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Effect of static and hold-relax stretching techniques on isokinetic measures of knee flexion

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Effect of Static and Hold-Relax Stretching Techniques on Isokinetic Measures of Knee Flexion

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ABSTRACT

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Larry R. Gurchiek

The purpose of this study was to compare the effects of static and proprioceptive neuromuscular facilitation techniques used as a warm-up on isokinetic measures of knee flexion. Fourteen female subjects (age = 22.43 ± 2.44 years, height = 65.00 ± 2.75 inches, and weight = 131.50 ± 13.19 pounds) and 14 male subjects (age = 23.07 ± 2.64 years, height = 71.79 ± 2.46 inches, and weight = 196.36 ± 28.77 pounds) consented to participate in all testing procedures. All 28 subjects (age = 22.75 ± 2.52 years, height = 68.39 ± 4.30 inches, and weight = 163.93 ± 39.66 pounds) were habitually active and denied any recent history of knee or muscle injury.

Immediately prior to testing, subjects received one of three treatments to their dominant leg. Treatments consisted of the following: (1) no stretching or warm-up (control); (2) a modified hurdler's stretch (static), with the stretch being held for six seconds for six repetitions; or (3) a hold-relax (PNF) stretching technique using six-second isometric contractions of the hamstrings, followed by four seconds of relaxation, for six repetitions. The untreated leg served as control during static and PNF

sessions. Six maximal knee extension/flexion repetitions were performed at 180 degrees per second on a Cybex 340 dynamometer. The effects of treatment were determined by comparing the treated leg with the untreated leg. Univariate analysis was used to determine differences, and the .05 level of probability was considered significant. None of the differences between means were significant. The results of the analyses indicate that static stretching or hold-relax stretching has no significant effect on peak torque, peak torque percent bodyweight, peak torque at 45 degrees of knee flexion, torque accelerated energy, average power percent bodyweight, and total work for females, males, and female and male subjects combined.

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DEDICATION

To Joanna, Jay, and Jennifer, whose love and support made this work possible.

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CHAPTER 1

Introduction

Participants of sport, recreational, and physical events perform various physical and psychological activities as a precursor to the actual event. Many perform these activities in ritualistic fashion under the guise of increasing performance or injury prevention, while others may simply consider this a time to mobilize themselves both mentally and physically in anticipation of performance (Alter, 1988).

These pre-event activities are usually referred to as warm-up and include rhythmic submaximal exercises, consisting of general movement patterns designed to raise body temperature and/or activity specific movements designed to provide an opportunity for skill or motor pattern rehearsal.

Stretching as a component of warm-up has been utilized by athletic trainers, coaches, and physical educators in the conditioning programs designed for athletes and students. Many warm-up routines include stretching exercises of various types with a wide range of purpose and expectation. These programs have been designed and directed by athletic trainers, coaches, and physical educators with specific goals and objectives. They have also been developed and executed by the participants through trial and error in an attempt to model their preparatory activities after what they see others doing.

One of the most common practices is to include stretching or flexibility training as a component of warm-up, and a wide variety of flexibility training protocols has been developed. Exercise physiology textbooks offer conflicting information addressing principles of stretching as warm-up. McArdle, Katch, and Katch (1991) include a number of vague terms to describe general warm-up: ". . . calisthenics, stretching, and general body movements or 'loosening-up' exercises generally unrelated to the specific neuromuscular action of the anticipated performance . . ." (p. 511). E. L. Fox, Bowers, and Foss (1993) suggested flexibility exercises as a warm-up activity for the prevention of injuries and the enhancement of range of motion. Others (Alter, 1988; American Academy of Orthopaedic Surgeons, 1991; Arnheim & Prentice, 1993; Sapega, Quedenfeld, Moyer, & Butler, 1981) have been quite adamant about stretching techniques designed to increase range of motion being performed after warm-up or in the middle of a workout when muscle temperatures have risen.

Therefore, this study was designed to clarify the effects of two different types of flexibility warm-up techniques on muscular strength parameters of the knee flexors. This study specifically investigates the effects of static and hold-relax methods on the isokinetic measures of peak torque, peak torque percent bodyweight, peak torque at 45 degrees of knee flexion, torque accelerated energy, average power percent bodyweight, and total work on the knee flexion.

Significance of the Study

A thorough search of the literature produced no findings of previous research conducted to compare the effect of static and hold-relax stretching techniques, when used as a component of warm-up, on isokinetic measures of knee flexion. Observations and trends of mean values produced by the male, female, and combined group are presented, but were not statistically analyzed.

The results of this study can be applied by athletic training educators and physical education teachers in teaching undergraduate students how to develop the proper type of conditioning and training programs for various activities and athletic events. Application of these findings will better enable students to distinguish between flexibility training and flexibility warm-up and place these training techniques within training and rehabilitation programs that allow participants to receive optimal benefits.

Within the clinical setting, athletic trainers and physical therapists may better determine the benefits of flexibility warm-up as a precursor to isokinetic testing or other diagnostic tests. These findings may also provide information concerning the type of stretching to be performed. Normative data related to gender differences for isokinetic testing are also available for sports medicine practitioners and educators, physical therapists, and physical educators and will serve as reference for further research.

Delimitations

All subjects were physical education or health and wellness majors at Middle Tennessee State University. The study was limited to 14 female and 14 male students who were habitually active and denied any history of knee joint or soft tissue injury.

Instrumentation was limited to the Cybex 340 Extremity Testing System located in the Human Performance Laboratory at Middle Tennessee State University. Testing speed was 180 degrees per second, and warm-up activities were either a static stretching technique or a hold-relax stretching technique of the knee flexors.

Definition of Terms

Average power--represents work per unit of time performed during the best work repetition of a six-repetition set.

Average power as a percentage of bodyweight--the average power divided by the subject's bodyweight and expressed as a percentage (Cybex 340 System User's Manual, 1989).

Ballistic stretching--a repetitive bouncing or bobbing type of movement that utilizes the momentum of the body or body part to stretch soft tissues at the end range of motion.

Contract-Relax stretching technique--a proprioceptive neuromuscular facilitation stretching technique that is performed by passively moving a body part through a range of motion until resistance is felt in the muscle being stretched.

Control--no warm-up exercises or any stretching technique prior to testing.

Dynamometer--a mechanism used by the Cybex 340 to measure torque and control the speed of movement.

Flexibility training--a planned and regular exercise routine that can permanently and progressively increase the range of motion of a joint or set of joints over a period of time (Aten & Knight, 1978).

Flexibility warm-up--a deliberate and regular exercise performed immediately before an activity to improve performance or reduce the risk of injury in the upcoming activity (Corbin & Nobel, 1980).

Gravity effect torque--the effect of gravity on torque produced by the leg and the input adapter of the dynamometer.

Hold-Relax stretching technique--a proprioceptive neuromuscular facilitation stretching technique that is performed by passively moving a body part through a range of motion until resistance is felt in the muscle being stretched.

Isokinetic movement--a process in which a body segment accelerates to achieve a preselected and fixed angular velocity against an accommodating resistance.

Modified hurdler's stretch--a method for stretching the hamstrings/knee flexors by placing the subject in a seated position with the leg to be stretched in extension, with the opposite leg bent at the knee and the sole of the foot positioned at the medial aspect of the extended leg.

Passively flexed--a joint is moved to a position of increased flexion by an outside force not requiring any active movement by the individual or body part being stretched.

Peak torque--the maximum amount of torque created in a specific movement pattern of one repetition or series of repetitions.

Proprioceptive neuromuscular facilitation (PNF)--a technique originally developed by physical therapists to hasten the response of the neuromuscular mechanism by stimulating or inhibiting the proprioceptors and recently adapted to increase flexibility by assisting the subject in a combination of isometric or isotonic contractions and relaxation of either or both agonistic and antagonistic muscle groups.

Static stretching--moving a body part through a range of motion in a slow gradual fashion that allows a muscle or muscle group to be placed on stretch and held there for a period of time.

Torque--a force that acts to produce rotation of a body or segment around an axis. Torque is the product of the force times its perpendicular distance from the axis of rotation.

Torque accelerated energy--the amount of power a muscle or group of muscles generates during the first one-eighth second of contraction.

Total work--torque multiplied by distance of the angular displacement of the leg being measured and is represented by the total area under the curve for each direction of movement.

Hypotheses

For the purposes of this study, the following hypotheses were statistically tested:

Hypothesis 1: No significant difference will exist between the treated and untreated leg for peak torque developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

Hypothesis 2: No significant difference will exist between the treated and untreated leg for peak torque percent bodyweight developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

Hypothesis 3: No significant difference will exist between the treated and untreated leg for peak torque measured at 45 degrees of flexion developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

Hypothesis 4: No significant difference will exist between the treated and untreated leg for torque accelerated energy developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

Hypothesis 5: No significant difference will exist between the treated and untreated leg for average power percent bodyweight developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

Hypothesis 6: No significant difference will exist between the treated and untreated leg for total work developed during knee flexion at 180 degrees per second following static stretching, hold-relax stretching, or control.

CHAPTER 2

Related Literature

The review of literature is divided into four sections. Section 1 reviews general concepts of flexibility addressing first the historical background, secondly the physiology of stretching, and finally traditional methods and techniques of stretching. The second area reviewed is flexibility training and its effect on performance, followed by the effects of flexibility warm-up on subsequent performance. Finally, isokinetic devices as a measure of strength parameters are reviewed.

Although this study investigated specifically the effects of flexibility warm-up on hamstring strength, flexibility training was compared and contrasted throughout the literature review. Therefore, the distinction between a flexibility-training program and a flexibility warm-up routine must be clarified. Flexibility training is described as a planned and regular exercise routine that can increase range of motion of a joint or system of joints for a long duration and in a progressive manner (Alter, 1988; Aten & Knight, 1978; Corbin & Nobel, 1980). Flexibility warm-up may be defined as a deliberate and regular exercise that is performed immediately before an activity to improve performance or reduce the risk of injury in the subsequent activity (Alter, 1988; Aten & Knight, 1978; Corbin & Nobel, 1980).

General Concepts of Flexibility and Stretching

As a general term, flexibility has been defined as mobilization, freedom to move, or technically as the measurement of range of motion in a joint or group of joints (Alter, 1988; Corbin & Nobel, 1980; Holland, 1968; Prentice, 1983). It may be thought of as a continuum, with one end representing no movement, ankylosis, and at the other end extreme flexibility or instability (Surburg, 1983). Although it is difficult to determine when an athlete has developed an ideal level of flexibility (Aten & Knight, 1978), somewhere between the two extremes lies an optimal level that permits efficient execution of movements (Surburg, 1983). It has been suggested that flexibility implies just flexion and is actually a misnomer which should be replaced with a more appropriate term (Holland, 1968). However, it is commonly used and accepted in the fields of physical education, athletics, physical therapy, and athletic training today.

Historical Background

Flexibility has long been considered an important component of fitness and has been studied since the early 1900s. With a large number of orthopedic injuries from the war and the epidemic of polio, interest in flexibility increased through the end of the World War I decade (Corbin

& Nobel, 1980). Most investigators have indicated two major components of flexibility: static and dynamic (Alter, 1988; Corbin & Nobel, 1980; Holland, 1968; Shellock & Prentice, 1985; Stamford, 1984).

Static flexibility is the range of motion possible around a joint with no emphasis on speed (Corbin & Nobel, 1980; Holland, 1968) or the degree to which a joint can be passively moved to the end ranges of motion (Shellock & Prentice, 1985). Dynamic flexibility has been defined as the maximum range of movement that can be executed using speed of movement as a distinguishing factor (Holland, 1968) or the ability to use a range of joint motion in the performance of a physical activity at its normal or rapid rate of movement (Corbin & Nobel, 1980). Others have described dynamic flexibility as simply the resistance to motion at the joint (Stamford, 1984) or the degree to which a joint can be moved as a result of muscle contraction (Beaulieu, 1980; Shellock & Prentice, 1985).

Early studies indicated that there was little evidence of a correlation of body build, age, and skill level to flexibility (Harris, 1969). However, it was found that flexibility has a high degree of specificity by joint and by static or dynamic component (Corbin & Nobel, 1980; Harris, 1969). The review of the literature conducted by Harris (1969) revealed that no evidence indicated that flexibility exists as a general characteristic of the human body.

Cureton (1941), a physical educator and an early advocate for the importance of flexibility as a component of physical fitness, developed four standardized tests of flexibility. Trunk flexion, trunk extension, and shoulder flexibility were measured by sliding wood calipers. The fourth test was of ankle flexibility, measuring the range of movement from the end range of dorsiflexion to the end range of plantar flexion. These test-retest reliabilities were high, and a literature review by Cureton found these to be the only standardized tests at that time (Harris, 1969; Holland, 1968). These tests were later modified by McCloy and Young and then again by Hall (cited in Harris, 1969).

Leighton (1942) submitted that geometric errors were inherent in using linear assessments of rotational dimensions and developed a device for measuring joint range of motion called a flexometer. The apparatus consisted of a circular scale of 360 degrees with a weighted dial and a weighted needle. The flexometer is strapped to the body part being measured with the dial and needle pointing to zero. As the body part is moved, gravity pulls the weighted needle down. Leighton describes 13 different measurements of flexibility with reported reliabilities of .89 to .997 in the use of the flexometer.

Public and professional interest in flexibility rose in the early 1950s as the results of the Kraus-Weber Tests of Minimum Muscular Fitness received sensationalized publicity concerning "weakly" American children. Lawther (1956) and others (M. G. Fox & Atwood, 1955; Phillips, 1955) challenged the validity of the test and questioned norms concerning optimal flexibility. The central thesis of these articles addressed specificity of flexibility throughout the body and specific needs for flexibility to participate in varied activities and sports with a common question of: "How flexible does one need to be?"

A number of common devices were used to measure static and dynamic joint action, including tape measures, rulers, and calipers (Corbin & Nobel, 1980; Harris, 1969). More sophisticated instruments were developed in the 1940s and 1950s with a desire for more objective data. These instruments included arthrometers for measuring joints, flexometers which measure the degree of bending, and goniometers that measure angles. Karpovich developed the electrogoniometer (elgon) which was in essence a goniometer with a potentiometer substituted for a protractor (cited in Harris, 1969). Of all of these instruments, the most common device for measuring was reported to be some type of manual goniometer, while Leighton's flexometer appeared to be the most objective (Harris, 1969).

Kraus and Raab proposed in 1961 that poor flexibility was a result of residual neuromuscular tension particularly associated with low back pain (cited in Holland, 1968). Davis, Logan, and McKinney (1961) postulated an optimal range of motion for injury prevention, stating that stretching one well past the range of normal limits may predispose one to joint injury, just as limited ranges of joint motion well below normal may result in tearing connective tissue. Too great of an increase in flexibility may destroy the supporting function of the ligaments and joint capsule (Davis et al., 1961).

The importance of flexibility and interest of investigators in the 1950s and 1960s centered around claims for the beneficial effects of flexibility. Corbin and Nobel (1980) summarized these hypothetical benefits as prevention and care of back injuries, reducing postural afflictions associated with muscular imbalance, improving sports performance, reducing muscle injuries, and relieving some types of muscle soreness.

H. A. deVries conducted two studies to investigate the effectiveness of static stretch in relieving delayed onset muscle soreness. In the first study, 17 subjects allowed muscular distress to be induced to their wrist extensors (deVries, 1961a). Static stretching was performed on the nondominant arm immediately and at 2, 6, 20, and 22 hours after the pain-inducing exercise. Pain ratings for both arms were taken from a subjective questionnaire at 4, 8, 24, 48, and 72 hours after exercise. deVries concluded that static stretching reduced muscular soreness. Seven subjects who were suffering muscular distress were utilized in the second study (deVries, 1961a). A stretch was held for one to three minutes. Action potentials were recorded and compared for pre- and post-stretching. Six of the seven subjects exhibited reduced action potentials following a regimen of stretching. Evaluations from subjective pain surveys indicated that static stretch was effective in the relief of soreness. From the results of these studies, deVries hypothesized that the reduction in pain was associated with relaxation of local muscular spasm which he believed to be responsible for the delayed onset of muscular soreness.

Cureton (1941) and other authors (Davis et al., 1961; Leighton, 1942; Weber & Kraus, 1949) espoused the benefits of flexibility in preventing injuries. A common notion was that a "short" muscle is more likely to be overstretched, especially in a ballistic or explosive activity, and is therefore more susceptible to injury. Since the work of these early researchers, literally hundreds of books and articles have extolled the value of flexibility exercises in preventing musculotendinous injuries (Corbin & Nobel, 1980). Though much of this work is not substantiated by scientific research, many authorities in the field of sports medicine, physical education, and athletics accept this premise and use flexibility exercises for the benefits of injury prevention.

Physiology of Stretching

Biophysical factors that affect flexibility. Joint range of motion or flexibility may be limited by tendons, ligaments, capsules, aponeuroses, fascial sheaths, and other soft tissues (Holland, 1968; Luttgens, Deutsch, & Hamilton, 1992; Nordin & Frankel, 1989; Sapega et al., 1981; Thigpen, 1988). The effectiveness of each of these structures in limiting range of motion is specific for each joint. Skeletal muscle tissue possesses the properties of contractility, extensibility, and elasticity, while the other soft tissues that contribute to joint stability and limit range of motion possess only the properties of extensibility and elasticity to varying degrees, depending on tissue type (Luttgens et al., 1992).

Tendons, ligaments, and joint capsules consist of two different types of fibers, collagenous and elastic, and a ground substance. A protein thread is the basic structure of collagen. These fibers possess high tensile strength, are inextensible, and are subject to rupture rather than stretch under excessive strain (Breit, 1977; Holland, 1968). Collagen is the major organic component of all connective tissues and is organized into these various joint structures, producing varying degrees of tensile strength. Ground substance is a matrix of highly structured gel-like material that acts as a cementing substance between collagen fibers and helps stabilize the collagenous skeleton of tendons and ligaments (Nordin & Frankel, 1989). Elastic fibers are composed of sulfate polysaccharide threads combined with the protein, elastin (Breit, 1977).

Muscles, unlike tendons, joint capsules, and ligaments, are not primarily connective tissue. However, when a muscle is placed on stretch, most of the resistance to stretch is derived from the connective framework within and around the muscle, not the muscle's contractile elements (Breit, 1977; Sady, Wortman, & Blanke, 1982; Sapega et al., 1981; Thigpen, 1988). Therefore, it is most important for those individuals designing flexibility training and flexibility warm-up programs to understand and appreciate the physical factors and viscoelastic properties that control various connective tissues, as well as the tissue's mechanical response to tensile stress or stretch.

Sapega et al. (1981) define stretch as elongation or linear deformation that increases length. They define two different types of stretch and explain the term viscoelastic as follows:

> Elastic stretch represents spring-like behavior, where elongation produced by tensile loading is recovered after the load is removed. It is therefore also described as temporary or recoverable elongation. Plastic stretch refers to putty-like behavior, where the linear deformation produced by tensile stress remains even after the stress is removed. This is described as nonrecoverable or permanent elongation.
>
> The term viscoelastic describes any substance that exhibits both viscous and elastic properties. Viscous properties permit plastic or permanent deformation. . . . Elastic properties, on the other hand, result in elastic or recoverable

> deformation. . . . The preceding definitions are pertinent to range-of-motion exercise because the clinician must understand and take advantage of the fact that under tensile stress, connective tissue behaves in a viscoelastic manner. (Sapega et al., 1981, p. 59)

Another property of viscoelastic materials is their sensitivity to rate of loading and duration of the load. Norkin and Levangie (1983) stated that, generally, speaking, the higher the rate and the longer the duration of loading, the greater the deformation. They further stated that when connective tissue is subjected to sudden, prolonged, or excessive forces the limits of the tissue may be exceeded and the tissue may enter the plastic range. The plastic range denotes permanent deformity, and the tissue may no longer return to its original state. However, when the plastic range is exceeded, failure of the tissue occurs.

Sapega et al. (1981) identified a third factor that determines the proportion of elastic and plastic deformation as tissue temperature at the time of stretching. They stated, "as tissue temperature rises, stiffness decreases and extensibility increases" (Sapega et al., 1981, p. 60). Also, the degree of permanent elongation may increase by elevating tissue temperature to 103 degrees Fahrenheit. These authors were quick to caution that tissue lengthening results in some degree of tissue weakness. They believed the amount of weakening depended on the way the tissue was stretched, as well as how much it was stretched, and that warming the tissue decreased structural weakening.

The connective tissue that surrounds the muscle fibers are said to be parallel with the fibers and form a parallel elastic component, while the tendon of a muscle lies in series with the contractile fibers (Norkin & Levangie, 1983). As a muscle shortens or stretches, the connective tissue must act in parallel with the fibers. However, as the muscle contracts and shortens, the tendon is stretched, and as the muscle relaxes and lengthens to normal resting length, the tendon shortens.

Breit (1977) explains that quantifying which specific tissue contributes most to inflexibility in normal, aged, or diseased joints has long been a problem. He cited two studies: one conducted by Johns and Wright (1962) and another conducted by deVries (1971) who analyzed stiffness in mid-range and dynamic movement in general, respectively. Both of these studies determined the majority of limitation in healthy normal joints was limited by the joint capsule and muscle structures collectively, with the least amount of resistance coming from tendons and skin tissues. Johns and Wright (1962) determined that, within the mid-range of movement, the joint capsule was slightly more restrictive than the gross muscle tissue, while deVries (1971) stated the gross muscle tissue was somewhat more limited than the joint capsule during dynamic movements.

As one attempts to stretch a muscle or muscle group, the stretch is initially elastic. Then as the stretch is held, the gross structure of the muscle is further elongated as a result of the viscosity of the muscle-tendon structure enabling one to move farther through the range of motion. The events that take place during flexibility training and flexibility warm-up are complex and not completely understood. It appears that these events are controlled or modified by proprioceptors located within muscles, tendons, and other connective tissue. Most stretching techniques are based on a neurophysiological phenomenon involving the stretch reflex and, theoretically, allowing the stretch to continue for longer periods or increase the amount of tension the muscles and connective tissue will tolerate (Beaulieu, 1980; Holland, 1968; Prentice, 1983; Shellock & Prentice, 1985).

Neurological phenomena pertaining to stretching. Breit (1977) briefly describes the role of the nervous system in volitional movement:

> The quality of movement is partially dependent on the neurological information fed back from sensory organs to higher brain centers. . . . During a movement the cerebellum integrates the sensory impulses coming to the brain and helps regulate or refine motor activity. The sensory impulses originate in proprioceptors of joints and muscles and give information such as joint inhibition of desired neuromuscular function and for controlling the tone of antigravity muscles. These are but a few ways volitional movement is regulated. (p. 35)

Proprioceptors are end organs which are sensitive to stretch and pressure. Those that provide information for movement and "muscle sense" are often referred to as kinesthetic receptors. The muscle spindle, Golgi tendon organ, pacinian corpuscle, and Ruffini receptors are commonly considered to be instrumental in providing this "muscle sense" or kinesthesis (deVries, 1986).

The muscle spindle is the most abundant proprioceptor found within the muscle (Alter, 1988; E. L. Fox et al., 1993). The spindle is a modified muscle fiber contained in a capsule with a sensory nerve spiraled around its center (E. L. Fox et al., 1993). Located throughout the muscle and being facilitatory by nature, they are sensitive to stretch, causing the muscle in which they lie to contract when stimulated, thus initiating the stretch reflex (McArdle et al., 1991). Two types of intrafusal fibers are located within the spindle: nuclear bag fibers and nuclear chain fibers. The nuclear bag fibers are usually larger than the chain fibers and normally number two per spindle. Nuclear chain fibers usually range in number from four to seven (deVries, 1986; McArdle et al., 1991). Both of these types of fibers possess striated contractile elements at the ends, with the central portion being noncontractile.

The intrafusal fibers are innervated by three types of nerve fibers, two of which are afferent or sensory and one which is efferent or motor. The annulospiral nerve fibers and flower spray fibers are sensory neurons and have different functions. Annulospiral fibers are larger sensory fibers and respond directly to dynamic (phasic) stretch, as well as to the degree of stretch (static length). These primary endings are highly sensitive in phasic response, but only while change is occurring, and the static response declines sharply in frequency of impulse as the tissue becomes static. Only one annulospiral ending innervates with each spindle, but divides into many branches which coil around the central noncontractile portion of both nuclear bag fibers and nuclear chain fibers (Luttgens et al., 1992).

The flower spray afferents are not only smaller, but are less sensitive to stretch. They are found at either end of the noncontractile midsection of the nuclear chain fibers only and respond only to static length of the fiber. Since both annulospiral and flower spray endings innervate the nuclear chain fibers, Luttgens and her colleagues (Luttgens et al., 1992) surmise the nuclear chain fibers must be responsible for static response. Likewise, only the annulospiral fibers innervate the nuclear bag fibers, making these most responsible for producing strong phasic responses.

Motor neurons termed gamma fibers, innervate the contractile ends of the intrafusal fibers. Motor neurons which innervate the extrafusal fibers of skeletal muscle are classified as alpha fibers. The gamma fibers are smaller in diameter than the alpha fibers and provide the mechanism for maintaining the spindle at optimal length regardless of the gross muscle length, thus allowing maximum sensitivity (McArdle et al., 1991).

Golgi tendon organs are embedded within the muscle tendon close to the muscle tendon junction and cause relaxation of the muscle when stimulated. Unlike the spindles which lie in parallel, the Golgi tendon organs lie in series with the muscle fibers possessing an end-to-end relationship (Luttgens et al., 1992). The result of the series arrangement allows stimulation of the Golgi tendon organ as the muscle shortens in contraction and brings about a greater tension within the muscle. The Golgi tendon organs are less sensitive to stretch than the spindles and therefore require a stronger stretch to be activated (Luttgens et al., 1992). If the stretch is significant enough to elicit a response from the tendon organ, then the muscle spindle response is overridden, and the muscle relaxes, producing a protective mechanism against excessive tension which could damage tissues.

Pacinian corpuscles are found in joint capsules, ligaments, and tendon sheaths. They are relatively large end organs capable of sensing rapid changes in joint angle with rapid volleys of signals being produced, but only for brief periods. Ruffini endings are located in joint capsules and are also stimulated strongly by sudden joint movement. Each of the Ruffini receptors is responsive to changes in the range of motion, but their ability to respond is limited to a specific range. They are very sensitive, responding to changes as small as 2 degrees (Luttgens et al., 1992). These receptors are slower to respond than the pacinian corpuscles, but continue to transmit signals, allowing them to be important in sensing continuous states of pressure.

The pacinian corpuscles and Ruffini endings do not have any contractile components or motor neurons innervating and affecting these tissues as the spindle has directly and the Golgi tendon has indirectly. If these structures are overstretched, there is no mechanism to adjust the tissue length and maintain an optimal level of tension, thus providing appropriate feedback from these joint proprioceptors.

Methods and Techniques of Stretching

Although stretching techniques have changed over the years, methods employed today are based on a neurophysiological phenomenon involving the stretch reflex (Beaulieu, 1980; Holland, 1968; Prentice, 1983; Shellock & Prentice, 1985). There are three general classifications or types of stretching: ballistic, static, and proprioceptive neuromuscular facilitation (PNF) techniques. Ballistic stretching which is usually described as bouncing or bobbing in repeated rhythmic motions or patterns is probably one of the oldest stretching techniques (Beaulieu, 1980; Harris, 1969; Holland, 1968). A second technique places a muscle on stretch to a position of mild discomfort and then holds that position for a specified period of time and is referred to as static stretching. This technique gained preference in the late 1960s due to deVries' work which postulated decreased muscle soreness through the use of static methods (Cornelius, 1978). The third classification of stretching techniques was popularized by Knott and Voss (1968) and has been used extensively in physical therapy. These techniques are commonly termed proprioceptive neuromuscular facilitation techniques.

A great deal of controversy developed, in the early 1980s, over which of the different flexibility techniques were most effective in increasing flexibility, and a number of studies were performed and appeared in the literature throughout the decade (Etnyre & Lee, 1987). Today the controversy remains complicated due to inconsistent terminology and protocols and the lack of research on ballistic flexibility and dynamic range of motion. Most studies focused on flexibility training and concentrated on differences in static range of motion, with very few studies examining the effects of the stretching programs on performance.

Irrespective of which stretching technique one practices or whether or not the stretching routine is designed for warm-up or increased range of motion, the optimal stretching program should address four factors, as stated by Alter (1988): the intensity of stretch, the duration of stretch, the number of movements or stretches in a given period, and the velocity of the stretch or movement pattern. All stretching techniques attempt to decrease resistance in the target muscle by lengthening connective tissue or by relaxing the myotatic reflex (Surburg, 1983).

Ballistic stretching. Ballistic, the oldest method of stretching, can be traced back to Per Henrik Ling at the Royal Gymnastic Institute in Sweden in 1843, but the need to incorporate flexibility training into strength and conditioning programs was not apparent until the onset of the two world wars (Norman, 1970). Proponents of this method usually recommend performing ballistic exercise with each muscle group for a period up to 30 seconds (Hardy & Jones, 1986) or up to one minute (deVries, 1962). Ballistic stretches should be performed in series, gradually increasing the length of swing to a maximum, with repetitions ranging in number from 8 to 12 for beginners and up to 40 or more for well-trained athletes (Alter, 1988). Alter (1988) stated some advantages of ballistic stretching were: the development of camaraderie when done in cadence in team warm-up, beneficial gains in developing dynamic flexibility, less boring than static stretching, and an effective means of increasing flexibility.

Most recommendations today for a flexibility program would not include ballistic stretching as a preferred method for increasing range of motion (American Academy of Orthopaedic Surgeons, 1991; Arnheim & Prentice, 1993; Etnyre & Lee, 1987). Most believe that injury or soreness will result if sedentary individuals perform an abrupt stretch (American Academy of Orthopaedic Surgeons, 1991; Arnheim & Prentice, 1993; Beaulieu, 1980; deVries, 1986). However, Arnheim and Prentice (1993) state that there is little chance of a well-conditioned athlete injuring himself/herself through ballistic stretching.

By initiating movement of the body or body part and then allowing the weight of the body part to carry it through the range of motion, one creates momentum, promoting an increase in range past the limits of tight muscles and connective tissue. This creates a quick stretch on muscles and connective tissue and also elicits the myotatic or stretch reflex.

Other arguments against ballistic stretching include tissue adaptation and neurological adaptation. As stated earlier, viscoelastic tissues that are stretched too rapidly do not have time to adapt, and optimum flexibility cannot be developed. Most research indicates that optimal and more permanent lengthening occurs with lower force and longer duration (Alter, 1988). Neurological adaptation cannot take place in the time it takes one to bounce down and touch their toes. Also, the frequency of response of stretch receptors is increased with movements of higher velocity and diminished by lower velocity movements. As one performs movements quickly, the stretch receptors do not have time to adapt and continue to send rapid volleys of signals--again, initiating the stretch reflex without enough time to bring about a stimulation of the Golgi tendon organ.

With this information available one may still consider that most all athletic activities and skills are ballistic in nature. In order for participants to move in skillful and efficient patterns, they must perform these patterns ballistically. Most would choose to practice or rehearse those activities with formal and specific movement patterns as close to the actual event as possible.

Static stretching. Static stretching has been widely accepted as a method of improving flexibility (Prentice, 1983), with many authorities preferring it to ballistic stretching (Alter, 1988). H. A. deVries was one of the first who suggested the superiority of static methods because of the following: it requires less energy than ballistic methods, it will probably result in less muscle soreness, and it can provide more quality relief from muscular distress (Alter, 1988). deVries (1961a) found no significant differences in flexibility gains between static and ballistic stretching and therefore preferred the use of static methods.

Static stretching methods attempt to overcome the myotatic reflex through slow prolonged stretches, thus not provoking the stretch reflex, but possibly producing tension within the tendon to produce stimulation of the Golgi tendon organ and the subsequent inhibitory effects of the reverse myotatic reflex (deVries, 1986; Nordin & Frankel, 1989).

The recommendation for an optimal holding time of the stretch varies from as little as 3 seconds to as much as 60 seconds (Arnheim & Prentice, 1993), with most authorities suggesting a time of 10 to 30 seconds (Etnyre & Lee, 1987; E. L. Fox et al., 1993). Three to four repetitions for each body part are usually recommended (Arnheim & Prentice, 1993; E. L. Fox et al., 1993). E. L. Fox et al. (1993) state that some authorities would suggest static stretching has some negative components and would argue that it can be boring resulting in poor compliance, while others contend that, if performed habitually, it may lead athletes to use static stretching techniques exclusively and not incorporate any ballistic training into their routine.

Proprioceptive neuromuscular facilitation stretching.

Proprioceptive neuromuscular facilitation techniques were originally developed by Kabatt in association with Knott and Voss (1968). This method utilized diagonal patterns of movement to treat patients suffering from paralysis, a limited range of motion, and/or loss of strength. The term was defined by its originators as follows: techniques that are useful in promoting or hastening the response of the neuromuscular mechanism by stimulating the proprioceptors (Knott & Voss, 1968). Knott and Voss extended the application of these techniques to treat a variety of patients with limited range of motion and strength. A simpler one-dimensional approach (movement and exercise in one plane) has been widely utilized in flexibility training and flexibility warm-up programs (Arnheim & Prentice, 1993; Holt, Travis, & Okita, 1970; Prentice, 1983; Surburg, 1981).

Although a variety of PNF techniques exists today, all utilize muscle relaxation, reciprocal inhibition, or a combination of each. Muscle facilitation and inhibition are produced by muscular resistance of concentric, eccentric, or isometric contractions. Most techniques require active muscle contractions, ranging from 5 to 10 seconds of the target muscles, to bring about the desired response (Etnyre & Lee, 1987). An isometric contraction of the muscle placed on stretch will be followed by relaxation of the same muscle due to autogenic inhibition (Alter, 1988; Cornelius, 1981; Prentice, 1983; Tanigawa, 1972). The relaxation due to inhibition will then allow for greater range of motion as the relaxed muscle is again placed on stretch.

Contract-relax and hold-relax are two PNF techniques commonly used today in athletic training and physical therapy settings and are described as follows by the

American Academy of Orthopaedic Surgeons (1991). The contract-relax method begins as the subject's affected body part is moved passively until resistance is felt. The athlete is then told to contract the antagonistic (muscle to be stretched) muscle isotonically. Movement is resisted as much as possible by the athletic trainer or therapist for 6 to 10 seconds or until fatigue is felt by the operator. The subject is then instructed to let go or relax for up to five seconds. The trainer or therapist then moves the limb to a new stretch position. The exercise is usually repeated two or three times.

The second technique, hold-relax, is often inappropriately referred to as contract-relax and is a source of confusion throughout the literature. The two techniques are similar; however, the hold-relax technique utilizes a maximum isometric contraction during the resistance phase as motion is resisted for 6 to 10 seconds or the onset of fatigue. The subject is then instructed to relax for up to five seconds, and the body part is passively or actively moved to a new position. This exercise is repeated two or three times.

Etnyre and Lee (1987) compared a number of studies and found that none of the studies examined concluded that either static stretching or ballistic stretching was significantly better than proprioceptive neuromuscular facilitation techniques for producing an increase in range of motion. The superiority of proprioceptive neuromuscular facilitation techniques has also been claimed by Arnheim and Prentice (1993), Cornelius (1983), Holt et al. (1970), Prentice (1983), Sady et al. (1982), Surburg (1983), and Tanigawa (1972). Alter (1988) cited various authors who endorsed proprioceptive neuromuscular facilitation techniques with a variety of claims and potential benefits, including greater strength, better muscular balance across the joint, greater joint stability, improved circulation and endurance, enhanced coordination, superior relaxation of muscles, and greater ease of passive motion.

Although there are many proponents of proprioceptive neuromuscular facilitation techniques and many potential advantages cited throughout the literature, there are also some disadvantages. These techniques require the assistance of a partner that is knowledgeable in the application techniques for, if performed incorrectly, they may cause injury (Cornelius, 1983). These techniques are not always comfortable and may cause some pain, requiring the participants to be highly motivated (Moore & Hutton, 1980).

Flexibility Training and Performance

Review of Related Studies

Many authors have alluded to the benefits of flexibility training for the purposes of increasing performance (Aten & Knight, 1978; Beaulieu, 1980; Corbin & Nobel, 1980; Cureton, 1941; Holland, 1968; Prentice, 1983;

Stamford, 1984). Holland (1968) states that, because of the limited and conflicting data reported, it is difficult to hypothesize regarding the relationship between improved flexibility and human motor performance, but they are probably not as highly correlated as once believed. With much attention focused on flexibility, it is possible that many of the claims made for the importance of flexibility in increasing performance may have been generalizations beyond the facts (Corbin & Nobel, 1980). Some of the confusion may stem from the fact that much of the research has been laboratory research. In an attempt to control or eliminate specific components and unrelated factors, the experimenter may be establishing unrealistic conditions.

Dintiman (1964, 1965a) used a flexibility-training program, a weight-training program, and a combination of both and compared the effects of each on running speed. One hundred and forty-five subjects were randomly assigned to one of five training groups to complete an eight-week training program. Group assignments were as follows: flexibility and sprint training; weight training and sprint training; flexibility, weight training, and sprint training; sprint training alone (control 1); and inactive (control 2). Before and after the eight-week training program, the subjects were tested for flexibility, leg strength, and running speed. Dintiman (1965a) found that the two groups that received the flexibility increased significantly in each of the areas measured from pre-test to post-test. The two groups that received strength training increased significantly in leg strength. He concluded that neither the flexibility nor strength training when combined with traditional sprint training techniques had any significant effect on sprinting speed. However, the combination of both flexibility and strength training with traditional sprint training techniques did increase running speed significantly more than sprint training alone. Dintiman emphasized the importance of both static and dynamic flexibility training when designing programs to develop running speed.

Norman (1970) investigated the effects of a passive, partner-assisted flexibility training program of the quadriceps and hamstring muscle groups on velocity of leg extension at the knee. Twenty-nine male students with a mean age of 19 volunteered for the study and were randomly assigned to one of three groups. Group 1 participated in a flexibility training program designed to elongate the hamstrings. Group 2 completed the same exercises as group 1 for hamstring stretching, but also performed three extra quadriceps stretching exercises. Both of these groups exercised four evenings each week for six weeks, while group 3 served as control and participated in pre-testing and post-testing with no flexibility training. Norman found that both experimental groups significantly increased hip flexion, while the flexibility routine for quadriceps stretching was not significantly effective at increasing knee flexion. Velocity of leg extension at the knee was significantly improved for group 2 only.

Carr (1971) cites a study conducted by Nickason in which a PNF technique, reversal of antagonist, was utilized, along with resistive exercise, to determine its effect on baseball-throwing velocity. Strength and range of motion of the throwing arm were also measured. Physical education students at Southern Illinois University volunteered to participate in this study and were randomly assigned to one of three groups. Control, PNF, and progressive-resistive exercise constituted the three groups. Wrist extension for the PNF group was the only range of motion variable to increase significantly among or between groups. The progressive-resistive exercise group produced a significant reduction of shoulder horizontal extension, and both training programs had a negative effect on ball-throwing velocity. The authors postulated that PNF stretching exercises had reduced the tension present in the muscle, thereby diminishing the muscle's ability to produce force. Nickason further hypothesized the decreased velocity may be attributed to resistance that was applied in different movement patterns than were normally used by the subjects and this may have caused the subjects to alter their throwing pattern. Training at a slower rate of movement than is normally used in throwing was yet another suggestion from Nickason for reduced throwing velocity.

Carr (1971) used 26 volunteer subjects from physical education classes at Southern Illinois University to examine the effects of slow stretch and PNF-reversal of antagonist on sprinting velocity. The subjects were assigned to three groups (group 1--control, group 2--slow stretch, and group 3--PNF), based on the subject's running velocity to equate each group's mean running velocity. Each subject was pre-tested and post-tested for hip flexibility, and pre-training and post-training filming was completed to measure linear velocity, stride cycle length, and angular velocity of lower limb segments. Groups 2 and 3 underwent seven weeks of flexibility training designed to increase hip flexibility. Group 1 did not receive any training during this period. Both slow stretch and the PNF-reversal of antagonist techniques used in this study produced a significant increase in sprinting velocity, but neither the slow stretch nor PNF technique caused the training groups to change more than the other. The slow stretch and PNF training had no effect on stride cycle length or angular velocity of the lower limb segments. Carr theorized that the increase in sprinting velocity did not result because of increases in stride length or rate of movement of lower limb segments, but possibly strength may have been developed during the training, causing the increase in sprinting velocity.

Jones (1973) explored the effects of changes in ankle flexibility and ankle exercises on the vertical jump of boys in grades 4 through 7. Pre-test and post-test data were recorded in conjunction with the six-week training program. A total of 120 boys participated in the experiment, with the experimental group completing eight specific ankle flexibility exercises five times each week. Jones found that the utilization of the exercises did not result in any significant improvement in the vertical jump or ankle range of motion for all grades combined.

In a study designed to examine the effects of three different flexibility training exercises on performance of the 50-yard dash, Greene (1974) selected 104 high school females enrolled in high school physical education classes as subjects to participate in a training program. The subjects were randomly assigned to one of two groups. The experimental group participated in a specialized flexibility training program consisting of cross-legged toe-touching, hurdler's stretch, and inverted leg scissor, plus regular physical education warm-up exercises. The control group participated in only the regular physical education warm-up exercises. Both groups participated daily for a six-week training period. A pre-test and post-test were conducted before and after the training period and consisted of the best of two trials in a 50-yard dash. Greene concluded that the static stretching exercises did not significantly increase performance in the 50-yard dash.

Early (1975) compared the effects of agility and flexibility training on volleyball players. Nineteen male volunteer subjects from Eastern Kentucky University were divided into two groups, with 10 players from the varsity volleyball team serving as the experimental group and 9 other students serving as a nontraining control group. Both groups were tested three times. Test 1 was administered to the experimental group prior to the 10-week training program. Test 2 was given five weeks later, and test 3 was given at the completion of the 10-week program. The experimental group was subjected to specialized training designed to improve flexibility and agility, while the control group did not participate in any specialized training. Early found that the experimental group did not significantly improve their score on the tests that were designed to measure volleyball-playing ability.

All of the preceding studies investigated the effects of flexibility training or flexibility training combined with warm-up, strength training, or other training techniques on subsequent motor performance. Very few of the studies (Carr, 1971; Dintiman, 1964, 1965a; High & Jeziorowski, 1988; Norman, 1970) report any significant change, with no consistent trends for increase in performance within each of the studies.

The relationship between muscle length and strength has not been adequately researched (Hornsby, Nicholson, Gossman, & Culpepper, 1987). The few studies that have been conducted have produced conflicting results. Hlasney (1988) claims that past research may indicate a prolonged stretching program causes a significant decrease in muscle strength. He further states, "not only has a decrease in torque been seen, but also decrease in the total area under the length-tension curve and a change at the angle at which peak torque occurs" (Hlasney, 1988, p. 1). Both Hlasney (1988) and Remington (cited in Hlasney, 1988) report significant decreases in peak torque and the area under the curve after subjecting the subjects to a PNF regime.

Movement dysfunction associated with length-associated changes in muscle was reported by Gossman, Sahrmann, and Rose (1982). They stated that these length-associated changes can occur in a relatively short period of time, ranging from a few hours to a few weeks, and that the results of these changes can be deleterious, as well as beneficial. The term stretch-weakness was defined as "the effect of muscles remaining in an elongated condition beyond the neutral physiological rest position, but not beyond the normal range of motion" (Gossman et al., 1982, p. 1799).

Inherent Muscle Length and Strength Parameters

Gossman, Delitto, and Rose (1983) studied the relationship between imposed hamstring muscle length and torque production in 26 healthy men and women. Two groups were examined: 13 with "loose" hamstrings and 13 with "tight" hamstrings. Maximum isometric contractions were performed, and peak torque was measured at the following hip angles: 15, 30, 45, 60, 75, and 90 degrees. Isometric torque was measured on a Cybex II dynamometer, with the subject seated with the knee positioned at 45 degrees of flexion.

When comparing the "loose" and "tight" groups, a greater rate of rise in torque production occurred in the "tight" group. The shorter muscle generated a greater magnitude of force, regardless of the imposed length.

In a follow-up study, Gossman, Clendaniel, Delitto, Katholi, and Rose (1984) examined the same relationship in 42 healthy women. The subjects were divided into three groups based on resting hamstring length: tight, moderate, or loose. The same procedures were utilized, and a change in peak torque was observed as a function of hip angle. With the exception of the position of 60 degrees hip flexion, no differences were noted between the groups for peak torque or rate of rise of peak torque production between tight and loose hamstrings.

These data disagree with a previous study by Gossman et al. (1983) which found a greater rise in slope and magnitude of force in tight muscles. Gossman et al. (1984) suggested this may be due to a gender bias and stated further their 1984 study may place the issue of "stretch weakness" in question.

Hornsby et al. (1987) investigated the relationship between inherent muscle length of plantar flexors and peak torque produced by isometric contractions of the plantar flexors. Fifty-nine women participated in the study, with peak torques recorded at 7 degrees dorsiflexion, 0 degrees or neutral position, and 30 degrees of plantar flexion. Women with tight plantar flexors comprised the first quartile, and women with loose plantar flexors represented the fourth quartile. Range of motion values were recorded for each subject with the knee flexed to 90 degrees flexion and with the knee straight at 0 degrees flexion. Testing was also performed with the knee flexed to 90 degrees and in complete extension. This allowed the investigators to focus on both one- and two-joint muscles as they attempted to distinguish between any differences in muscle length-tension relationships. The gastrocnemius, a two-joint muscle, crosses both ankle and knee joints, while the soleus crosses only the ankle joint.

The results indicated that torque produced by the tight-muscle group was significantly greater than that of the loose-muscle group at each ankle position and both knee positions. These results supported the findings of Gossman et al. (1983) who found that a greater magnitude of tension was produced by the tight hamstring-muscle group in comparison with the loose hamstring-muscle group. However, the results did not support the follow-up study of Gossman et al. (1984) which reported that no difference existed between tight and loose hamstring muscles in terms of magnitude of peak torque, except at 60 degrees of hip flexion.

Hornsby et al. (1987) offered two explanations for tight-muscle groups producing significantly more torque than loose-muscle groups. The tighter muscle may present a more optimal overlap or alignment of actin and myosin filaments and therefore allow for greater production of force. Hornsby and his associates believed this "overlap deficit" resulting in inferior cross-bridge interaction may relate to muscle stretch-weakness as previously described. The second explanation involved the influence of connective tissue as a viscoelastic component capable of creating passive tension within the muscle-tendon unit. It was theorized that the connective tissue of tighter muscles have more inherent tension than loose muscles. The tighter muscles would be able to create a stretch on the connective tissue more quickly than the loose muscles with loose or stretched connective tissue, resulting in great force generated.

Millsaps (1984) and Loving (1984) also conducted research studies concerning the relationship between hamstring muscle length and strength parameters. However, unlike the previous studies which utilized isometric measurements, Millsaps and Loving both measured isokinetic torque and power production.

Millsaps (1984) used 60 male volunteer subjects between the ages of 20 and 40 to characterize the relationship between inherent hamstring length. The subjects were partitioned into quartiles, with the first quartile being represented by 15 subjects with tight hamstrings and the fourth quartile composed of 15 subjects with loose hamstrings. All measurements were made using a noninvasive clinical procedure with a standard plastic goniometer. The 30 subjects in both groups were then tested on the Cybex II isokinetic dynamometer.

Subjects were required to perform four maximal knee extension/flexion repetitions at a speed of 180 degrees per second, with seat-back adjustments being made to accommodate each of the following hip angles: 15, 30, 45, 60, 75, 90, 105, and 120 degrees of hip flexion. Each of these angles was presented at random to negate the effect of treatment order, and a two-minute rest was administered between each set of four repetitions. Data were gathered on peak torque and torque at 15 and 70 degrees of knee flexion. Power was also measured at each hip angle. A Cybex data-reduction computer was used to measure the greatest torque in the first three repetitions only. Power was determined by dividing the total work in all four repetitions by the total time of contraction.

The results indicated no significant differences between the means of the two groups at any of the hip angles. However, a significant curvilinear relationship between peak torque and hip angles was obtained for the two groups. The analysis of mean power values for each group also indicated no significant difference for the interaction of group and hip angle, nor was the main effect of the groups statistically significant.

Millsaps (1984) concluded the curvilinear relationship that was demonstrated between peak torque and hip angle substantiated claims an optimal length at which a muscle generates its greatest tension exists, but the evidence was insufficient to support the hypothesis that possessing tight hamstring muscles produced greater peak torque, power, and torque at functional ranges of knee flexion at 15 and 70 degrees flexion, when compared to those with loose hamstrings.

The design of Loving's (1984) study was identical to Millsaps' (1984) design, but utilized 60 healthy adult females as subjects. After being partitioned into quartiles, those demonstrating tight hamstrings were placed in the first quartile, and the loose-hamstring group was assigned to the fourth quartile. Methodology for testing procedure was the same as in Millsaps' (1984) study, with subjects required to perform four maximal knee extension/ flexion repetitions on the Cybex II dynamometer at a speed of 180 degrees per second. Eight different hip angles were used, ranging from 15 to 120 degrees of hip flexion in 15-degree increments. Peak torque, torque at 15 and 70 degrees of knee flexion, and power were measured at each hip angle.

A maximal mean peak torque of 38.00 foot-pounds occurred at 75 degrees of hip flexion for the tight-hamstring group, while the maximal mean peak torque for the loose-hamstring group was reported to be 36.20 foot-pounds at 90 degrees of hip flexion. The interaction of group and hip angle was not statistically significant. Therefore, there was no difference in mean peak torque between the two groups at each hip angle. However, the main effects of angle were statistically significant as the means for the combined groups displayed a significant curvilinear trend.

Maximal mean peak power was found to be 110.31 watts and occurred at 75 degrees of hip flexion for the tight group. The maximal mean peak power for the loose group occurred at 60 degrees and was 113.73 watts. The analysis between loose and tight groups again produced no significant difference in power production. The results obtained by Loving (1984) were quite similar to those of Millsaps (1984). Both of these studies contradict previous studies which found a significant difference between tight and loose hamstrings in terms of torque production. Both Millsaps and Loving cited differences in types of testing as a probable cause for differing results. Previous studies used isometric testing on the Cybex, while these two studies utilized isokinetic methods which allowed subjects a complete range of motion.

Effects of Flexibility Training on Hamstring Strength

Gladson (1984) utilized 22 healthy adult males with "tight" hamstrings to investigate the effects of an increase in resting muscle length on isometric torque production in the hamstrings. Peak isometric torque was measured at eight hip angles (15, 30, 45, 60, 75, 90, 105, and 120 degrees), with the knee stabilized in 45 degrees of flexion.

Gladson's (1984) investigation examined two aspects of change that accord as a function of increasing resting muscle length: the change in length-tension relationship and the change in either magnitude or location of peak torque. Indirect measurements of relative hamstring length were taken with a standard clinical goniometer. A Cybex II dynamometer was used to measure peak isometric torque of the hamstrings. Subjects were divided into two groups, with group 1 participating in a two-week stretching program, while group 2 served as control. At the end of two weeks, all subjects in both groups were retested for muscle length and isometric torque production. No differences in torque production between sessions were found in either group. However, a significant difference in peak torque as a result of hip angle was found. Gladson stated the curvilinear relationship between hip angle and torque indicates there is an optimal length at which muscle develops its greatest torque.

Fitzsimmons (1984) studied both the long- and short-term effects of increasing the resting muscle length on peak isometric force produced by the hamstrings in 20 healthy women with "tight" hamstrings. All subjects were measured indirectly with a standard clinical goniometer, and isometric peak torque was recorded at eight hip angles, with the knee fixed at 45 degrees of flexion as in Gladson's (1984) study.

Subjects were randomly assigned to one of two groups. Group 1 participated in a two-week active stretching program, and subjects in group 2 served as controls. All subjects were retested at the end of two weeks and again at the end of four weeks for muscle length and peak torque. Comparisons were then made between subjects who increased muscle length and those where muscle length did not increase. No significant differences in muscle length were found between the control and experimental groups. Fitzsimmons (1984) suggested a high variability of length changes within the population and poor compliance with the home program as a possible cause for the varied response. No significant differences were found in peak torque or location of peak torque between exercising and nonexercising groups.

A statistically significant curvilinear trend was seen for peak torque at each hip angle, which Fitzsimmons (1984) cited as an indication of an optimum length at which a muscle will generate peak torque. The greatest peak torque in this study was displayed at 105 degrees for both groups.

In a more recent similar study, Ogletree (1991) investigated the relationship between knee joint range of motion and isometric torque production of hamstrings with males ($\underline{n}$ = 4) and females ($\underline{n}$ = 12). Testing for muscle strength parameters was performed on a Biodex isokinetic dynamometer, and range of motion was measured indirectly with a standard goniometer. Subjects were seated on the Biodex, with hips flexed to 90 degrees with the knee joint fixed at 45 and 90 degrees; pre-test and post-test isometric measurements for peak torque were made.

Subjects were instructed in a static stretching program to be performed actively on their own, five times a week for four weeks, to increase range of motion. At the end of the four week program, significant increases in joint range of motion were noted; however, no significant change was seen in peak torque at either 45 or 90 degrees. Ogletree (1991) postulated that a learning effect may have occurred from pre-test to post-test or possibly inconsistent efforts by the subjects existed during pre-test and post-test sessions as some subjects complained of cramps during the pre-test and seemed fearful of a recurrence. Ogletree explained that the increase in range of motion may have been obtained by a lengthening or stretching of connective tissues and not the muscle. Stretching exercises are known to lengthen connective tissue and not the actual muscle fiber as previously stated. Results of this study were consistent with Fitzsimmons' (1984) and Gladson's (1984) findings.

High and Jeziorowski (1988) designed a study to investigate the effect of active stretching on range of motion, sprint speed, and quadriceps/hamstring peak torque performance. Healthy, sedentary subjects, ranging in age from 19 to 21 years, were assigned randomly to the experimental or control group. A six-week training period called for the experimental group to perform 10 static stretches with a 10-second hold on the hamstrings and hip flexors four to five times per week. Pre-test and post-test measurements were taken for range of motion, sprint speed, and peak torque. Sprint speed was determined by using the mean of two 40-yard dashes, while peak torque was measured isokinetically on a Cybex system at 60 degrees per second, with each subject performing five repetitions of knee extension/flexion. Range of motion was assessed with the manual goniometer. High and Jeziorowski found a significant increase in hip extension range of motion and peak torque generated by the hamstrings. No significant differences were seen in 40-yard sprint speeds, but an inverse relationship was noted with range of motion characteristics.

Flexibility Warm-Up and Performance

Review of Related Studies

B. A. Pacheco (1957) conducted two experiments to determine the effects of flexibility warm-up and other warm-up activities on performance in the vertical jump. In both experiments, she found that performance was improved for each individual and by each of the three exercises, with the average gains showing highly statistical significance. Pacheco utilized 10 graduate students (nine males and one female) in experiment 1. Subjects were required to perform six jumps, with a 90-second rest period between each jump on each day of testing. A different warm-up activity was performed before jumping on each day. The preliminary warm-up activities consisted of no activity (which served as control) and three other exercises: a static stretching technique of lunging, with one foot placed about 22 inches in front of the other and held there for 15 seconds before changing foot positions and holding the position again for 15 seconds, alternating back and forth for three minutes; stationary running for three minutes; and six deep knee bends completed in 30 seconds for four sets with a 15-second rest between each set for a total warm-up time of approximately three minutes. Experiment 2 utilized only deep knee bends for flexibility warm-up activities and measured the effects of these on jumping performance of 50 male university students. Each was required to perform five instead of six jumps on different days, with deep knee bends as warm-up activity on one day and deep knee bends being performed after jumping on the other day. The order of testing was randomized to minimize the effect of order. Observed gains averaged from 2.9 percent to 7.3 percent.

deVries (1961c) hypothesized that motor performance could be improved by reducing the resistance of the muscles which are antagonistic to the desired movement. He designed three experiments to determine the effects of stretching and relaxation techniques used as warm-up on gross motor performance. In the first experiment, 11 track athletes were required to perform the 220-yard run. Warm-up consisted of running, static stretching, ballistic stretching, and use of a relaxation technique. No significant increase in performance was noted in any of the warm-up techniques. The second experiment used times in the 50-yard swim as a measure of performance. Sixteen male members of an advanced swim class participated in three different warm-up routines consisting of the following: no activity, a combination of static stretch and a relaxation technique, and a combination hot shower and 100-yard swim. Again, no significant differences were seen for any of the warm-up routines. In the final experiment, deVries measured the effects of no activity, combination static stretching and a relaxation technique, and ballistic stretching exercises on jumping ability. Twenty-one male members of a "corrective" physical education class were pre-tested and post-tested in the standing long jump, with the best of three trials being used as a criterion measure. Ballistic stretching did seem to have a positive effect as a warm-up to the standing long jump. He concluded that there was no evidence to suggest that resistance offered by antagonistic muscles could be reduced through preliminary stretching or relaxation techniques.

In another study, deVries (1963) examined what he termed the looseness factor in sprinting. He postulated that this factor was particularly important in high-level performances involving high speed, with alternate limb movement, such as sprint running or sprint swimming. However, experiments in which range of motion was significantly improved after the static stretch as a warm-up failed to significantly affect oxygen consumption and running times of the 100-yard dash. Again, deVries was unable to confirm his hypothesis of decreasing negative forces or resistance by increasing flexibility and therefore increasing performance in running and improving speed.

Effects of Flexibility Warm-Up on Hamstring Strength

In Axtell's (1985) study, stretching was one of the four warm-up procedures investigated for the effect different warm-up routines have on isokinetic muscle testing. Using 15 female volunteers from graduate physical education classes, he measured peak torque of knee flexors and extensors, using a Cybex II dynamometer at speeds of 30, 60, 180, and 300 degrees per second. Each subject was required to undergo one of the five different treatment procedures, on five different occasions, prior to testing on the Cybex. The five procedures consisted of the following: no treatment, which served as control; static stretching; 10 submaximal (50%) isokinetic repetitions at speeds of 90, 150, and 240 degrees per second; five-minute submaximal bicycle ride at a rate of 90 revolutions per minute at a resistance to provide 50 percent of their maximum heart rate; and a 15-minute bicycle ride of the same rate and resistance. Axtell found that there was no significant difference between the type of warm-up administered and knee flexion/extension torques in all but one of the speeds tested. A significant difference was found between the type of warm-up at 60 degrees per second. The two submaximal bicycle warm-ups both produced significantly higher mean torque recordings at 60 degrees per second.

Static stretching as a warm-up consisted of two stretching techniques designed to stretch the knee flexors and plantar flexors. Stretch 1, a modified hurdler's stretch, required the subject to sit on the floor with one leg flexed at the knee, with the bottom of the foot placed upon the medial aspect of the opposite knee. Subjects were instructed to lean forward over the extended leg as far as possible and hold the position for six seconds, then relax for six seconds. Stretch 2 was designed to stretch the posterior aspect of the leg, primarily the plantar flexors of the foot. Subjects stood facing a wall and placed both hands on the wall, with arms extended and both feet placed three to five feet from the base of the wall. The subject then lowered herself to the wall, as in performing a push-up, while keeping her heels on the floor. She then held the static stretch for six seconds, followed by a six-second rest period as in stretch 1. Both stretches were repeated six times, and all six stretches were performed using the same leg before switching to the opposite leg.

After completion of the stretching warm-up and all other warm-up protocols, the subject was allowed a three-minute rest prior to the beginning of the test. The subjects then performed three maximal voluntary efforts of extension and flexion on the Cybex prior to the actual test at each speed. These maximal efforts were performed for each testing session, regardless of the specified warm-up. Mean peak torque values for 180 degrees per second were reported as follows: (1) for the right knee flexors with no warm-up, 64.71 foot-pounds, and with stretch, 60.03 foot-pounds, and (2) for left knee flexors with no warm-up, 61.36 foot-pounds, and with stretch and warm-up, 59.76 foot-pounds.

Wiktorsson-Moller, Oberg, Ekstrand, and Gillquist (1983) also studied the effects of various warm-up routines on strength parameters of the lower limb. In addition, they compared the effects of these various warm-up protocols on changes in joint range of motion. Massage, general warm-up, warm-up and massage, and warm-up with stretch were administered as pre-event warm-up to eight male volunteers. General warm-up was performed on a bicycle ergometer, with a load of 50 watts for 15 minutes. Massage was completed by a professional masseur, with treatment times ranging from 6 to 15 minutes and with an average treatment time of 12 minutes. Stretching consisted of hold-relax stretching technique, with a maximal isometric contraction of the target muscle lasting four to six seconds, followed by a two-second relaxation phase, then an eight-second passive stretch, moving the limb through an increased range of motion. This cycle was repeated five to six times for each muscle or muscle group, with the entire stretching routine lasting approximately 15 minutes. A Cybex II was utilized in a standard knee extension/flexion protocol at speeds of 0, 30, and 180 degrees per second. The isometric measurement was made with the knee in 60 degrees of flexion, and the best effort was then used in analysis at each testing speed. Range of motion of each of the six tested movements was increased due to warming-up and stretch in combination. Both quadriceps and hamstring peak torque decreased, although not significantly at all of the test speeds. Only massage was found to have a significant effect on strength, producing diminished peak torque recordings of the hamstrings at 30 and 180 degrees per second. The quadriceps strength was also reduced in the isometric contraction following massage. The authors speculated that this decrease in peak torque following massage may be the result of the manual elongation of the muscle. However, this postulate may be questioned as massage was not effective in increasing joint range of motion in five of the six tested movements. Only ankle dorsiflexion was significantly increased by massage. The effects of stretch may have diminished, as the entire stretching program lasted 15 minutes. The target muscles were not secured for testing in the elongated state immediately before testing. At 180 degrees per second, the mean value for hamstring peak torque for initial recordings was 102.55 foot-pounds (SD = 4.06); after warm-up with stretch, the mean value was 101.07 foot-pounds (SD = 3.47).

Thigpen (1988) investigated the effects of flexibility warm-up on torque production of the knee flexors and extensors. She utilized 30-second static toe-touching with 24 male, nonsedentary subjects, ranging in age from 22 to 39 years. Subjects were asked to perform four maximal efforts in extension and flexion at speeds of 0, 60, 150, and 240 degrees per second on the Cybex II. This was done after a control situation of no activity or static stretching on two consecutive days. However, on both testing days, five minutes of stationary cycling of no load preceded the stretching or control activity. Stretch was found to have no effect on peak torque production of the hamstrings or quadriceps. Both the hamstrings and quadriceps torques were measured at 45 degrees of knee flexion. However, there was no statistical difference between mean values recorded following the stretching techniques. The amount of time to peak torque was also unaffected by static stretch. Pre-testing to post-testing at 150 degrees per second indicated the mean values of peak torque and standard deviations of hamstring production during the control condition were 83.66 foot-pounds (SD = 19.54) to 84.58 foot-pounds (SD = 18.97), respectively. Pretesting to post-testing during the experimental condition in which warm-up and static stretching were applied between testing sessions resulted in mean values of 87.95 foot-pounds (SD = 15.58) and 87.80 foot-pounds (SD = 16.59), respectively. These data were also gathered at 150 degrees per second.

Isokinetic Measures of Muscle Function

Isokinetic Testing Apparatus

Isokinetic strength measurement is an accepted objective method for quantifying a muscle group's dynamic strength through a joint's range of motion (Rathbone, 1992). Isokinetic devices utilize a dynamometer to develop an accommodating resistance to compensate for the modifying effects of the anatomical lever system of changing force arms and resistance arms throughout the range of motion. As a subject exerts maximum force against the resistance offered by the lever arm of the dynamometer, the subject experiences maximum resistance throughout the entire range of motion (Gould & Davies, 1985).

More traditional isotonic and isometric exercises and devices control the resistance and limit the distance of movement, respectively. The velocity of muscular contraction decreases as the force it is capable of exerting increases. This is referred to as the force-velocity relationship and is described by Luttgens et al. (1992). When a load is increased to a point that is equal to the maximum force a muscle can exert, the velocity drops to 0 degrees per second, resulting in an isometric contraction. The value of isotonic methods for strengthening exercises and testing techniques is limited by its inability to impose maximal tension on the muscle throughout the range of motion (Hislop & Perrine, 1967). The subject must be presented with a weight which can be moved through the weakest point in the range so complete range of motion is possible.

Isokinetic devices can control the speed of rotation of the moving body part or segment by presetting the speed of the dynamometer. This predetermined speed is held constant, despite any changes in tension developed by the muscle as a subject attempts to exert force. The dynamometer contains a load cell which records the amount of force the subject applies to the lever arm at all points in the range of motion.

Hislop and Perrine (1967) published one of the first articles concerning the concept and application of isokinetic exercise. Thistle, Hislop, Moffroid, and Lowman (1967), along with Moffroid, Whipple, Hofkosh, Lowman, and Thistle (1969), later established the reliability and validity of isokinetic devices in determining torque, work, range of motion, and power. Most of the early research on isokinetic testing was done on a Cybex (Lumex Corp., Ronkonkoma, NY) dynamometer (Feiring, Ellenbecker, & Derscheid, 1990). The reliability of these and other isokinetic testing devices is of concern to therapists, trainers, and researchers to establish patient baseline status and collect data for a variety of strength, power, and range of motion parameters (Axtell, 1985) and rehabilitation applications (Rankin & Thompson, 1983). A number of investigations have reported high interclass correlation coefficients, demonstrating these devices to be highly reliable (Bohannon & Smith, 1989; Farrell & Richards, 1986; Feiring et al., 1990; Gross, Huffman, Phillips, & Wray, 1991; J. Johnson & Siegel, 1978; Mawdsley & Knapik, 1982; Thigpen, Blanke, & Lang, 1990; Winter, Wells, & Orr, 1981; Wyatt & Edwards, 1981).

Normative Data

Wyatt and Edwards (1981) compared hamstring and quadricep torques, using a Cybex II dynamometer. They investigated peak torque at speeds of 60, 180, and 300 degrees per second with male (n = 50) and female (n = 50) subjects. They found the following: torque values decreased as testing speeds increased; quadriceps peak torque values were significantly higher than hamstrings at each speed; the ratio of hamstring to quadriceps peak torque values significantly increased as the test speed increased; dominant and nondominant leg peak torque values differed significantly for males, but not for females; the ratio of nondominant to dominant leg torque values was 97 percent or greater in all tests; and the absolute difference in peak torque values between each subject's leg was 12 foot-pounds or less. Subjects for this study were described as normal healthy individuals free from any history of hip or lower extremity injury who had not participated in collegiate or professional sports, were not familiar with isokinetic exercise equipment, and ranged in age from 25 to 34 years. Mean values of hamstring peak torque for dominant and nondominant limbs at 180 degrees per second for males were 77 foot-pounds (SD = 13) and 74 foot-pounds (SD = 15), respectively. Mean values of hamstring peak torque for dominant and nondominant limbs for females were: 46 foot-pounds (SD = 10) and 45 foot-pounds (SD = 9), respectively.

Gross et al. (1991) utilized 10 subjects (men, n = 5; women, n = 5) in a study and reported mean peak torques of the knee flexors to be 63.15 foot-pounds (SD = 28.51) and 60.58 foot-pounds (SD = 25.54) in two different trials, at a testing speed of 180 degrees per second using a Cybex II dynamometer. Mean values obtained using a Biodex dynamometer were 65.88 foot-pounds (SD = 18.68) during trial 1, and 65.14 foot-pounds (SD = 15.84), in trial 2. All subjects ranged in age from 21 to 40 years.

Strength is closely related to an individual's height and weight, and raw scores do not reflect these individual differences. For this reason, Davies et al. (1981) proposed a strength to bodyweight ratio. Their results produced a .65 hamstring to bodyweight ratio for professional football players at 45 degrees per second.

Rankin and Thompson (1983) studied 1,519 varsity athletes at Michigan State University and found significant differences between female and male hamstring to bodyweight ratios. Rankin and Thompson's study indicated mean values to be comparable to Davies et al. (1981) when comparing hamstring torque to bodyweight ratios at 60, 180, and 300 degrees per second. They found mean values to be .35 for all female athletes and .39 for all male athletes at 180 degrees per second. Rankin and Thompson's 1983 normative data are also similar to Davies (1987) data for hamstring peak torque percent bodyweight of .35 for females and .43 for males.

Using 25 healthy male subjects who were habitually active and free of any lower extremity pathology, Thorstensson, Grinby, and Karlsson (1976) investigated peak torque for knee flexors and extensors at specific joint angles through the range of motion. The results of their investigation indicate a mean value of hamstring peak torque of 87.80 foot-pounds (SD = 3.62) at a speed of 180 degrees per second.

Relatively little agreement is found between studies as to the testing speeds, length and type of warm-up, and whether or not training, learning, or fitness levels affect maximum voluntary peak torque production (Axtell, 1985; Mawdsley & Croft, 1982). Although a wide variety of protocols does exist in the literature of physical therapy and sports medicine, the lack of protocol consistency between them makes comparisons difficult. Original studies were conducted at relatively slow speeds of 120 degrees per second or less, with more recent studies reporting data at speeds between 180 and 300 degrees per second (Wyatt & Edwards, 1981).

CHAPTER 3

Methods

A pilot study was conducted prior to the start of this study to insure the feasibility and appropriateness of the two stretching protocols chosen for this dissertation (see Appendix A). The original research design was modified as a result of the pilot study which indicated residual muscle soreness occurred after the application of the hold-relax stretching technique.

Subjects

Volunteer subjects that were habitually active were selected from physical education classes at Middle Tennessee State University to participate in this project. Participants were required to exhibit no history of knee injury which had not completely resolved and no current muscular or soft tissue injury involving the knee flexors or extensors. All subjects agreed to maintain normal daily activity levels and not begin any new exercise or flexibility programs.

The Research Committee for the Protection of Human Subjects at Middle Tennessee State University granted approval for this study (see Appendix B). Each subject read and signed an informed consent form prior to participation (see Appendix C). All participants were instructed in the testing procedure through verbal and written directions read by the researcher from a prepared script.

A total of 33 students agreed to participate in the study. The group was represented by 15 females and 18 males. However, one female and one male sustained injuries of the lower extremities while going about daily activities and were not able to complete the testing. One other male subject was deleted from the study when a deficit in quadriceps and hamstring strength appeared in the initial testing session. The deficit was apparently from a mild knee injury which had not completely resolved. Two additional males did not report for the final testing session, and complete data were not obtained. A total of 28 subjects, 14 females and 14 males, complied with all requirements of the study. The physical characteristics of the subjects are presented in Table 1.

The females had a mean age of 22.43 years, ranging from 19 to 28 years. The mean female height was 65 inches, ranging from 62 to 72 inches. The female bodyweights ranged from 110 to 153 pounds with a mean of 131.50 pounds. The males had a mean age of 23.07 years, ranging from 20 to 29 years. The mean male height was 71.79 inches, ranging from 67 to 76 inches. The male bodyweights ranged from 153 to 250 pounds with a mean of 196.36 pounds.

When males and females were combined, the mean age for the group was 22.75 years, and the ages ranged from 19 to 29 years. Mean height for the group was 68.39 inches, and heights ranged from 62 to 76 inches. Mean bodyweight for the entire group was 163.93 pounds, and bodyweights ranged from 110 to 250 pounds.

Table 1

Physical Characteristics of Subjects

	Age (years)	Height (inches)	Weight (pounds)
Females (n = 14)			
Mean	22.43	65.00	131.50
Standard deviation	2.44	2.75	13.19
Males (n = 14)			
Mean	23.07	71.79	196.36
Standard deviation	2.64	2.46	28.77
Females and Males (n = 28)			
Mean	22.75	68.39	163.93
Standard deviation	2.52	4.30	39.66

Each subject answered a series of questions prior to being positioned for the isokinetic test. These questions provided information concerning height, weight, lower extremity dominance, and history of knee injuries or surgery. Subjects were also questioned with respect to muscle soreness during the initial testing session and all subsequent testing sessions.

Instrumentation and Procedures

Participants were tested on the Cybex 340 for knee extension/flexion, utilizing the standard protocol recommended in the Cybex manual. The Cybex 340 was calibrated each day before testing began, following the guidelines described in the Cybex 340 System User's Manual (1989). Notes were made concerning the position of the subject and testing apparatus to assume proper positioning on the following testing sessions. These notes included dynamometer pedestal height, torque arm length, seat fore and aft adjustment, seat-back fore and aft adjustment, and seat-back tilt adjustment.

A familiarization period was allowed and consisted of submaximal efforts and a liberal number of repetitions to allow the subject to become accustomed to the dynamometer and feel comfortable with the apparatus and testing procedure. The dynamometer was then set at the test speed of 180 degrees per second. The subjects were instructed to perform three submaximal repetitions of knee extension/ flexion and one maximal repetition to insure that the subject understood the procedures and experienced the actual testing speed with maximum effort applied.

Control Testing Session

After a rest period, testing began, with the subject performing six maximal repetitions at a speed of 180 degrees per second with the dominant (treated) leg. (The dominant leg will hereafter be referred to as the treated leg for clarity.) No stretching treatment was applied during this session. Verbal commands were used to encourage the subject to give maximal effort during all three testing sessions. This procedure was then repeated on the nondominant (untreated) knee. Dominance was determined by questioning each subject as to with which foot they preferred to kick a soccer ball or football.

The treated leg received the static stretch in the form of the modified hurdler's stretch in the second testing session and the hold-relax stretching technique in the third testing session. These stretching techniques were applied two minutes prior to testing, and no other type of warm-up or rhythmic movements were allowed. The untreated leg served as control, as it was tested in the same manner as the treated leg during each testing session.

Static Stretching Session

After one day of rest, the second testing session took place at approximately the same time of day for each subject. A modified hurdler's stretch was employed as the static stretching technique. The modified hurdler's stretch is described as follows.

The treated knee remained straight, as the opposite leg was bent at the knee so the sole of the foot of the contralateral leg was facing the medial aspect of the treated leg. The subjects were instructed to stretch the back of the treated thigh (hamstrings) by bending forward from the hips until a mild easy stretch was felt. This position was held for six seconds, followed by a four-second relaxation period. The procedure was repeated a total of six times.

The subject was then quickly moved to the Cybex 340 which had been prepared and set to the same specifications as in the control session. Testing was administered to the treated leg first within two minutes of the flexibility warm-up, using the hurdler's stretch. Then, as in the control session, the untreated leg was tested.

Hold-Relax Stretching Session

Again, as in the static stretching session, one day of rest was allowed between testing sessions, and the subjects reported at the appropriate times. The hold-relax technique employed in this session was as follows.

The subject was placed in a supine position on a treatment table. The knee of the dominant leg was fully extended, with the ankle dorsiflexed to 90 degrees. The hip was passively flexed to the point where the subject confirmed a sensation of tightness in the hamstring muscles. The subject was then instructed to push against the investigator's resistance by contracting the hamstrings attempting to produce hip extension. This was a slow gradual isometric contraction, building to a maximal isometric contraction. The maximum contraction was held for six seconds, followed by a relaxation phase of four seconds. The subject's leg was then moved passively to a position of increased hip flexion as far as the subject would tolerate, thereby increasing the knee flexor stretch. The three-phase cycle of passive stretching, isometric contraction, and relaxation was completed three times. The subject's leg was lowered to the flat surface of the treatment table for a 30-second rest.

The entire three-phase stretch was then completed three more times for a total of six complete cycles. The subject moved to the Cybex 340, and the testing procedure described in the static stretching session was followed.

Statistical Analysis

A repeated measure analysis of variance was used to determine significance between treatments. Repeated *t* tests were used to determine the differences in means between the treated leg and the untreated leg for each variable. All statistical tests were performed using Statistical Analysis System, Version 6.07. The .05 level of probability was considered to be significant.

CHAPTER 4

Data Analyses and Discussion

This chapter presents results together with a discussion of the results to improve cohesiveness and provide more meaning for the reader. For each hypothesis the investigator chose to present data that would be most pertinent to the practice of athletic training and athletic training education. Additional data for each hypothesis are included in the appendices.

Peak Torque

Torque is measured in foot-pounds and represents muscular tension capability. Measurements made during this study were all taken with the Cybex set at 180 degrees per second. Peak torque represented the maximum muscular tension achieved through the active range of motion. Mean values for peak torque are presented for all groups--female, male, and female and male combined--in Table 2.

Mean peak torque in the control session was smallest in each of the three groups, females, males, and combined. Measurements made during the control session, with no stretching techniques being applied to either the treated leg or the untreated leg, indicated mean peak torque of the treated leg was larger than the untreated leg for all three groups, with deficits of the untreated leg being relatively small. However, none of these differences were statistically significant. Females' mean peak torque for the treated leg was 44.00 foot-pounds (SD = 9.00) and 41.57 foot-pounds (SD = 8.15) for the untreated leg. A 6 percent difference in absolute strength was indicated. Males recorded mean peak torque of 83.00 foot-pounds (SD = 15.79) and 82.64 foot-pounds (SD = 15.59), respectively, for treated and untreated legs, with a difference of four-tenths of 1 percent. The combined group's mean peak torque for knee flexors was 63.50 foot-pounds (SD = 23.52) on the treated leg and 62.11 foot-pounds (SD = 24.22) on the untreated leg. This resulted in a 2 percent deficit on the untreated leg.

Baseline values recorded during the control session illustrated mean peak torque for women to be roughly one-half or 53 percent on the treated leg and 50 percent on the untreated leg, when compared to the treated and untreated legs of the male group for peak torque, respectively. This 1:2 ratio was consistent through the other two treatment sessions measuring static stretch and PNF stretch for both treated and untreated knee flexors.

Mean peak torque of the treated leg was lower after both static and PNF flexibility warm-up than the untreated leg in the male sample, although the difference was not statistically significant. These mean values for static and PNF sessions for the treated leg were 88.00 foot-pounds (SD = 16.50) and 92.36 foot-pounds (SD = 17.74),

Table 2

Peak Torque Means and Standard Deviations

(Foot-Pounds) for All Groups

Condition	Leg	Means	SD
	Females (n = 14)		
Control	Treated	44.00	9.00
	Untreated	41.57	8.15
Static	Treated	44.57	8.31
	Untreated	43.50	8.02
PNF	Treated	46.86	8.39
	Untreated	44.86	8.24
	Males (n = 14)		
Control	Treated	83.00	15.79
	Untreated	82.64	15.59
Static	Treated	88.00	16.50
	Untreated	88.14	16.46
PNF	Treated	92.36	17.74
	Untreated	93.64	15.44
	Females and males combined (n = 28)		
Control	Treated	63.50	23.52
	Untreated	62.11	24.22
Static	Treated	66.29	25.56
	Untreated	65.82	26.04
PNF	Treated	69.61	26.87
	Untreated	69.25	27.65

respectively, while mean values for the untreated leg were 88.14 foot-pounds (SD = 16.46) during the static stretching session and 93.64 foot-pounds (SD = 15.44) during the PNF session. However, peak torque measurements taken after static and PNF warm-up for the female group indicated greater mean values on the stretched leg than the unstretched leg in both sessions. For the combined group, results were similar to the males, with mean peak torque for static and PNF treated legs showing deficits of less than 1 percent, when compared to the untreated nondominant leg (see Table 2).

Davies (1987) suggests normative values representing knee flexor peak torque developed at 180 degrees per second to be 35 percent bodyweight for females ranging in age from 15 to 40 years. For males aged 18 to 35 years, Davies suggests hamstring peak torque should be 43 percent bodyweight. Mean values reported during the PNF session in this study were approximately 34 percent of average bodyweight for females and approximately 47 percent for males. These mean values for peak torque seem to be in agreement with normative data as reported by Davies (1987).

However, Axtell (1985) found peak torque of the knee flexors to be 64.71 foot-pounds on the right leg and 61.36 foot-pounds on the left leg at a speed of 180 degrees per second for young adult females whose ages ranged from 22 to 38 years. These values were recorded with no warm-up or stretching and are considerably higher than those values recorded in this study (34.79 and 33.00 foot-pounds). Axtell (1985) also utilized a flexibility warm-up on the knee flexors when investigating the effects of different warm-up techniques on isokinetic muscle testing. Although statistically not significant, Axtell's results indicated a decrease in mean values of peak torque when comparing the no warm-up condition of 64.71 foot-pounds to the flexibility warm-up condition of 60.03 foot-pounds on the right leg. Similar results were reported on the left leg, while comparing no warm-up to flexibility warm-up, resulting in means of 61.36 and 59.76 foot-pounds, respectively.

Using male subjects, Thigpen (1988) examined the effects of static toe-touch stretching as a flexibility warm-up on peak torque at a speed of 150 degrees per second. During control conditions, she reported mean values of 83.63 and 84.58 foot-pounds during pre-testing and post-testing, respectively, with no flexibility warm-up. These data were consistent with the results of this study (82.64 and 83.00 foot-pounds). No significant differences were found as a result of treatment; however, a decrease was reported in mean values of peak torque from pre-testing to post-testing, with flexibility warm-up administered between tests. These values were 87.95 for pre-test and 87.03 for post-test.

Wiktorsson-Moller et al. (1983) also used male subjects and reported mean values of peak torque for knee flexion at

180 degrees per second to be 102.52 foot-pounds during baseline measurement. This value seems to be unusually high, compared to normative data and baseline mean values found in this study (82.64 and 83.00 foot-pounds). However, a reduction in mean peak torque was also reported after a treatment of general warm-up combined with a static stretch, with a value of 101.07 foot-pounds. Wiktorsson-Moller et al. (1983) report that this reduction in peak torque was not statistically significant.

High and Jeziorowski (1988) reported results that are not in agreement with this study or other investigations (Axtell, 1985; Thigpen, 1988; Wiktorsson-Moller et al., 1983) discussed in this section. Eighteen subjects of unspecified gender underwent a six-week flexibility training program to increase hamstring flexibility. Pre-testing and post-testing results indicated significant increases in hamstring flexibility and peak torque as measured isokinetically at 60 degrees per second. Although significant differences were noted between groups for 40-yard sprint speeds, the values represented an inverse relationship with range of motion.

Results of this study indicate the effects of treatment within groups, static stretch or PNF stretch as a flexibility warm-up, were not significant for any of the groups. Nor was there a significant difference between static stretching and PNF stretching effects on peak torque recorded for any group. Data gathered from the difference in mean values from the control to static session, from control to PNF session, and from static to PNF session comparing the amount of change between the treated and untreated legs were analyzed using a _t_ test. Results of these analyses are presented for females, males, and the combined group in Appendix D.

Peak Torque as a Percent of Bodyweight

During the control session, mean values for peak torque as a percentage of bodyweight were recorded. Mean values and standard deviations are presented for all testing sessions and all three groups in Table 3.

The female group produced values of 25.36 percent bodyweight for the leg to be treated and 24.07 percent bodyweight for the untreated leg. The male group produced somewhat higher values during the control session, with values representing 33.93 percent bodyweight for the treated leg and 34.14 percent bodyweight for the untreated leg. When comparing females to males, mean differences of 25 and 29 percent were observed for treated and untreated knee flexors, respectively, during the control session. The difference between female mean values was consistently depressed 25 to 30 percent, when compared to mean values for the male group during static and PNF flexibility warm-up conditions (see Table 3).

Table 3

Peak Torque Percent Bodyweight Means and Standard Deviations (Percent Bodyweight) for All Groups

Condition	Leg	Means	SD
Females ($\underline{n}$ = 14)			
Control	Treated	25.36	11.08
	Untreated	24.07	10.34
Static	Treated	33.29	4.32
	Untreated	32.43	4.01
PNF	Treated	34.79	4.56
	Untreated	33.00	3.76
Males ($\underline{n}$ = 14)			
Control	Treated	33.93	13.58
	Untreated	34.14	14.09
Static	Treated	44.43	6.20
	Untreated	44.71	6.84
PNF	Treated	45.86	8.28
	Untreated	47.71	7.24
Females and males combined ($\underline{n}$ = 28)			
Control	Treated	29.64	12.92
	Untreated	29.10	13.16
Static	Treated	38.86	7.73
	Untreated	38.57	8.33
PNF	Treated	40.32	8.65
	Untreated	40.36	9.39

Means for peak torque as a percent of bodyweight were largest among the PNF sessions for all groups. The treated leg exhibited somewhat smaller values than the untreated leg in the male group, with mean values of 45.86 percent (SD = 8.28) and 47.71 percent (SD = 7.24) for treated and untreated legs, respectively. The female group displayed mean values of 34.79 percent (SD = 4.56) for the treated leg and 33.00 percent (SD = 3.76) for the untreated leg during the PNF session.

The difference in mean values recorded during each treatment session, compared to the other treatment sessions, was analyzed for the main effect of treatment, as compared to the untreated leg. Mean differences, standard deviations, and results of a t test comparing these differences are presented for all groups in Appendix D. These differences were not found to be statistically significant for data, compared with the combined group, as well as the male and female groups. Table 4 contains data for the combined group. Comparing the static session to the control session revealed mean differences of 9.22 percent (SD = 10.14) for the treated leg and 9.47 percent (SD = 10.82) for the untreated leg. The analysis of mean differences resulted in a nonsignificant t ratio of .09, with a probability of .93. When PNF session data were compared to the control session, mean differences of 10.68 percent bodyweight (SD = 10.53) for the treated leg and

Table 4

Univariate Analysis for Peak Torque Percent Bodyweight

(Females and Males Combined, n = 28)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	38.86	29.64	9.22	10.14		
					.09	.93
Untreated	38.57	29.10	9.47	10.82		
Leg	**PNF mean**	**Control mean**	**Mean difference**	**SD**	**t**	**Probability**
Treated	40.32	29.64	10.68	10.53		
					.20	.84
Untreated	40.36	29.10	11.26	10.88		
Leg	**PNF mean**	**Static mean**	**Mean difference**	**SD**	**t**	**Probability**
Treated	40.32	38.86	1.46	3.45		
					.37	.71
Untreated	40.36	38.57	1.79	2.94		

Note: Means and SDs are expressed in foot-pounds percent bodyweight.

11.26 percent bodyweight (SD = 10.88) for the untreated leg resulted in a nonsignificant t score of .20, with a probability of .84. Differences in mean values derived when comparing PNF to static sessions indicated a difference of 1.46 percent bodyweight (SD = 3.45) and 1.79 percent bodyweight (SD = 2.94) for the treated and untreated legs, respectively. Using these values, a nonsignificant t score of .37, with a probability of .71, was obtained.

Utilizing values of peak torque as a percentage of bodyweight are thought by some researchers as a way to normalize data and offset gender differences. However, the normative mean data comparing males and females in this study agree with Rankin and Thompson's (1983) means which found a significant difference between male and female values of peak torque when expressed as a percentage of bodyweight. Mean hamstring peak torque for all female athletes was 35 percent bodyweight. Mean hamstring peak torque was 39 percent bodyweight for all male athletes. Differences in female and male mean values were found to be statistically significant at the .001 level of confidence in Rankin and Thompson's study. The male values in this study (see Table 3) were slightly higher, probably due to variability of subject weight and lean body mass in Rankin and Thompson's study.

The results of this study indicate that the application of static stretching techniques or PNF (hold-relax) stretching techniques did not create a significant change in peak torque percent bodyweight when applied to females, males, or a combined group. The hold-relax technique did not create a significant change in peak torque percent bodyweight in any of the three groups, when compared to the static hurdler's stretch.

Peak Torque at 45 Degrees of Knee Flexion

Evidence suggests that differences in peak torque may not occur in isokinetic testing following stretching techniques, but that differences may occur in the length-tension curve as a result of stretching (Gossman et al., 1982; Hlasney, 1988; Hornsby et al., 1987). To examine the possible change in the length-tension curve, peak torque was measured at a specific angle to monitor muscle length for each subject. This was accomplished by measuring peak torque at 45 degrees of knee flexion. This angle also provided a torque measurement that was not expected to be the subject's maximum.

Table 5 presents mean values and standard deviations for peak torque at 45 degrees of knee flexion for all groups. Mean female hamstring peak torques recorded at 45 degrees for the treated leg for control, static, and PNF sessions were as follows: 40.93 foot-pounds (SD = 7.33), 42.57 foot-pounds (SD = 7.87), and 44.00 foot-pounds (SD = 7.71), respectively. Mean female hamstring peak torques measured at 45 degrees for the untreated leg during control, static, and PNF sessions were as follows: 38.57 foot-pounds (SD = 7.69), 41.57 foot-pounds (SD = 7.63), and 42.79 foot-pounds (SD = 7.99), respectively. When analyzed for treatment effects, the mean value of the untreated leg was slightly depressed, compared to the treated leg, under each condition, but these differences were not statistically significant.

Although not statistically significant, the male group consistently produced higher mean values on the untreated leg as compared to the treated leg during each testing session. Mean peak torques at 45 degrees of knee flexion for the treated leg during control, static, and PNF sessions were recorded as follows: 76.57 foot-pounds (SD = 14.98), 84.43 foot-pounds (SD = 18.20), and 87.79 foot-pounds (SD = 17.84). Mean peak torques at 45 degrees of knee flexion for the untreated leg are presented in order of application: 78.71 foot-pounds (SD = 16.78), 84.50 foot-pounds (SD = 16.60), and 89.14 foot-pounds (SD = 15.36), respectively. These results seem to be consistent with values of 87.80 foot-pounds, with a standard deviation of 3.62 foot-pounds for male hamstring peak torque at 45 degrees, as demonstrated by Thorstensson et al. (1976).

Using all male subjects, Thigpen's 1988 results were very similar to this study. When examining the peak torques occurring at 45 degrees, she used speeds of 60, 150, and 240 degrees per second and found no significant differences in

Table 5

Peak Torque at 45 Degrees of Knee Flexion Means and Standard Deviations (Foot-Pounds) for All Groups

Condition	Leg	Means	SD
	Females (n = 14)		
Control	Treated	40.93	7.33
	Untreated	38.57	7.69
Static	Treated	42.57	7.87
	Untreated	41.57	7.63
PNF	Treated	44.00	7.71
	Untreated	42.79	7.99
	Males (n = 14)		
Control	Treated	76.57	14.98
	Untreated	78.71	16.78
Static	Treated	84.43	18.20
	Untreated	84.50	16.60
PNF	Treated	87.79	17.84
	Untreated	89.14	15.36
	Females and males combined (n = 28)		
Control	Treated	58.75	21.52
	Untreated	58.64	24.12
Static	Treated	63.50	25.37
	Untreated	63.04	25.27
PNF	Treated	65.89	26.05
	Untreated	65.96	26.49

mean values. It is interesting to note that post-testing values decreased in both the control and experimental treatment groups. Mean values were reported to be 78.79 foot-pounds (SD = 21.49) and 78.73 foot-pounds (SD = 19.80) for pre-testing and post-testing during the control condition and 81.62 foot-pounds (SD = 15.01) and 79.02 foot-pounds (SD = 15.06) during the experimental condition.

Mean values for the combined group under the control session were found to be very similar when comparing treated and untreated legs: 58.75 foot-pounds (SD = 21.52) for the leg to be treated and 58.64 foot-pounds (SD = 24.12) for the untreated leg. Neither the static treatment session nor PNF treatment session resulted in differences that were statistically significant when comparing the effects of treatments. Means for the treated and untreated legs for the static session were 63.50 foot-pounds (SD = 25.37) and 63.04 foot-pounds (SD = 25.27), while the PNF session means for treated and untreated legs were 65.89 foot-pounds (SD = 26.05) and 65.96 foot-pounds (SD = 26.49), respectively.

Gossman et al. (1983) used both female and male subjects to investigate the relationship between inherently tight and loose hamstrings on peak torque measured isometrically and produced at 45 degrees of knee flexion. Results from their study indicated that the torque produced by the tight hamstring group was significantly greater. In theory, connective tissue of tighter muscles have more inherent tension than loose muscles. While results from this study may not be in direct conflict with Gossman et al. (1983), comparison of results does not imply similar trends. However, comparison and discussion of similar studies seem appropriate.

Other studies (Gossman et al., 1984; Hornsby et al., 1987; Loving, 1984; Millsaps, 1984) investigated changes in length-tension relationship in comparison to inherent muscle length. All have utilized isokinetic devices for testing peak torque, but only Loving (1984) and Millsaps (1984) allowed for dynamic movement by using a testing speed of 180 degrees per second. Results from Loving and Millsaps seem to indicate similar results as reported by this investigator, but contradict Gossman et al.'s 1983 findings, as both reported no significant change in peak torque at specific joint angles using female and male subjects, respectively.

Gossman et al. (1984) used females and measured changes in peak torque isometrically at 45 degrees of knee flexion. Results indicated similar results to this study and to Loving's 1984 study, with no significant change in peak torque at 45 degrees, when comparing tight and loose hamstrings. Gossman and her associates postulated that there may have been a gender bias. They further speculated that the concept of stretch weakness may be in question.

Hornsby et al. (1987) found significant differences in peak torque at specific angles, when comparing groups possessing tight plantar flexors to those with loose plantar flexors. Subjects were female, and isometric measurements were taken. Results from this study are dissimilar to the findings of Hornsby et al. (1987).

The effects of the flexibility training on the length-tension curve have also been investigated through isometric measures of specific joint angles using isokinetic dynamometry. All of the related studies (Fitzsimmons, 1984; Gladson, 1984; Ogletree, 1991) reviewed for this study produced similar results. There were no significant differences in peak torque at specific joint angles following a flexibility training program. Gladson (1984) used males; Fitzsimmons (1984) used females; and Ogletree (1991) utilized both males and females in his study. All of these studies produced similar results to this study and found no significant differences in peak torque at 45 degrees after stretch was applied.

This study did not attempt to create a change in muscle length or distinguish between inherently tight and loose muscles. Stretching techniques that are commonly used as warm-up by individuals and athletic teams were investigated to determine the short-term effects of static and PNF (hold-relax) stretching on peak torque at 45 degrees of knee flexion. A literature search produced only one other study

(Thigpen, 1988) that has investigated the effects of flexibility warm-up on changes in the muscle length-tension relationship. Results from this study agree with Thigpen (1988) and indicate that static stretching, when used as a warm-up, had no effect in the length-tension curve. The PNF technique (hold-relax) used produced no significant changes in peak torque at 45 degrees of knee flexion, when compared to the control condition of no flexibility warm-up or the static stretching technique. Consequently, flexibility warm-up using static stretching or PNF techniques should not affect torque production of a muscle in isokinetic testing.

Torque Accelerated Energy

Torque accelerated energy (TAE), the amount of work performed in the first one-eighth of a second, was measured for each subject. Table 6 illustrates TAE means and standard deviations for both the treated and untreated legs under all conditions and for all three groups. TAE is expressed in foot-pounds of work and is thought to express muscular "explosiveness." Female TAE measures under the control condition resulted in mean values of 9.50 foot-pounds of work (SD = 2.03) and 9.43 foot-pounds of work (SD = 2.14) for treated and untreated legs, respectively. Male TAE measures under the control condition produced mean values of 18.00 foot-pounds of work (SD = 3.37) and 18.21 foot-pounds of work (SD = 4.39) for treated and untreated legs, respectively. Comparing the treated and untreated legs, respectively, for both groups indicated that female mean values represented only 52 and 53 percent of the TAE produced by the male group. This 1:2 ratio was consistent throughout all treatment sessions comparing static to control, PNF to control, and PNF to static for female to male mean TAE values. The relationship between female and male groups for TAE mean values was consistent with peak torque values which also appeared to exhibit a 1:2 ratio.

For the combined group, TAE mean values were 13.75 foot-pounds of work (SD = 5.12) and 13.82 foot-pounds of work (SD = 5.61) for treated and untreated legs during the control session. The effect of treatment was not statistically significant between any of the sessions or for any of the groups. However, it is interesting to note that mean values for TAE were consistently lower on the treated leg, as compared to the untreated leg for both the combined group and the male group during all treatment sessions. These results seem unusual, considering the treated leg was also the dominant leg.

The female group's mean TAE values were higher on the treated leg during control and PNF sessions, while they demonstrated somewhat smaller values on the treated leg during the static stretching session. Again, these differences were not statistically significant. However, considering the trend for lower mean TAE values on the treated dominant leg, some consideration to a cross-over

Table 6

Torque Accelerated Energy Means and Standard Deviations (Foot-Pounds of Work) for All Groups

Condition	Leg	Means	SD
	Females (n = 14)		
Control	Treated	9.50	2.03
	Untreated	9.43	2.14
Static	Treated	9.21	2.22
	Untreated	9.29	2.58
PNF	Treated	10.07	2.20
	Untreated	9.64	2.34
	Males (n = 14)		
Control	Treated	18.00	3.37
	Untreated	18.21	4.39
Static	Treated	18.93	4.63
	Untreated	19.64	4.80
PNF	Treated	18.86	4.47
	Untreated	20.14	4.52
	Females and males combined (n = 28)		
Control	Treated	13.75	5.12
	Untreated	13.82	5.61
Static	Treated	14.07	6.10
	Untreated	14.46	6.49
PNF	Treated	14.46	5.65
	Untreated	14.89	6.41

training effect or possibly a negative effect of static and PNF flexibility warm-up techniques that are gender specific might be in order.

The neuromuscular mechanisms, including proprioception, may play an integral role in isokinetic performance. Using stretching techniques immediately before performance may have some residual effects on motor performance. The same techniques used to diminish muscle spindle response and the stretch reflex, along with stimulation of Golgi tendon organs to inhibit muscle contraction, may have some carryover effect on subsequent motor skills. Ruffini ending and pacinian corpuscles found in joint capsules and connective tissues may not function at an optimal level if the viscoelastic joint capsule or connective tissue they are imbedded in have just recently been elongated or stressed.

Another possible explanation for the lower dominant leg values may simply be associated with a lessening of the resistance of the connective tissue, allowing the joint range of motion. The increase in range of motion may be relatively small and of short duration, but may diminish the mechanical advantage by changing the angle of pull for the muscles involved in knee flexion. This lessening of the mechanical advantage and a loss of some of the elastic property of the musculotendinous unit may account for a portion of the lower TAE of the knee flexors in the male subjects.

The results of this study seem to indicate the flexibility warm-up techniques utilizing a modified hurdler's stretch as a static method and a hold-relax stretch as a PNF method had no significant effect on torque accelerated energy (TAE) for any of the groups investigated. Further, there were no significant differences between the static method and the more aggressive PNF technique on mean values of TAE recorded for females, males, or the combined group.

Average Power Percent Bodyweight

The subjects performed six maximum repetitions at a testing speed of 180 degrees per second, with the best work repetition of the six used to determine average power. During each testing session, the best work repetition was divided by the actual contraction time to determine average power expressed in watts. This value was then divided by the subject's bodyweight to provide average power percent bodyweight. Table 7 presents the means and standard deviations for average power percent bodyweight for treated and untreated legs under all three treatment conditions and for all groups.

Female subjects demonstrated mean values of 77.29 watts percent bodyweight (SD = 32.89) and 74.71 watts percent bodyweight (SD = 32.67) for the treated and untreated legs during the control session. Data gathered during the static session for treated and untreated legs produced mean values of 99.93 watts percent bodyweight (SD = 12.52) and 99.29 watts percent bodyweight (SD = 13.28), respectively. Comparing mean values gathered during control and static conditions produced an increase of 24.75 percent for the untreated leg and an increase of only 22.64 percent for the treated leg. However, the difference in the amount of change between legs was not statistically significant.

The largest mean values for females measuring average power percent bodyweight were gathered under the PNF session and were recorded as 105.43 percent (SD = 11.59) and 100.57 percent (SD = 12.20) for treated and untreated legs, respectively. The percent of change for the untreated leg was 26 percent, comparing PNF to control sessions, and 1.27 percent, comparing PNF to static sessions. Mean values for the treated leg increased 26 percent when comparing PNF to control and 5.5 percent between static and PNF sessions. Again, none of these differences were found to be statistically significant for treatment effects.

The trend for a relatively large increase of approximately 25 percent between control and static sessions and a relatively small increase (5% or less) from static to PNF session was demonstrated on both the treated dominant leg and the untreated nondominant leg, respectively. A similar trend also occurred for both the male group and the combined group. The large increase and then a tendency of the values to level off may be attributed to motor learning

Table 7

Average Power Percent Bodyweight Means and Standard Deviations (Watts Percent Bodyweight) for All Groups

Condition	Leg	Means	SD
Females ($\underline{n}$ = 14)			
Control	Treated	77.29	32.89
	Untreated	74.71	32.67
Static	Treated	99.93	12.52
	Untreated	99.29	13.28
PNF	Treated	105.43	11.59
	Untreated	100.57	12.20
Males ($\underline{n}$ = 14)			
Control	Treated	98.36	39.84
	Untreated	102.57	43.53
Static	Treated	130.43	21.03
	Untreated	130.79	22.64
PNF	Treated	135.71	21.87
	Untreated	138.57	22.68
Females and males combined ($\underline{n}$ = 28)			
Control	Treated	87.82	37.42
	Untreated	88.64	40.34
Static	Treated	115.18	23.01
	Untreated	115.04	24.27
PNF	Treated	120.57	23.08
	Untreated	119.57	26.34

that takes place between each session. The subjects in this study were given an opportunity to become familiar with and perform on the dynamometer, and many had participated in other isokinetic testing of the knee flexors and extensors. However, the change in variability of the values from session to session seems to indicate inconsistent efforts or performance.

As previously stated, the values derived as average power percent bodyweight actually represent the best effort out of six. Utilizing only one value for each subject of maximum effort, the variability of subject scores should remain relatively consistent between sessions. However, a trend was present here also as the percent of change in standard deviations between sessions was reduced approximately 60 percent for the females and 50 percent for the males between control and static sessions. The change in standard deviation of mean values between static and PNF sessions was only 8 percent for the females and less than 4 percent for the males.

Pacheco (1957) and deVries (1961c, 1963) conducted studies to investigate the effects of flexibility warm-up on power. Pacheco (1957) reported a significant increase (4.99 percent) in the vertical jump following a warm-up routine of static stretching, compared to the control condition of no warm-up. The results of this study do not agree with Pacheco's 1957 study.

deVries (1961c) reported a positive effect of ballistic stretching as warm-up on the standing long jump; however, the increase was not statistically significant. Static stretching and ballistic stretching, when used as a warm-up, did not cause a significant increase in performance in the 220-yard dash, 50-yard swim, or a standing long jump. The results of this study seem to be in agreement with deVries' 1960 study, as well as the 1963 study which indicated no significant effect on 100-yard dash performance or oxygen consumption during the run, following static stretching activities which significantly improved range of motion. These data are consistent with the results of this study.

Total Work

Total work, or torque multiplied by angular displacement, is represented by the total area under the torque curve and is expressed in foot-pounds. Total work represents all six maximal repetitions produced by each subject. Therefore, it requires concentration to produce maximum effort for each repetition consistently.

Means and standard deviations for total work of the treated and untreated knee flexors under all treatment conditions are listed for female, male, and combined groups in Table 8. Female subjects produced mean values of 332.93 foot-pounds of work (SD = 82.10) and 321.79 foot-pounds of work (SD = 73.54) for treated and untreated legs, respectively, during the control session. These values represented approximately 50 percent of the males' mean values recorded during the control session which are as follows: treated leg, 634.43 foot-pounds of work (SD = 126.24), and untreated leg, 632.79 foot-pounds of work (SD = 142.63). When comparing female to male mean values between static and PNF sessions, the trend for female mean values continued to remain approximately 50 percent of those recorded by the male group.

It is interesting to note the consistency between mean values from the treated leg to the untreated leg in all treatment sessions for both female and male groups. This may indicate good consistent efforts by each subject or possibly suggest motor learning between repetitions. Another arresting observation was the consistently higher male values of the treated knee flexors as compared to the untreated leg for the female group. The male group produced higher mean values for the treated leg during the control condition, with lower mean values for the treated leg during static and PNF sessions. However, none of these differences were statistically significant.

When comparing mean differences between control and static sessions, the work for the female group increased 8.07 foot-pounds (SD = 29.05) for the treated leg and 18.28 foot-pounds (SD = 28.85) for the untreated leg. Univariate analysis indicated a t ratio of .93, with a probability of .36. Table 9 presents the univariate analysis of

Table 8

Total Work Means and Standard Deviations

(Foot-Pounds of Work) for All Groups

Condition	Leg	Means	SD
	Females (n = 14)		
Control	Treated	332.93	82.10
	Untreated	321.79	73.54
Static	Treated	341.00	76.78
	Untreated	340.07	71.67
PNF	Treated	361.93	69.18
	Untreated	347.43	71.34
	Males (n = 14)		
Control	Treated	634.43	126.24
	Untreated	632.79	142.63
Static	Treated	696.71	131.81
	Untreated	699.50	146.42
PNF	Treated	708.71	130.52
	Untreated	721.43	127.94
	Females and males combined (n = 28)		
Control	Treated	483.68	185.71
	Untreated	477.29	193.58
Static	Treated	518.86	209.78
	Untreated	519.79	215.15
PNF	Treated	535.32	204.17
	Untreated	534.43	215.86

differences in mean values for the treated and untreated legs between each treatment session for the female group. Between PNF and control sessions, the gains were measured as 29.00 foot-pounds of work (SD = 41.83) for the treated leg and 25.64 foot-pounds of work (SD = 33.22) for the untreated leg. The t test revealed a ratio of .24 and a probability of .82. The difference in mean values for the sessions comparing static to PNF stretching indicated an increase in total work of 20.93 foot-pounds (SD = 32.54) on the treated leg and 7.36 foot-pounds (SD = 33.73) on the untreated leg. This represented a difference of 13.57 foot-pounds which was also the largest increase for total work demonstrated in the female group. A univariate analysis resulted in a t ratio of 1.08, with a probability of .29. None of these differences were found to be statistically significant for the female group, nor were any of the t tests for the male group or the combined group statistically significant.

The trend within the male group was more consistent as the untreated leg produced a greater increase than the treated leg for each comparison between treatment sessions, although, as previously stated, all of these differences were not statistically significant. Univariate analysis for this data recorded by the male group is included in Table 10. Values representing mean differences of work between control and static sessions were 62.28 foot-pounds (SD = 48.58) for the treated leg and 66.71 foot-pounds

Table 9

Univariate Analysis for Total Work

(Females, $\underline{n}$ = 14)

Leg	Static mean	Control mean	Mean difference	SD	$\underline{t}$	Probability
Treated	341.00	332.93	8.07	29.05		
					.93	.36
Untreated	340.07	321.79	18.28	28.85		

Leg	PNF mean	Control mean	Mean difference	SD	$\underline{t}$	Probability
Treated	361.93	332.93	29.00	41.83		
					.24	.82
Untreated	347.43	321.79	25.64	33.22		

Leg	PNF mean	Static mean	Mean difference	SD	$\underline{t}$	Probability
Treated	361.93	341.00	20.93	32.54		
					1.08	.29
Untreated	347.43	340.07	7.36	33.73		

Note: Means and SDs are expressed in foot-pounds of work.

(SD = 74.44) for the untreated leg. The t test resulted in a value of .19 for t and a probability of .85. Comparing control to PNF, the knee flexors on the treated leg exhibited a work increase of 74.28 foot-pounds (SD = 49.59) and 88.64 (SD = 67.09) foot-pounds for the untreated knee flexors. This difference in gain of 14.35 foot-pounds represented the largest difference for all three groups. A t ratio of .64, with a probability of .53, indicated no statistical significance. The effect of PNF stretching compared to static resulted in differences in mean work values of 12.00 foot-pounds (SD = 23.49) on the treated leg and 21.93 foot-pounds (SD = 49.24) on the untreated leg, with a t of .68 and a probability greater than .50.

With all 28 subjects combined, the differences in mean values reflected larger gains on the untreated leg, when comparing control to static and control to PNF sessions with t ratios of .50 (P = .62) and .37 (P = .72), respectively. The static to PNF comparison resulted in mean differences showing greater gains on the treated leg, with a t ratio of .19 and a probability of .85. These differences, as in the other two groups, were not significant. Table 11 contains the univariate analysis of mean differences between treatment sessions for treated and untreated legs for the combined group.

Although some research indicates that prolonged stretching programs cause a significant decrease in muscle

Table 10

Univariate Analysis for Total Work

(Males, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	696.71	634.43	62.28	48.58		
					.19	.85
Untreated	699.50	632.79	66.71	74.44		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	708.71	634.43	74.28	49.59		
					.64	.53
Untreated	721.43	632.79	88.64	67.09		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	708.71	696.71	12.00	23.49		
					.68	.50
Untreated	721.43	699.50	21.93	49.24		

Note: Means and SDs are expressed in foot-pounds of work.

Table 11

Univariate Analysis for Total Work

(Females and Males Combined, n = 28)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	518.86	483.68	35.18	48.00		
					.50	.62
Untreated	519.79	477.29	42.50	60.63		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	535.32	483.68	51.64	50.57		
					.37	.72
Untreated	534.43	477.29	57.14	61.05		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	535.32	518.86	16.46	28.22		
					.19	.85
Untreated	534.43	519.79	14.64	42.07		

Note: Means and SDs are expressed in foot-pounds of work.

strength (Hlasney, 1988), the results of this study do not indicate any significant reduction in total work following static or PNF techniques used as a component of warm-up. Hlasney conducted a study and cited a second study by Remington in 1975 that produced results indicating a significant reduction in peak torque and total area under the length-tension curve measuring hamstring strength following a regimen of PNF stretching. Hlasney (1988) theorized that the elastic energy stored in the connective tissues of the muscle had been removed through PNF stretching.

General Discussion

Past research has indicated that flexibility training used alone and in combination with other training modalities can produce significant gains in performance. These studies (Carr, 1971; High & Jeziorowski, 1988; Norman, 1970) display results that are dissimilar to the findings of this study. These researchers used stretching techniques designed to produce an increase in range of motion over a period of time and then measured the effects of training programs on running speed, peak torque, or angular velocity of the legs involved. However, the effect of these and similar stretching techniques applied as a component of warm-up requires further research.

The results of this study seem to agree with a number of previous studies that examined the effects of flexibility training on physical performance. Jones (1973), Greene (1974), and Early's (1975) research demonstrated no significant effects of stretching on subsequent performance and appear to agree with the results of this study. Dintiman, one of the more prolific writers on sprint training, published a number of research articles addressing the effects of flexibility training on running speed (1964, 1965a, 1965b, 1965c, 1974). The conclusion was that flexibility training had no effect on sprinting velocity. He recommended careful consideration of both static (passive range of motion) and dynamic (active range of motion) flexibility training. This recommendation came after determining that significant increases in sprinting velocity were achieved when flexibility training was combined with strength training, along with traditional "workouts" for sprinters.

The results of a 1971 investigation by Nickason (cited in Carr, 1971) indicated a significant reduction in baseball pitching velocity following the application of a PNF (reversal of antgonist) stretching technique. Nickason's results were most interesting to this investigator as these results seem to be consistent with empirical testimony from some baseball pitchers who offered complaints that partner-assisted static stretching decreased the velocity of their "fast ball." These statements usually came from high caliber collegiate or professional athletes that were not only inherently powerful, but would also be classified as "tight" by most athletic trainers and coaches.

CHAPTER 5

Summary, Conclusions, Recommendations, and Implications for Teaching

Summary

The purpose of this study was to identify the effects of static and hold-relax (PNF) stretching techniques used as a flexibility warm-up on isokinetic measures of the knee flexors. All subjects attended an orientation session prior to testing to insure familiarity with the testing equipment and procedures.

Testing was administered during the Fall Semester of 1992 at Middle Tennessee State University in three sessions on three different days, with a one day's rest between each session. The dominant leg was used as the experimental or treated leg throughout the study, while the nondominant leg received no treatment. The treated leg received one of the three treatments immediately prior to isokinetic testing on the Cybex 340 dynamometer. Treatment consisted of the following: control, no flexibility warm-up; static stretch, a modified hurdler's stretch; or a proprioceptive neuromuscular stretching technique, hold-relax.

Four maximum efforts of knee extension/flexion were performed at a speed of 180 degrees per second in the seated position. Measurements were obtained first from the treated leg then the untreated leg, with data being gathered on peak torque, peak torque percent bodyweight, peak torque at 45 degrees of knee flexion, torque accelerated energy, average power percent bodyweight, and total work during all testing sessions.

The effects of treatment were determined by comparing the treated leg with the untreated leg. These data were analyzed using mean differences, and the .05 level of probability was considered significant. The results of *t* tests suggest that none of the differences between means were significant for either static or hold-relax flexibility warm-up.

Conclusions

Within the limits of this study, the following conclusion seems warranted. Neither the static method of stretching, a modified hurdler's stretch, nor the proprioceptive neuromuscular facilitation technique of hold-relax affects peak torque, peak torque percent bodyweight, peak torque at 45 degrees of knee flexion, torque accelerated energy, average power percent bodyweight, or total work when measured isokinetically at 180 degrees per second.

Recommendations

1. Flexibility warm-up should be perceived as gentle static stretching that allows the athlete to be cognizant of muscle soreness or acute changes in flexibility when preparing for physical activity and not aggressive attempts

to increase range of motion under the auspices of increasing performance.

2. When applying stretching techniques as part of warm-up to an athletic population, similar benefits should be expected for muscular strength, muscular power, work, and acceleration.

3. Future studies utilizing isokinetic testing should allow subjects multiple sessions of performance on the testing apparatus to allow for greater skill development and diminish the effects of motor learning within the actual testing sessions.

4. The effects of flexibility warm-up should be investigated following a period of general warm-up.

5. Investigations of a similar nature should compare the effects of flexibility warm-up utilizing isotonic strength power and work measures.

Implications for Teaching

Most curricula that serve athletic training and physical education majors contain introductory course work designed to prepare future trainers, physical educators, and coaches in the prevention and care of athletic injuries. The implications of this study will assist instructors in preparing a unit on flexibility training and flexibility warm-up. Students must not only recognize and comprehend terminology and limits in range of motion and distinguish between stretching techniques and protocols, but make appropriate application to normal healthy athletes, as well as those suffering from acute, chronic, and post-surgical trauma.

Athletic trainers, physical educators, and coaches cannot assume that specific techniques designed to produce changes in joint range of motion through excitation and inhibition of proprioceptors will be transferred to the body's physiological and psychological need for flexibility warm-up and motor skill rehearsal. It is imperative that students develop and apply sound principles addressing: (1) warm-up exercise and cool-down; (2) optimal flexibility training; (3) the effects and limitations of warm-up modalities on injury prevention, muscle soreness, and performance; and (4) social facilitation and psychological factors related to individual, partner, and team stretching.

The results of this study indicate no significant difference between static stretching and the more aggressive proprioceptive neuromuscular facilitation technique of hold-relax on measures of muscular strength, power, and work. However, past research indicates there may be some associated risks with the proprioceptive techniques. Students must understand the goal of flexibility warm-up is to prepare the athlete both physically and mentally for performance, while the goal of flexibility training is to increase range of motion. They must comprehend basic biophysical and neurophysiological factors that are associated with stretching techniques and the body's response to different techniques.

As the athlete begins the daily routine, regardless of expectations for a day of practice, competition, or rehabilitation, he/she must first assess and adapt to physical changes from previous performance. Athletes must be aware of any alteration in joint range of motion, muscle soreness, strength, fatigue, and effusions or edema that may be present. A brief period of static stretching for the trunk, lower back, and major joints allows the athlete to make these assessments and adjust his/her warm-up routine accordingly. Three to six repetitions of very low intensity and short duration (four to six seconds) are recommended.

As the athlete proceeds through the warm-up routine, rhythmic movements, such as walking, jogging, and movements using large muscle groups performed at a mild intensity and gradually increasing will promote an increase in body temperature. If muscle soreness, tightness, or limits in range of motion persist, the athlete may benefit from a second bout of static stretching of longer durations and higher intensity, with the muscle temperature now elevated and damage to connective tissue less likely.

This first phase of flexibility warm-up may be followed by a second phase of more specific movement patterns that tend to be more ballistic and are associated with motor rehearsal. This type of regimen may be more appropriate than aggressive stretching techniques used in warm-up, as it allows the athlete to practice movement patterns in a slow progressive manner. Proprioceptors assist the athlete in developing movement patterns that are within their normal limits of joint motion. To attempt to inhibit these receptors that determine kinesthetic sense may be contraindicated.

Proprioceptive neuromuscular facilitation techniques will provide the athlete with an increase in passive range of motion. However, the new end range may be outside the limits of the functional range. This may predispose a sprinter to overstriding or a baseball pitcher to poor throwing mechanics. Most athletes possessing healthy muscles and joints need to develop dynamic flexibility that is within the limits of normal range for their sport.

When designing a flexibility training programs for those athletes that have a significant deficit in flexibility, research indicates that optimal gains will be produced if the stretching is performed after the muscle is warm. Therefore, flexibility training should be placed within the athlete's workout following general warm-up, but not immediately prior to activities requiring skilled movements or powerful dynamic movements. This may be accomplished best at the end of a workout, as opposed to the beginning.

APPENDICES

APPENDIX A

RESULTS FROM PILOT STUDY

APPENDIX A

RESULTS FROM PILOT STUDY

Perceived Pain (Distance in Standing Long Jump Measured in Inches)

Day Subject	(1) S*	Fri. Control	(4) S	Mon. PNF	(6) S	Wed. Static	(8) S	Fri. Control
1	0	86.75	0	88.75	2	89.00	0	85.50
2	0	64.00	0	72.75	0	68.00	0	70.00
3	0	76.50	0	80.25	2	82.00	0	72.50
4	0	81.50	0	78.50	3	80.00	1	81.50
5	0	52.50	0	50.25	3	48.00	1	52.50
6	0	50.00	0	52.25	0	55.50	0	50.00
7	0	81.75	0	80.00	2	84.50	1	81.00
8	0	66.25	0	75.75	2	78.50	1	77.00
9	0	72.00	0	72.50	2	69.50	1	70.00
10	0	68.25	0	74.00	0	68.50	0	66.00
11	0	71.25	0	64.00	2	62.00	0	69.50
12	0	59.00	0	58.25	2	56.00	0	59.00

*S = soreness.

Note: 0 = no pain; 1 = dull vague ache, 2 = slight persistent pain, 3 = more than slight pain, 4 = painful, 5 = very painful, and 6 = unbearably painful.

APPENDIX B

APPROVAL LETTER FROM RESEARCH ETHICS COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS

APPENDIX B

APPROVAL LETTER FROM RESEARCH ETHICS COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS

TO: Dr. Powell D. McClellan
HPER

FROM: Peter Heller PH
Chair, MTSU Research Ethics Committee

RE: Review: Use of Human Subjects

Date: September 15, 1992

The purpose of this memo is to inform you that the MTSU Research Ethics Committee has favorably evaluated your research proposal entitled, "The Effects of Static and Contract-Relax Stretching Techniques on Isokinetic Measures of Knee Flexors" in terms of its ethical utilization of human subjects. Best of luck on the successful completion of your project.

APPENDIX C

INFORMED CONSENT FORM

APPENDIX C

INFORMED CONSENT FORM

Explanation of Testing Procedures

The purpose of this study is to examine the effects of static and contract-relax stretching techniques on isokinetic measures of knee flexors. Each testing session will require the subject to complete six maximal efforts of knee flexion and extension on the Cybex 340 dynamometer located in the Human Performance Laboratory (Room 154 of Alumni Gymnasium). All subjects will be exposed to a baseline measurement, and receive no treatment, which will serve as a control during the first testing session. Following an interval of one day of rest, each subject will be exposed to a static stretching technique, then measured on the dynamometer. Another day of rest will be allowed; then each subject will undergo the contract-relax stretching treatment and measurement. The experiment will then be repeated as above, beginning with no treatment and a second baseline measurement being recorded. Each testing session will take approximately 20 minutes to complete.

Risks and Discomforts

Participation in this study is contraindicated for those who have experienced an acute or chronic injury to the knee or knee musculature that has not resolved. Any discomfort experienced during the test should be limited to mild muscular discomfort associated with any intense exercise. If the subject experiences a level of pain or discomfort above their normal tolerance, they should STOP the exercise immediately.

Freedom of Consent

Your participation in this study is voluntary. You are free to terminate participation in this experiment now or at any point during the study.

Consent to Participate

I hereby acknowledge that I have read this form in its entirety and that I understand the conditions of the experiment and the conditions of my voluntary participation. I consent to participate in the study.

____________________________________ ____________________
Signature Date

APPENDIX D

UNIVARIATE ANALYSIS MEAN DIFFERENCES

APPENDIX D

UNIVARIATE ANALYSIS MEAN DIFFERENCES

Table A-1

Univariate Analysis for Peak Torque

(Females, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	44.57	44.00	0.57	1.04		
					1.07	.29
Untreated	43.50	41.57	1.93	0.70		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	46.86	44.00	2.86	5.74		
					2.50	.81
Untreated	44.86	41.57	3.29	2.89		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	46.86	44.57	2.29	4.51		
					0.57	.57
Untreated	44.86	43.50	1.36	3.71		

Note: Means and SDs are expressed in foot-pounds.

Table A-2

Univariate Analysis for Peak Torque

(Males, _n_ = 14)

Leg	Static mean	Control mean	Mean difference	SD	_t_	Probability
Treated	88.00	83.00	5.00	3.66		
					0.23	.82
Untreated	88.14	82.64	5.50	7.23		

Leg	PNF mean	Control mean	Mean difference	SD	_t_	Probability
Treated	92.36	83.00	9.36	5.79		
					0.67	.51
Untreated	93.64	82.64	11.00	7.17		

Leg	PNF mean	Static mean	Mean difference	SD	_t_	Probability
Treated	92.35	88.00	4.35	4.65		
					0.59	.56
Untreated	93.64	88.14	5.50	5.55		

Note: Means and SDs are expressed in foot-pounds.

Table A-3

Univariate Analysis for Peak Torque

(Females and Males Combined, *n* = 28)

Leg	Static mean	Control mean	Mean difference	SD	*t*	Probability
Treated	66.29	63.50	2.79	4.35		
					0.69	.49
Untreated	65.82	62.11	3.72	5.64		
Leg	**PNF mean**	**Control mean**	**Mean difference**	**SD**	***t***	**Probability**
Treated	69.61	63.50	6.11	6.55		
					0.59	.56
Untreated	69.25	62.11	7.14	6.64		
Leg	**PNF mean**	**Static mean**	**Mean difference**	**SD**	***t***	**Probability**
Treated	69.61	66.29	3.32	4.76		
					0.08	.94
Untreated	69.25	65.82	3.42	5.09		

Note: Means and SDs are expressed in foot-pounds.

Table A-4

Univariate Analysis for Peak Torque Percent Bodyweight

(Females, _n_ = 14)

Leg	Static mean	Control mean	Mean difference	SD	_t_	Probability
Treated	33.29	25.36	7.93	8.66		
					0.13	.90
Untreated	32.43	24.07	8.36	9.25		

Leg	PNF mean	Control mean	Mean difference	SD	_t_	Probability
Treated	34.79	25.36	9.43	9.43		
					0.14	.89
Untreated	33.00	24.07	8.93	8.86		

Leg	PNF mean	Static mean	Mean difference	SD	_t_	Probability
Treated	34.79	33.29	1.50	3.28		
					0.85	.40
Untreated	33.00	32.43	0.57	2.47		

Note: Means and SDs are expressed in foot-pounds percent bodyweight.

Table A-5

Univariate Analysis for Peak Torque Percent Bodyweight

(Males, _n_ = 14)

Leg	Static mean	Control mean	Mean difference	SD	_t_	Probability
Treated	44.43	33.93	10.50	11.62		
					0.02	.99
Untreated	44.71	34.14	10.57	12.45		

Leg	PNF mean	Control mean	Mean difference	SD	_t_	Probability
Treated	45.86	33.93	11.93	11.74		
					0.36	.72
Untreated	47.71	34.14	13.57	12.47		

Leg	PNF mean	Static mean	Mean difference	SD	_t_	Probability
Treated	45.86	44.43	1.43	3.73		
					1.23	.23
Untreated	47.71	44.71	3.00	2.95		

Note: Means and SDs are expressed in foot-pounds percent bodyweight.

Table A-6

Univariate Analysis for Peak Torque Percent Bodyweight

(Females and Males Combined, n = 28)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	38.86	29.64	9.22	10.14		
					0.09	.93
Untreated	38.57	29.10	9.47	10.82		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	40.32	29.64	10.68	10.53		
					0.20	.84
Untreated	40.36	29.10	11.26	10.88		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	40.32	38.86	1.46	3.45		
					0.37	.71
Untreated	40.36	38.57	1.79	2.94		

Note: Means and SDs are expressed in foot-pounds percent bodyweight.

Table A-7

Univariate Analysis for Peak Torque at 45 Degrees of Knee Flexion

(Females, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	42.57	40.93	1.64	4.45		
					0.87	.39
Untreated	41.57	38.57	3.00	3.74		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	44.00	40.93	3.07	5.85		
					0.62	.54
Untreated	42.79	38.57	4.22	3.68		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	44.00	42.57	1.43	4.55		
					0.12	.90
Untreated	42.79	41.57	1.22	4.26		

Note: Means and SDs are expressed in foot-pounds.

Table A-8

Univariate Analysis for Peak Torque at 45 Degrees of Knee Flexion

(Males, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	84.43	76.57	7.86	7.13		
					0.69	.49
Untreated	84.50	78.71	5.79	8.62		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	87.49	76.57	11.22	8.91		
					0.26	.80
Untreated	89.14	78.71	10.43	7.18		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	87.79	84.43	3.36	5.51		
					0.51	.61
Untreated	89.14	84.50	4.64	7.56		

Note: Means and SDs are expressed in foot-pounds.

Table A-9

Univariate Analysis for Peak Torque at 45 Degrees of Knee Flexion

(Females and Males Combined, *n* = 28)

Leg	Static mean	Control mean	Mean difference	SD	*t*	Probability
Treated	63.50	58.75	4.75	6.37		
					0.20	.84
Untreated	63.04	58.64	4.40	6.67		

Leg	PNF mean	Control mean	Mean difference	SD	*t*	Probability
Treated	65.89	58.75	7.14	8.48		
					0.09	.93
Untreated	65.96	58.64	7.32	6.42		

Leg	PNF mean	Static mean	Mean difference	SD	*t*	Probability
Treated	65.89	63.50	2.39	5.06		
					0.35	.73
Untreated	65.96	63.04	2.92	6.27		

Note: Means and SDs are expressed in foot-pounds.

Table A-10

Univariate Analysis for Torque Accelerated Energy

(Females, n =14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	9.21	9.50	-0.29	1.54		
					0.28	.78
Untreated	9.29	9.43	-0.14	1.09		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	10.07	9.50	0.57	1.70		
					0.63	.53
Untreated	9.64	9.43	0.21	1.25		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	10.07	9.21	0.86	1.40		
					1.03	.31
Untreated	9.64	9.29	0.35	1.15		

Note: Means and SDs are expressed in foot-pounds of work.

Table A-11

Univariate Analysis for Torque Accelerated Energy

(Males, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	18.93	18.00	0.93	3.37		
					0.60	.35
Untreated	19.64	18.21	1.43	4.63		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	18.86	18.00	0.86	2.77		
					0.99	.33
Untreated	20.14	18.21	1.93	2.95		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	18.86	18.93	-0.60	4.39		
					0.82	.40
Untreated	20.14	19.64	0.50	4.79		

Note: Means and SDs are expressed in foot-pounds of work.

Table A-12

Univariate Analysis for Torque Accelerated Energy

(Females and Males Combined, _n_ = 28)

Leg	Static mean	Control mean	Mean difference	SD	_t_	Probability
Treated	14.07	13.75	0.32	5.12		
					0.21	.83
Untreated	14.46	13.82	0.64	6.20		

Leg	PNF mean	Control mean	Mean difference	SD	_t_	Probability
Treated	14.46	13.75	0.71	2.26		
					0.58	.56
Untreated	14.89	13.82	1.07	2.39		

Leg	PNF mean	Static mean	Mean difference	SD	_t_	Probability
Treated	14.46	14.07	0.39	6.09		
					0.25	.84
Untreated	14.89	14.46	0.43	5.65		

Note: Means and SDs are expressed in foot-pounds of work.

Table A-13

Univariate Analysis for Average Power Percent Bodyweight

(Females, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	99.93	72.79	22.64	25.18		
					0.19	.85
Untreated	99.29	74.71	24.58	27.79		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	105.43	77.29	28.14	27.93		
					0.22	.83
Untreated	100.57	74.71	25.86	26.48		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	105.43	99.93	5.50	8.80		
					1.35	.19
Untreated	100.57	99.29	1.28	7.63		

Note: Means and SDs are expressed in watts percent bodyweight.

Table A-14

Univariate Analysis for Average Power Percent Bodyweight

(Males, _n_ = 14)

Leg	Static mean	Control mean	Mean difference	SD	_t_	Probability
Treated	130.43	98.36	32.07	33.02		
					0.29	.78
Untreated	130.79	102.57	28.22	37.59		

Leg	PNF mean	Control mean	Mean difference	SD	_t_	Probability
Treated	135.71	98.36	37.35	32.38		
					0.10	.92
Untreated	138.57	102.57	36.00	38.88		

Leg	PNF mean	Static mean	Mean difference	SD	_t_	Probability
Treated	135.71	130.43	5.28	5.88		
					1.09	.28
Untreated	138.57	130.79	7.78	6.14		

Note: Means and SDs are expressed in watts percent bodyweight.

Table A-15

Univariate Analysis for Average Power Percent Bodyweight

(Females and Males Combined, n = 28)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	115.18	87.82	27.26	29.21		
					0.12	.90
Untreated	115.04	88.64	26.40	32.49		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	120.57	87.82	32.75	30.03		
					0.22	.83
Untreated	119.57	88.64	30.93	32.94		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	120.57	115.18	5.39	7.35		
					0.43	.67
Untreated	119.57	115.04	4.53	7.56		

Note: Means and SDs are expressed in watts percent bodyweight.

Table A-16

Univariate Analysis for Total Work

(Females, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	341.00	332.93	8.07	29.05		
					0.93	.36
Untreated	340.07	321.79	18.28	28.85		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	361.93	332.93	29.00	41.83		
					0.24	.82
Untreated	347.43	321.79	25.64	33.22		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	361.93	341.00	20.93	32.54		
					1.08	.29
Untreated	347.43	340.07	7.36	33.73		

Note: Means and SDs are expressed in foot-pounds of work.

Table A-17

Univariate Analysis for Total Work

(Males, n = 14)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	696.71	634.43	62.28	48.58		
					0.19	.85
Untreated	699.50	632.79	66.71	74.44		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	708.71	634.43	74.28	49.59		
					0.64	.53
Untreated	721.43	632.79	88.64	67.09		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	708.71	696.71	12.00	23.49		
					0.68	.50
Untreated	721.43	699.50	21.93	49.24		

Note: Means and SDs are expressed in foot-pounds of work.

Table A-18

Univariate Analysis for Total Work

(Females and Males Combined, n = 28)

Leg	Static mean	Control mean	Mean difference	SD	t	Probability
Treated	518.86	483.68	35.18	48.00		
					0.50	.62
Untreated	519.79	477.29	42.50	60.63		

Leg	PNF mean	Control mean	Mean difference	SD	t	Probability
Treated	535.32	483.68	51.64	50.57		
					0.37	.72
Untreated	534.43	477.29	57.14	61.05		

Leg	PNF mean	Static mean	Mean difference	SD	t	Probability
Treated	535.32	518.86	16.46	28.22		
					0.19	.85
Untreated	534.43	519.79	14.64	42.07		

Note: Means and SDs are expressed in foot-pounds of work.

APPENDIX E

RAW DATA

APPENDIX E

RAW DATA

SUB GEN	CON	LEG	PT	PT%	45	TAE	P%W	TW
1M	1	1	81	16	63	13	41	542
1M	1	2	80	16	77	14	45	600
1M	2	1	85	37	84	14	96	608
1M	2	2	78	34	75	13	94	526
1M	3	1	81	35	77	14	98	592
1M	3	2	79	34	78	14	99	606
2M	1	1	68	17	66	15	52	579
2M	1	2	59	15	54	12	45	465
2M	2	1	75	42	71	14	124	617
2M	2	2	84	48	82	19	134	650
2M	3	1	76	43	73	14	122	594
2M	3	2	87	53	81	18	141	670
3F	1	1	42	15	39	9	43	303
3F	1	2	42	15	34	9	41	322
3F	2	1	45	35	38	9	101	273
3F	2	2	46	36	41	9	107	340
3F	3	1	44	34	39	8	97	335
3F	3	2	42	33	35	9	92	312
4F	1	1	61	42	52	14	122	499
4F	1	2	54	37	50	12	113	398
4F	2	1	59	41	56	10	122	471
4F	2	2	53	37	49	13	111	394
4F	3	1	63	44	58	12	130	504
4F	3	2	54	37	53	11	113	437
5M	1	1	79	18	73	18	56	624
5M	1	2	80	19	75	19	58	637
5M	2	1	86	45	82	21	133	693
5M	2	2	88	46	81	24	142	738
5M	3	1	94	49	88	22	150	747
5M	3	2	98	51	96	24	151	815
6M	1	1	61	39	55	16	120	466
6M	1	2	59	38	50	13	139	382
6M	2	1	66	43	58	15	128	589
6M	2	2	61	39	55	13	118	493
6M	3	1	72	47	68	15	133	593
6M	3	2	66	43	61	15	127	537

SUB GEN	CON	LEG	PT	PT%	45	TAE	P%W	TW
7F	1	1	31	11	30	8	34	197
7F	1	2	39	14	35	9	44	271
7F	2	1	34	28	34	8	85	237
7F	2	2	39	32	39	8	100	285
7F	3	1	45	33	42	10	101	301
7F	3	2	47	34	46	9	102	357
8F	1	1	31	12	31	8	40	239
8F	1	2	25	10	24	7	34	191
8F	2	1	34	30	34	7	87	253
8F	2	2	29	26	29	6	79	213
8F	3	1	37	33	35	8	102	271
8F	3	2	29	26	29	6	82	215
9F	1	1	44	15	42	10	48	347
9F	1	2	39	13	36	12	45	347
9F	2	1	42	32	39	9	97	357
9F	2	2	44	34	42	10	106	394
9F	3	1	45	35	43	11	110	400
9F	3	2	47	36	46	11	114	399
10F	1	1	39	15	35	8	44	294
10F	1	2	34	13	30	7	36	245
10F	2	1	39	33	38	6	96	308
10F	2	2	39	33	39	7	96	309
10F	3	1	39	33	37	7	99	304
10F	3	2	35	29	34	6	84	261
11M	1	1	73	17	70	15	51	614
11M	1	2	70	16	69	14	50	550
11M	2	1	77	41	71	19	126	668
11M	2	2	75	40	72	19	118	595
11M	3	1	77	41	71	19	129	661
11M	3	2	80	42	77	19	130	653
12M	1	1	83	22	78	20	68	658
12M	1	2	80	21	74	19	65	669
12M	2	1	88	51	85	20	153	691
12M	2	2	84	49	78	20	145	678
12M	3	1	91	53	90	17	153	688
12M	3	2	87	50	80	20	157	653

SUB GEN	CON	LEG	PT	PT%	45	TAE	P%W	TW
13M	1	1	96	55	88	19	156	709
13M	1	2	103	59	103	26	180	837
13M	2	1	103	59	98	28	177	853
13M	2	2	107	61	97	26	179	833
13M	3	1	104	59	101	22	178	864
13M	3	2	113	64	112	27	191	885
14M	1	1	96	40	95	19	112	697
14M	1	2	97	40	96	21	115	725
14M	2	1	104	43	99	19	120	745
14M	2	2	102	42	97	20	111	717
14M	3	1	103	43	96	19	116	754
14M	3	2	105	43	100	20	120	767
15F	1	1	49	15	49	7	45	385
15F	1	2	42	13	39	9	39	338
15F	2	1	41	28	40	6	87	351
15F	2	2	40	27	35	8	76	334
15F	3	1	44	30	42	9	90	377
15F	3	2	45	31	40	9	90	378
16M	1	1	116	46	105	22	124	835
16M	1	2	112	44	112	22	129	829
16M	2	1	127	50	127	23	139	985
16M	2	2	127	50	126	28	147	1,030
16M	3	1	135	54	131	24	150	985
16M	3	2	124	49	118	27	139	941
17M	1	1	86	43	86	22	133	701
17M	1	2	88	44	85	20	129	752
17M	2	1	86	43	85	20	129	748
17M	2	2	93	47	93	21	141	822
17M	3	1	93	47	81	22	139	745
17M	3	2	107	54	104	24	155	886
18M	1	1	64	33	55	15	79	390
18M	1	2	77	40	77	15	93	413
18M	2	1	74	38	65	13	105	468
18M	2	2	73	38	73	13	101	523
18M	3	1	84	29	77	12	111	504
18M	3	2	92	48	88	12	118	551

SUB GEN	CON	LEG	PT	PT%	45	TAE	P%W	TW
19F	1	1	41	30	40	10	96	313
19F	1	2	41	30	38	10	97	335
19F	2	1	46	34	45	11	102	369
19F	2	2	44	33	42	10	109	406
19F	3	1	51	38	49	14	114	424
19F	3	2	45	33	45	12	109	403
20F	1	1	39	28	37	10	90	305
20F	1	2	36	26	35	8	80	286
20F	2	1	38	27	38	9	86	300
20F	2	2	35	25	34	7	76	286
20F	3	1	41	29	41	9	90	317
20F	3	2	38	27	37	7	82	293
21F	1	1	36	32	34	7	100	286
21F	1	2	33	30	33	6	91	254
21F	2	1	36	32	33	8	97	275
21F	2	2	34	30	32	6	94	272
21F	3	1	33	30	30	8	99	267
21F	3	2	35	31	34	8	101	270
22F	1	1	49	32	43	9	91	394
22F	1	2	52	33	49	11	101	441
22F	2	1	51	33	48	10	97	424
22F	2	2	55	35	54	13	110	481
22F	3	1	51	33	48	9	100	426
22F	3	2	58	37	55	13	114	459
23F	1	1	53	36	50	13	113	396
23F	1	2	51	35	48	13	118	436
23F	2	1	58	40	57	14	124	443
23F	2	2	55	37	53	14	114	418
23F	3	1	49	33	46	13	107	393
23F	3	2	50	34	46	13	110	388
24M	1	1	85	37	80	17	107	649
24M	1	2	83	36	77	16	109	675
24M	2	1	88	39	87	14	111	682
24M	2	2	86	38	81	15	113	726
24M	3	1	97	43	97	15	122	718
24M	3	2	91	40	87	19	117	726

SUB GEN	CON	LEG	PT	PT%	45	TAE	P%W	TW
25F	1	1	44	31	40	10	97	263
25F	1	2	46	33	44	11	102	272
25F	2	1	49	35	47	12	107	284
25F	2	2	50	36	48	10	106	286
25F	3	1	56	40	53	13	121	329
25F	3	2	52	37	51	11	110	314
26M	1	1	70	40	68	16	121	566
26M	1	2	72	42	72	19	132	594
26M	2	1	70	40	67	19	130	573
26M	2	2	79	46	78	21	142	646
26M	3	1	72	42	70	22	134	617
26M	3	2	81	47	79	21	146	631
27F	1	1	57	41	51	10	119	440
27F	1	2	48	35	45	8	105	369
27F	2	1	52	38	49	10	111	429
27F	2	2	46	33	45	9	106	343
27F	3	1	58	42	53	10	116	419
27F	3	2	51	37	48	10	105	378
28M	1	1	104	52	90	25	157	852
28M	1	2	97	48	81	25	147	731
28M	2	1	103	51	103	26	155	834
28M	2	2	97	48	95	23	146	816
28M	3	1	114	57	109	27	165	860
28M	3	2	101	50	87	22	149	779

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