IMPACT OF DIFFERENT WARM-UP CONDITIONS ON HAMSTRING TORQUE AND POWER

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ABSTRACT

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A general warm-up including stretching is common procedure in many athletic endeavors and has been shown to have multiple benefits (Corbin & Noble, 1980; Cross & Worrell, 1999; Liemohn, 1988; Schilling & Stone, 2000; Schramm, Latin, Berg, & Stuberg, 2001; Shellock & Prentice, 1985). However, the effects of acute stretching immediately prior to maximal strength and power based activities is not conclusive. The hamstring muscle group is of interest because of its high incidence of injury, and it is also a common measure of flexibility.

The purpose of this study was to determine how three different warm-up conditions prior to exercise influence active range of motion (AROM) and peak and average isokinetic muscle torque at two different speeds. Participants were moderately active males (N=19) between the ages of 18 and 25 years. All participants completed three warm-up conditions: jogging only (JO), jogging + stretching (JS), and jogging + stretching + 15-minute rest period (JSR). Nine dependent variables of the hamstrings were measured: concentric average torque, concentric peak torque, eccentric average torque, eccentric peak torque, and hamstring active range of motion. Each torque measure was taken at 60° and 120° per second. Data was measured using a Kin-Com isokinetic machine and manual goniometer.

A two-way MANOVA was used to analyze data. AROM data was also assessed using a repeated measures (2x3) ANOVA to detect significant changes over time. Muscular torque data was not significantly different between warm-up conditions (p>0.05). AROM showed significant increases after all 3 warm-up conditions (p<0.05).
These results demonstrate that a pre-activity warm-up which includes a minimum of 5 minutes of jogging was sufficient to promote increases in AROM, and these effects lasted for at least 15 minutes after warm-up was completed.
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INTRODUCTION

Flexibility training, usually via stretching activities, has been common practice for both competitive athletes and daily fitness exercisers. The basic purposes of stretching are to help muscles and joints become more prepared for physical endeavors, optimize performance, reduce soreness, and prevent injury (Corbin & Noble, 1980; Schilling & Stone, 2000; Schramm, Latin, Berg, & Stuberg, 2001; Shellock & Prentice, 1985). Stretching has been shown to significantly decrease the incidence of musculotendinous strains (Cross & Worrell, 1999). Flexibility is a key part of overall physical fitness and can improve low back problems and posture, reduce muscle soreness, muscle strains and muscular imbalances (Corbin & Noble, 1980; Liemohn, 1988). However, all of these proposed benefits have not been substantiated.

Some athletes emphasize strength and power more than others as an integral basis of their physical training. There is a minimum requirement of flexibility in most physical activities, which is specific to the demands of each sport (Corbin & Noble, 1980). Stretching, often dynamic, typically becomes a less significant component in the warm-up prior to strength and power based athletics. Static stretching occurs more often after workouts or performances in these athletes (Schilling & Stone, 2000). Since the amount of flexibility one demonstrates or can gain is directly related to the muscle, tendons, and ligaments (Corbin & Noble, 1980), the relationship between muscle strength and flexibility has been a topic for many researchers.
Various literature that targets those involved in fitness, athletics, and health commonly propose recommendations for stretching and flexibility routines (Shellock & Prentice, 1985; Walter, Figoni, Andres, & Brown, 1996). Liemohn (1988), for example, discusses how “a total body development and maintenance of flexibility and muscular fitness are desirable” (p. 38). Many authors in popular magazines widely recommend stretching for enhancing strength, increasing muscular endurance, and the ability to exercise at high intensities (Wadyka, 2000; Wallack, 2002). Westcott and La Rosa Loud (2000) reported greater strength gains were achieved when stretching was incorporated into resistance training programs. They also stated that “joint flexibility and muscle strength are improved when stretching is coupled with strength training” (p. 45). These magazines, whose audience is lay people, do not necessarily use information from peer-reviewed, scholarly literature. Health and fitness professionals need to establish common and well supported facts about the role of stretching, flexibility and muscular strength.

The effects of both acute and chronic stretching have been investigated with contradictory results. Young and Behm (2003) related acute stretching to reduced strength and muscle performances following static stretches. Others have revealed that acute static stretching decreased muscle activation, or the number of motorneurons recruited within the muscle, but did not affect tetanic force production (Behm, Button, & Butt, 2001). An isokinetic study revealed that muscle performance at slow speeds was inhibited by acute stretching, yet remained unaffected at higher speeds (Nelson, Guillory, Cornwell, & Kokkonen, 2001). Many researchers have examined the effects of acute stretching, which is done once before performance, while other studies investigate the effects of chronic stretching, several bouts of stretching performed over a period of time.
Worrell, Smith, & Winegardner (1995) have found that performance at high isokinetic speeds was better following chronic stretching and performance was unchanged at slower speeds.

Stretching has also been examined in conjunction with muscular strength training, and again produced contradictory results. Girouard and Hurley (1995) showed that strength training may inhibit or slow flexibility gains, while a descriptive study (Beedle, Jessee & Stone, 1991) found that athletes, whose focus was on achieving strength gains, had the best measures of upper body flexibility. Research has demonstrated that light strength training combined with an activity program caused an increase in flexibility, whereas the absence of weights in a similar activity program did not increase flexibility (Silvestri & Oescher, 1990). These research studies have not been conclusive in any aspect of the effects of flexibility upon performance.

**Purpose**

The effects of acute static stretching on hamstring muscle torque was investigated. The purpose of this study was to determine how three different warm-up conditions prior to exercise influenced active range of motion, and peak and average isokinetic muscle torque at two different speeds.

**Significance**

In this study, we examined hamstring torque of moderately physically active males undergoing three different warm-up conditions. Certain warm-ups may play an advantageous or disadvantageous role in activities involving strength performance. Results may be used to help establish an optimal stretching and warm-up protocol in fitness programs prior to competition.
Hypotheses

The following null hypotheses will be tested:

H1: Participants will demonstrate no change in hamstrings active range of motion following warm-up conditions.

H2: Participants will demonstrate no change in hamstring average torques at slow or moderate speeds following any of the warm-up conditions.

H3: Participants will demonstrate no change in hamstring peak torques at slow or moderate speeds following any of the warm-up conditions.

Definitions

- Average torque- the tension produced by the muscle throughout the entire range of motion tested (Perrin, 1993)

- Hamstring active range of motion- the degrees of knee extension achieved without assistance, while the participant’s hip is held at a fixed point of 120° of hip flexion in a supine position.

- Isokinetic muscle torque- amount of force produced by a muscle or group of muscles about a joint’s axis of rotation as measured and quantified by an isokinetic dynamometer (Perrin, 1993)

- Muscle stiffness- the ratio of stress to strain, or change in force to change in muscle length (Alter, 2004)

- Muscular power- the product of strength and speed of movement (Wilmore & Costill, 1999)
- Passive range of motion- movement through available, pain-free range of motion, performed by another individual without participation by the subject (Kendall, McCreary, & Provance, 1993).

- Passive extensibility- maximum elongation of a musculotendinous unit (Halbertsma, Bolhuis, & Goeken, 1996)

- Peak torque- the point in the range of motion tested where the greatest force or torque was produced (Perrin, 1993)

- Stretch tolerance- the ability to feel less pain for the same force applied to a muscle (Shrier & Gossal, 2000); the individual subject’s limitation of the movement defined by extensibility (Halbertsma, Bolhuis, & Goeken, 1996)
CHAPTER II

REVIEW OF THE LITERATURE

Stretching and Flexibility

The precise protocol for warm-up that can effectively promote optimum performance in strength based activities is not well established. Certain stretching techniques used in preparation for exercise are practiced more because some investigations support the efficacy of these methods, while other techniques may need more study. A general warm-up prior to activity is common in any exercise program because it has been found to increase blood flow to extremities, increase body temperature, enhance coordinated movement and reduce the incidence of injury (Ninos, 1999; Smith, 1994). However, different types of stretching are still examined in an attempt to determine which is most appropriate for athletic endeavors. Static, ballistic, dynamic, and proprioceptive neuromuscular facilitation stretching have all been studied to determine the effectiveness of each, with respect to increasing flexibility or to influence another variable such as muscular performance.

There are four general types of stretching protocols used to increase and maintain flexibility. Static stretching, ballistic stretching, and proprioceptive neuromuscular facilitation (PNF) (Shellock & Prentice, 1985) are established stretching techniques. Static stretching emphasizes the range of motion a joint has without the additional factor of speed of motion (Alter, 2004). Joints are usually stretched to an end point of slight discomfort and held for a short period of time. PNF stretching involves stretching a
muscle to a point of resistance, followed by an isometric muscle contraction and another slow stretch (Alter, 2004). Ballistic stretching is controversial because of the jerky, bouncy movements performed at the end point in a range of motion which may increase the risk for injury (Alter, 2004; Bandy, Irion, & Briggler, 1998; Shellock & Prentice, 1985) and thus is not practiced regularly. These safety concerns have become better known among health and fitness professionals.

There are also several variations of each stretching technique. For example, static stretches can be held for 5-45 seconds and repeated from 1-10 times (Bandy, Irion & Briggler, 1998; Behm, Button & Butt, 2001; Girouard & Hurley, 1995; Johanson, Lindstrom, Sundelin & Lindstrom, 1999). PNF variations include contract-relax-contract, (Worrel, Smith, and Winegardner, 1995), hold-relax (Alter, 2004) and also contracting either the antagonist or agonist muscles. Dynamic stretching is another type of stretching which has many different forms because it can be customized to any sport.

**Dynamic Stretching**

Dynamic stretching has recently become better defined and incorporated into workouts. Stretching dynamically involves a combination of one or more traditional stretching techniques and a sport specific skill (Bandy, Irion, & Briggler, 1998). For example, track sprinters may perform walking lunges at a moderate speed because this motion may promote a greater, more specific range and speed of motion in both hips than could be achieved using static or using PNF stretching. Ballistic stretching is often defined synonymously with dynamic stretching (Corbin & Noble, 1980; Liemohn, 1988; Young & Behm, 2002). For these authors, ballistic and dynamic techniques are both described under either one of the techniques. Other researchers consider dynamic
stretching different from ballistic (Alter, 2004; Bandy, Irion, & Briggler, 1998; Moore & Hutton, 1980; Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003). Dynamic stretches can take multiple joints through a range of motion more similar to specific sport related movements than either PNF or static stretching alone (Young & Behm, 2002). Ballistic stretching does not usually replicate sport-specific movements (Alter, 2004; Bandy, Irion, & Briggler, 1998).

**Static Stretching**

Liemohn (1988) argues for the use of static stretching stating that it has fewer inherent drawbacks than dynamic stretching, such as static stretching can be more specific to stretching the hamstrings or lumbar spine than dynamic. Another author (Ninos, 1997) notes that because of tissues’ viscoelastic properties, the rate of change in length and elasticity or return to a normal length following a stretch, “only gradual, low load, and sustained stretching forces are recommended for elongation of the musculotendinous unit” (p. 13). The influence of acute static stretching on specific muscle properties were studied by Halbertsma, Bolhuis, and Goeken (1996). Ten minutes of static stretching was found to significantly increase passive hamstrings range of motion (+8.9°) and passive extensibility (+6.4°, \( p < 0.01 \)). However, one session of stretching did not affect the passive muscle stiffness. The increased hamstrings muscle extensibility was caused by a greater stretch tolerance. Stretch tolerance as defined by Shrier and Gossal (2000) is the ability to “feel less pain for the same force applied to a muscle. The result is increased range of motion, even though true stiffness does not change” (p. 58).
Funk, Swank, Mikla, Fagan, and Farr (2003) compared the effectiveness of acute static and PNF stretching. Results showed that PNF stretching produced lasting significant increases in acute flexibility as pre- and post- active range of motion measurements were taken one hour apart, whereas static stretching did not. No long term data were examined. The participants were Division I intercollegiate athletes undergoing training at the time, which is not representative of the average college-aged population. Further, athletes may be more responsive to PNF stretches which tend to be more aggressive than static.

PNF and static stretching were also studied by Moore & Hutton (1980), who measured EMG activity following stretching. They found there were no differences in the amount of hamstring muscle activity between conditions and that both conditions demonstrated increased range of motion in the hamstrings. Sullivan, DeJulia and Worrell (1992) also found no differences between hip flexibility gained between passive static and PNF stretching techniques which were done over a 2-week training period (F=0.060, p> 0.05).

Bandy, Irion and Briggler (1998) compared the effects of passive static stretching and dynamic stretching. They found that one 30-second static stretch, 5 days per week, was significantly better at producing flexibility gains in the hamstrings muscle group via hip flexion (+11.42°) as compared to dynamic stretching performed for the same frequency and duration (+4.26°).

**Stretching Duration and Frequency**

Duration, frequency, and intensity are important factors when comparing the effects of flexibility training. Some people may require more stretching than others
(Ninos, 1999). An investigation showed that PNF stretching 3-5 times per week can increase flexibility, while stretching once per week is only enough to maintain one’s flexibility (Wallin, Ekblom, Grahn, & Nordenberg, 1985). They also found that ballistic stretching did not produce significant increases in flexibility following 30 days of training. The duration of static stretches for flexibility improvements over 5 consecutive days of flexibility training were examined by Walter, Figoni, Andres, and Brown (1996). A 30-second static stretch produced greater flexibility than a static stretch held for 10 seconds on a sit-and-reach test (+5.08 vs. +2.76 cm, p< 0.01).

Bandy, Irion and Briggler (1997) studied the effects of static stretching techniques held for different durations on the hamstrings muscle group. Groups participated in four combinations of static stretching held for different durations and repetitions. All groups stretched 5 times per week for six weeks. Stretches were held for 30 seconds and 60 seconds, and performed one time or 3 times, making four combinations of stretching for each group. All groups increased hip flexion (degrees) and there were no differences among groups.

The search for an optimal amount of flexibility is ongoing. Some individuals may already possess more than adequate joint range of motion. Excessive flexibility may compromise the stability of a joint, as discussed later, therefore it is also important not to overstretch (Ninos, 1999).

**Flexibility and Gender**

Many studies have shown the differences in flexibility and strength between genders. In general, males tend to be less flexible than females (Schramm, Latin, Berg, & Stuberg, 2001; Laubach, 1976). This is due to several different factors. For example,
males have more connective tissue in muscle and greater muscle mass, which reduces their muscle and tendon extensibility when compared to females (Alter, 2004). Hormonal differences (e.g., estrogen, testosterone) between genders also allow females to have some flexibility advantages over males. While both genders have both sex hormones, the quantities are in very different in each gender. The increase in testosterone in adolescent males is related to a greater overall muscle mass than females and, in turn, decreases extensibility. In young females, there is more estrogen than males, which encourages fat accumulation, not muscle (Haywood & Getchell, 2001).

Some studies that measure range of motion usually indicate that females have greater flexibility (Manire, Adams, Swank, Kipp, & Stamford, 2004), but both genders show similar gains in range of motion after training (Walter, Figoni, Andres, & Brown, 1996). Koslow (1987) and Corbin and Noble (1980) showed that females tended to be more flexible on multiple measures of different joint range of motions such as shoulder, ankle and hip, but especially in the lower extremities. One such investigation found that gender was moderately correlated ($r = -0.400$, $p < 0.05$) with total flexibility measures including the sit-and-reach, hip flexion and shoulder flexion (Schramm, Latin, Berg, & Stuberg, 2001). A study of 3-weeks of static stretching found no differences in the amount of flexibility gained between male and female adults (Decoster, Scanlon, Horn, & Cleland, 2004). No studies were found that include large samples of both sexes for comparison purposes.

*Flexibility & Dominant Limbs*

Another variable that may contribute to flexibility is whether the dominant or non-dominant limb is used. Bilateral differences may exist in many individuals (Corbin
& Noble, 1980), which necessitates determining limb dominance prior to testing for consistency throughout participants. Unilateral stretching has advantages as compared to bilateral stretching, such as detecting imbalances between left and right sides. For example, stretching only one hamstring at a time can help maintain position of the pelvis. This prevents extreme flexion at the hip and lower trunk (Liemohn, 1988) because the leg not being stretched requires the pelvis to stay closer to a neutral position. It has also been demonstrated that there tends to be a notable difference between dominant and non-dominant hip flexibility in adults on a sit-and-reach test, and also in shoulder flexion and extension (Koslow, 1987).

The Stretch Reflex

When joints go through a range of motion and muscles are stretched, there are protective mechanisms which the body has to prevent injury. In a healthy person, resistance during stretching usually occurs as a result of tension from the muscle fibers. Muscle spindles, a type of proprioceptor, are within the muscle fibers and are an integral part of the neuromuscular system. When an agonist muscle contracts to stretch its antagonist, the muscle spindles activate nerves via the spinal cord to contract the antagonist muscle reflexively to attempt to prevent excessive stretching (Alter, 2004), inhibit the agonist, and thus prevent injury.

Stretches that are held for approximately 6-8 seconds may stimulate another proprioceptor called the golgi tendon organ (GTO). GTOs monitor the tension within the musculotendinous unit. After an extended stretch, the GTOs within the tendons of the stretched muscle cause a reflex activation of the antagonist muscle, allowing for reduced
tension in the musculotendinous unit of the stretched muscle to prevent damage to muscle fibers (Alter, 2004; Anderson, Hall & Martin, 2000).

For example, when stretching the hamstring muscles into hip flexion while in a supine position, the limb is moved in the direction of the agonist, the quadriceps and hip flexors. Antagonist muscles, the hamstrings, are stretched and the muscle spindles are stimulated to contract the hamstrings to prevent excessive movement and damage. With a held stretch, the GTOs activate to override the muscle spindles and relax the hamstrings, allowing for a greater stretch. Ninos (1997) states that increasing “the rate of loading will increase the stiffness of the tissue, in turn increasing its resistance to stretch.” This means that stretches which are performed quickly will cause the muscle to tighten and not allow full range of motion. Therefore, the reasoning behind the argument against ballistic stretching is that ballistic involves bouncy movements that cause the muscle spindles to fire and may not allow the GTOs to activate (Anderson, Hall, & Martin, 2000) and thus, a tense muscle and tendon is not stretched to its limits. The firing muscle spindle which causes muscle contraction in combination with excessive stretch is also dangerous because it may cause injury.

**Warm-Up**

A warm-up is defined as exercises that are done before an activity to help the body adjust from rest to exercise. It is universally recognized that warm-up activities should precede exercise in order to increase body and muscle temperature (Alter, 1988). It has also been shown to improve performance and reduce injury (Alter, 1988; Corbin & Noble, 1980; Safran, Garrett, Seaber, Glisson, & Ribbeck, 1988). Safran et al. (1988) found that increased muscle temperature due to a physical warm-up was associated with
the ability of that muscle to produce increased force. Smith (1994) stated that warm-up exercises raise the body’s temperature by stimulating circulation to the periphery and that in doing so, the warm-up primes the musculoskeletal system for activity. Increasing body temperature from warm-up exercises also decrease blood viscosity and increase blood flow.

Viscosity can be defined as “the resistance to flow” (Alter, 2004, p. 127). Body temperature has a negative relationship with viscosity; increased temperature of body tissues and fluids reduce its viscosity (Alter, 2004). In turn, increasing tissue temperature helps the ability of connective tissue, specifically collagen and elastin, to deform and return to its initial length (Prentice, 1999). “The most common method of elevating body temperature and reducing tissue viscosity is the warm-up” (Alter, 2004, p. 127). Other methods of increasing tissue temperature, such as warm packs, warm baths, and ultrasound, tend to be too superficial and do not have the lasting effects of exercise (Alter, 2004; Corbin & Noble, 1980).

**Effects of Flexibility on Muscular Strength**

Muscular strength is one of the main components of physical fitness. It is the ability of muscles to produce force to cause motion through joints. Optimal range of motion in joints is as unique for each individual as it is for every activity, sport and position. Excessive flexibility may have harmful effects upon soft tissue structures. Excessive range of motion may cause a joint to become unstable. This solidifies the argument to include strengthening with flexibility training (Corbin & Noble, 1980). Many joints rely on bone, ligamentous and muscular restrictions to remain stable and work properly. “There is a basic principle regarding joint movements: the more
flexibility, the less stability; the more stability, the less flexibility” (Peterson Kendall, Kendall McCreary & Geise Provance, 1993, p. 3). When the muscular strength component is deficient because of its excessive length, it takes away from the muscles’ ability to keep a joint stable and strong. Ninos (1999) states, “adequate strength is needed by the surrounding muscle groups to control the laxity that may be present within the joint” (p. 58). For example, weak hamstrings have been associated with instability in the knee joint, a predisposing factor in knee ligament tears. Therefore, it has been suggested to keep a balance between flexibility and strength. However, the exact amounts of strengthening and flexibility training necessary for proper joint stability are not well known.

While flexibility training has been shown to increase range of motion over time, flexibility training in combination with strength training may produce different results. In 1995, Girouard and Hurley found that a flexibility and strength training combination resulted in lower extremity strength gains (43 ± 14%, p< 0.001) compared to control measures, but did not produce significant increases in range of motion in hip flexion (+5.6%, p> 0.01), whereas the same flexibility treatment without strength training produced significant increases in hip flexion range of motion (+15%, p< 0.01). There was no group who performed strength training only in this investigation. A strength training only group would have been interesting to compare to the strength and flexibility group and the flexibility only group. According to this investigation, strength training may have inhibited flexibility gains.

The musculotendinous unit connects muscle fibers to the skeletal system and may possess certain characteristics that affect how much force is generated. Musculotendinous
stiffness has been found to have some positive impact on muscle performance (Wilson, Murphy, & Pryor, 1994). A group of individuals who had significant muscle stiffness in their chest musculature were compared to a group who did not. Muscle stiffness was measured using an “oscillation technique whereby the subjects maintained a loaded bar in an isometric bench press” (Wilson, Murphy, & Pryor, 1994, p.2715) at different percentages of their maximum weight, and then the bar underwent perturbations. This test was shown to have a test re-test correlation of 0.89. The group who had high muscular stiffness, or oscillated the bar less, performed better on bench press in an isometric force test ($p<0.01$) and also concentric bench press measures ($p<0.05$). Stiffness was significantly related to how much and how quickly force could be developed in this study. These findings indicate that greater stiffness and less flexibility enabled these participants to produce greater forces with concentric and isometric muscle contractions.

Another study examined eight weeks of upper extremity flexibility training, twice per week on chest musculature performance (Wilson & Murphy, 1995). Flexibility training caused a 14% increase in flexibility. As measured using a bench press, isometric force increased 5.4% and concentric force increased for the maximum lifts 10.7%. Interestingly, muscular stiffness also increased by 10% in participants who went through the flexibility training. The researchers account for this increase in stiffness being the facilitator for the improvements in concentric and isometric performance.

As previously mentioned, flexibility and the amount of muscle mass may have an influence on each other. Beedle, Jessee and Stone (1991) studied how strength gains and muscle hypertrophy are related, and also examined flexibility as active range of motion. All participants’ right sides were measured regardless of individual dominance, and the
reliability of the measurements ranged between 0.85 and 0.99. Researchers found that hypertrophy seen with strength gains may hinder shoulder flexibility in weight training populations including bodybuilders, Olympic style lifters, college football players, and recreational lifters. One interesting outcome was that the Olympic style lifters, probably the group most focused on muscular strength to lift large amounts in competition, performed best on shoulder flexion and horizontal flexion measures. There was no mention of how much flexibility training was incorporated into their training.

Silvestri & Oescher (1990) compared two similar activity groups doing whole-body aerobic exercise; one group used 1-pound hand weights. Using light weights improved two measures of strength, grip strength and bar hang scores, and also improved results on a sit-and-reach test. None of these improvements occurred in the activity group without weights, implying that strength and flexibility can be gained with the addition of light weights. There was no measure of hamstring strength, which may have been helpful when comparing results on the sit-and-reach measures. Resistance training may have no negative effects upon range of motion and flexibility when weight or resistance training is done throughout the full range of motion (Corbin & Noble, 1980), as demonstrated by Silvestri and Oescher.

Recently, studies have looked at the effect of muscular stretching on muscle performance measured by electromyography (EMG). Behm, Button, and Butt (2001) studied the effects of 5 sets of 45-second static stretching on muscle recruitment. Following stretching, muscle inactivation as measured in surface iEMG increased 20.2% in the quadriceps muscle group and 16.8% in the hamstrings, indicating the muscles were less active. No changes in flexibility were measured in this study. Additionally, Young
and Behm (2003) found through an EMG analysis that neural inhibition followed a run and stretch warm-up, and no neural inhibition was present after a warm-up of only running. No quantitative data were reported.

Carter, Kinzey, Chitwood, and Cole (2000) found that acute PNF stretching decreased muscle activity in only one muscle of the hamstring muscle group in response to a rapid stretch in a group of young women. The treatment group underwent PNF stretching prior to testing. Testing included involuntary knee extensions using a free fall weight attached to an ankle cuff through a pulley system. The hamstring muscle group is comprised of three muscles, and the biceps femoris produced less muscle activity than the semitendinosus in this study. Reduced muscle activity as measured using EMG was ascribed to muscle spindle desensitization. This study concluded that acute PNF stretching decreased muscle’s response to rapid elongation, and this may increase the risk of muscle and tendon injury.

Muscular strength endurance, or muscular endurance, was found to be negatively affected by 10 minutes of passive static stretching (Nelson, Kokkonen & Arnall, 2005). These researchers defined muscular endurance as the number of repetition performed at 40% and 60% of body weight, which was found to decline by 9% and 24% respectively. This study examined 15 minutes of static stretching which was focused on knee flexion musculature.

**Effects of Flexibility Training on Muscular Power**

The association between strength and flexibility is important for understanding muscular power and flexibility. Muscular power is similar to strength, with the addition of time to perform work. Some research using acute stretches has been done to examine
power. Muscular power and flexibility were investigated in a 2003 study by McNeal and Sands. Adolescent female gymnasts performed drop jumps immediately following lower body stretching exercises, and then on the next day, performed the drop jump without prior stretching. Jump time in the air was significantly greater without prior stretching (0.44 vs. 0.46 seconds, \( p < 0.001 \)), and overall jumping performance following static stretching was reduced 9.6% compared to the control session which did not include stretching prior to jumping.

Young and Behm (2003) also compared power in various combinations of stretching and warm-up. They found that a stretch only group had the lowest jump heights (28.3 cm) and the lowest peak force (1.73 x body weight) compared to other warm-up combinations (run only group, run + stretch group, and run + stretch + practice jump group). The run only warm-up resulted in better performances (3-15%) versus the run and stretch condition on several variables including concentric jump height (3.4% increase of 30.2±3.7 vs. 29.2±3.2 cm), drop jump height (3.2% increase of 27.7±6.4 vs. 26.5±5.6 cm), and concentric rate of force developed (15.4% increase of 17784±7057 vs. 15408±4068 N/s). The run + stretch + practice jump group, a typical warm-up, performed the best on jump heights. Performance was recorded two minutes after each treatment warm up condition. These studies demonstrate a decrease in power and strength immediately following stretching activities alone, and that conditions without prior stretching produced positive results.

**Effects of Flexibility on Muscular Torque**

Torque is defined as the force about a joint’s axis of rotation (Perrin, 1993). Nelson, Guillory, Cornwell, and Kokkonen (2001) examined how acutely stretching the
quadricep muscles affects the different torques produced using an isokinetic knee extension machine. At lower speeds (1.05 rad.s-1 or 60°/s, 1.57 rad.s-1 or 90°/s), maximum torque produced was lower following their stretching protocol (-7.5%, -4.5%). At higher speeds (2.62 rad.s-1 or 150°/s, 3.67 rad.s-1 or 210°/s, and 4.71 rad.s-1 or 270°/s), maximal torques were not different following the same stretches. This suggests that static stretches have a hindering affect on muscle performance at slow speeds, whereas static stretching does not affect higher speed activities. In most sport performances, power movements are done at higher speeds. However, during most weight training sessions, it is customary to lift resistance in a slow controlled manner.

Another study examined hamstring performance on a Kin-Com isokinetic dynamometer immediately following either static or ballistic stretches (Purdam, Davies, Finlay & Hilly, 1999). Pre and post-tests were measured at 60 degrees per second, and done 10 minutes apart. Results showed that there was reduced eccentric hamstring torque following the static stretching treatment (7%, p< 0.05), whereas no changes were demonstrated following ballistic stretching in either concentric or eccentric muscular contractions.

Hamstrings responses to repeated static stretches were examined in another study (Magnusson, Simonsen, Aagaard, & Kjaer, 1996). Significant reductions in muscle energy (p< 0.01), stiffness (p< 0.05) and passive torque (p< 0.001) were discovered 10-minutes following acute static stretches. However, in repeated testing conducted one hour after stretching, all variables returned to baseline measures, showing that performance immediately following acute stretches is only temporarily affected. The effects of repeated, chronic stretching or flexibility training were not investigated.
Few investigations involving chronic (instead of acute) stretching and muscular power have been reported. In a study conducted by Worrel, Smith, and Winegardner (1995), increases in hamstring flexibility resulting from a stretching program were shown to increase hamstring performance in certain isokinetic situations. Two different types of stretching methods were examined: proprioceptive neuromuscular facilitation and static stretching. Following a 5 days per week, 3-week flexibility training program, both techniques increased concentric (12.6 Nm, 11.2%) and eccentric peak torque (15.1 Nm, 13.5%) of the hamstring muscles at 120 degrees/sec. No changes were observed at a lower speed (60°/sec). However, neither technique produced significant changes in flexibility. As shown in these studies, stretching activities may influence isokinetic performance, but there are inconsistencies between performance results at different speeds.

**Summary**

The relationship of flexibility upon physical performance has brought on an increasing amount of interest from health professionals, non-professionals and those physically active. Past experiments concerning the relationship of muscle performance and flexibility training, or stretching activities, are non-conclusive. There is an ongoing controversy of different ways to stretch, such as differing stretching techniques, durations and frequencies, and different strength measurements taken such as anthropometric values, EMG and isokinetic values. Research has found that stretching caused a positive affect on strength and flexibility results (Silvestri and Oescher, 1990), while another found no resultant changes (Girouard & Hurley, 1995). Strength measures, including neuromuscular recruitment, have declined as a result of acute flexibility training (Behm,
Research has not provided a good sense of what we should do and is insufficient at determining a pre-exercise method demonstrated to be most optimal for performance. A majority of these studies used results immediately following acute stretching techniques and do not examine the amount of time between stretching and performance. Not enough studies examine the effects of subacute or chronic stretching. A difference between the effects of stretching between genders may also exist. Stretching, in conjunction with an exercise program, may have different effects than stretching alone in the absence of strength training or aerobic exercise. The effects upon speed of contraction, or muscular torque, as a result of stretching are unknown. More examinations should be performed to investigate any causal link between stretching and specific components of power, such as amount of force production alone. The goal of this study was to examine stretching routines similar to many athletic and fitness programs, and determine a variation which is most beneficial towards producing optimal muscle torque and increasing active range of motion.
CHAPTER III

METHODS

The purpose of this study was to determine how three different warm-up conditions prior to exercise influenced active range of motion and peak and average isokinetic muscle torque at two different speeds. In this chapter, the methods are described under the following headings: (a) sample size determination, (b) participants, (c) research design, (d) apparati, (e) procedures, and (f) statistical analyses.

Sample Size Determination

To determine sample size, a one-way repeated measures analysis of variance was used for a G Power post hoc Power Analysis. A large effect size, by the G Power program’s convention, was $f^2 = 0.35$. Other factors entered into G Power are degrees of freedom for the numerator ($df_{num} = 2$), degrees of freedom for the denominator ($[N-1][m-1]= df_a = 58$), and alpha level ($\alpha = 0.05$). These calculations resulted in a desirable sample size of 30 for adequate power (0.8141) (Faul & Erdfelder, 1992).

Participants

Nineteen healthy males between the ages of 18-25 years from the Bowling Green State University (BGSU) community participated in the study. This study used male participants to control for any possible influences from hormonal or anatomical factors. Three participants were African American, and the remaining participants were Caucasian. Participant characteristics are presented in Table 1. All participants completed a Health History and Physical Activity Questionnaire (Appendix A). Any participants with recent lower extremity injuries, such as muscle strains or ligament sprains, or
significant health problems, such as uncontrolled diabetes, hypertension, or other
uncontrolled cardiovascular disorders were excluded from the study. All participants
were moderately active which was defined for this study as engaging in some physical
activity such as intramural sports, recreational running, etc., for a minimum of at least 30
minutes, twice per week. This study was approved by the Human Subjects Review Board
(#H05T143GE4) of Bowling Green State University. All participants were volunteers
and gave informed consent.

Table 1.

*Participant Characteristics (Means ± SD)*

<table>
<thead>
<tr>
<th>Participants</th>
<th>n</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>21.3 (±1.9)</td>
<td>182.4 (±6.1)</td>
<td>83.9 (±12.0)</td>
<td></td>
</tr>
</tbody>
</table>

**Research Design**

For the independent variable, there were three levels: jogging only (JO), jogging +
stretching (JS), and jogging + stretching + 15-minute rest period (JSR). Nine dependent
variables of the hamstrings were measured: concentric average torque, concentric peak
torque, eccentric average torque, eccentric peak torque, and hamstring active range of
motion. Each torque measure was taken at 60° and 120° per second (Nelson, Guillory,
Cornwell, & Kokkonen, 2001; Purdam, Davies, Finlay, & Hilly, 1999; Worrel, Smith, &
Winegardner, 1995).

**Apparati**

A Kin-Com Isokinetic dynamometer (Chattanooga Group, Chattanooga, TN) was
used for measuring muscle torque. It was used to quantify each participant’s ability to
produce force at a constant rate of speed, or torque, numerically as foot-pounds and force
curve graphs. Peak, or maximum, torque and average torque were analyzed throughout the full range of motion (Perrin, 1993). Isokinetic exercise was used because it is considered safer than other forms of exercise, such as isotonic, and because the dynamometer does not produce force so movement ceases once the user stops producing force (Perrin, 1993). Therefore, if the user experiences any discomfort or pain and stops muscle contraction and force, the dynamometer does not move.

A standard 12-inch goniometer was used to measure hip and knee range of motion. The goniometer has two protractor arms. In joint movement, degrees of range of motion were measured by aligning the arms of the goniometer with the two segments involved in motion about a specific joint (Prentice, 1999). For hip range of motion, the arms were aligned with the femur and the horizontal plane of the supine torso, and the axis was held against the greater trochanter of the hip. For knee range of motion, the arms of the goniometer were aligned with the femur and the fibula, while the axis was placed against the knee joint.

A Polar Beat heart rate monitor (model #1901201, Port Washington, NY) was used to monitor participants’ heart rates. The Polar Beat model has a chest strap to detect the heart rate which is transmitted to a wrist strap device which displays the number of beats per minute.

**Procedures**

Throughout the participants’ involvement in the study, they were instructed to follow their normal physical activity patterns. Participants were instructed not to participate in any exercise on the days of testing, and any maximal or new exercise 48
hours prior to testing. Each participant’s testing was done at the same time of day, and all sessions were completed within an 8-week period.

Data were collected by the experimenter who was trained in Kin-Com isokinetic procedures and evaluation. All participants performed a 5-minute general warm-up of jogging at approximately 5-5.5 mph. To ensure a similar and nonstrenuous warm-up, participants exercised at an intensity in which the heart rate was between 120-140 beats per min. Heart rate was assessed using a heart rate monitor during warm-up procedures.

All participants performed the same three experimental conditions before being tested on the isokinetic system: a jogging only condition (JO), a jogging + static stretch condition (JS), and a jogging + static stretch + 15-minute period of no activity (JSR). Each condition was completed on a different day to control for any muscular fatigue resulting from stretching or maximal muscle contractions. Testing occurred at the same time of day for each participant and the order of the conditions was randomized.

The static stretching protocol involved various lower extremity stretches as shown in Appendix C (Alter, 1998). For effective stretching of the hamstrings, it has been noted that an anterior pelvic tilt allows for better stretching because the proximal attachment site, the ischial tuberosity, is moved superiorly, contributing to further lengthening of the hamstring muscles (Sullivan, DeJulia, & Worrell, 1992). The flexibility exercises primarily involved the hamstrings, but some also incorporated the lumbar back extensors, gluteals, thigh adductors, and gastrocnemius. These stretches were verbally instructed to each participant with visual aids (Appendix C). All stretches were held at a point of discomfort for 10-20 seconds and repeated three times.
For flexibility, active range of motion (AROM) of the hamstrings was measured. Participants laid supine and moved their dominant leg into 120 degrees of hip flexion as measured by a 12-inch standard goniometer. The goniometer was aligned with anatomical landmarks: the lateral condyle of the femur and a line parallel to the surface the trunk was laying on for each goniometer arm, and the great trochanter of the femur for the axis of rotation point. Participants stabilized their thigh in that position with the support of their arms, and then actively extended their knee as far as they could. Anatomical landmarks were marked for easier locating during measurement. The goniometer’s axis was against the center of the joint line of the knee, and one arm was aligned with the shaft of the femur according the greater trochanter, and the other arm aligned against the line of the lower leg according to the lateral malleolus of the ankle. A similar technique of measuring hamstring AROM was implemented by Decoster, Scanlon, Horn, and Cleland (2004), but they set the hip at 90 degrees of hip flexion. Less hip flexion was used in that study because participants with poor flexibility were purposely sampled. Normal, healthy adults may be able to reach full knee extension while the hip is at 90 degrees of hip flexion, therefore, hip flexion was set at to 120 degrees in order to widen the range of measurements for this study. Active range of motion (degrees) of knee extension was measured using the goniometer and recorded. AROM was measured before each warm-up condition and immediately after each warm-up condition. For the jogging + static stretch + 15-minute period of no activity condition, AROM was also measured immediately after the 15-minute rest period.

To produce maximal hamstring muscle force, the prone position leg curl was chosen. The hamstring group is a biarticulate muscle (Luttgens & Hamilton, 1997)
crossing both the hip and knee joints. In a seated leg curl, the hip is flexed and pelvis is in anterior rotation causing the hamstring to be in a more lengthened position. Optimal muscle performance occurs when the muscle is in midrange of joint motion (Kendall, McCreary, & Provance, 1993) and not when fibers are overly lengthened or shortened giving the muscle fibers its greatest mechanical advantage (Perrin, 1993). In a prone position, the hip joint is in neutral position between flexion and extension, creating optimal position for hamstring muscle work at the distal attachment through the knee joint.

Leg dominance was determined by Coren and Porac’s (1978) test of lateral preference. For this test, participants self-selected which leg is used to kick a ball and initiate stair climbing. This leg is then identified as the dominant leg.

For the purpose of this study, muscular force was measured as torque, which is the force about a joint’s axis of rotation (Perrin, 1993). Participants were instructed on how to perform concentric and eccentric hamstring contractions on the isokinetic system. Participants were positioned in the machine and their dominant leg passively guided through the range of motion of testing for familiarization. In the prone position, the range of motion tested was from 5° of knee extension through approximately 85° of knee flexion to isolate the hamstrings. Participants performed maximal hamstring contractions with their dominant leg by performing three consecutive submaximal contractions and then at least three, but not more than six, consecutive maximal contractions (Perrin, 1993) at 60 and 120 degrees per second. This was done in order to achieve a maximal contraction until a consistent decline in performance was observed.
**Statistical Analyses**

For the independent variable, there were three levels: jogging only (JO), jogging + stretching (JS), and jogging + stretching + 15-minute rest period (JSR). Nine dependent variables of the hamstrings were measured: concentric average torque, concentric peak torque, eccentric average torque, eccentric peak torque, and hamstring active range of motion. Each torque measure was taken at 60° and 120° per second (Nelson, Guillory, Cornwell, & Kokkonen, 2001; Purdam, Davies, Finlay, & Hilly, 1999; Worrel, Smith, & Winegardner, 1995).

Correlation matrices were performed on the multiple dependent variables. High correlations (r=0.86-0.98) which were found among the dependent variables demonstrated that a MANOVA was an appropriate analysis. MANOVA protects against type I errors with multiple dependent variables, and analyzes the underlying factors among dependent variables, which were of interest in this study (Norman & Streiner, 2000; Vincent, 1999).

A two-way MANOVA was used to analyze data from the three conditions: hamstring active range of motion, peak hamstring torque, and average hamstring torque. Data were analyzed at a significance level of $\alpha = .05$. Any significant differences found between groups were then analyzed using Tukey’s *post hoc* analysis. The AROM pre- and post- data were also analyzed using a 2x3 repeated measures ANOVA to determine any significant changes among conditions.
CHAPTER IV

RESULTS

The purpose of this study was to determine how three different warm-up conditions, prior to exercise, influence active range of motion, and also peak and average isokinetic muscle torque at two different speeds. This chapter will provide a description and interpretation of the results.

Muscular Torque

A total of eight measures of torque were collected from each participant using the isokinetic system. Torque results at 60° and 120° per second are presented in Tables 2 and 3, respectively. A MANOVA was used to analyze the data. Data were not significantly different between the three warm-up conditions for any of the eight torque measurements. All eccentric data were consistently higher than the respective concentric data. Eccentric contractions are expected to be greater because eccentric contractions can undertake greater loads and produce more force than concentric contractions (Wilmore & Costill, 1999). The significance levels of each variable are presented in Table 4. All torque data presented small effect sizes and low levels of observed power.

Table 2.
Isokinetic Results at 60° per second (M ±SD)

<table>
<thead>
<tr>
<th></th>
<th>Concentric Average (ftlbs)</th>
<th>Concentric Peak (ftlbs)</th>
<th>Eccentric Average (ftlbs)</th>
<th>Eccentric Peak (ftlbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JO</td>
<td>24.7 (±14.8)</td>
<td>31.8 (±17.2)</td>
<td>31.9 (±18.1)</td>
<td>43.6 (±23.3)</td>
</tr>
<tr>
<td>JS</td>
<td>27.1 (±14.8)</td>
<td>35.4 (±16.8)</td>
<td>30.3 (±16.0)</td>
<td>41.8 (±17.7)</td>
</tr>
<tr>
<td>JSR</td>
<td>26.6 (±17.8)</td>
<td>34.8 (±19.1)</td>
<td>32.2 (±19.6)</td>
<td>44.7 (±24.8)</td>
</tr>
</tbody>
</table>
Table 3.

Isokinetic Results at 120° per second (M ±SD)

<table>
<thead>
<tr>
<th></th>
<th>Concentric Average (ftlbs)</th>
<th>Concentric Peak (ftlbs)</th>
<th>Eccentric Average (ftlbs)</th>
<th>Eccentric Peak (ftlbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JO</td>
<td>25.7 (±17.9)</td>
<td>30.6 (±16.5)</td>
<td>31.4 (±17.5)</td>
<td>43.5 (±22.6)</td>
</tr>
<tr>
<td>JS</td>
<td>23.3 (±13.8)</td>
<td>31.8 (±16.5)</td>
<td>31.6 (±15.3)</td>
<td>43.9 (±17.6)</td>
</tr>
<tr>
<td>JSR</td>
<td>25.7 (±16.0)</td>
<td>33.0 (±18.2)</td>
<td>32.7 (±18.6)</td>
<td>43.9 (±24.0)</td>
</tr>
</tbody>
</table>

Table 4.

MANOVA Summary Table of Statistical Significance between Warm-Up Conditions

<table>
<thead>
<tr>
<th></th>
<th>F Value</th>
<th>p</th>
<th>Observed Power</th>
<th>$f^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in AROM</td>
<td>3.079</td>
<td>0.054*</td>
<td>0.571</td>
<td>0.113</td>
</tr>
<tr>
<td>Concentric Average @ 60°/s</td>
<td>0.116</td>
<td>0.891</td>
<td>0.067</td>
<td>0.004</td>
</tr>
<tr>
<td>Concentric Peak @ 60°/s</td>
<td>0.229</td>
<td>0.796</td>
<td>0.084</td>
<td>0.008</td>
</tr>
<tr>
<td>Eccentric Average @ 60°/s</td>
<td>0.062</td>
<td>0.940</td>
<td>0.059</td>
<td>0.002</td>
</tr>
<tr>
<td>Eccentric Peak @ 60°/s</td>
<td>0.082</td>
<td>0.922</td>
<td>0.062</td>
<td>0.003</td>
</tr>
<tr>
<td>Concentric Average @120°/s</td>
<td>0.139</td>
<td>0.871</td>
<td>0.070</td>
<td>0.005</td>
</tr>
<tr>
<td>Concentric Peak @ 120°/s</td>
<td>0.099</td>
<td>0.906</td>
<td>0.064</td>
<td>0.004</td>
</tr>
<tr>
<td>Eccentric Average @ 120°/s</td>
<td>0.032</td>
<td>0.968</td>
<td>0.055</td>
<td>0.001</td>
</tr>
<tr>
<td>Eccentric Peak @ 120°/s</td>
<td>0.001</td>
<td>0.999</td>
<td>0.050</td>
<td>0</td>
</tr>
</tbody>
</table>

*p < 0.05

Hamstrings Active Range of Motion

Pre- and post- measures of AROM were collected for each warm-up condition. The JSR condition post measurement was taken following 15 minutes of inactivity, whereas for the JO and JSR conditions, AROM was taken immediately after warm-up. AROM data are presented in Table 5.

A MANOVA was also initially used to analyze AROM. For this statistical analysis, the difference between the pre- and post- AROM measures were used for change in AROM, which was not significantly different. No significant differences were
found for any of the conditions. Moderate effect size and power existed for the change in AROM data. The active range of motion data among the three conditions was close to reaching significance ($p=0.054$) as shown in Table 5.

A 2x3 repeated measures ANOVA was also performed on the AROM data shown in Table 5. Pre-AROM and post-AROM data were used to determine significant changes before and after each warm-up. There was a significant increase found only in the JS condition ($p<0.05$) from pre to post measurements. This statistic showed that there was a main effect for time. Time from pre to post measurements demonstrated high power and a large effect size. There was no significant difference among the different warm-up conditions for any of the dependent variables, nor was there a significant interaction for time and warm-up condition ($p=0.745$, $p=0.058$ respectively). However, moderate power and a large effect size occurred for the AROM ANOVA statistic. These data are presented in Table 6.

Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Pre AROM</th>
<th>Post AROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>JO</td>
<td>130.9 (±10.7)</td>
<td>136.4 (±10.7)</td>
</tr>
<tr>
<td>JS</td>
<td>128.5 (±11.1)</td>
<td>136.4 (±11.8)</td>
</tr>
<tr>
<td>JSR</td>
<td>130.3 (±10.9)</td>
<td>134.8 (±11.9)</td>
</tr>
</tbody>
</table>

Table 6.

ANOVA Summary Table of Statistical Significance for AROM

<table>
<thead>
<tr>
<th></th>
<th>F Values</th>
<th>$p$</th>
<th>Observed Power</th>
<th>$f^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>76.344</td>
<td>0.000</td>
<td>1.00</td>
<td>4.235</td>
</tr>
<tr>
<td>Condition</td>
<td>0.299</td>
<td>0.745</td>
<td>0.090</td>
<td>0.001</td>
</tr>
<tr>
<td>Time*Condition</td>
<td>3.372</td>
<td>0.058</td>
<td>0.556</td>
<td>0.397</td>
</tr>
</tbody>
</table>
CHAPTER V

DISCUSSION

The purpose of this study was to determine how three different warm-up conditions prior to exercise influence active range of motion and peak and average isokinetic muscle torque at two different speeds. A discussion and conclusions based on the results of this study is included in this chapter.

Muscular Torque

This study examined the amount of muscular torque, peak and average, which could be maximally produced by participants after three different warm-up conditions. The null hypotheses for all torque measures were supported by the results of this study. Specifically, there was no difference between warm-up conditions in affecting maximal force production by the participants. These results are not supported by similar investigations. Previous research suggests that acute stretching may depress some properties of muscular strength when tested immediately after stretching. For example, there has been a reduction in eccentric, but not concentric hamstring strength at 60° per second after static stretching (Purdam, Davies, Finlay and Hilly, 1999).

Other investigations (Worrell, Smith, & Winegardner, 1994) have shown that chronic stretching increases hamstring torque at isokinetic speeds similar to this study, as well as isometric force (Wilson & Murphy, 1995). In the current investigation, only 60°/second and 120°/second were examined with acute stretching, so differences may exist at other speeds. However, joint movements faster than 120°/second are more difficult to reproduce and isolate in an isokinetic situation although they occur frequently.
in many sport skills. Examining higher speeds of isokinetic testing was attempted by Nelson, Guillory, Cornwell and Kokkonen (2001). Using the quadriceps, they found that torque measures declined post-acute stretch at the slower speeds tested (60°/s, 90°/s), while similar to the current study, it remained unaffected at higher speeds (150°/s, 210°/s, 270°/s). These authors demonstrated that acute stretching reduced force production at slower speeds and chronic stretching improved muscular torque at slow speeds, and so the impact of stretching on muscular torque remains unresolved.

The current results demonstrated that muscle performance following stretching versus not stretching was not different. This agrees with Church, Wiggins, Moode and Crist (2001), who measured muscular power by assessing jump height. Their results showed that an acute static stretch with warm-up produced jump heights that were not different from performances following a warm-up without static stretching. Negative jump performances following acute stretching have been shown by others (McNeal & Sands, 2003; Young & Behm, 2003), whereas no negative changes occurred with this study.

Another goal of this study was to determine if a period of inactivity following warm-up had any negative effect on hamstring performance. The only difference between the JS and JSR conditions were the 15-minutes of rest following static stretching. This study showed that 15-minutes of rest following a warm-up did not have any positive or negative affect upon muscular torque production. Further, the stretching and jogging warm-up was not different from the jogging warm-up as determined by muscular torque production. Intensity and duration of stretching utilized in this investigation, similar with many past studies, did not have any effect upon muscular torque. Magnusson, Simonsen,
Aagaard and Kjaer (1996) found that soft tissue structures which had shown increases in passive stretch and torque after a warm-up, which then returned to baseline measurements when reassessed one hour after exercise. Fifteen minutes of rest did not lead to any negative changes in the current study. This research may help to define the appropriate timing of warm-up prior to activity, however, more work is needed.

**Hamstring Active Range of Motion**

Significant differences in hamstring active range of motion over time, between pre- and post-, were observed. Time was the significant variable having a large effect size and observed power, showing that post AROM was better than pre AROM for all conditions. The type of warm-up was not found to have any effect upon AROM. All conditions of warm-up had the same duration and intensity of jogging, suggesting that including jogging in a warm-up procedure may be enough to improve active range of motion. It is possible that the effects from jogging may be more important in affecting musculotendinous AROM than 5-minutes of moderate static stretching. This supports the idea that warm-up activities should precede exercise in order to increase body and muscle temperature (Alter, 1988).

Another goal of this study was to determine if any differences occurred with a period of inactivity following warm-up. Fifteen minutes of rest following a jogging and stretching combination warm-up did not elicit declines in AROM and was not different from the jogging only warm-up or the jogging + stretching warm-up. However, a longer rest period may result in a decline in AROM. The amount of time required to cool down muscles affecting the musculotendinous active range of motion was not determined after these warm-ups in this study. This study did show that activity increasing physical
activity immediately prior to performance, or within 15-minutes of performance, was enough to cause increases in AROM. Stretching and jogging did not elicit better range of motion when compared to the condition of jogging only.

There were a few limitations that proved to be difficult to control for during this study. During the course of collecting data, several participants noted that while lying prone on the Kin-Com equipment, the shape of the seat curved convexly and pressed into their quadriceps causing some discomfort during exercise testing. A few participants had difficulty becoming accustomed to performing eccentric contractions on the isokinetic machine and maintaining enough force throughout the range of motion, however overcame this with sufficient trials without getting fatigued. These participants required up to four practice contractions to successfully move throughout the hamstring curl, while many others only needed one. Another limitation of this study was that conclusions regarding stretching and muscle torque may only be made towards moderately active, young adult males within a college population.

Recommendations

There are many opportunities for future research to expand upon the findings of this study. Jogging seemed to be the key factor in promoting gains in AROM, perhaps based on an increase in blood flow and tissue temperature. It may be interesting to examine range of motion and flexibility with increases in tissue temperature from external heating methods, such as a hot pack or diathermy. Testing different speeds, different muscle groups and different stretching routines may also be of future interest. Environmental temperature may be another interesting factor to investigate concerning warm-up and soft tissue structures.
Conclusion

Even though there were no differences found in muscular torque following the three warm-up conditions, this study showed that these warm-ups equally affected how much torque the musculotendinous unit produced both concentrically and eccentrically at two different speeds. Higher speeds, which are observed during many sport skills, may produce different results. This study found that force did not necessarily increase following different types of warm-up. This study did show that range of motion performances were significantly better following a warm-up including jogging or within 15-minutes of ceasing warm-up activity than before the warm-up. This is significant because a general muscular warm-up that increases blood flow to muscles and other soft tissue structures may be adequate at preparing muscles for physical activity and may reduce the incidence of injury. After 15 minutes of stopping warm-up activity, torque was not negatively affected. This is significant because some competitive athletics, particularly team sports, may perform warm-up exercises and then have a period of inactivity such as a team meeting prior to beginning competition.
Reference List


Baltimore, MD: Lippincott Williams & Wilkins.


Massey, B. H. & Chaudet, N. L. (1956). Effects of systemic, heavy resistive exercise on


APPENDIX A

Health History and Physical Activity Questionnaire
Health History and Physical Activity Questionnaire

All information given is personal and confidential. It will enable us to better understand you and your health and fitness habits. Please let us know if and when you have changed your medication (dose & type), diet, exercise or sleeping habits within the past 24 or 48 hours. It is very important for you to provide us with this information.

NAME(print)_______________________
AGE____________DATE___________
ASSOCIATION TO BGSU___________

Family History
Check each as it applies to a blood relative:

* Heart Attack  yes______ no______ unsure______
   If yes, age at onset____________ years.
* Sudden Death  yes______ no______ unsure______
   If yes, relation to you____________________
   Age of relative at onset____________ years.
Tuberculosis    yes______ no______ unsure______
Stroke     yes______ no______ unsure______
Asthma     yes______ no______ unsure______
High Blood Pressure yes______ no______ unsure______
Circulatory Disorder  yes______ no______ unsure______
Heart Disease    yes______ no______ unsure______

Personal History
Height______ Weight______
Do you have:
High Blood Pressure  yes______ no______ unsure______
   If yes, give value if known: ________/_______ mmHg.
High Blood Cholesterol yes______ no______ unsure______
   If yes, give value if known:__________________ mg.
Diabetes Mellitus yes______ no______ unsure______
   If yes, age of onset:____________________ years.

Sedentary lifestyle/physical inactivity (sedentary as defined by a sedentary job that involves sitting for a large part of the day and no regular exercise or activity recreational).  
   yes______ no______ unsure______

With which foot do you kick a ball?

Have you ever had:
Tuberculosis  yes______ no______ unsure______
Heart Attack  yes______ no______ unsure______
Angina    yes______ no______ unsure______
EKG Abnormalities yes______ no______ unsure______
Asthma     yes______ no______ unsure______
Emphysema  yes______ no______ unsure______
Major Surgery yes______ no______ unsure______
Stroke     yes______ no______ unsure______
Severe Illness yes______ no______ unsure______
Hospitalized  yes______ no______ unsure______
Black Outs  yes______ no______ unsure______
Gout       yes______ no______ unsure______
Joint Problems yes______ no______ unsure______
Convulsions yes______ no______ unsure______
Paralysis  yes______ no______ unsure______
Headaches yes______ no______ unsure______
Chest Pain yes______ no______ unsure______
Arm Pain   yes______ no______ unsure______
Shortness of Breath yes______ no______ unsure______
Ulcers     yes______ no______ unsure______
Overweight yes______ no______ unsure______
Hernia     yes______ no______ unsure______
Back Pain  yes______ no______ unsure______
Leg Cramps yes______ no______ unsure______
Low Blood Pressure  yes______ no______ unsure______
Numbness/tingling yes______ no______ unsure______

Have you ever taken:
Digitalis  yes______ no______ unsure______
Nitroglycerin yes______ no______ unsure______
High Blood Pressure Medication yes______ no______ unsure______
Sedatives  yes______ no______ unsure______
Stimulants yes______ no______ unsure______
Inderal    yes______ no______ unsure______
Insulin    yes______ no______ unsure______
Promestyl  yes______ no______ unsure______
Vasodilators yes______ no______ unsure______

Date of your most recent physical examination________
Are you worried about your health?
   Yes_______ No_______ Unsure____
Do you exercise? Yes_______ No_______
How long have you been exercising?__________
What activities?__________________________
How many days do you exercise?__________
How many minutes per day?________
Do you monitor your pulse during your workout?____
APPENDIX B

Informed Consent
Informed Consent Statement

**Title of Research Study:** Impact of Different Warm-up Conditions on Hamstrings Torque and Power

You are invited to be in a research study on flexibility and muscular strength. You give consent for the researcher, Sara Sonnekalb, Graduate Student in the School of Human Movement, Sport, and Leisure Studies, to conduct this research study with your participation. This study is in partial fulfillment of the requirements for a Master in Education Degree.

The objective of this research study is to examine the effects of 3 different warm-ups upon the strength the hamstring muscles. Participation in this study will require your time and involvement in 3 sessions, each on different days, within a 1-3 week period.

**Procedures**

You will be asked to complete a Health History and Physical Activity Questionnaire. It will require approximately 5 minutes to complete the questionnaire.

Flexibility measurements will be taken immediately before each testing session. You will be required to lie on your back and bring your thigh to your chest. Then you will be asked to extend your knee straight as far as you can.

A machine to measure your strength, specifically a Kin-Com isokinetic system, will be used in this study. This machine will move at a set speed. Resistance from the machine will occur only when you, the participant, attempt to move your lower leg at an equal or greater speed as the machine. For successful data measurement in this study, use of this machine requires you to push and pull as hard and as fast as you can.

On different days, you will perform three different warm-up conditions. One of the conditions is a 5-minute general warm-up of jogging. You will wear a heart rate monitor during jogging to be sure you have reached an adequate warm-up and beats per minute. Flexibility will be measured prior to and following the warm-up. Then you will be instructed on how to use the strength testing machine, which is located in the Exercise Physiology Laboratory in the Eppler Complex South. You will perform three moderate contractions to familiarize you with the machine and work expected of you, and then 3-6 contractions at your maximum effort for actual testing. This session will require approximately 15 minutes.

Another warm-up condition will be a 5-minute jogging warm-up, and 5 minutes of thigh muscle stretches. Your flexibility will be measured again before the warm-up
condition. Following the same 5-minute jogging warm-up, you will perform lower extremity and thigh stretches, which primarily involve your muscles on the back of your thighs. The researcher will show you these stretches. Your flexibility will be assessed again, and then you will perform the same contractions on the strength testing machine. This session will require approximately 20 minutes.

The third warm-up condition is a 5-minute jogging warm-up, and heart rate check, plus 5 minutes of lower extremity static stretches plus a 15-minute rest period. The same warm-up of jogging and static stretches as previously described will be done, with the addition of a 15-minute period of no activity following warm-up. Flexibility will be assessed prior to warm-up, after warm-up, and then again immediately prior to strength testing. You will perform the same strength testing as previously described. This session will require approximately 30 minutes.

Sessions will be done in a randomized order as determined by the researcher. Your testing will be done at the same time of day for all three sessions.

**Risks:** As in all research, there may be unforeseen risks to you as a participant. If an accidental injury occurs, appropriate emergency measures will be taken. Medical care expenses as a result of this study will be the responsibility of you, the participant. Your participation in this study may result in muscle fatigue, strains or soreness. Precautions will be taken to minimize these risks, including instruction on proper stretching and lifting techniques, and performing a general warm up prior to each activity session.

**Benefits:** The benefits of this study may contribute to the body of knowledge in exercise science, physical training and performance. The results of this study may give researchers a better understanding of the relationship between muscle strength and flexibility, or range of motion. Participants may benefit from this study by learning about their lower extremity flexibility and strength, and components of physical fitness, and becoming more knowledgeable in this area.

**Confidentiality:** Confidentiality of this research study will be kept to the best of the researchers’ ability. Only members of the research team will have access to the data / information you provide. Information you provide will remain confidential and your identity will not be revealed.

Your participation in this research study is entirely voluntary. You may refuse to participate in this investigation or withdraw your consent and discontinue participation in this research study without penalty and without affecting your relationship to the university at anytime.
Title of Research Study: Impact of Different Warm-up Conditions on Hamstrings Torque and Power

I, (print name) __________________________________________ have been informed of the risks and procedures of this research study. The researchers have answered all of my questions I have about the research to my satisfaction.

Signature of Participant ____________________________     ______________
Date ____________________________

Please sign two copies. Keep one and return the other to the investigator.

If you have questions about the conduct of this study or your rights as a research participant, you may contact the Chair of Bowling Green State University's Human Subjects Review Board at (419) 372-7716 (hsrb@bgnet.bgsu.edu). If you have any questions regarding this study, you may directly contact Sara Sonnekalb at (716) 679-8592 (sonnes@bgnet.bgsu.edu) or advising faculty Dr. Amy Morgan, (419) 372-0596.
APPENDIX C

Lower Extremity Static Stretches
Sit on the floor with both legs extended in front. Exhale and keep the legs straight while extending the upper back. Bend forward at the hips.

Lie on the back with the knees flexed and the heels close to your buttocks. Inhale and extend one leg upward. Exhale and slowly pull the raised leg toward the face, keeping the leg straight.

Sit on the floor, with legs flexed and spread, and heels touching each other. Grasp the feet or ankles and pull them as close to your groin as possible. Place elbows on the inner thighs or knees, exhale, and push the legs to the floor.

Sit on the floor with one leg straight and the other bent at the knee with the heel touching the inside of the opposite thigh. Exhale, keeping the extended leg straight, and lower the upper torso towards the thigh.
From a push-up position, move hands closer to feet to raise the hips and form a triangle. At the highest point of the triangle, slowly press the heels to the floor, or alternate slowly flexing one knee while extending the opposite leg.

Squat with the heels flat, chest against the thighs, and your hands on the floor. Exhale and slowly straighten your legs until tension is felt. Flex the knees and return to starting position.

Stand with hands on the hips and cross one leg over the other. Exhale and keep one leg straight and extend the upper back. Then bend at the hips and lower the trunk to the thighs.

Stand with the legs spread and flex at the hips, keeping your legs straight. Exhale and pull the chest closer to your legs. Bend the knees to return to the starting position.
Sit on the floor, spread the legs as wide as possible. Exhale, rotate the trunk, slowly extend the upper torso towards one leg and grasp the foot.

Sit on the floor, with legs flexed and spread, and heels touching each other. Grasp the feet or ankles and pull them as close to your groin as possible. Place elbows on the inner thighs or knees, exhale, and push the legs to the floor.