resistance comes from the contraction of skeletal muscles, which resists elongation. Active resistance comes from muscle reflex activity (Muir, Chesworth, & Vandervoort, 1999). Within the skeletal muscles, sensory receptors called proprioceptors provide information (feedback) to the central nervous system (CNS) about conditions within the muscles and tendons. The purpose of feedback is to

help the CNS determine orientation and position of the muscle. The main proprioceptors are muscle spindles and golgi tendon organs (GTO). Muscle spindles provide information on changes in muscle length and are sensitive to the rate and velocity of stretch.

When a muscle is rapidly stretched, the muscle spindles are activated and send a signal to the CNS, which responds by causing motor units to contract and overcome the stretch (Enoka, 1994; Sady et al, 1982). Ballistic stretches are considered undesirable because they stimulate the muscle spindles (Wallin et al, 1985). The tension in the musculotendinous unit caused by the high rate of ballistic stretching has often been considered strong enough to potentially injure the musculotendinous unit and is therefore not a recommended form of stretching (Knudson, 1998). In contrast, static stretches move the musculotendinous unit to its end range of motion slowly and where it is held for several seconds. Electromyographic (EMG) investigations have shown that there is low muscle activity with static stretch (Klinge, Magnusson, Simonsen, Aagaard, Klausen, & Kjaer, 1997; Mohr, Pink, Elsner, & Kvitne, 1998; Moore & Hutton, 1980). These findings are also dependent on the subject voluntarily relaxing and being comfortable with the stretch.

Theoretically, PNF techniques increase range of motion through the stimulation of the proprioceptors (Alter, 1996). Taylor, Dalton, Seaber, and Garrett (1990) explained that voluntary isometric contraction of the stretched muscle group leads to self-inhibition (Autogenic inhibition) through the GTO reflexes. Voluntary isometric contraction of the antagonistic muscle group results in a subsequent reflex inhibition on the muscle groups being stretched.

The neuromuscular facilitation designed to increase contractile excitability in the agonist (or contracted) muscle. At the same time the agonist muscle is facilitated, the antagonistic (opposite side of joint) muscle is inhibited or relaxed. This reciprocal inhibition of the antagonistic muscle combines with GTO facilitation to produce a greater muscle relaxation by inhibiting reflex activity.

Moore and Hutton (1980) conducted a study to determine the relative muscle relaxation during PNF and static stretching. They found that PNF resulted in higher muscle activity with stretching then did static stretching; nevertheless, PNF produced greater increases in range of motion. Their findings contradicted the theory that increased muscle reflex activity in the stretched muscle would decrease range of motion. Their conclusions are only speculative, but the greater short-term increases in range of motion found in PNF may have been attributed to larger total hip torques due to contraction. Moore and Hutton (1980) additionally explained that the voluntary discomfort felt in the antagonistic muscle during the agonist muscle contraction of PNF might have also attributed to increased range of motion by increasing the tolerance of stretching discomfort, which would alter the point where the stretch was stopped and held. Therefore, factors other than muscle relaxation are important in attaining increased range of motion (Osternig, Robertson, Troxel, & Hansen, 1989; Moore & Hutton; 1980).

Avela, Kyrolainen, and Komi (1999) applied repeated and prolonged passive static stretches to the plantar flexors for one hour to determine if muscle reflex sensitivity could be altered. Pre and post testing revealed a 23.2% decrease in maximal voluntary contraction and 19.9% decrease in EMG activity. These changes were associated with the

immediate reductions in neuromuscular activity. Total neuromuscular recovery occurred within 15 minutes of stopping the stretch.

Another proprioceptor is the golgi tendon organ (GTO). The GTO is less complex than the muscle spindle in that it has only afferent neurons going to the CNS. The GTO is located within the musculotendinous junction. In this position, the GTO is able to sense the pulling or tensile force of the skeletal muscle fibers. If the force is too great, the GTO will activate the afferent neurons, which will elicit an inhibitory signal from the CNS to the agonist muscle fibers to decrease muscle force, called autogenic inhibition (Moore, 1984). For example, when a muscle stretches, the musculotendinous unit lengthens and tension increases. At a certain stretch intensity, the GTO responds with an inhibitory signal to the stretched muscle. This autogenic inhibition serves as a protective function by letting the CNS know when the musculotendinous unit has reached it's physiological limits in relation to range of motion and to avoid injury (Moore, 1984). To reduce or avoid neuro-stimulation, recommendations of stretching have been to stretch to mild discomfort (Kenny, 1995). Knudson (1998) described mild discomfort as being "just before discomfort" or "just to the point of pain."

<u>Connective tissue</u>

The last factor that limits range of motion comes from connective tissue and is referred to as passive resistance to range of motion. The muscle's connective tissue has three mechanical components: the parallel elastic component, the series elastic component, and the contractile component (Alter, 1996). The parallel elastic component runs in parallel with the muscle's contractile elements (i.e. actin and myosin overlap). It produces the passive and resting tension in the muscle. The series elastic component is

directly in line with the muscle's contractile element and is mostly tendon. The contractile component is the actin and myosin crossbridge overlap. The force generated by the contractile component is proportional to the number of binding sites in the crossbridge overlap.

These mechanical components of the muscle display viscoelastic behavior. Viscoelastic refers to the musculotendinous unit having both viscous and elastic properties. Viscosity refers to resistance of a fluid to flow at low speeds (Daintith & Clark, 1999). Musculotendinous unit acts viscously, in that it is both time and rate-change dependent (Enoka, 1994). Elasticity is the tendency of the musculotendinous unit to return to its original length after a deforming stress has been removed (Daintith & Clark, (1999). The elastic property of the musculotendinous unit implies that length changes are directly proportional to the force applied. Passive torque is the measured resistive force when a muscle is relaxed. The force measured by the passive torque of the musculotendinous unit is related to range of motion. This relationship can be graphed as passive torque to range of motion. A steeper slope (greater passive torque to range of motion) indicates that the musculotendinous unit is stiffer and will produce more stretching resistance. If the musculotendinous unit is less stiff (decreased passive torque to range of motion), then the more compliant it is to increase length during stretch.

The musculotendinous unit has four main viscoelastic characteristics (Enoka, 1994). The first characteristic is creep, which refers to the lengthening that occurs in the musculotendinous unit under a constant tensile force (stretch). Stress relaxation is the second viscoelastic characteristic. It describes the gradual decrease in passive force resistance when the musculotendinous unit is stretched. Third is Hysteresis, which also

has a load-deformation relationship; however, it takes place between loading and unloading where greater energy is loaded in the musculotendinous unit than is dissipated during unloading. Lastly, strain rate dependence is a viscoelastic property that describes how higher tensile stresses occur with faster strain rates. That is to say, when a tensile force is applied rapidly to the musculotendinous unit as in ballistic stretching, there is a higher passive force observed than when compared to a tensile force that was applied at a slower rate as in static stretching.

To help explain how stretching increases range of motion Taylor et al (1990), investigated the viscoelastic properties of the muscle in rabbits. They confirmed the principle of strain rate dependence. The faster a load was placed on the musculotendinous unit, the less time there was for stress relaxation to occur, thereby increasing the peak force in the musculotendinous unit. Due to the high rate of ballistic stretching, it was thought to be a potentially more dangerous form of stretching compared to static stretching, dynamic stretching, and PNF techniques. It is recommended in static stretches, that an individual move to the end range of motion slowly and with a low force because of the property of strain-rate dependence. By performing a static stretch for several seconds, creep and stress relaxation take place, which increases the length of the musculotendinous unit, and subsequently, joint range of motion (Knudson, 1999). Kenny (1995) and Holcomb (2000) have also recommended that stretches be performed slowly and with a low intensity to reduce the risk of musculotendinous injury and minimize muscle reflex activity.

As previously mentioned, active resistance is low during static stretching (Klinge at al, 1997). McHugh, Kremenic, Fox, and Gleim (1997) attempted to attribute the

resistance to stretch to passive resistance. Their study determined whether musculotendinous passive resistance to stretch or the active resistance of stretch-induced contractile responses limited hamstring range of motion. Passive resistance (measured by torque) and active resistance (measure by EMG activity) were recorded in a passive static stretch of the knee flexors. They reported that hamstring range of motion was positively related to total energy absorbed. During the stretch, minimal stretch-induced knee flexor muscle activity was elicited and EMG activity was found to be unrelated. Analysis revealed that 79% of the variability in maximum range of motion could be explained by the viscoelastic properties of the musculotendinous unit, thereby confirming that resistance to flexibility can be better explained by passive resistance rather than active resistance. Other studies (Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, McHugh, & Kjaer, 1996; McHugh, Magnusson, Gleim, & Nicholas, 1992) have also researched the viscoelastic stress relaxation in humans and their findings agree with Taylor et al (1990) and McHugh et al (1997).

The time in which the stretch is held will also influence the amount of change in the viscoelastic properties of the muscle. Muir et al (1999) tested whether calf-stretching exercises affected resistive torque during passive ankle dorsiflexion. Four, 30-second static stretches were performed. No significant reduction in the resistive torque during ankle dorsiflexion was observed. It was concluded that static plantar flexor stretching exercises of short duration did not reduce connective tissue resistance.

Magnusson, Simonsen, Aagaard, and Kjaer (1996) also examined whether repeated static stretches would have a measurable effect on the passive properties of the knee flexors. They performed five repetitions of 90-second static stretches on the knee

flexor group. Results revealed a significant decrease (18-21%) in passive torque of the knee flexors. However, on a follow up study, Magnusson, Aagaard, and Nielson (2000) reduced the time of the stretch to three repetitions of 45-sec static stretches. This time, they reported no significant short-term effects on the viscoelastic properties of the knee flexors. It was noted that all three stretches produced 18-20% viscoelastic stress relaxation; however, the reduction in resistance was recovered in the musculotendinous unit within the allotted 30-second rest period between stretch repetitions. Results may have been different if there was less time between repetitions, allowing the stretches to have a summation effect. McNair, Dombroski, Hewson, and Stanley (2001) found similar findings, in their study, various static-stretch times and sets were performed in the plantar flexors. One set by 60-seconds, two sets of thirty seconds, and four sets of fifteen seconds were compared to continuous passive motion for 60 seconds. Neither of the different stretching combinations produced significant stress relaxation or decrease in stiffness. Only continuous passive motion significantly reduced stiffness.

Recent studies have suggested that it is possible to get an increase in range of motion without a decrease in musculotendinous stiffness (Knudson, 1999; Magnusson et al, 1996). It is believed this is due to an increased tolerance to the stretch. In other words, a person becomes better able to tolerate the stretching discomfort.

The Lasting Effect of Stretch

There is little reported on how long the effect of stretching lasts. This could be important information; for example, a basketball player, who after 30 minutes of sitting

on the bench is suddenly required to play. Does he still have the effects from stretching done before the start of the game?

DePino, Webright, and Arnold (2000) used four consecutive knee flexor static stretches of 30-seconds. They showed that knee range of motion (measured by knee extension range of motion) was maintained for three minutes. Additionally, knee range of motion had returned to pre-stretched levels in six minutes. Kirsch, Weiss, Dannenbaum, and Kearney (1995) using a 60-second stretch concluded that plantar flexor passive torque returned to baseline within five minutes. Zito, Driver, Parker, and Bohannon (1997) stretched the ankle for two repetitions of 15 seconds. They found no significant change in dorsiflexion range of motion. Magnusson et al (2000) observed a 18-20% decrease in plantar flexor musculotendinous stiffness with a 45-second stretch, but within a 30-second rest period, musculotendinous stiffness returned to baseline.

Others have found that increased range of motion from stretching remained up to 90 minutes (Moller, Ekstrand, Oberg, & Gillquist, 1985; Flowles & Sale, 1997). Zito et al (1997) stated that these differences could be explained by variations in warm-up, stretching position, stretching force, and stretching duration. Moller et al (1985) used an extensive warm-up, which included a light (50 Watt) 15-minute bicycle ergometer aerobic exercise followed by one maximal isometric contraction of the muscle to prepare for stretch. DePino et al (2000) and Magnusson et al (2000) used no warm-up to better isolate the effect of stretching, rather than testing the effect of stretching with warm-up. Additionally, Flowles and Sale (1997) performed passive cyclic stretching instead of active static stretching. They also performed stretches for 30 minutes when others stretched as little as 30 seconds.

After six weeks of flexibility training, Willy, Kyle, Moore, and Chleboun (2001) tested whether ranges of motion could be maintained for four weeks. They found that flexibility returned to baseline levels during the four weeks. The flexibility program was then re-implemented and six weeks later flexibility was reassessed. The gains in flexibility in the second six-week were no different from the gains in the first six-week. The significance of this finding could be applied to sports programs, where greater flexibility gains are desired but due to long intervals between seasons, any gained flexibility will most likely be lost. Flexibility should therefore be compared to cardiovascular fitness in that it will be lost rapidly without training (Knudson, 1998; Wilson & Costill, 1994). Wallin et al (1985) have found that stretching at least once a week after a 30-day training program will maintain the gained flexibility.

Stretching Time and Frequency

Studies have varied the duration of stretch to determine what effect holding the stretch has on increased range of motion. Madding, Wong, Hallum, and Medeiros (1987) compared one repetition of 15-second, 45-second, or 120-second of passive stretches on increases in hip abduction range of motion. Range of motion was assessed immediately following each stretch. Results showed that hip abduction range of motion was significantly increased after each of the three stretches. However there was no significant difference between the three stretches. They therefore concluded there was no difference between holding a stretch for 15, 45, or 120 seconds.

In a six-week study, Bandy, Irion, and Briggler (1994) attempted to show which length of time of stretching was most beneficial at increasing knee range of motion

(measured by knee extension). Three groups went through six weeks of stretching five days a week. The lengths of stretching were 15, 30, and 60 seconds. Data analysis showed significant increases in knee range of motion in all groups. Between the treatments, 30 and 60 seconds were found to be significantly more effective than 15 seconds. However, 60 seconds did not significantly differ from 30 seconds.

Bandy, Irion, and Briggler (1997) questioned the length of time and frequency of stretching at increasing knee range of motion (measured by knee extension). As in their previous study, the stretching programs were implemented five days a week for six weeks. Stretching treatments were three one-minute stretches, three 30-second stretches, one one-minute stretch, and one 30-second stretch. Results found that increasing the frequency of the stretching did not significantly increase the range of motion. The three repetitions stretch group did not have significantly greater gains in range of motion than the one-repetition group. Additionally, the one-minute stretch group produced no greater results than the 30-second stretch group. Bandy et al (1997) concluded that one repetition of 30 seconds was the optimal time for increasing flexibility.

Roberts and Wilson (1999) compared 5 seconds of passive stretching to 15 seconds of passive stretching. They found no difference in passive range of motion (partner assisted movement), but found a significant difference in active range of motion (no assistance or self moving) in the 15-second stretch.

The specific duration, frequency, and number of repetitions have varied among the studies. When testing the effect of stretching by musculotendinous stiffness there is a principle referred to as diminished returns. Simply stated, it means decreases in stiffness will be greater at the beginning of stretching as opposed to at the end of a prolonged

stretch. McNair et al (2001) pointed out when stretching the ankle joint the greatest change in stress relaxation was found in the first 20 seconds. This is consistent with Magnusson et al (1996), who showed that the greatest changes in stress relaxation occurred in the first 15-20 seconds. It has been shown that cyclical stretching of the musculotendinous unit increases elongation up to 80% in the first four cycles of stretching (Taylor et al, 1990).

In the acute stretching studies (where testing is performed immediately following stretching), 15 seconds of stretching was the optimal time to increase range of motion (Madding et al, 1987; McNair et al, 2001; Roberts & Wilson 1999). In two long-term (6 weeks) studies (Bandy & Irion, 1994; Bandy et al, 1997) thirty seconds of stretching was most beneficial at increasing range of motion. The time difference could be explained by the greater increase in creep with 30 seconds compared to 15-seconds.

Warm-up and Stretching

Widely accepted warm-up protocols include two components: general and specific. General warm-up consists of 5-10 minutes of aerobic work. The specific warm-up includes movements of the activity or sport to be participated. Specific warm-ups are recommended to last 8-12 minutes and to include dynamic activities as well as specific stretches (Kenny, 1995; Holcomb, 2000). Traditionally, stretching has been included in specific warm-up because it was thought to increase performance and prevent injury (Smith, 1994). However, increasing performance and injury prevention have come under question, and the benefits of stretching prior to activity may be incorrect (Knudson, 1999; Gleim & McHugh, 1997).

The purpose of warm-up exercises is to prepare the body for the stresses it will encounter during an activity or sport. Warm-up exercises are believed to increase the core body temperature and disrupt transient connective tissue bonds (Smith, 1994). The effect of increased muscle temperature will (1) increase dissociation of oxygen from hemoglobin and myoglobin, (2) increase conduction velocities of action potentials, (3) increase metabolic rate, (4) increase blood flow to the muscles, (5) decrease viscosity of the muscles, and (5) increase connective tissue compliance (Enoka, 1994; Holcomb, 2000). These benefits can then help increase performance as observed by Davies and Young (1983) who studied the effect of temperature on contractile properties of the triceps surae. They found when muscle temperature increased 3.1°C above normal, the contractile elements of the muscle significantly increased the velocity on contraction (by seven percent) and relaxation time (by 22 percent).

Increased temperature also has an effect on range of motion. Henricson et al (1984) applied heat around the hip to determine its effect on range of motion with and without stretching. Heat alone did not improve hip range of motion. Stretching without heat did increase hip range of motion, and stretching with heat combined gave the greatest increase in range of motion and remained increased for 30 minutes. These results are in accordance with others (Hunter, Kerr, Whillians, 1952; Lehmann, Wasock, & Warren, 1970; Warren, Lehmann, Koblanski, 1971) who show that heat increases collagen extensibility and decreases musculotendinous stiffness.

Stewart and Sleivert (1998) studied the effect of warm-up intensity on range of motion and anaerobic performance. Subjects performed 15 minutes of treadmill running at 60, 70, and 80% VO_2 max. Following the warm-up, PNF (contract-relax) stretching

was performed. Results showed that ankle dorsiflexion range of motion significantly increased in all warm-ups and intensity of the warm-up did not change the range of motion obtained. Aerobic warm-ups at 60-70% VO_2 max were also shown to increase anaerobic performance (observed in a maximal treadmill run); however, the warm-up done at 80% VO_2 max did not improve performance.

Wiemann and Hahn (1997) studied how increased muscle temperature obtained through aerobic cycling decreased musculotendinous stiffness and increased range of motion, as well as how it compared to different types of stretching. They found that static stretching, ballistic stretching, and aerobic cycling all increased range of motion in the knee flexors; however, stress relaxation was only significant in aerobic cycling. Pre and post testing of the knee flexors revealed a decrease in EMG activity from static stretching, ballistic stretching, and cycling which would facilitate increases in range of motion. However, they found no decreases in musculotendinous stiffness, which agreed with Magnusson, Aagaard, Simonsen, and Bojsen-Moller (1998), who also found no significant decreases in musculotendinous stiffness in the knee flexors after 10 minutes of static and ballistic stretching. The constancy of the passive tension recorded in these studies indicates that a subject's short-term increase in range of motion may have been due to an increased tolerance to the stretching stress.

Taylor, Brooks and Ryan (1997) compared changes in the viscoelastic characteristics of the muscle using passive static stretching versus isometric muscular contractions. They found a significant stress relaxation and increase in range of motion from passive static stretching and isometric contractions. They concluded that the static stretching increased range of motion because it applied a tensile force, which resulted in

the elongation of muscle fibers and connective tissues (musculotendinous unit). The isometric contractions, on the other hand, increased range of motion by shortening the muscle fibers, which pulled and lengthened the tendons of the series elastic component because they are fixed at their origin and insertion.

Moller, Oberg, Ekstrand, and Gillquist (1983) studied the effects that warm-up, massage, and stretching had on range of motion. Contrasting other studies, their results showed that stretching alone was greater at increasing flexibility than massage, warm-up, and stretching combined with massage and warm-up.

If the goal of stretching is to increase flexibility, Cornelius, Hagemann, and Jackson (1988) found that including stretching in a 6-week workout program did not make a significant difference in increasing range of motion. In their study, static stretching was done before, after, and both before and after each workout. All produced significant increases in range of motion.

Gleim and McHugh (1997) reviewed the literature involving flexibility, stretching, and injury prevention. They stated that one of the most accepted reasons for adding stretching to warm-up is based on the concept that stretching will reduce the risk of muscular injury; however, they criticized the studies for not addressing real exposure to potential injury and were often retrospective (meaning the purpose of the study wasn't to find if stretching reduced injury but the collected data correlated in support of the stretching). They concluded that no real evidence exists to prove there is a decrease in injury due to stretching and increased flexibility. They recommended that a study with large number of subjects be done in order to provide statistical power to warm-up stretching and injury rates. Pope et al (1999) tested 1538 male army recruits in a 12-

week training program to observe the effect of static stretching on injury prevention. Army recruits were randomly divided into two groups (stretching and no-stretching). Both performed aerobic warm-ups; however, the stretch group included 20-seconds static stretching of all major leg muscle groups while the other group did not stretch. In 12 weeks, there were 333 lower-limb injuries, but there were no significant differences between stretching and no stretching groups. Fitness level (measure by a 20-meter shuttle run), weight, age, and date of enlistment were also recorded. Fitness level was found to be a strong predictor of injury risk. The least fit subjects were 14 times more likely to sustain an injury than the fittest. Recruits who were older and who had enlisted later in the exercise program were also more likely to be injured when compared to the younger recruits. Height, weight, and body mass index (BMI) had no correlation to injury prevention.

Stretching and Performance

Flexibility and functional performance

It has been assumed that stretching increases athletic performance, even though there is little conclusive research to support the assumptions (Lieber et al, 1991; Kokkonen & Nelson, 1996; Nelson et al, 1996). There are, however, plausible reasons why performance may be enhanced by flexibility training.

Coordination, endurance, power, strength, and mental toughness are all part of creating a maximum performance. Flexibility is recognized as an important factor in skilled performance (Alter, 1996). Increased flexibility can increase performance in many

activities where measured range of motion is necessary to perform certain skills, such as in gymnastics, diving, and figure skating (Knudson, 1999).

The same degree of flexibility is not needed for all sports. For example, sprinters do not require the same flexibility as gymnasts to perform in their respective sports. Significant differences in range of motion have been observed between athletes of different sports. These differences are likely to be both inherent and trained, but the contribution of these factors to performance is difficult to access (Gleim & McHugh, 1997). Gleim (1984) profiled American football players and found that each position required unique physical characteristics. In flexibility, he found that linemen differed from each position and were least flexible. Two others studies, showed differences in flexibility between pitching and non-pitching arms in professional baseball pitchers (Donatelli et al, 2000; Magnusson, Gleim, & Nicholas, 1994). The pitching arm had significantly greater range of motion in external shoulder rotation and less internal shoulder rotation range of motion when compared to the non-pitching arm.

Long-term flexibility effects

Few studies have tested the effect flexibility programs have on strength and performance after several weeks of flexibility training. Wilson, Elliott, and Wood (1992) studied the effect of an 8-week progressive static stretching program (6-9 sets, 8-30s for chest stretch) on chest musculotendinous unit stiffness and bench press performance. The stretch group significantly decreased musculotendinous stiffness and performed better in the rebound bench press performance than the no stretch group; however, no differences were observed in purely concentric bench press performance between the groups. Range of motion was only significant (13.1%) in the stretch group. They concluded that a

compliant musculotendinous unit (less stiff) was able to produce significantly more work due to the increased loading and release of energy in the series elastic component of the muscle.

Klinge et al (1997) determined whether isometric strength training or isometric strength training combined with static stretching changed the viscoelastic properties of the muscle. Subjects were randomly divided into two groups: isometric strength training group and isometric strength training with static stretching. After 13 weeks of training, isometric strength increased in both groups by 43 percent. Musculotendinous stiffness and passive torque also increased in both groups while EMG activity remained low. There was no significant difference between the groups in strength, stiffness, or passive torque. They suggest that strength training was a stronger stimulus than stretching because the viscoelastic properties of the muscle were not altered.

In an animal study, Ashmore (1982) stretched chicken wings for 6 weeks and found that muscle growth was much more profound than without stretch. Several studies in non-peer review journals have also clamed that flexibility programs, combined with resistance training will produce greater increases in strength, than resistance training alone (Westcott & Loud, 2000; Zulak, 1991).

<u>Short-term flexibility effects</u>

The short-term or acute affects that stretching has on performance have been more widely studied. Several studies provide evidence that acute stretching may increase performance. Godges et al (1989) performed a study to determine the effect of PNF and static stretching on hip range of motion and gait economy (the amount of O_2 consumed at a given speed). Hip flexors and extensors were stretched for two minutes using PNF and

static stretches. Both PNF and static stretches produced significant increases in hip range of motion. Improvements in range of motion were related to gait economy at running speeds of 40%, 60%, and 80% VO_2 max. Post-stretching running economy with static stretching significantly decreased VO_2 when compared to baseline running speeds. PNF stretching significantly improved gait economy, but only at 60% VO_2 max running speed.

The findings of Craib et al (1996) contradict Godges' et al (1989) study, in that they found that runners who were less flexible in the trunk and lower limbs were more economical. Their conclusions suggest that inflexibility, in certain muscle areas, increase the storage and return of elastic energy from the musculotendinous unit, which would decrease the need for muscular activity and thereby increase running economy.

Bender, Clark, Li, and Cornwell (2000) studied stretching and sprinting performance. Specifically, they examined the effect acute static stretching would have on musculotendinous stiffness and muscle spindle activity in initiation of the stretch-shorten cycle in a 200-meter sprint. Differences between pre and post-stretching 200-meter times failed to show significance. They noted that 200-meter time improved due to the exposure to testing, but that stretching may still have decreased performance because the rate of improvement in the 200-meter sprint was notably slower in the stretch group.

Although some studies do support the use of acute stretching, the majority of studies indicate acute stretching does not improve immediate post-stretching performance. Avela et al (1999) performed one hour of passive stretching of the plantar flexor muscle groups and found that maximal voluntary contraction (plantar flexor torque) and muscle activity (EMG) were all significantly reduced.

In an animal study, Lieber et al (1991) performed cyclical passive stretches for one hour and compared it to one hour of isometric and eccentric contractions. The decrease in maximal muscle force was greatest in eccentric contraction; however, the passive stretch still reported a significant decrease of 13% in muscular contraction performance. Fowles and Sale (1997) performed cyclical passive stretches in the ankle plantar flexors for 30 minutes. EMG recorded twitch torque and motor unit activation to determine maximal voluntary force and what is happening in the muscle. They showed that both twitch torque and motor unit activation were all significantly decreased and remained depressed for up to an hour.

Stretching prior to activity has also been shown to decrease maximal strength. Kokkonen and Nelson (1996) had three groups (N=32) who each performed 20 minutes of static stretches, ballistic stretches, or no stretches before performing a maximal knee flexion and extension. Stretching exercises targeted the hip flexors, hip extensors, knee extensors, knee flexors, and plantar flexors. Strength significantly decreased in knee extensions by 6.6 lbs. in static stretching and by 2.3 lbs. in ballistic stretching. Strength significantly decreased in knee flexion by 4.5 lbs. in static stretching and by 3.2 lbs. in ballistic stretching. Additionally, the strength deficit in static stretching was found to be significantly greater than the ballistic stretching strength deficit.

In another study by Kokkonen et al (1998), results confirmed that static stretching decreases maximal strength performance in knee flexion (7.3 percent) and extension (8.1 percent). Sit and reach scores showed that flexibility significantly increased (16 percent) due to stretching and correlated with strength deficits. Therefore, the acute increases in flexibility are related to decreases in strength performance.

Acute stretching has been found to affect joint torques at specific velocities. Guillary et al (1998) performed four sets of static stretches (one active and three passive) each for 30 seconds on the quadriceps muscle group. After stretching maximal torque was measured at 1.05rad/s, 1.57rad/s, 2.62rad/s, 3.67rad/s, and 4.71rad/s. Four maximal voluntary isokinetic torques were given at each of the five movement velocities with 30-second rest periods between contractions. Subjects were randomly assigned in a counterbalance design and given at least two minutes between velocities. Compared to the baseline torque measurements, torque significantly decreased only in the 1.05rad/s and 1.57rad/s. All other joint velocities were unaffected. The fact that stretching inhibited only slower velocities, lead them to conclude that stretching may concentrate primarily upon slow-twitch muscle fibers. Nelson, Guillary, Cornwell, and Kokkonen (2001) performed a similar study, only changing the amount of stretching to three sets. They observed the same significant decrease in torque at 1.05rad/s and 1.57rad/s. Their results, support the conclusions made by Guillary el al (1998), that stretching effects slower velocities and possibly only effected slow-twitch muscle fibers.

Nelson, Allen, et al (2001) found that the acute effects of stretching are joint angle specific. They performed three static stretches (one warm-up, two passive) of the knee extensors for 30 seconds. Knee joint angles for maximal joint isometric torque were at 90°, 108°, 126°, 144°, and 162°. The subjects (N=55) performed two passive static stretches after a specific warm-up. Four maximal voluntary isometric torques were recorded at each of the five knee angles with a 30-60 second rest period between each contraction. Subjects were randomly assigned in a counterbalance design and given at least two minutes between isometric torques. They showed that post-test average

maximal voluntary isometric torques were not significantly different from pre-stretch values at 90°, 108°, 126°, and 144°. Average maximal voluntary contraction for each joint angle was added and found to be significantly less (seven-percent) than pre-stretch values. They attributed the decrease in isometric torque at 162° to a shift in muscle-tendon length that placed the sarcomeres at a non-optimal position on the force-length curve. According to the force-length relationship of the muscle, isometric muscle contractions create a curved force-length relationship due to the overlapping of the sarcomere and number of cross-bridge attachments (Rassier, MacIntosh, & Herzog, 1999). Peak muscular force is created when the sarcomere has maximal cross-bridge overlap. As the sarcomeres elongate the ability of the muscle to produce force decreases. A stiff musculotendinous unit would better allow the sarcomeres to produce force at a longer length than would a more compliant musculotendinous unit. Therefore, during an isometric contraction, force would go through a period of shortening until the elastic components of the muscle were stiff enough to transmit the generated force to the bone. The effects of alterations in the force-length curve would be more apparent at points in range of motion on the descending side of the force-length curve as shown by Nelson, Allen, et al (2001).

Worrell et al (1994) attempted to determine the most effective form of stretching and how increasing hamstring flexibility effects isokinetic hamstring peak torque. They hypothesized that increased flexibility would allow more mechanical work to be absorbed by the series elastic component of the muscle as potential energy and thereby increase force production. Two groups performed four repetitions of 15-20 seconds of either PNF or static stretching of the knee flexors. They found no difference in increased flexibility

between the different stretches. The isokinetic measurements (eccentric and concentric) were recorded between 0° and 90° of knee flexion at 60°/sec and 120°/s. Isokinetic measurements of both groups were combined since there was no difference in flexibility between stretch groups. They found that significant increases in knee flexor eccentric force production occurred at 60°/sec and 120°/sec. Improvements in peak concentric force occurred only at 120°/sec. The increases in eccentric force production were attributed to the significant increases in flexibility and musculotendinous compliance (decreased stiffness) which allowed the musculotendinous unit to store more elastic energy for force production.

Like Worrell et al (1994), Nelson et al (1996) believed that stretching would effect musculotendinous stiffness and increase the amount of stored elastic energy to enhance performance. Specifically, they hypothesized that stretching would change the amount of stored elastic energy used to enhance vertical jump performance because stretching alters musculotendinous stiffness, and musculotendinous stiffness is related to magnitude of stored elastic energy (Bobbert, 2001). They used squat jumps and countermovement jumps. Squat jumps are vertical jumps that are initiated at a 90°-knee angle. Countermovement jumps are vertical jumps where an eccentric contraction precedes a concentric contraction, and uses stored elastic energy for increased force production. After stretching, both squat jump and countermovement vertical jump heights were significantly reduced, but no significant difference was found between them. Conclusions were that net force production for vertical jump was reduced due to stretching, but the performance decrease does not appear to be from changes in the elastic properties of the muscle.

Cornwell et al (1999) attempted to clarify which mechanism (musculotendinous stiffness or depression of muscle activity) was responsible for decreases in vertical jump performance found by Nelson et al (1996). Cornwell et al (1999) investigated the effect of passive stretching on the neuromechanical properties of the plantar flexors using squat jumps and countermovement jumps. Following the stretch, a significant difference in musculotendinous stiffness (2.8%) was noted. Countermovement jump decreased significantly in maximal vertical jump, but not in muscle activity (EMG). Squat jump had not changed in maximal vertical jump, but a significant decrease in muscle activity (EMG) was observed. The performance decrease was concluded to be due to a change in plantar flexor musculotendinous stiffness rather than from changes in motor activation because countermovement jumps, which rely on musculotendinous stiffness, significantly decreased in MVJ while there was no significant changes in squat jumps MVJ. This was contrary to the earlier mentioned study by Nelson et al (1996).

Recently, Kundson et al (2001) performed static stretches and analyzed the kinematics of the vertical jump in twenty active adults post-stretching. They hypothesized that if stretching affected musculotendinous stiffness, it would be observed in kinematic changes from pre to post-stretching in vertical velocity, knee angle, and/or the durations of eccentric and concentric phases of the countermovement jumps. Observations resulted in no significant biomechanical changes. These findings suggest that the mechanism of stretching cannot be explained in changes in musculotendinous stiffness.

Vertical Jump Testing

Coaches and trainers evaluate players' talent and ability by assessing skill and talent through performance tests. Once assessed, results help provide a measurable level of feedback for the athlete and coach on current ability and progress. It also forms a way to compare individuals.

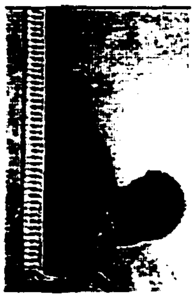
Vertical jump tests are used to measure maximal muscular power (Semenick, 1990). It is a specific test for sports such as volleyball and basketball. Several tests and devices have been developed to assess maximum vertical jump: such as the Just Jump System®, the Vertical Jump Mat®, the Standing Long Jump Test Mat®, the Reach 'N' Jump Board®, and the Vertec® (see Figure 1). Of these, the Vertec® is the most widely used.

While these tests have been developed, most are fundamentally no different then the original Sargent's Jump test (Sargent, 1921) which measured maximal vertical jump as the difference between two chalk marks on a wall. The first chalk mark was the reach height and the second was the jump height mark. With the new devices, athletes avoid chalk use and increase safety by not having a wall to hinder the jump.

Just Jump System®

The Vertical Jump Mat®

The Standing Long Jump Mat®



The Reach 'N' Jump®

The Vertec®

Figure 1. The following are pictures that describe many of the new popular ways of measuring jump performance. On the top row going left to right is the Just Jump System®, the Vertical Jump Mat®, and the Standing Long Jump Mat®. On the bottom row are the Reach 'N' Jump Board® and the Vertec®. The Just Jump System® calculates vertical jump based on flight time. The Vertical Jump Mat® has a measuring tape tied to the waist when vertical jumping. The difference between starting and ending length will be the vertical jump height. Standing Long Jump Test Mat® starts at zero, and where the back heels land there will be the distance of a long jump. The Reach 'N' Jump Board® and Vertec® both subtract standing reach-height from maximal jump height to acquire maximal vertical jump height.

Since there are many vertical jump instruments, Young et al (1997) performed a study that evaluated the specificity, validity, and reliability of two tests: the Board

Method (similar to Sargent Jump Test) and a modified Vertec® method (using a Yardstick jumping device). The Board Method required subjects to jump and touch a wall at peak height. The Yardstick jumping device required a touch at peak height against horizontal vanes spaced 0.01m apart. They tested vertical jump off one-leg and two-leg standing, and with one, three, five, and seven strides. The lowest recorded vertical jump was with no step. Vertical jump increased with one leg up to five strides and decreased at seven strides. It was believed that seven strides take-offs produced lower MVJ due to the inadequate leg strength required for propulsion. Two leg jumps improved with one and three strides, but leveled at five and then decreased for the same reasons. They concluded that run-up resulted in better vertical jump performance and noted that in order to obtain MVJ, jumpers would need at least three strides. Young et al (1997) also compared MVJ between the Yardstick and Board methods. The Yardstick produced significantly greater mean vertical jumps compared to the Board Jump with all jumps except the seven-stride. Lower MVJ's in the Board methods were thought to have occurred because of adjustments made in avoiding injury against the marking wall. Lastly, they tested the inter-day reliability of both methods and found them to be reliable. However, reliability of MVJ with the run-up conditions produced poorer scores than standing positions. Much of the variation was thought to be caused by the added skill of subjects taking off at the right time and contacting the wall/vanes at the highest point. Any variation would produce altered vertical jump height.

Isaacs (1998) performed a study that compared the Vertec® with the Just Jump System® for measurement of MVJ in young children (7-11 years) (N=580). The Just Jump System® is equivalent to a force plate, where vertical jump is mathematically

calculated by flight time. The subjects followed a standing two-legged jump protocol and reached with both hands. While jumping using the Vertec®, the mat of the Just Jump System® was positioned on the ground under the feet of each subject. The subject's jumps were then simultaneously recorded on both devices. Results revealed a significant difference between recorded MVJ's of the Vertec® and Just Jump System®. The MVJ's of the Just Jump System® were significantly higher (0.93-inch). The association between scores of the measuring systems yielded a correlation (r) equal to 0.69. Differences in MVJ could be explained in the element of accuracy in contacting the Vertec's® horizontal vanes at peak height. Contact before or after peak height would result in lower vertical jump scores. Landing technique variation may also explain the difference. If the subject's landing style altered (i.e., bending legs more before ground contact versus straightening the knees), airtime would increase or decrease and result in a changed MVJ without a difference being observed on the Vertec®. Given that both systems can generate acceptable measures of MVJ, the Just Jump System® may be more advantageous than the Vertec® because it can calculate MVJ with or without arm-swing. It is also easier to evaluate MVJ for a large group of people because of its easy use and portability. When a reaching jump is desired, the Vertec® would then be recommended.

In vertical jump tests, the coordination of body segments can be a factor in jumping height. Luhtanen and Komi (1978) performed a study to determine the segmental contribution of forces in producing a vertical jump. Cinematography and force-platform techniques were used. Their data revealed that knee extensors produced 56% of force, with the plantar flexors producing 22%, the trunk extensors 10%, arm swing 10%, and head swing 2%. They reported great variances in the total performance

despite the similarities performed in individual segments. Such differences indicated that body segments do differ in the their contribution of force with varying coordination of movements in jumping.

With vertical force being effected by the coordination of segments, Feltner, Fraschetti, and Crisp (1999) did a study that determined the augmentation of the countermovement vertical jump with arm swing. Resultant average joint force and torque were compared. They found that significantly larger recorded values for vertical velocity of the center of mass at take-off with arm swing than without. It is therefore suggested that vertical jump can be increased with the use of arm swing. In a practical and competitive high jump setting, Lees, Ceperos, Soto, and Gutierrez (2000) calculated the overall whole-body momentum to increase by 7.1 percent with the use of free limbs in elite high jumpers.

Summary and Purpose of Stretching

Stretching is performed to relax the muscles, decrease the risk of injury, increase flexibility, and increase sports performance (Smith, 1994; Wilkinson, 1992). The type of stretch, the time the stretch is held, and intensity of the hold will all factor into the results obtained from stretching (Knudson, 1999). General and specific aerobic warm-ups are beneficial at increasing flexibility and result in increases in range of motion similar to that of stretching (Holcomb, 2000; Kenny, 1995). Stretching benefits will be maximized if stretching is done when the muscle temperature is increased (Fowles & Sale, 1997; Moller, et al, 1985). Stretching and warm-up decrease muscle stiffness and the increased

compliance will be able to better withstand the stresses placed on the musculotendinous unit (Taylor et al 1990).

Several studies have investigated the performance benefits of stretching. Long-term flexibility programs increased strength performance (Klinge et al, 1997; Wilson et al, 1992). Acute stretching decreases maximal strength and vertical jump (Cornwell et al, 1999; Guillary et al, 1998; Kokkonen & Nelson, 1996; Kokkonen et al, 1998; Nelson et al, 1996). The exact mechanism to explain why acute stretching decreases performance has not been strongly identified; however, biomechanical alterations of musculotendinous unit and decreased muscle activity are presumed to be the limiting factors (Cornwell et al, 1999; Guillary et al, 1998; Kokkonen & Nelson, 1996; Kokkonen et al, 1998; Magnusson et al, 1996; Magnusson et al, 2000; McHugh et al, 1992; Nelson et al, 1996; Nelson, Guillory, et al, 2001; Taylor et al, 1990).

The effect that static stretching has on performance needs to be further studied. Manipulation of variables that effect stretching (stretch time, type, warm-up, and performance activity tested) in study design could help to explain differences observed in stretching and performance study outcomes (Knudson, 2001; Nelson et al, 1996). One major factor in flexibility programs is total stretching time (Bandy et al, 1994; Bandy et al, 1997; Madding et al, 1987) (see Table 1). Increasing the duration of stretch or the number of stretch sets increases total stretching time. Stretch times used in performance studies have been from 15-40 seconds, and for one to six repetitions. If stretching did affect performance, time of stretch may be a primary reason. By increasing the number of static stretching sets, the stretch effect may also be increased and a difference in performance may be observed.

CHAPTER 3

METHODOLOGY AND DATA DESCRIPTION

Subjects

Twenty-five (N = 25) apparently healthy and active male (n = 15) and female (n = 10) subjects between the ages of 21-40 volunteered to be in the study. The subjects consisted of active adults whose mean height, mass, and age were 1.78m (+/- 0.17m), 78.1Kg (+/- 15.0Kg), and 27 years (+/- 5.3 years) (see Appendix A). All subjects signed a university approved informed consent form (see Appendix B). All were free from disease and had no muscle or joint problems. Subjects were briefed on the purpose of the study, and were encouraged to perform as consistently as possible in all conditions.

Stretching Protocol

The stretching program consisted of five different stretches targeting the plantar flexors (triceps surae), knee flexors (hamstring and gastrocnemius), knee extensors (quadriceps), hip extensors (gluteus), and trunk extensors (erector spinae). Subjects were instructed to slowly move into the stretch to the point of discomfort and hold for 30 seconds.

The plantar flexors were stretched using the wall stretch (see Figure 2). This was done by having the subject stand and face the wall with feet shoulder-width apart and

toes approximately one foot from the wall. The subject leaned forward, placed hands on the wall and then stepped back approximately 2-3 feet with the stretch leg while the opposite knee flexed. The knee of the stretch leg was extended, which lowered the heel to the floor and applied the stretch. When the stretch was completed, the stretch was then changed to the opposing leg in the same manner.

Figure 2: The wall stretch.

The knee flexors were stretched with the sitting toe touch (see Figure 3). The subject sat on a mat with the upper body nearly vertical and the legs straight in front. The subject leaned forward and grasped the toes of each foot with each hand. If toes could not be grasped, then the subject grabbed the ankle or furthest part of the leg.

Figure 3: The sitting toe stretch.

The knee extensors were stretched with the side quadriceps stretch (see Figure 4). The subject lay on a mat on his/ her left side with both legs straight. The forearm was placed at a 45-degree angle to the torso. The subject was instructed to flex the right knee, moving the right heel of the foot toward the buttocks. The front of the ankle was grasped with the right hand and pulled toward the buttock. After stretching the right side, the subject rolled to the left side and stretched the left side in the same manner.

Figure 4: The side quadriceps stretch.

The hip extensors were stretched with the spinal twist (see Figure 5). While sitting with the legs straight and upper body nearly vertical, the subject placed the left foot to the right side of the left knee. The back of the right elbow was placed on the bent knee. The

left palm was on the floor behind the hips. The stretch was applied by pushing the left knee to the right and rotating the trunk to the left as far as possible. After stretching the left side, the subject stretched the right side in the same manner.

Figure 5: The spinal twist stretch.

The trunk extensors were stretched with the semi leg straddle (see Figure 6). The subject sat on a mat with the knees flexed comfortably at 30 to 50 degrees and the legs completely relaxed. The knees were pointed outward (hip abduction), while the subject leaned forward from the waist and reached forward with the arms and hands. The legs were bent sufficiently to increase stretch more in the spine extensors than the hamstrings.

Figure 6: The semi leg straddle stretch.

Maximum Vertical Jump Protocol

Subjects' age, height, weight, and percentage bodyfat (%BF) were assessed on the first day before testing. Weight was measured to the nearest tenth of a kilogram on a digital scale with the subject dressed, as they would perform the MVJ. Percent bodyfat was determined from the triceps, abdomen, suprailiac, and thigh skinfolds using the Jackson & Pollock sum of 4-site formula (Golding, Sinning, & Myers, 1989).

On the first testing day, subjects received instructions and a demonstration on how to perform a vertical jump on the Vertec® prior to performing any of the testing protocols. When tested, subjects were verbally encouraged to jump as high as possible for each jump. Vertical jump height obtained after each jump was reported to the subject to increase motivation to jump higher. The subjects were given four submaximal vertical jump trials in preparation for their three maximal effort trials.

The MVJ testing procedure followed the National Strength and Conditioning Association guidelines for testing vertical jump using the Vertec® device (Harman, Garhammer, & Pandorf, 2000). The Vertec® was placed on a flat surface with good traction. The subject was instructed to stand next to the Vertec®, so that when the dominant hand reached straight upward, it was directly below the center of the vanes. The subject then reached as far up as possible while the Vertec® height was adjusted so that the first horizontal vane could just be touched and pushed forward while standing flat-footed. This determined the standing touch height. The height of the vertical column of the Vertec® was adjusted for each subject before the maximal jumping performance. The vertical column was raised higher than the starting reach height if it was anticipated that the subject would exceed a 24-inch jump or that on the first MVJ the subject exceeded a

24-inch vertical (which was at the top on the horizontal vanes). Added height was measured and added to the vertical jump height measured by the horizontal vanes. This was necessary for five subjects on the first day in the pre-test MVJ for NS. For the next treatments, the Vertec was raised to the same reach or jump height as on the first day.

The subject moved into the starting position under the horizontal vanes, with the dominant hand side toward the Vertec® upright. The subject was allowed countermovement jump and to swing the arms as much as was comfortable for them, but they were not instructed to do so. Additionally, subjects were told preparatory or stutter steps were not allowed. If a preliminary step was used, the jump was not counted and the subject was given another trial. At the highest point in the jump, the subject reached up with the dominant hand and hit the highest possible vane. The score recorded was the distance between the highest vane tapped during the standing vertical reach and the vane tapped at the highest point of the jump. This height was recorded in inches to the nearest one half inch, which was the distance between the horizontal vanes. The highest vertical jump of the three jumps was considered the subject's MVJ.

Experimental Protocol

The experimental protocol consisted of three testing sessions completed within a five-day period. Testing was conducted at the same time of day for all three days. The three treatments were: one set of 30-second static stretching (1SS); three sets of 30-second static stretching (3SS); and no stretching (NS). Subjects were randomly assigned to a group one or two. Both groups first treatment was the NS. For group one subjects, the second treatment was 1SS and the last treatment was 3SS. For group two subjects, the

second treatment was 3SS and the last treatment was 1SS. Testing was performed at a local fitness facility.

The subjects followed a recommended general and specific warm-up routine (Kenny, 1995; Holcomb, 2000) (see Figure 7). The general warm-up was performed by all subjects prior to each treatment on a treadmill for 5-minutes. Using the Karvonen Method, exercise intensity was set at 50% heart rate reserve (HRR). For example, a 30 year old subject's maximum heart rate would calculate 220-30 (age) = 190bpm. This calculated maximum heart rate (190bpm) was subtracted from the person's average resting heart rate (average RHR), or 190bpm-70bpm = 120bpm. This would be multiplied by 50% (120 x 50%), which equals 60. Sixty is then added to average RHR (60 + 70) to get 130bpm HRR.

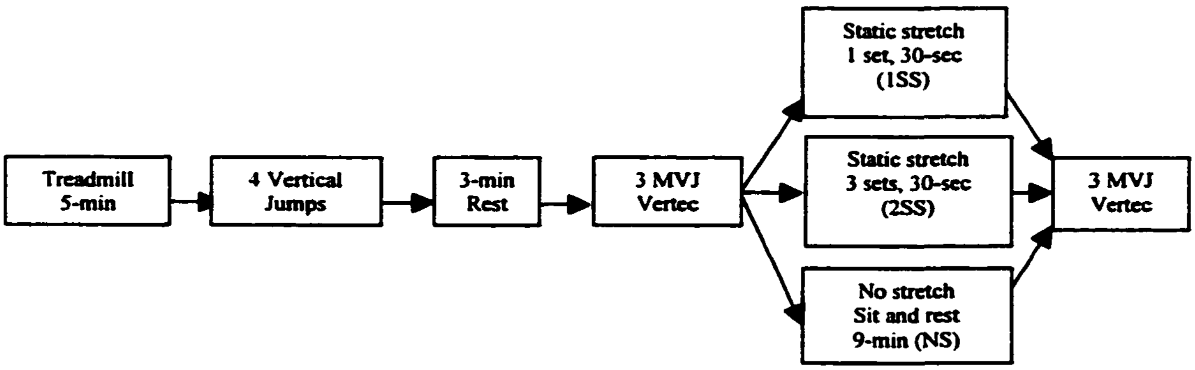


Figure 7: Summary of protocols.

Following the general treadmill warm-up, subjects were given time to do a specific warm-up by performing four dynamic jumps. They performed four jumps and were instructed to jump with increasing intensity until maximal intensity was obtained. After the four warm-up and practice jumps, the subjects were given a 3-minute rest and

then performed three MVJ. The height of each MVJ was recorded. The highest of the three jumps was considered the MVJ and was used as the baseline jump height for that test day.

After performing the three MVJ, one of the three treatments was immediately started. On the stretch days, five different static stretches were used to stretch the plantar flexors (see Figure 2), knee flexors (see Figure 3), knee extensors (see Figure 4), hip extensors (see Figure 5), and trunk extensors (see Figure 6) muscle groups. These were chosen because of their contribution in force production in vertical jump (Luhtanen & Komi, 1978). Subjects performed the stretches on a mat. Stretching treatments were one set of 30-second static stretching for the five different muscle groups (1SS), three sets of 30-sec static stretching for the five different muscle groups (3SS), and no static stretching (NS). In the NS treatment, subjects sat and rested for nine minutes, which was the equivalent time the subjects would have been stretching.

Immediately following the treatment (NS, 1SS, & 3SS), the subjects performed three MVJ using the Vertec®. All jumps were recorded and the highest of the three jumps was considered the MVJ and was used for statistical comparison.

Statistical Design

The study was a two by three within-subjects design. The dependent variable was maximum vertical jump (MVJ). The independent variables were test (pre, post) and static stretching sets (NS, 1SS, 3SS). Significant interactions were analyzed with simple main effects analysis and Tukey's test.

CHAPTER 4

RESULTS AND DISCUSSION

Results

The study was statistically treated using a two (pre-test, post-test) by three (NS, 1SS, and 3SS) ANOVA with repeated measures (see Appendix C). The main effect for "Treatment" (NS, 1SS, 3SS) was $F(2,48) = 2.877$, $p = .066$. The main effect for "Test" (pre, post) was $F(1, 24) = 14.727$, $p=.000$. The interaction effect was significant at $F(2, 48) = 3.848$, $p = .028$ (see Figure 8). A "simple main effects" analysis was used in three steps because the interaction was significant.

Step 1: One-way repeated measures (RM) ANOVA on the three pre-tests: $F(2, 48) = 1.33$, $p =.273$.

Step 2: One-way RM ANOVA on the three post-tests: $F(2, 48) = 4.99$, $p = .011$. Tukey's test was used to compare the three pairs of means. NS vs. 1SS: mean difference = .14, $p = .442$. NS vs. 3SS: mean difference = .42, $p = .042$. 1SS vs. 3SS: mean difference = .56, $p = .005$.

Step 3: Paired t-tests were run between pre and post of NS, 1SS, and 3SS. NS: $t(24) = 3.703$, $p = .001$ – mean difference = .4 inches. 1SS: $t(24) = 4.413$, $p = .000$ – mean difference = .56 inches. 3SS: $t(24) = 5.662$, $p =.000$ – mean difference = .92 inches.

According to Step 1 (above), the pre-test scores did not differ (see Figure 9). This indicates that in the population, MVJ did not change from day to day before stretching. According to Step 2 (above), MVJ did not differ between the post-test on the no stretch day and the post-test on the 1SS day. However, post-test MVJ was significantly less on 3SS day than on the NS day or 1SS day (see Figure 10). It appears that the long bout of stretching led to a significantly greater decrease in MVJ when compared to NS and 1SS. However, according to Step 3 (above), MVJ was significantly less in each post-test when compared to the pre-test on each day. This included the NS day (see Figure 11).

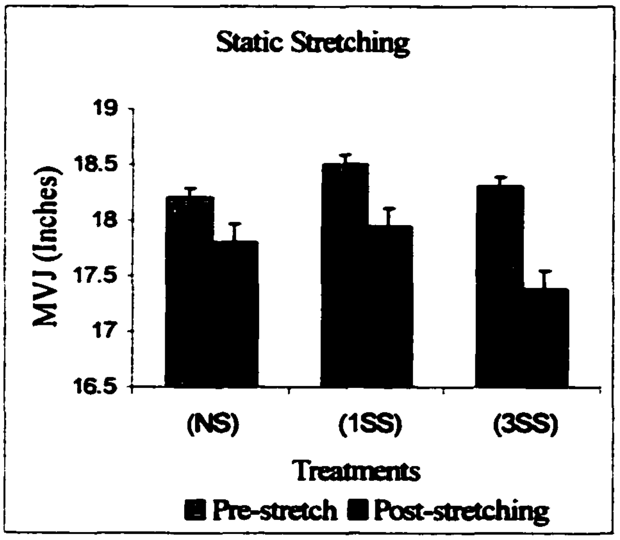


Figure 8: Data summary of mean pre-test and post-test MVJ values for NS, 1SS, and 3SS treatment days.

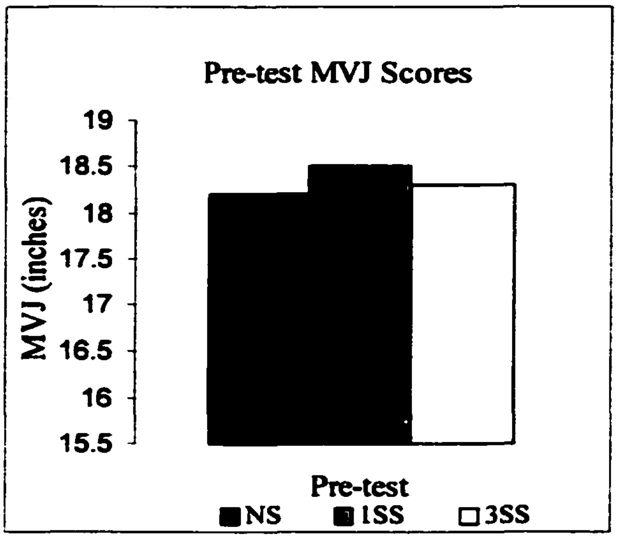


Figure 9: Mean pre-test MVJ for each of the treatments were not significantly different (NS = 18.20 inches, 1SS = 18.5 inches, and 3SS = 18.3 inches).

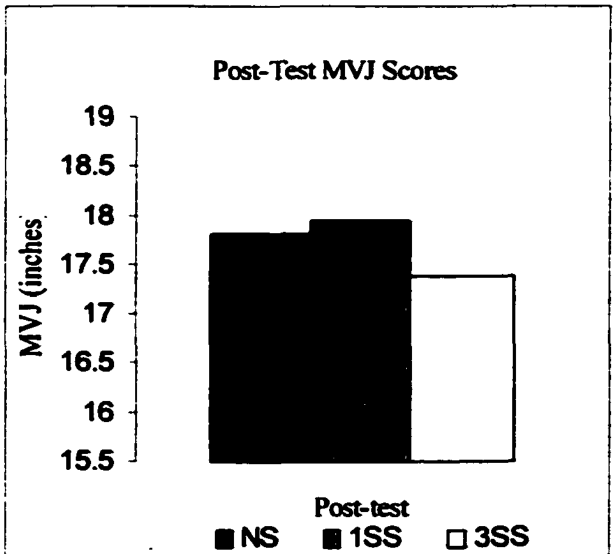


Figure 10: Mean post-test MVJ for each of the treatments were not significantly different between NS and 1SS, but significantly different between NS and 3SS as well as 1SS and 3SS. (NS = 17.80 inches, 1SS = 18.5 inches, and 3SS = 18.3 inches)

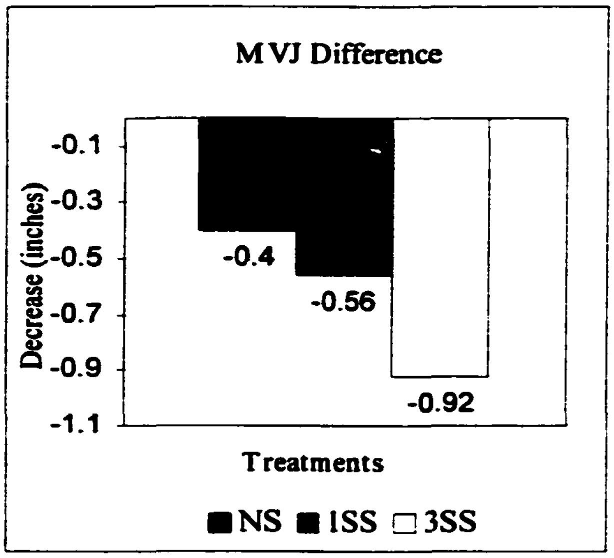


Figure 11: The difference between mean pre-test and post-test MVJ for NS, 1SS, and 3SS treatments.

Discussion

Warm-up

A general warm-up protocol was followed in this study as recommended by Holcomb (2000), in preparation for physical activity. The five-minute treadmill walk/ jog performed at 50% HRR and four practice-jumps served to prepare the subject not only for MVJ testing but also to enhance the effect of stretching (Hunter, et al, 1952; Lehmann, et al, 1970). The present study resulted in all post-test MVJ heights being significantly lower than all pre-test MVJ heights (see Figure 8). The purpose of this study was to determine the effect of changing stretch sets on MVJ performance. It was hypothesized that stretching was going to change MVJ as stretching sets changed. The NS day was to serve as a control for the study. However, when no stretching was performed in the NS

treatment, MVJ unexpectedly decreased. A possible explanation for such a result could be explained in terms of warm-up. The NS treatment required that the subject sit for nine minutes between pre-test and post-test MVJ. The NS pre-test and post-test MVJ mean scores were significantly lower while the subject had done nothing but sit and rest for nine minutes. A possible explanation could come from Davies and Young (1983), who found that the time to contract a muscle was decreased because of warm-up. Meaning that increasing muscular heat can increase performance and by allowing the muscle to cool down (or return to a resting state) time to contract increases. It is possible then that the 50% HRR treadmill walk/ jog served as a warm-up and increased the pre-test MVJ performance. As the subjects rested for nine minutes, the muscles returned back to their resting state (cooled down) and a longer contraction time could have possibly occurred that decreased MVJ performance. Therefore, the time between pre-test and post-test MVJ in each treatment was a factor that could have contributed to the observed decrease in MVJ performance.

There was no significant difference between the pre-test and post-test MVJ mean scores of the 1SS and NS treatments (see Figure 11). This indicates that one set of static stretching did not have a significant effect on vertical jumping performance when compared to the NS treatment. Therefore, it wouldn't be unreasonable to conclude that time between pre-test and post-test, rather than stretching decreases performance. Although, it is important to note that 3SS significantly decreased MVJ performance over NS and 1SS. Again, the stretching period (like the sit and rest period) can be considered a cooldown, where aerobic metabolism and the heat created return to normal levels as the subject sits and rests or performs the various stretches. Therefore, if the time between

pre-test and post-test decreases performance, than it could be logical to say that the greater time between pre-test and post-test would equal a greater decrease in performance. The total time of stretch for the 1SS was five minutes. This was nearly half of the time (nine-minute) of the NS sit and rest period. Therefore, if the time between pre-test and post-test negatively effected performance and the decrement in the 1SS was due to the time between pre-test and post-test instead of stretching, then the decrease should not have been greater, but less than the NS value because it had less time to between tests. With less the time between pre-test and post-test, there was no difference between the 1SS day and the NS day. However, at this time it cannot be determined whether one set of acute static stretching decreases MVJ performance.

Duration of stretching

Thirty-second static stretching is more effective at increasing range of motion when compared to 15-second and as effective when compared to 60-second static stretches (Bandy & Irion, 1994). One set of 30-second static stretching is also equal to three sets of 30-second and to three sets of 60-second static stretching (Bandy et al, 1997). From these studies, 30-second of static stretching was used in this study with one and three sets of static stretching. If these findings applied in the present study, then there should not have been a difference in MVJ performances between one and three sets of static stretching. However, in this study, three sets of static stretching significantly decreased MVJ performance when compared to one set of static stretching. Therefore, although Bandy et al (1997) showed that there was no difference in outcomes between one and three sets of static stretching, this study resulted in significant differences by changing the number of stretching sets. A possible reason for the significance of

stretching three sets over one set in this study compared to Bandy et al (1997) could be explained in the method of data collection measurement. Bandy et al (1997) measured hip range of motion while this study measured vertical jump. Range of motion was not measured in this study. However, because the same time and type of stretching was applied in this study as with Bandy et al (1997), it would not be unreasonable to assume that range of motion was also increased. The correlation between increased range of motion from stretching and vertical jump performance has not been investigated. Kokkonen et al (1998) reported a strong correlation between increased range of motion from stretching and a decrease in performance. In their study, ROM (measured by a sit and reach test) increased by 16% and maximal strength (1RM) performance of a leg curl exercise decreased by 7.3%, while leg extension 1RM decreased by 8.1%.

<u>Mechanical mechanisms</u>

This study demonstrated that acute static stretching decreases vertical jump performance and is in agreement with Cornwell et al (1999) and Nelson et al (1996) who also demonstrated how acute stretching decreased vertical jump performance. The decreases in MVJ performance observed in the three sets of static stretching can most likely be attributed to both mechanical and neurophysiological factors (Mohr et al, 1998).

It has been shown that by static stretching, the musculotendinous unit becomes less stiff and increases in length thereby allowing a greater range of motion (Taylor et al, 1990). Nelson, Allen, et al (2001) proposed that this increased range of motion from stretching shifts the force-length curve. In their study, maximal voluntary isometric torque of the knee extensors was decreased at 162° because the shift in the force-length curve put the muscle's contractile components at a less optimal point for force

production. In their study, acute stretching negatively impacted the muscle's ability to generate force at knee angles near full range of motion. They therefore advised against stretching just before activities where joints will be working in the terminal ends of their range of motion. Maximum vertical jumps are an activity that requires force production at the latter end of range of motion of the knee, so acute stretching would not be advised according to Nelson, Allen, et al (2001). In this study, vertical jump performance was negatively affected as anticipated by Nelson, Allen, et al (2001). MVJ was only significantly less when three sets of static stretching were implemented as opposed to the one set of static stretching done by Nelson, Allen, et al (2001). It is possible that the increased sets of stretching further decreased the musculotendinous stiffness, which presumably caused a shift in the force-length curve that might have created greater decreases in performance as seen in the 3SS over the 1SS (Magnusson et al 2000).

Kokkonen et al (1998) reported that by stretching the quadriceps muscle group, 1RM of a leg extension could be significantly decreased. Maximum vertical jump was performed in this study instead of 1RM, but as in Kokkonen's et al (1998) study the knee extensors were stretched. It is possible that, like observed in their study, maximal strength of the knee extensor muscle group was decreased. The knee extensors produce as much as 56% of force in maximal vertical jumping and if their strength was decreased, MVJ performance would also decrease (Luhtanen & Komi, 1978). MVJ was decreased in this study; therefore, it is possible that strength was decreased in all the muscle groups stretched and each contributed to the reduction in MVJ.

Neuromuscular mechanisms

Alterations in neuromuscular activation could also explain the decrement in MVJ performance from static stretching. If done at a low intensity, static stretching produces low levels of muscle activity, which are not sufficient enough to contribute to resistance to stretching (Mohr et al, 1998). The static stretches performed in this study were held at a recommended intensity that correlated with what the subject felt to be "just to the point of pain" or "mild discomfort" (Knudson, 1998). The intention of this suggestion was to keep neuromuscular activity low, thereby not activating the proprioceptors of the muscle, namely the golgi tendon organs (Enoka, 1994; Holcomb, 2000). Unfortunately, stretching intensity is subjective and cannot be uniformly applied at a given intensity (Kenny, 1995). Therefore, if a subject's threshold of pain were high, a more intense stretch than intended may have occurred and the GTO activity would have been reinforced (Moore, 1984). Increased GTO activity could have caused reflexive inhibition (autogenic inhibition) and become a major factor in decreased force production for MVJ performance (Holcomb, 2000). It was assumed in the present study that subjects did not stretch at the same intensity even though they all received the same instructions. However, with the same instructions it was also assumed that each day they would have stretched consistently at their chosen intensity. If some subjects chose to stretch at the "point of pain" that increased golgi tendon organ activity, than there would have been autogenic inhibition of the agonist muscle and its synergists. If this occurred, the muscle activation would have been depressed and less able to create force to perform a MVJ. With long duration-intense static stretching, as in the 3SS, the likelihood of reciprocal

inhibition occurring was increased and could have been a primary reason for the MVJ performance decrements (see Figure 11).

Stretch time

One area in which most of the acute stretching studies vary is in the duration of stretching (see Table 1). In the studies where subjects stretched two sets or more, there was a significant decrease in performance (Cornwell et al, 1999; Guillary et al, 1998; Kokkonen et al, 1998; Kokkonen & Nelson, 1994; Nelson et al, 1996; Nelson, Allen, et al, 2001; Nelson, Guillary, et al, 2001). These studies then support the result observed in this study, that three sets of 30-second static stretches were enough to produce significant decreases in performance. The only exception found was Knudson et al (2001), who had subjects stretch for three sets of 15 seconds and had no measurable decrease in vertical jump performance. The total stretching time of three sets of 15 seconds is 45 seconds and may not have been significantly more than the time of the one set of 30-second static stretches performed in this study. Additionally, Bender et al (2000) had subjects stretch only one set of 30-40 seconds and observed no decrease in sprinting performance. Like Bender et al (2000), the one set of static stretching performed in the present study had a total stretch time of 30 seconds and had no significant effect on MVJ performance when compared to NS. Interestingly, when three sets of static stretching were performed, significant decreases in MVJ performance were recorded (see Figure 10). Therefore, if mechanical factors cause decreased performance, then the amount of stretching time performed needs to be longer than 30 seconds to decrease performance (Magnusson et al, 2000).

Other factors

Subject motivation was variable of the study. Although not measured, it probably influenced performance. Feedback as to the height of each jump was given to all subjects immediately following each jump. Each subject was encouraged to jump as high as possible on every jump. The test administrator noted that some subjects appeared to try harder on the post-test jumps, wanting to due better than on the pre-test values. All subjects were told that the purpose of the study was to determine which warm-up program was most effective at increasing their vertical jump. It is possible, due to increased motivation to perform better and from traditional beliefs that stretching increases performance, that post-test MVJ values for stretching treatments were increased. Therefore, subject's post-test scores, although significantly lower, may have been higher than if the subject's motivation was lower. Therefore, if motivation remained constant, decreases in MVJ from stretching might have been more significant.

The jumping experience of each subject may have influenced the results. Each subject was instructed to jump according to the jumping protocol. No effort was made to improve or change the subject's jumping form. It was anticipated that without outside influence, the subject would select the same technique for each trial jump, whether good or bad. It has been observed that differences between jumps can be caused by changes in the timing of body segments (Feltner et al, 1999; Isaacs, 1998; Luhtanen & Komi, 1978; Young et al, 1997). It is possible that significant alterations in the timing involved in touching the highest horizontal vane of the Vertec® were a factor in MVJ scores. However, the fact that pre-test MVJ scores did not differ significantly from the post-test scores supports the reliability of vertical jump testing using the Vertec® (see Figure 9).

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary and Conclusions

The purpose of this study was to determine whether changing the number of static stretching sets during warm-up would also change MVJ performance. Increasing the number of stretching sets increased stretch time. If the number of static stretching sets were to affect MVJ performance, differences or changes in MVJ performance would have been observed with the different number of static stretching sets. There were significant changes in MVJ associated with increases in static stretching sets (see Figure 8). Three sets of static stretching decreased vertical jump performance significantly more than no stretching and one set of static stretching. Therefore the null hypothesis, which was that there would be no difference in MVJ between the number of static stretches, was rejected. The alternate hypothesis, that the number of static stretching sets would change MVJ was supported.

From this study, three set of static stretching has been determined to decrease vertical jump performance. It is recommended that those who wish to prepare for activities, such as the vertical jump, where maximum performance is required do not stretch more than 3 sets of static stretching in order to avoid decreases in performance.

The time between warm-up and post-testing appeared to also negatively affect performance. It is therefore recommended that the time between warm-up and maximum performance activity be reduced as much as possible, being no more than five minutes.

Recommendations for Further Study

Stretching time

Futures studies can pursue how increasing the total time of stretching will effect the performance. This increase in time should be studied by increasing the duration of the stretch itself (i.e., 15-sec, 30-sec, 45-sec, etc) and by continuing to increase the number of sets (i.e., 1, 2, 3, 4, 5, etc). From this study, it would appear that a minimum amount of stretching is required before the Acute effects of stretching are evident. It would therefore be interesting to find out whether the decrease in MVJ found in the 3SS would have continued to decrease with further stretching and at what point does the decrease in performance level off (Magnusson et al 1996, Magnusson et al 2000).

Determine a mechanism

It is generally agreed that mechanical and neuromuscular alterations are the two prevailing theories contributing to decreases in performance due to acute static stretching (Cornwell et al, 1999; Knudson et al, 2001; Kokkonen et al 1998). To understand how stretching is effecting performance, further study into these mechanisms is needed. Kinematic analysis, ground reaction forces, and neuromuscular activity in the stretched muscles should all be monitored in an acute stretching study to determine which mechanism is contributing to performance decreases. If such analysis were applied in this study, then a mechanism would have been identifiable. After three sets of static

stretching, there may have been decreased neuromuscular activity or just variations in the kinematics of the countermovement jumps due to decrease musculotendinous stiffness, or maybe even a contribution of both facts that lead to a decrease in MVJ.

Test specific populations

Nearly all of the stretching and performance studies have used a wide sample base of men/women, active/inactive, and athletes/non-athletes (Cornwell et al, 1999; Knudson et al, 2001; Kokkonen & Nelson, 1996; Kokkonen et al 1998; Nelson et al, 1996). The effects that stretching has on performance should be studied in specific populations. Acute stretching may effect these populations differently. For example, highly trained athletes may react differently than sedentary people. This may also apply to men verses women, or people in their 50's verses people in their 20's.

Test different stretching techniques

Dynamic stretching, ballistic stretching, static stretching, and PNF techniques are all used to increase range of motion (Etnyre & Lee, 1987). All of the stretching and performance studies have only studies passive and active static stretches (Cornwell et al, 1999; Fowles & Sale, 1997; Guillary et al, 1998; Lieber et al, 1991; Nelson, Allen, et al, 2001; Nelson, Guillory, et al, 2001). Other methods of stretching, such as ballistic, PNF, and dynamic should be implemented to determine if they would affect performance differently than static stretching.

Test effects on different skills

This study showed that three sets of static stretching will decrease MVJ, but that does that mean it will decrease performance in all performance areas of different sports? For example, since stretching decreases the vertical jump would it also decrease the long

jump or even a 100m swim? Further testing is needed and should therefore focus on identifying the varying effects on performance sports and specific skills.

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APPENDIX A

SUBJECT DATA

SUBJECT DATA

Subject	HRR (bpm)	Speed (mph)	Group	Age (years)	Weight (lbs)
1	134	3.5	1	22	170
2	131	5.6	2	28	220.1
3	125	3.8	1	40	190.2
4	127	3.2	2	37	150
5	127	4	2	36	117.7
6	131	3.9	1	29	170.7
7	129	6	2	32	191
8	134	4.7	1	23	176.7
9	132	4.2	2	26	149.1
10	133	4	1	25	133.1
11	131	4.7	2	29	198.4
12	132	4.5	1	26	197.7
13	135	4.6	1	21	197.5
14	135	3.8	1	21	151.8
15	133	4.4	1	25	133.3
16	134	5.1	2	22	188.5
17	134	4.6	1	23	159
18	132	4	2	26	130
19	129	5.6	1	32	139
20	134	5	2	22	187.7
21	133	3.8	1	24	190.3
22	133	4.2	2	24	214.7
23	130	3.3	2	31	115.5
24	136	4.8	1	25	236.8
25	129	4.7	2	32	196.1
Average =	132	4.4		27.2	172.2
Standard Deviation =	2.8	0.7		5.2	33.0

Subject	Suprailiac (mm)	Abdomen (mm)	Thigh (mm)	Bodyfat %	Height (inches)	Reach Height (inches)_
1	24	24	15	16.9	68	87.25
2	31	35	26	24.2	76.25	98.25
3	23	31	19	22.1	63.25	89.25
4	34	39	35	24.4	68.25	86.75
5	30	38	15	25.7	54	82
6	37	40	30	27.6	71	91.25
7	33	29	13	20.4	72	91.5
8	15	16	10	12.7	73.25	108.25
9	19	19	32	25.2	67.5	85.25
10	33	24	33	30.8	64.5	81
11	34	27	11	19.5	69.25	87.25
12	33	36	7	18.8	74.5	97.5
13	9	13	10	8	76.75	104.75(+6)
14	26	23	24	25	69.5	91.5
15	15	15	25	20.3	67	85.5
16	7	6	8	5	71	103 (+10)
17	6	8	7	5.2	66.75	96.75 (+10)
18	23	15	35	20.9	65	84.5
19	11	13	26	20.1	71	90
20	33	35	28	24.3	91.75	94.75
21	55	51	23	29.1	70	90.25
22	40	37	13	22.7	69.75	102.5 (+12)
23	20	20	18	21.7	62.5	80.25
24	47	50	13	24.8	74.25	97.24
25	21	34	13	18.6	73.75	45.5
Average =	26.36	27.12	19.56	20.56	70.03	87.86
Standard Deviation =	12.3	12.4	9.3	6.7	6.7	34.6

INFORMED CONSENT

CONSENT FOR RESEACH PARTICIPATION
UNIVERSITY OF NEVADA, LAS VEGAS

TITLE: The Effects of Static Stretching during Warm-up on Maximum Vertical Jump Performance

PURPOSE: You are being asked to participate in a research study designed to learn what effect stretching within a warm-up has on vertical jump performance.

PARTICIPANT: You have been asked to participate in this study because you are in good health and have no joint injuries or problems.

PROCEDURES: If you decide to volunteer in this study, will be tested on three different days. On each day, you will perform a 5-minute warm-up on a recumbent cyclometer (bike) followed by four practice jumps and then three maximal vertical jumps. On one of the three days you will stretch for 30 seconds, stretch for two sets of 30 seconds, or sit and rest during the stretching period. Afterwards, maximal vertical jump will be assessed again. On the last day, your weight will be measured and percent body fat determined by the skinfold technique. (Four skinfold measurements taken at the abdomen, Ilium, triceps and thigh).

RISKS: There are always some risks involved in doing any physical performance test. The vertical jump test will require maximal effort. While unlikely, you could strain a muscle as a result of the maximal effort.

BENEFITS: The risks from participating in this study are minimal. By participating you will learn what your body fat percent is, and how well you perform on a test of muscular power.

CONFIDENTIALITY: All data will be kept in a locked file cabinet at UNLV and only research personnel will have access to these files. Your identity will not be revealed in any presentation of the results of this study.

RIGHT TO REFUSE OR WITHDRAW: You may refuse to participate in any part of this study and you may withdraw at any time without jeopardy to your standing in the Department of Kinesiology or UNLV.

QUESTIONS: If you have any questions regarding the study, please ask us. Dr. Golding, Director of the Exercise Physiology Laboratory (895-3766) or David Pestana (454-4821). Any questions regarding your rights as a research subject can be directed to the UNLV Office for the Protection of Research Subjects at 895-2794. You will be given a copy of this form to keep.

I have read the description of this study and agree to participate. I am unaware of having any existing health problems that would exclude me from participating. I understand that any questions I may have regarding my participation in this study will be answered and that I am free to withdraw from the study at any time without penalty.

Subject's Signature Date

Subject's Name (Print) Date

Witness Signature Date

Witness' Name (Print) Date

UNLV

DATE: June 29, 2001

TO: David Pestana
Kinesiology
M/S 3034

FROM: Dr. Jack Young, Chair
UNLV Biomedical Sciences Institutional Review Board

RE: Status of Human Subject Protocol Entitled:
"The Effects of Static Stretching during Warm-up on Maximum Vertical Jump Performance"

OPRS #504s0501-042

This memorandum is official notification that the protocol for the project referenced above has been reviewed by the Office for the Protection of Research Subjects and has been determined as having met the criteria for exemption from full review by the UNLV Biomedical Sciences Institutional Review Board. In compliance with this determination of exemption from full review, this protocol is approved for a period of one year from the date of this notification and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond one year from the date of this notification, it will be necessary to request an extension. Should you require any change(s) to the protocol, it will be necessary to request such change through the Office for the Protection of Research Subjects in Writing.

If you have any questions or require assistance, please contact the Office for the Protection of Research Subjects at 895-2794.

cc: OPRS File

Office for the Protection of Research Subjects
4505 Maryland Parkway - Box 451046 - Las Vegas, Nevada 89154-1046
(702) 895-2794 - FAX (702) 895-4242

APPENDIX C

RAW DATA

RAW DATA

Subject	NS pre-test (inches)			MVJ (inches)	NS post-test (inches)			MVJ (inches)	DIFF (inches)
1	15.5	17	16	17	15.5	15	15.5	15.5	-1.5
2	21	20	18	21	21	20	18.5	21	0
3	17.5	17	16.5	17.5	17	16.5	16.5	17	-0.5
4	9	10	8	10	10	8.5	10	10	0
5	11	11.5	10.5	11.5	11	11.5	11	11.5	0
6	10.5	11	12	12	11	11	11.5	11.5	-0.5
7	18.5	19	19	19	18.5	19.5	18.5	19.5	0.5
8	26.5	27.5	27.5	27.5	27.5	26.5	27	27.5	0
9	18	18	19	19	17.5	17.5	18	18	-1
10	10	9	9	10	8.5	9	9.5	9.5	-0.5
11	17	17.5	17.5	17.5	17.5	16	17	17.5	0
12	20.5	19.5	21	21	20	20.5	19.5	20.5	-0.5
14	22.5	23.5	22.5	23.5	23.5	23	23	23.5	0
15	18.5	20	19.5	20	18	19.5	20	20	0
16	13.5	14	12.5	14	12.5	12.5	13	13	-1
17	26.5	27	27.5	27.5	25.5	26	26.5	26.5	-1
18	23	24.5	24	24.5	24	24	24	24	-0.5
19	8.5	8.5	9	9	8	8.5	8.5	8.5	-0.5
20	13	12.5	13	13	11	12	12	12	-1
21	18.5	19.5	20	20	20.5	20.5	19.5	20.5	0.5
22	16.5	17.5	17	17.5	17	16.5	16	17	-0.5
23	26.5	27	27	27	25.5	26.5	26.5	26.5	-0.5
24	13	13.5	14	14	14.5	14	14	14.5	0.5
25	19	20	21	21	20	19	19	20	-1
26	20	20.5	21	21	18.5	20	20	20	-1
Average =	17.4	17.8	17.7	18.2	17.3	17.3	17.4	17.8	-0.4
Standard Deviation =	5.4	5.6	5.7	5.5	5.5	5.5	5.4	5.5	0.5

Subject	1SS pre-test (inches)			MVJ (inches)	1SS post-test (inches)			MVJ (inches)	DIFF (inches)
1	15.5	17	18	18	16.5	16.5	17.5	17.5	-0.5
2	19.5	21	20.5	21	20.5	19.5	20	20	-1
3	18	16.5	17	18	17	16	17.5	17.5	-0.5
4	9.5	9.5	10.5	10.5	9.5	9	9	9.5	-1
5	10.5	11	12	12	10	10.5	12	12	0
6	12	12	11.5	12	10.5	12	12	12	0
7	21	21	20.5	21	19.5	19.5	19.5	19.5	-1.5
8	26.5	27	28	28	27	27	26.5	27	-1
9	18.5	18.5	18.5	18.5	17.5	18	17.5	18	-0.5
10	8.5	10	9.5	10	10	9.5	9.5	10	0
11	17.5	18	17	18	16.5	17.5	17.5	17.5	-0.5
12	20.5	21	20.5	20.5	20.5	20.5	20.5	20.5	0
14	23.5	24.5	24	24.5	24	24	24.5	24.5	0
15	17.5	18	18	18	17.5	17.5	18	18	0
16	13	14	13	14	12.5	13.5	12.5	13.5	-0.5
17	26	27.5	27.5	27.5	27.5	27	28	28	0.5
18	23	24	24	24	24	23.5	24	24	0
19	7.5	8	8.5	8.5	6.5	7.5	8.5	8.5	0
20	12.5	13	12	13	11.5	12.5	12.5	12.5	-0.5
21	21.5	21	21.5	21.5	20	20.5	20.5	20.5	-1
22	17.5	18.5	19.5	19.5	17	17.5	17.5	17.5	-2
23	25.5	27	27.5	27.5	26.5	26.5	27	27	-0.5
24	14	16	15.5	16	14.5	15.5	15.5	15.5	-0.5
25	19.5	20	19	20	18	18	17	18	-2
26	20.5	20	21	21	20	19.5	20	20	-1
Average =	17.6	18.2	18.2	18.5	17.4	17.5	17.8	17.9	-0.56
Standard Deviation =	5.5	5.6	5.6	5.5	5.8	5.5	5.5	5.5	0.63

Subject	3SS pre-test (inches)			MVJ (inches)	3SS post-test (inches)			MVJ (inches)	DIFF (inches)
1	16.5	16.5	16.5	16.5	15	15	16	16	-0.5
2	20	20.5	19.5	20.5	18.5	17.5	18.5	18.5	-2
3	15.5	17.5	17.5	17.5	17	16	17	17	-0.5
4	7.5	9.5	10.5	10.5	7	9	9.5	9.5	-1
5	10.5	11.5	11.5	11.5	11	11	11	11	-0.5
6	11.5	12	10.5	12	10	11	11.5	11.5	-0.5
7	20.5	19	20.5	20.5	19	19	20	20	-0.5
8	26	25.5	26	26	26	26	25.5	26	0
9	18	18.5	18	18.5	17.5	18	17.5	18	-0.5
10	9.5	9	9.5	9.5	8.5	9	9.5	9.5	0
11	17.5	18	18.5	18.5	15.5	17	17.5	17.5	-1
12	21	22	22.5	22.5	21	20.5	20	21	-1.5
14	25	25	24	25	23.5	23	21.5	23.5	-1.5
15	19	18	18.5	19	18	17	17.5	18	-1
16	13.5	14	13.5	14	12	12.5	13	13	-1
17	26.5	26.5	27.5	27.5	23.5	24.5	24	24.5	-3
18	22	23	25	25	22.5	22.5	23	23	-2
19	6	8	8.5	8.5	6.5	7.5	9.5	9.5	1
20	12.5	13.5	12.5	13.5	11.5	12.5	12.5	12.5	-1
21	20.5	21	20.5	20.5	19	19	19	19	-1.5
22	17.5	15	18	18	15.5	16	16.5	16.5	-1.5
23	27	27.5	28	28	26	26.5	27	27	-1
24	13.5	13	15	15	14	13.5	15	15	0
25	18	18.5	18.5	18.5	18	18	17	18	-0.5
26	20	20.5	21	21	19	18.5	19.5	19.5	-1.5
Average =	17.4	17.7	18.1	18.3	16.6	16.8	17.1	17.4	-0.9
Standard Deviation =	5.8	5.5	5.6	5.6	5.6	5.3	4.9	5.1	0.8

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Thesis: The Effects of Static Stretching Sets in Warm-up on Maximum Vertical Jump Performance