1990

Comparison of three stretching techniques designed to increase hip range of motion

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**Comparison of three stretching techniques designed to increase
hip range of motion**

Johnson, Kathryn L., M.S.

San Jose State University, 1990

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COMPARISON OF THREE STRETCHING TECHNIQUES
DESIGNED TO INCREASE HIP RANGE OF MOTION

A Thesis

Presented to

The Faculty of the Department of Human Performance

San Jose State University

In partial fulfillment

of the Requirements for the Degree

Master of Arts

By

Kathryn L. Johnson

August, 1990

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

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APPROVED FOR THE UNIVERSITY

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ABSTRACT

COMPARISON OF THREE STRETCHING TECHNIQUES DESIGNED TO INCREASE HIP RANGE OF MOTION

by Kathryn L. Johnson

Research findings have yet to conclusively indicate the superiority of one specific mode of stretching over another for increasing joint range of motion. The purpose of this study was to investigate three hamstring stretching techniques, specifically, (1) static stretch (SS), (2) hold-relax (HR), technique of proprioceptive neuromuscular facilitation (PNF), or (3) modified hold-relax (MHR), non-PNF stretch to determine if a difference existed in hip flexion range of motion (ROM) following a program of stretching both limbs five days per week for four weeks. Thirty-one female high school students (mean age, 14.1 ± 1.0 years) who were involved in a required physical education class participated in the study. The one-way ANOVA performed on the absolute change in degrees of hip flexion ROM (+ or -) from pretest to posttest revealed a significant main effect for the stretching techniques ($p < .03$). Post-hoc analysis utilizing the Tukey HSD test revealed a significant difference between the MHR and the HR techniques ($p < .05$). The results of this study indicate that the PNF stretching technique (HR) was more effective in increasing hip flexion ROM than were the sagittal plane stretching techniques (MHR and SS).

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CHAPTER 1

INTRODUCTION

Anatomical range of motion has been defined as the angular distance a particular body segment traverses about a joint, and is influenced by several components: (a) the bony configuration of a joint; (b) the elasticity of surrounding muscles; and (c) the tension in joint capsular ligaments and tendons (Arnheim, 1985; Galley & Forster, 1981). Limited range of motion has been widely acknowledged as an important factor affecting muscular rehabilitation, injury frequency, and athletic performance (Beaulieu, 1981; Cornelius & Hinson, 1980; deVries, 1962; Ekstrand & Gillquist, 1982; Hoover, 1969; Houglum, 1975; Williford & Smith, 1985). Improvement in range of motion has long been a concern of researchers for both injury prevention and optimal athletic performance (deVries, 1962; Kottke, Pauley, & Ptak, 1952; Prentice, 1983; Williford & Smith, 1985). Numerous research studies have demonstrated that range of motion can be improved as the direct result of muscular stretching techniques (Cornelius & Hinson, 1980; Holt, Travis, & Okita, 1979; Medeiros, Smidt, Burmeister, & Soderberg, 1977; Moller, Ekstrand, Oberg, & Gillquist, 1985; Perez & Fumasoli, 1984; Tanigawa, 1972; Williford & Smith, 1985).

There are several methods which are believed to maximize the elastic characteristics of soft tissue (Eldred, 1967; Houghlum, 1975; Tanigawa, 1972). Historically, the most recognized and most frequently researched methods of improving range of motion are the ballistic and static stretching techniques (deVries, 1962; Holt et al., 1970; Williford & Smith, 1985). Since ballistic stretching involves a bouncing motion, the involved muscle spindles are repetitively stretched and there is continuous resistance by the muscle to further stretch (Carlson, 1974; Sady, Wortman, & Blanke, 1982). The ballistic stretch is not normally continued long enough to allow the Golgi tendon organs to activate and produce any relaxing effect. Sady and associates suggested that the ballistic stretching technique could induce injury due to the repetitive jerking motions. Due to a significant risk of injury, ballistic stretching techniques were not selected for investigation in this study.

Static stretching techniques are characterized by continuous, slow and gradual movement through the range of motion of the muscle involved to a terminal position; this position is held for a designated period of time (Basmajian & DeLuca, 1985). Recommendations for the optimal time holding the stretched position vary from 3 to 60 seconds (Bates, 1971; Beaulieu, 1981). deVries (1974) observed that athletes who engaged in a static stretching program before and after activity reduced their chances of exercise-induced muscle soreness or traumatic injury.

Proprioceptive neuromuscular facilitation (PNF) techniques were developed in the 1940's and first published by Herman Kabat in 1950. Kabat (1952) based many of his theories on Sherrington's (1947) work with proprioception. Proprioceptive neuromuscular facilitation utilizes proprioceptive,

cutaneous, and auditory input to increase the recruitment of motor units (Kabat, 1952; Prentice & Kooima, 1986). The original applications of PNF techniques were intended for the rehabilitation of paralytic patients. As described by Kabat (1952), PNF combines passive stretching techniques with alternating contractions of agonist and antagonist muscle groups designed to accomplish muscle relaxation to improve range of motion and/or increase muscular strength.

Knott and Voss (1968) described three techniques of PNF used for muscular stretching and four PNF techniques used to strengthen muscles. The stretching techniques place emphasis upon the application of "maximal resistance" throughout the normal range of motion in order to increase flexibility (Holt et al., 1970; Knott & Voss, 1956). In this specific application, maximal resistance was defined as the greatest amount of manual resistance which can be applied without overpowering the patient's hold (Knott & Voss, 1968).

A manual assistive type of stretch, PNF techniques are commonly used by clinicians to improve joint range of motion (Hartley-O'Brien, 1980; Markos, 1979; Prentice & Kooima, 1986; Sady et al., 1982; Surburg, 1981). Houghlum (1975) observed an increase in the number of athletic trainers using PNF techniques compared to previous years. In a later study, Surburg (1981) found the use of PNF widespread in a survey of 111 college athletic trainers.

Based upon a thorough review of the literature, the hold-relax (HR) technique of PNF was determined to be the preferred method of the three PNF stretching techniques to effect a change in range of motion (Cornelius & Hinson, 1980; Hartley-O'Brien, 1980; Holt et al., 1970; Perez & Fumasoli, 1984; Surburg, 1981, Tanigawa, 1972). Additionally, modifications of PNF stretching

techniques have been developed and subsequently employed to increase range of motion.

Currently, no consensus of opinion exists to indicate the superiority of static, ballistic or PNF stretching methods for the increase of joint range of motion (Hartley O'Brien, 1980; Markos, 1979; Perez & Fumasoli, 1984; Prentice & Kooima, 1986; Sady, et al., 1982; Surburg, 1981). Furthermore, Knott and Voss (1968) claimed that during PNF stretching techniques, stretching with concomitant rotation around a joint axis produced muscle relaxation, but presented no data to support this theory. The need to determine which stretching method is most effective in improving joint range of motion still exists.

Statement of the Purpose

This study was designed to investigate three hamstring stretching techniques, specifically (1) the static stretch (SS), (2) the hold-relax technique of proprioceptive neuromuscular facilitation (HR), or (3) modified hold-relax, non-PNF stretch, (MHR), to determine if a difference existed in hip flexion range of motion (ROM) following a program of stretching both limbs five days per week for four weeks.

Hypothesis Statement

No statistically significant differences ($\alpha = .05$) in hip flexion range of motion, as measured by a passive straight leg raise to the point of discomfort (Cornelius & Jackson, 1984; Prentice, 1983), were hypothesized to be found between pretest and posttest measurements following a four week hamstring muscle stretching program designed to increase range of motion.

Furthermore, no differences were expected between groups performing the HR, MHR, or SS techniques.

Assumptions

The following statements are basic assumptions made in the formulation of the study:

1. Subjects were assumed to be healthy, as they were carefully screened for any previous significant musculoskeletal injuries to the thigh, hip, and low back.
2. It was assumed that each subject was physiologically capable of improving joint range of motion.
3. It was assumed that subjects performed all stretching techniques to the best of their ability.
4. It was assumed that the clinician was accurate and reliable in the application of the measurement techniques.
5. It was assumed that the subjects did not interact with one another during the stretching techniques.

Limitations of the Study

The following are limitations of the current study:

1. The personal habits of the subjects, such as exercise, diet, and the amount of sleep during the study were not controlled.
2. Subjects were volunteers from an intact-group (a high school physical education class) and thus were not fully randomized.
3. The reliability of the clinician's measurement of range of motion with the Leighton flexometer was not determined.

4. This study utilized a relatively small, homogenous sample population.
5. Application of stretching techniques may have been applied inconsistently by the subjects.
6. All three groups performed stretching techniques in the same room and therefore subjects might have received similar training stimulus.

Delimitations

The following delimitations in the interpretation of the data and generalization of results are acknowledged.

1. The participants in the study were female California high school students, involved in required physical education classes, ages 14-15.
2. Only one of the three known PNF stretching techniques was selected for use in the study.

Definition of terms

The following terms were used in the study and defined as follows:

Autogenic Inhibition: a decrease in excitability in muscle activity which is associated with the Golgi tendon organs, resulting in muscle relaxation (Galley, 1982; Prentice & Kooima, 1986).

Facilitation: the increased excitability of a muscle (Knortz & Ringel, 1985).

Hold-Relax (HR): a technique of PNF stretching in which an isometric contraction of the antagonistic muscle group is manually resisted, then followed by a period of relaxation, and finally passive movement into an extended range of motion. Patterns involve diagonal and rotational movement (Knott & Voss, 1968; Sullivan, Markos, & Minor, 1982).

Irradiation: an overflow effect of nerve impulses resulting in the contraction of synergistic muscles (Prentice & Kooima, 1986; Surburg, 1981).

Modified Hold Relax: a modification of the PNF hold-relax technique of stretching. Unlike the HR technique, this pattern is performed only in the sagittal plane and is not a true PNF stretch (Knott & Voss, 1968).

Proprioceptive Neuromuscular Facilitation (PNF): a set of manually-assisted muscle strengthening and stretching techniques developed by Herman Kabat (1950). These methods involve alternating contractions of agonist and antagonist muscle groups with emphasis placed on maximal resistance throughout the range of motion (Knott & Voss, 1968).

Static Stretch : a slow and gradual movement through the range of motion of the muscle involved to a terminal position. This technique, applied to the hamstring muscle group, is limited to the sagittal plane (Arnheim, 1985; Basmajian, 1978).

Successive Induction: an increase in agonistic effort achieved after antagonistic contraction (Holt, 1976; Surburg, 1981).

Synergists: muscles that assist a specific function during a contraction and act to prevent other muscles from performing unwanted motions (Basmajian & Deluca, 1985; Sweigard, 1974).

CHAPTER II

REVIEW OF LITERATURE

Improvement of range of motion through stretching is advocated to enhance physical performance and decrease the chances of injury (Beaulieu, 1981; Prentice, 1983). Some researchers believe that maintaining flexibility is important in preventing injury to the musculotendinous unit (Beaulieu, 1980; Bobath, 1955; Sapega, Quedenfeld, Moyer, & Butler, 1981; Tanigawa, 1972). This study investigated three stretching techniques, specifically, the static stretch (SS), the hold-relax (HR) technique of proprioceptive neuromuscular facilitation (PNF), and the modified hold-relax (HR), non-PNF technique, to determine if a difference existed in hip joint range of motion following a four week hamstring muscle stretching program. Within the scope of this study, discussion of: (a) the functional anatomy of the hamstring muscle group, (b) the limits to range of motion, (c) the tissue components, (d) the effects of stretching, and (e) the theoretical foundation of PNF was also warranted.

Stretching Techniques

Various types of stretching techniques designed to increase range of motion have evolved over the years (deVries, 1962; Holt et al., 1970). The oldest type stretching techniques are the ballistic techniques which utilize

repetitive bouncing motions (Holland, 1968). Ballistic stretching techniques employ repetitive bouncing motions to stretch the muscle. These techniques have been virtually abandoned due to the likelihood of injury as a result of the jerking motions associated with this type of stretch. Static stretching (SS) techniques stretch the muscle to a point of discomfort, and then are held at that point for a designated period of time (Beaulieu, 1980, Cornelius, 1981; Sady et al., 1982). A third group of stretching techniques is known collectively as proprioceptive neuromuscular facilitation (PNF) and involves alternation of contraction and stretching of agonist and antagonistic muscle groups (Knott & Voss; 1968, Markos, 1979; Prentice, 1983; Prentice & Kooima, 1986).

Functional Anatomy of the Hamstring Muscle Group

The hamstring muscle group is comprised of the semimembranous, semitendinosus, and the biceps femoris muscles (Galley & Forster, 1982). The semitendinosus muscle arises from the ischial tuberosity by a tendon common to it and the long head of the biceps. The semitendinosus then traverses on the medial side of the posterior aspect of the thigh and behind the knee joint, courses anteriorly, and inserts on the tibia medial and inferior to the tibial tuberosity where it is closely associated with the insertions of the gracilis and sartorius (Basmajian, 1985; Carlson & Wilkie, 1974).

The semimembranosus muscle arises from the lateral aspect of the ischial tuberosity and crosses anterior to the semitendinosus and long head of the bicep femoris (Gray, 1974). This tendon passes on the posteromedial aspect of the knee to be inserted on the posteromedial side of the tibial condyle.

The biceps femoris muscle has two heads; the long head originates from the ischial tuberosity along with the semitendinosus, while the short head arises from the linea aspera on the posterior aspect of the femur (Gray, 1974). The biceps forms the upper lateral border of the popliteal fossa, while the semimembranosus and semitendinosus form its upper medial border (Basmajian, 1985). As a group, the hamstrings flex the knee and extend the hip. The long head of the biceps femoris extends the hip while the short head does not. Furthermore, the long and short heads combine to externally rotate the knee (Basmajian, 1985; Galley & Foster, 1982; Gray, 1974). In conjunction to these actions, the semimembranosus and semitendinosus rotate the knee internally when the knee is flexed. The hamstring muscle group is innervated by the first, second and third sacral nerves through the sciatic nerve (Arnheim, 1985; Morris, 1984).

Limits to Range of Motion

Stretching techniques to improve range of motion have shown significant results (Beaulieu, 1981; Cornelius, 1984; Leighton, 1960). However, specific genetic factors exist, such as age and gender, which may restrict range of motion.

Hupperich and Sigerseth (1950) reported that females demonstrated a significantly greater range of motion than males. In a later, but similar study, Leighton (1960) concurred with Hupperich and Sigerseth's conclusion. Additionally, it has been determined that as age increases, range of motion decreases (Leighton, 1950). Jones (1975) supported the theory by stating that to some extent, range of motion is genetically determined.

Other factors which might limit range of motion include muscle weakness, muscle imbalance, fascial or skin tightness, and/or poor posture habits (deVries, 1986; Galley & Forster, 1982). The specific factors which limit range of motion can be altered through exercise because the connective tissue involved has an intrinsic extensibility (Medeiros et al., 1977). In order to gain a more complete understanding of flexibility, a discussion on the properties of tissues which influence flexibility is needed.

Tissue Components

Normal range of motion relies on the type of joint, its bony configuration, and the soft tissue surrounding the structure (Galley & Forster, 1982). To increase range of motion, primary emphasis should be directed at modification of specific connective tissue (Sapega et al., 1981). As muscle length increases tension develops, this is due to the connective tissue elements (Safran, Garrett, Seaber, Glisson, & Ribbeck; 1988).

Connective tissue, composed of a fiber component, a ground substance component, and a cellular component, is widely distributed throughout the body and provides support and protection (Gould & Davies, 1985; Kingsley-Levy, 1979). The latter two components of connective tissue are not relevant to this study. However, the fiber component has extensive significance. The fiber component is further categorized into three types: collagen, elastin, and reticular fibers (Beresford, 1983; Leonhardt, 1973).

Collagen

Collagen is a protein which is the principal component of connective tissue in muscle (Leonhardt, 1973, Safran, et al., 1989). Collagen fibers are arranged in wavy bundles around joints in order to allow motion to occur

until the slack of each bundle becomes taut (Crouch, 1985; Hollinshead, 1960). This slack is also referred to as a "crimp" which may be removed by stretching the connective tissue 3 to 4 percent. This serves as a compliance mechanism, which will prevent damage during a rapid contraction (Ruggeri & Motta, 1984). These collagen fibers provide most of the tensile strength in the fibril matrix, this tensile strength is positively correlated with the diameter of the fiber. Likewise, the collagen fibril diameter is closely related to the duration of stress encountered by the tissue (Kingsley-Levy, 1979; Ruggeri & Motta, 1984). These properties render fibrous tissue eminently suitable for forming tendons and ligaments (Crouch, 1985).

Elastic Fibers

Elastic fibers are long, cylindrical, branching fibers which form interwoven networks (Crouch, 1985). Their main component, elastin, gives the fibers the capacity of returning to their original lengths after being stretched, their elasticity renders elastin to maintain structural integrity, and elastin is abundant in tissues subject to stress (Crouch, 1985; Ruggeri & Motta, 1984). These fibers vary in thickness and length and add resiliency to the skin (Hollinshead & Jenkins, 1981).

Reticular Fibers

The reticular fibers are composed of loosely packed thin fibrils, and similar to connective tissue, are inelastic (Crouch, 1985). Reticular fibers are among the first to appear at wound sites, and later will be joined by collagen fibers in the healing process (Beresford, 1983). The main function of reticular fibers are to add bulk to an organ (Gould & Davies, 1985).

Stretching Techniques

A variety of techniques are currently used to increase joint range of motion. The three most common types of stretching techniques, ballistic, static, and PNF, are discussed in the following section.

Ballistic

The ballistic technique of stretching utilizes repetitive contractions of the antagonist muscle in order to produce quick stretches of the agonist muscle (Basmajian, 1978). The ballistic stretching technique, while somewhat effective, has been virtually abandoned because increased range of motion is achieved through a series of bouncing motions (Carlson & Wilkie, 1974). This dynamic stretching method increases the risk of injury to the muscle because the Golgi tendon organs can not inhibit a contraction fast enough to protect the antagonist muscle (Kreighbaum & Barthels, 1981). Furthermore, muscle soreness and/or injury may also result if forces from bouncing motion are greater than the extensibility of the tissues (Bates, 1971; Beaulieu, 1981; Kreighbaum & Barthels, 1981).

Static

The static stretching (SS) technique is an extremely effective and popular method of stretching (Beaulieu, 1981; deVries, 1962). This method involves the passive stretch of a muscle by placing it in an elongated position of stretch and remaining isometric for a specific time period. The static stretch of a muscle causes stimulation of the Golgi tendon organs, located in that same muscle, resulting in a decreased tension. Thus, the muscle is permitted to be stretched to a greater length (Prentice, 1983; Schmidt, 1987).

Traditionally, the SS technique was thought to decrease a muscle's resistance to change in length (Smith, Hutton, & Eldred, 1974). Moore and Hutton (1980) determined, through electromyography, the presence of a low level of muscle activity during a static stretch, indicating a slight gain in range of motion. However, observations have suggested that a static contraction promotes a "lingering facilitation" of the same muscle (Hagbarth, 1962; Smith et al., 1974). When the SS was compared to other active stretching methods that involved directional combinations of active leg movements, it was found to be less effective for increasing hip joint range of motion (Hartley-O'Brien, 1976; Holt et al., 1970; Medeiros, 1977; Moore & Hutton, 1978; Tanigawa, 1972).

Proprioceptive Neuromuscular Facilitation

Herman Kabat (1952) developed proprioceptive neuromuscular facilitation (PNF) in the 1950's to treat patients with various types of neuromuscular paralyses. According to Knott and Voss, PNF is "a method of promoting or hastening the response of the neuromuscular mechanism through stimulation of the proprioceptors" (1968, p.4).

Further, PNF involves a series of techniques which promote facilitation of the agonist muscle and simultaneously causing inhibition of the antagonist (Knott & Voss, 1968). For this reason, inhibition and facilitation are important neurophysiological phenomena in PNF. If relaxation of the antagonist muscle occurs during contraction of the agonist, it is referred to as "autogenic inhibition." Conversely, if inhibition of the antagonist is achieved through facilitation of the agonist it is termed "reciprocal inhibition" (Sullivan, Markos, & Minor, 1982).

Theoretically, the additive effects of autogenic inhibition and reciprocal inhibition resulting from PNF stretching techniques allow the muscle to be stretched to a greater extent than either the static or ballistic technique (Sady, Wortman, & Blanke, 1982; Denny-Brown, Creed, Eccles, Liddell, & Sherrington, 1972).

Manual resistance is an important aspect of PNF in the rehabilitation setting (Kabat, 1952). The amount of resistance applied may be modified throughout the range of motion, while the involvement of inappropriate muscle groups can be controlled (Houghlum, 1975). Moving through a guided pattern can increase the number of motor units being fired, which can produce a stronger muscular contraction. As a result of this stronger muscular contraction more efficient movement patterns will develop (Houghlum, 1975; Knott & Voss, 1968).

Resistance used with precise diagonal movement patterns has been shown to enhance irradiation (Surburg, 1981). Kabat (1952) defined the term irradiation as the spread of excitation in the central nervous system which facilitates contraction of synergistic muscles in a specific pattern. Increased irradiation is accomplished by transferring energy from larger to smaller muscle groups (Voss, 1967). Knott (1973) suggested that muscle fibers are spiral in character and that everyday activities occur in diagonal planes. The spiral diagonal patterns used in PNF place the muscles to be facilitated under maximal stretch and terminate with the muscles at the end of their range (Basmajian, 1978). Knott and Voss (1968) claimed that stretching with concomitant rotation around a joint axis produced muscle relaxation, but

presented no empirical evidence nor experimental data to support their theory.

The theories of PNF are based on the neurophysiologic mechanisms involving the stretch reflex (Beaulieu, 1980; Prentice, 1983). Two receptors in the central nervous system which are important in the stretch reflex are the muscle spindle and the Golgi tendon organ.

Muscle Spindles. The muscle spindles are mechanoreceptors which are found in connective tissue of a muscle and are sensitive to change in length as well as the rate of change in length of the muscle fiber (deVries, 1986). The muscle spindle consists of two types of fibers; the intrafusal fibers, and the Ia afferent fibers. The intrafusal fibers contribute to the tension on the central region of the spindle, while the Ia fibers output is related to the amount of deformation of this region (Schmidt, 1987). The muscle spindle provides excitation from the central nervous system to the muscle when it is stretched (Schmidt, 1987). Impulses return to the muscle from the central nervous system which cause the muscle to reflexively contract and resist the stretch.

Golgi Tendon Organs. Golgi tendon organs (GTOs) are mechanoreceptors located in muscles at their junction with tendons. They are stimulated by changes in tension produced by active stretching or muscle shortening (Basmajian & Deluca, 1985). Stimulation of the GTOs results in inhibition of the muscle in which it is located (Schmidt, 1987). This inhibition serves as a protective mechanism to prevent the muscle from contracting so forcefully that it would cause damage to the muscle fibers, or actually rupture a tendon (Schmidt, 1987). Golgi tendon organs are, however, limited in their

signalling of information about movement because they cannot distinguish between static or dynamic muscular contractions (Schmidt, 1988).

Proprioceptive Neuromuscular Facilitation

Stretching Techniques

Proprioceptive neuromuscular facilitation (PNF) techniques have been widely used for the strengthening or stretching of muscles (Holt et al., 1970, Sady et al, 1982, Tanigawa, 1972; Williford & Smith, 1985). As this study compared the hold-relax (HR) technique of PNF to a modified hold-relax (MHR) technique and the static stretch, these specific stretching procedures are discussed in detail in the following section.

Hold-Relax

The hold-relax (HR) technique of PNF is based on an isometric contraction of the antagonistic muscle group against resistance, which is then followed by relaxation of the agonist muscle group by the subject. The clinician or partner then applies light pressure and moves the body part passively through the subject's range to the point of discomfort. In the present study, two lower limb PNF patterns for the HR technique were used. For each pattern, the subject's limb was taken passively by the investigator to the position in which the PNF pattern began (Surburg, 1977).

In the "diagonal 1" (D1) pattern described by Knott and Voss (1968), the subject's knee is extended while the clinician or partner resists hip extension, abduction, internal rotation, and plantar flexion. "Diagonal 2" (D2) requires that the subject's knee also be extended. The clinician or partner then manually resists hip extension, adduction, external rotation, and plantar

flexion. The isometric contraction is typically held for five seconds, followed by three seconds of relaxation before moving into the newly expanded range of hip flexion (Markos, 1979; Osternig, Robertson, Troxel, & Hansen, 1990; Tanigawa, 1972). Several investigators have used experimental protocols which repeat this temporal pattern three times for the D1 and D2 patterns (Perez, 1984; Prentice, 1983; Sady et al., 1982; Tanigawa, 1972; Williford & Smith, 1985). The diagonal patterns selected, D1 & D2, were chosen because the biceps femoris muscle contracts optimally in D1 extension and semimembranosus muscle contracts optimally in D2 extension (Markos, 1979). To ensure activation of these muscles, both patterns were performed (Knott & Voss, 1968).

Modified Hold-Relax

Several modifications of PNF have been developed and clinically investigated (Bobath, 1955; Brunnstrom, 1970; Holt, 1976, Holt et al., 1970; Moore & Hutton, 1980). For this study, a modification of the hold-relax (MHR) technique was examined. This method begins as the leg is passively raised in the sagittal plane into hip flexion. Rotation is not a component. Hip extension is resisted for ten seconds. The duration of the muscle contraction was doubled to compensate for the HR technique of PNF which consisted of two patterns. The resting time for MHR doubled as well.

Previous Studies on Range of Motion

Many scientific investigations have evaluated various stretching protocols. It is within the scope of this study to compare the hold-relax, modified hold-relax, and static stretching techniques. Studies which had direct implications to these specific techniques are included in this section.

DeVries (1962) performed a study on 57 male college students and found that while both ballistic and static stretch techniques increase range of motion, neither method was superior to the other. More recently, Holt et al. (1970) conducted a study comparing static, ballistic, and modified PNF stretching methods. The effects of the stretching exercises were measured with an instrument designed by the investigators, which is comparable to the sit and reach test. In this comparison, the mean improvements for the static and ballistic stretch were .75 inches. The modified PNF method proved to be superior with a mean increase of 2.1 inches.

Sady et al. (1982) compared the effects of a static, ballistic, and a modified PNF stretching technique on the flexibility of the shoulder, trunk, and hamstring muscles of 32 college men following a three day per week, 6 week flexibility program. Using the Leighton Flexometer as a measurement device, the authors reported that the modified PNF group had overall statistically significant increase ($p < .05$) in range of motion when compared to the control group (10.6 degree increase). Sady and associates concluded that PNF may be the preferred technique for improving range of motion.

Hartley-O'Brien (1980) compared six mobility exercises to determine which active flexibility exercise would most improve daily (short term) or long term gains in hip flexion. The findings of this study revealed that the active PNF method was not as effective at increasing hip range of motion when compared to more conventional stretching methods as indicated by Holt et al. (1970). The active methods employed by Hartley-O'Brien (1980) differed significantly in their overall contributions to active range of hip flexion. The authors concluded that further research with a different

experimental design was needed to permit significant differences to be identified among the six stretching exercises.

Ambrosius, Langholz, and Davis (1987) measured the effectiveness of a passive hamstring stretching program during a 5 week study. Mean increases in hip joint range of motion of 15% were reported by these authors. These results suggest that a three day per week passive stretching program enhanced hamstring flexibility.

During an eight day study on 30 men, Medeiros et al. (1977) compared the effects of a modified PNF stretching program and passive stretching. The modified PNF technique group gained an average of 7.3 degrees in range of motion, while passive stretch group had an average of a 5.7 degree increase. Mean differences in pelvofemoral angle measurements indicated that both treatment groups significantly increased ($p < .01$) their range of passive hip flexion.

Moller et al. (1985) investigated the duration of stretching effect on range of motion after incorporating a modified PNF stretching program on the lower extremity. The results of goniometry revealed a 4 to 18% increase in range of motion remaining up to 90 minutes after the stretching technique was performed.

In a 1972 study by Tanigawa, the hold-relax method of PNF was compared to passive stretching techniques of the hamstring muscle group. Statistical analysis of the data showed the PNF stretching method to have a 7.6 degree improvement in range of motion. Tanigawa (1972) concluded that the PNF HR procedure is preferred due to the participation of the patient, and

because this method utilizes isometric movements, therefore, pain caused by movement is avoided.

Studies by both Surburg (1981) and Holt (1976) suggested valuable outcomes result when proper techniques utilizing proprioceptive neuromuscular facilitation are incorporated. Perez and Fumasoli (1984) noted 13 to 22 degree increases in range of motion during hip flexion as the result of a modified hold-relax stretching technique being performed by an already flexible group of female high school gymnasts.

Summary

Currently, there are a number of studies which have investigated methods to increase range of motion (deVries, 1962; Hartley-O'Brien, 1980; Holt, 1976; Holt et al., 1970; Perez & Fumasoli, 1984; Sady, 1982; Smith, 1985; Surburg, 1981). To date, no studies exist which compare the hold-relax, modified hold-relax, and static hamstrings stretching techniques. This review of literature was intended to give an overview of the hamstring muscle group, tissues involved and limiting factors in increasing range of motion, various stretching techniques, and past studies in range of motion.

Chapter III

PROCEDURES

The purpose of this study was to investigate three hamstring stretching techniques, specifically (1) the static stretch (SS), (2) the hold-relax technique of proprioceptive neuromuscular facilitation (HR), or (3) modified hold-relax, non-PNF stretch, (MHR), to determine if a difference existed in hip flexion range of motion (ROM) following a program of stretching both limbs five days per week for four weeks.

Subjects

The participants in this study were female subjects who were involved in a required ninth grade physical education class at Santa Clara (California) High School. Since subjects were minors, the subjects and their parent/guardian were required to sign the human subjects informed consent form in order to participate. No volunteers who had sustained a recent muscular injury to the low back or lower extremity were accepted for participation. The subjects were divided into groups of either hold-relax (HR), modified hold-relax (MHR), and static stretching (SS). The subjects were then randomly paired into partners within the groups. Each subject performed her specified stretching procedure five times per week on both limbs during the four week study period. Partners remained the same

throughout the study; however, in the case of a subject's absence from school, an alternate partner was assigned for that day.

Methods

Hold-Relax Technique

The hold-relax (HR) technique of PNF involves an isometric contraction of the hamstring muscle group. The subject's leg was passively raised by her partner to the point of discomfort. The point of discomfort was defined as a verbal signal from the subject of a feeling of discomfort. The subject then extended the hip against the manual resistance of their partner for five seconds (Holt et al., 1970; Osternig, Robertson, Troxel, & Hansen, 1990). Each subject was instructed to relax for three seconds before actively moving into the new range of hip flexion. At this time, the subject's partner applied light pressure to produce a maximal stretch of the hamstring muscle group (Tanigawa, 1972). The diagonal patterns selected for the HR technique, based on the work of Knott and Voss (1968), were diagonal 1 extension (D1) and Diagonal 2 extension (D2). In the D1 technique, the subject's knee was extended while the investigator resists hip extension, abduction, internal rotation, and ankle plantarflexion (Figure 1). Each subject was asked to hold this position while the partner resisted the pattern. For the D2 pattern, the subject's knee was again extended while the partner manually resisted hip extension, adduction, external rotation, and ankle plantarflexion (Figure 2). The isometric contraction was held for five seconds, followed by three seconds of relaxation before moving into the new range of hip flexion. Each pattern was repeated a total of three times on both limbs.

D1 PATTERN
HOLD-RELAX

POSITION OF SUBJECT: HIP FLEXION, ADDUCTION, EXTERNAL ROTATION,
& ANKLE DORSIFLEXION

PARTNER RESISTS: HIP EXTENSION, ABDUCTION, INTERNAL ROTATION,
& ANKLE PLANTARFLEXION

COMMAND: "TURN YOUR HEEL, AND POINT YOUR FOOT DOWN AND
OUT TOWARD ME"

D2 PATTERN
HOLD-RELAX

POSITION OF SUBJECT: HIP FLEXION, ABDUCTION, INTERNAL ROTATION,
& ANKLE DORSIFLEXION

PARTNER RESISTS: HIP EXTENSION, ADDUCTION, EXTERNAL ROTATION,
& ANKLE PLANTARFLEXION

COMMAND: "TURN YOUR HEEL IN, AND POINT YOUR FOOT DOWN AND
AWAY FROM ME"

Modified Hold-Relax

The modified hold-relax technique (MHR) was similar to the HR stretching technique of PNF, except that motion was limited to the sagittal plane (Osternig et al., 1990; Surburg, 1981) (Figure 3). With the subject supine, the subject's partner passively raised their leg in the sagittal plane into hip flexion to the point of discomfort. Hip extension was resisted for ten seconds, followed by relaxation for six seconds. This pattern was repeated a total of three times on both limbs.

Static Stretch

The static stretching (SS) technique involved the passive stretch of the hamstring muscle group by placing it in an elongated position of stretch, approximately 90 to 140 degrees of hip flexion (Figure 4). From a supine position, the subject's partner passively raised her leg in the sagittal plane into hip flexion to the point of discomfort. This position was also held for ten seconds. This procedure was repeated two more times on the same limb, with the entire protocol repeated on the contralateral limb.

Protocol

Data Collection

All subjects underwent a pretest, and a subsequent posttest to measure any resultant changes in hip range of motion from the four week study. Each experimental group was randomly assigned a leader, who was not participating in the stretching protocol, to read the stretching instructions and count the number of seconds in which to hold the stretch.

The subjects were taught about the mechanics of the stretching techniques the same day that they were pretested. The researcher randomly

MODIFIED HOLD-RELAX

POSITION OF SUBJECT: HIP FLEXION

PARTNER RESISTS: EXTENSION

COMMAND: "PUSH DOWN TOWARDS FLOOR"

STATIC STRETCH

POSITION OF SUBJECT: HIP FLEXION

PARTNER RESISTS: NOTHING; NO MOVEMENT INVOLVED

COMMANDS: NONE

assigned the subjects into their stretching groups and described the specific stretching technique to each group. The subjects then participated in a mock trial to practice their newly-assigned stretching technique with their partner. Subjects were not stretched to the point of discomfort during this mock trial.

At the beginning of each physical education class, the subjects separated into their respective stretching group stations which were located in the same area. Each leader then read the instructions to their group and the stretching protocol began. In order not to confound the results, subjects were asked to refrain from any supplemental hamstring stretching outside the study.

For the pretest and posttest measurement sessions, subjects were asked to assume a supine position on a treatment table. This position was maintained with the use of a student assistant who manually held the leg in place that was not being measured. The subject's extended leg was raised passively to the point of discomfort. The investigator's hands were placed with the left hand just proximal to the patella and the right hand on the heel. Subjects were required to wear shorts which allow maximum freedom of movement at the hip joint.

Instrumentation

The instrument employed to measure range of motion was a Leighton Flexometer (Leighton, Spokane, Washington). Leighton (1955) developed this device which is a valid, objective, and reliable tool used in range of motion research. Through Leighton's (1955) range of motion experiments, he determined the Flexometer to have a correlation coefficient of .996.

The Leighton Flexometer consists of a weighted 360 degree dial and a weighted pointer which is mounted in a case. The dial and pointer operate

freely and independently, their movement controlled by gravity, always pulls the weighted end of the dial downward during execution of movement (Leighton, 1955) (Figure 5).

This instrument was chosen because it is easy to use, accurate, and is not affected by minor tilting in the process of movement because the moving parts are balanced on ball bearings (Leighton, 1942). The Leighton Flexometer is believed to be superior to its competitor, the goniometer, because little is known about the reliability of goniometry measurements (Boone, Azen, Chun-Mei, Spence, Baron, & Lee, 1978).

The Leighton Flexometer was attached to each subject prior to the range of motion measurement. The Flexometer was placed on the thigh parallel to the lateral aspect of the femur, 15 inches above the patella with the subject in a supine position. An adjustment was made to both weighted dials until they came to rest with the point of the outer dial resting on zero (Munroe & Romance, 1975). The outer dial was then unlocked and the investigator administered the trial by passively raising the test leg until the subject verbally communicated to the assistant a feeling of "discomfort." When the verbal signal from the subject was given, this position was held, the outer dial was then locked in position. This procedure was repeated three times on each limb, and these measurements were used to calculate a three trial average maximum range of motion value. This measurement was then recorded directly from the reading on the dial (Leighton, 1960). For consistency in the placement of the Flexometer, the same researcher always placed the device on the subject and set the dials to zero.

Leighton Flexometer

To obtain measurement efficiency and expertise prior to the beginning of the study, the researcher practiced the procedures of measuring range of motion with the Flexometer on ten female subjects ages 14 to 15 who were involved in high school athletics. A three trial measurement was taken on the subjects preseason and also postseason. A statistical analysis was not performed on these data, nor was the reliability of the tester or instrument established.

Tests for homogeneity of variance of the pretest scores were performed to determine the existence of significant differences in hip range of motion between the experimental groups at the beginning of the study. The one-way ANOVA was performed on the algebraic change in degrees of hip flexion ROM (+ or -). In the presence of a significant main effect for the stretching techniques, a post-hoc analysis utilizing the Tukey Honestly Significant Difference test was conducted ($\alpha = .05$).

CHAPTER IV

RESULTS AND DISCUSSION

This study was designed to investigate three hamstring stretching techniques, specifically (1) the static stretch (SS), (2) the hold-relax technique of proprioceptive neuromuscular facilitation (HR), or (3) modified hold-relax, non-PNF stretch, (MHR), to determine if a difference existed in hip flexion range of motion (ROM) following a program of stretching both limbs five days per week for four weeks.

Subjects:

Sixty-five female students involved in a required physical education class at Santa Clara (California) High School were invited to participate in the study. Thirty-one students returned their informed consent forms and participated in the study.

The subjects averaged 14.1 ± 1.0 years of age, had a mean self-reported weight of 52.8 ± 17.7 kilograms, and a mean height of 158.4 ± 2.6 centimeters.

Pretest measurements of hip range of motion (ROM) were collected on October 6, 1989. The experimental treatment commenced on October 9, 1989 but was interrupted by the October 17, 1989 Loma Prieta 7.1 earthquake. Santa Clara High School was closed for two days and, as a result, this study was extended two days beyond the intended four weeks (a net total of 20 days of the stretching routines). Posttest hip ROM measurements were taken on November 8, 1989.

Analysis of Variance

A test for homogeneity of variance of the pretest scores revealed no significant differences ($p > .05$) between the randomly-assigned experimental groups at the beginning of the study (Table 1).

TABLE 1
Test for Homogeneity of Variance Between Experimental Groups
based upon Pretest Hip Range of Motion Values

<u>Source</u>	<u>Sum of Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F ratio</u>	<u>F probability</u>
Between groups	68.43	2	34.21	.203	.82
Within groups	4730.69	28	168.95		
Total	4799.12	30			

The right and left limbs of each subject received the same treatment over the four week study period. Analysis of variance (ANOVA) performed on the posttest hip ROM values for the limbs did not reveal a significant right-left difference ($p = .82$). Therefore, the left limb was randomly selected for further statistical analysis.

The dependent variable utilized in this study, ROM change scores, was defined as the algebraic difference (+ or -) in hip ROM between the pretest measurement and the posttest hip ROM values. Twenty-five subjects (80.7%) demonstrated increased hip ROM values at the end of the study, while six subjects (19.4%) had decreased hip ROM values.

The one-way ANOVA performed on the algebraic change in degrees of left hip flexion ROM values from pretest to posttest revealed a significant difference for the stretching techniques ($p < .05$) (Table 2). Post-hoc analysis utilizing the Tukey Honestly Significant Difference test revealed a statistically significant difference between the modified hold-relax (MHR) and the hold-relax (HR) techniques ($p < .05$).

TABLE 2
Analysis of Variance Summary Table:
Pretest to Posttest Range of Motion Change Scores
(Left Limb Only)

Source	Sum of Squares	df	Mean Squares	F ratio	F probability
Between Groups	864.57	2	432.28	3.88	.03
Within Groups	3122.05	28	111.50		
Total	3986.62	30			

The pretest to posttest range of motion change scores revealed that a subject in the HR group demonstrated the greatest increase in hip ROM (+45.4 degrees), while a subject in the static stretch (SS) group had the greatest decrease in hip ROM (-8.6 degrees). A 422 percent difference in the average change in posttest hip ROM was observed between the MHR group (3.9 degrees) and the HR group (16.1 degrees). A complete summary of the measures of central tendency for the hip ROM change scores is provided in Table 3.

TABLE 3

Measures of Central Tendency for Pretest to Posttest Hip Range of Motion Change Scores*

(Left Limb Only)

<u>Stretching Technique</u>	<u>N</u>	<u>Pretest Mean</u>	<u>Posttest Mean</u>	<u>Average Absolute Change</u>	<u>Standard Deviation of Mean</u>	<u>Standard Error of Mean</u>	<u>Minimum Change</u>	<u>Maximum Change</u>
Static Stretch	10	97.80	105.55	+7.9	9.91	3.13	-8.6	+16.5
Modified Hold-Relax	10	100.77	104.65	+3.9	7.74	2.45	-8.3	+15.0
Hold-Relax	11	101.14	117.50	+16.1	13.04	3.93	-1.5	+45.4

*All descriptive statistical values are expressed in degrees of hip range of motion.

Discussion

The results of this study suggest that the hold-relax (HR) stretching technique of proprioceptive neuromuscular facilitation (PNF), which involved two diagonal patterns, was more effective in increasing hip flexion ROM than were two non-PNF, sagittal plane stretching techniques, the modified hold-relax (MHR) and the static stretch (SS). These results support the claims of Knott and Voss (1968), who theorized that during PNF stretching techniques, stretching with concomitant rotation around a joint axis produced muscle relaxation which permitted increased joint range of motion. Knott (1973) noted that muscle fibers are spiral in character and that every day activities occur in diagonal planes. The spiral, diagonal patterns used in PNF stretches place the muscles to be facilitated under maximal stretch and terminate with the muscles at the end of their range of motion (Basmajian, 1978). From the results of the present study, it appears that use of a diagonal stretching pattern was significantly more effective in increasing hip joint range of motion than were the other two techniques studied.

The main purpose of this study was to determine if any of the three selected hamstring stretching techniques yielded an increase in hip ROM values. Several research studies have reported modified hold-relax stretching techniques to be superior to static stretching techniques due to relaxation of the muscle after the isometric contraction, resulting in a passive lengthening of the agonist muscle (Holt et al., 1970; Moller, Oberg, & Gillquist, 1985). In the present study, a 4 percent greater increase in hip ROM occurred in the static stretch (SS) group when compared with the modified hold-relax (MHR) technique. This difference was not statistically significant, however ($p > .05$).

Hartley-O'Brien (1980) compared six active and passive range of motion exercises in 119 college age women to determine which flexibility exercise would most improve hip ROM. The six uniplanar exercises included: passive stretch and active hold, active PNF, dynamic stretch and hold, prolonged stretch, passive PNF and the relaxation method. The findings revealed significant gains in range of motion in all treatment groups ($p < .001$); however, the passive PNF method showed the least gain in range of motion. The PNF techniques used in this study are comparable to the modified hold-relax (MHR) techniques described in the present study. The present study also found gains in the MHR stretching group; however, the most significant increase was found in the HR technique of PNF which was not investigated by Hartley-O'Brien.

Holt et al. (1970) investigated 24 college students and compared the ballistic, static, and modified PNF technique, similar to the HR technique in the current study. Subjects were measured using the sit and reach test. Mean improvements for the static and ballistic stretch were 6/8 inch, and the modified PNF method 2.1 inches. Holt and associates found significant gains ($p < .001$) in ROM in the MHR technique when compared to the static and ballistic techniques.

Sady et al. (1982) compared the effects of a ballistic, a static, and a modified PNF stretching technique on the flexibility of the shoulder, trunk, and hamstring muscles of 32 college men following a three day per week, six week flexibility program. The authors reported that the modified PNF group had overall statistically significant increase ($p < .05$) in range of motion when compared to the control group (10.6 degree increase). Within the modified

PNF stretching group, hamstrings ROM (9.4 degrees increase) improved more than the trunk ROM (5.2 degrees increase) ($p < .05$). Sady and associates theorized that the reason for the effectiveness of the PNF method in increasing flexibility was due to a greater acute stretch of the muscle group during the stretching technique as opposed to the other stretching techniques.

Williford and Smith (1985) also compared the effects of a uniplanar modified PNF and a static stretching technique upon six upper and lower extremity joint movements in 45 college students. Their experimental design involved stretching two times per week for nine weeks. The results indicated that there was a decrease in ROM in three various joint movements. This decrease was found in the static stretch in two joint movements, and the modified PNF technique in one joint movement. Williford and Smith concluded that lack of improvement may be related to initial levels of flexibility for those joint movements; however, they do not offer explanation for the decrease in ROM. The greatest increase in ROM; however, was found in hip flexion/extension (19.57 degree improvement). They concluded that both stretching methods were effective in increasing ROM; however, neither method was found to be statistically superior to the other ($p = .076$). The findings of Williford and Smith are supportive of the present study which also found the modified PNF method effective in increasing ROM.

The experimental design in the present study did not permit assessment of a repeated facilitative effect associated with PNF stretches. Osternig et al. (1990) used electromyography (EMG) to investigate the facilitative effects of two PNF stretching techniques, the contract-relax (CR), agonist contract-relax (ACR), and the stretch-relax (SR) technique on knee

extensor ROM of 30 male and female subjects. Osternig and associates reported that the ACR stretching technique produced a 89 to 110 percent greater hamstring EMG activity ($p < .05$) than did the CR and SR stretching techniques. The results also revealed a 9 to 13 percent greater knee extension ROM than did CR and SR; however, no statistically significant differences were found between groups. The data suggest that the CR and ACR do not evoke sufficient relaxation in muscles opposing knee extension to overcome tension facilitation generated by stretch. Additionally, Osternig et al. (1990) suggested that a decrease in muscle activity may not be related to an increase in joint ROM and that muscle relaxation is not the only factor significant in achieving increased ROM. This study neither supports or contradicts the findings in the present study; however, Osternig and associates feel that the static stretch may be the safer stretching technique due to the amount of hamstring activity.

Additionally, Moore and Hutton (1980) used a PNF agonist contraction stretch technique and found significantly greater hamstring EMG activity during the contract-relax with agonist contraction stretch (CRAC) as compared to the static or contract-relax (CR) stretching techniques. The CRAC technique had a mean ROM of 136.6 degrees, static stretch 133.7 degrees, and the CR stretching technique 132.8 degrees. The CRAC stretch also produced the greatest increase in hip flexion, however, a significant difference did not exist ($p < .05$). The results of Moore and Hutton are supportive to the present study.

Markos (1979) compared two PNF stretching techniques, contract-relax (CR) and hold-relax (HR), among 30 women, ages 19 to 24. The stretching

technique was applied to the right lower extremity in two diagonal patterns while electrical activity was monitored. Comparison of pretest and posttest measurements of the angle of a straight leg raise indicated that the increase in range of motion of the right lower extremity in subjects in the contract-relax group was significantly greater than that in the hold-relax and control groups ($p < .01$). The mean difference in SLR measurements in the CR group on the right lower limb is +20.5 degrees, as opposed to +8.8 degrees in the HR group. The HR technique was identical to the HR technique in the present study and an isotonic contraction of the hamstring muscle was used in the CR technique, this was also a diagonal pattern. The results of the Markos study conflicted with the present study. The increase in ROM of the CR group may be partially explained by Golgi tendon organ (GTO) inhibition in the semimembranosus (SM) and biceps femoris (BF) muscles. During the CR technique, maximal manual resistance was applied to the SM and BF muscles during the entire contraction, whereas with the HR technique, the resistance was applied gradually. The CR technique may have recruited a larger number of GTO's (Markos, 1980). The CR group also obtained a greater ROM of the contralateral limb that was not stretched, 8.6 degrees as opposed to 7.5 degrees in the HR group.

From the discussion of the results of the present study, and of similar studies found in the literature, it is apparent that there is currently no consensus of opinion regarding the superiority of one stretching technique over another. The results of this study are not supported by the study of Markos (1980) which was the most comparable study. Decreases in range of motion were only mentioned by Williford and Smith (1985), and an

explanation was not offered. It is apparent that additional studies are needed on the HR technique of PNF.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study was designed to investigate three hamstring stretching techniques, specifically, (1) static stretch (SS), (2) hold-relax technique of proprioceptive neuromuscular facilitation (HR), or (3) modified hold-relax (MHR) to determine if a difference existed in hip flexion range of motion (ROM) following a program of stretching both limbs five days per week for four weeks.

Thirty-one female high school students (mean age, 14.1 years) who were involved in a required physical education class gave informed consent and participated in this study. The subjects were randomly assigned to three treatment groups (SS, HR, MHR) and performed a bilateral hamstring stretching program five days per week for four weeks. Pretest and posttest hip flexion ROM values were measured with a Leighton flexometer.

The static stretch (SS) technique involves a passive stretch of the hamstring muscle group. From a supine position, the subject's partner passively raised her leg in the sagittal plane into hip flexion to the point of discomfort. The point of discomfort was defined as a verbal signal from the subject of a feeling of discomfort. This position was held for ten seconds. This procedure was repeated three times on each limb.

In the modified hold-relax group (MHR), the subject was placed in a supine position and the subject's partner passively raised the subject's leg in the sagittal plane into hip flexion to the point of discomfort. Hip extension

was then resisted for ten seconds, followed by relaxation for six seconds. This procedure was repeated three times on each limb.

In the hold-relax (HR) group, an isometric contraction of the hamstring muscle group was elicited as the subject attempted to extend the hip against the manual resistance of their partner for five seconds. The subject was then instructed to relax for three seconds before actively moving into the new range of hip flexion. At this time the subject's partner applied light pressure to produce a maximal stretch of the hamstring muscle group. Two lower limb PNF patterns for the HR technique were used. In the "diagonal 1" (D1) pattern, the subject's knee was extended while the partner resists hip extension, abduction, internal rotation, and plantarflexion. "Diagonal 2" (D2) required the subject's knee to be extended. The partner then manually resists hip extension, adduction, external rotation, and plantarflexion. The isometric contraction is held for five seconds, followed by three seconds of relaxation before moving into the new range of hip flexion. Both patterns were repeated a total of three times on each limb.

A test for homogeneity of variance of the pretest scores revealed no significant differences between the three experimental groups at the beginning of the study. Analysis of variance (ANOVA) on the posttest ROM differences between left and right limbs did not reveal a significant difference ($p=.82$); subsequently, the left limb was randomly selected for further analysis.

The dependent variable utilized in this study, ROM change score, was defined as the algebraic difference (+ or -) in hip ROM between the pretest measurement and the posttest hip ROM values. The one-way ANOVA performed on the change in hip flexion ROM from pretest to posttest

revealed a significant difference for the stretching techniques ($p < .05$). Post-hoc analysis utilizing the Tukey Honestly Significant Difference test revealed a significant difference between the MHR and the HR techniques ($p < .05$). The SS technique resulted in an average increase of 7.8 degrees of hip flexion ROM, the MHR technique produced an average increase of 3.9 degrees, while the HR technique increased hip flexion ROM by an average of 16.4 degrees.

These data suggest that stretching techniques that use rotation accompanied with resistance are superior to those stretching methods which did not.

Conclusions

1. The PNF stretching technique (HR) was more effective in increasing hip flexion ROM than were the sagittal plane stretching techniques (MHR and SS).
2. The plane in which a limb is being stretched may be a contributing factor in an increase in ROM during a stretching protocol.
3. PNF stretching methods may produce gains in flexibility due to its multiplanar characteristics.
4. The SS, MHR, and HR stretching techniques are effective in increasing hip range of motion.

Recommendations

The following recommendations are made for further study:

1. Replicate this study using a larger, cross-sectional population to determine if subjects of varied ages and activity levels are similarly affected by these stretching techniques.

2. Further studies investigating different combinations of repetitions, sets, duration, and frequency of stretching to obtain the most efficient, maximal gains of flexibility.
3. Studies including males and females as an additional independent variable in a stretching program.
4. In future studies with this particular age group, the investigator should, if possible, be present to monitor compliance during the study.
5. Prior to activity, PNF stretching techniques should be employed.

References

- Arnheim, D.C. (1988). Modern principles of athletic training, (7th ed.). St. Louis: Times Mirror.
- Basmajian, J.V. (Ed.). (1978). Therapeutic exercise, (3rd ed.). Baltimore: . Williams & Wilkins Co.
- Basmajian, J.V. & DeLuca, C.J. (1985). Muscles alive (5th ed.). Baltimore: Williams & Wilkins Co.
- Bates, R.A. (1971). Flexibility training: the optimum time period to spend in a position of maximal stretch. Unpublished Thesis. University of Alberta.
- Beaulieu, J.E. (1981). Developing a stretching program. Physician and Sports-medicine, 9, 56-69.
- Beresford, W.A. (1983). Lecture notes on histology (3rd ed.). Bolson: Blackwell Scientific Publications.
- Bobath, B., (1955). The treatment of motor disorders of pyramidal & extra-pyramidal origin by reflex inhibition & by facilitation of movements. Psychotherapy, 41, 146.
- Boone, D.C., Azen, S.P., Chun-Mei, L., Spence, C., Baron, C., Lee, L. (1978). Reliability of goniometric measurements. Physical Therapy, 58, 1355-1360.
- Brunnstrom, S. (1979). Clinical kinesiology, (3rd ed.). Philadelphia: F.A. Davis Company.
- Carlson, F.D. & Wilkie, D.R. (1974). Muscle physiology. New Jersey: Prentice-Hall, Inc.

- Cornelius, W.L. & Hinson, M.M. (1980). The relationship between isometric contractions of hip extensors and subsequent flexibility in males. Journal of Sportsmedicine & Physical Fitness, 12, 20-21, 75-80.
- Cornelius, W. & Jackson, A. (1984). The effects of cryotherapy and PNF on hip extensor flexibility. Athletic Training, 19, 183-184, 199.
- Denny-Brown, D., Creed, R.S., Eccles, J.C., Liddell, E.T. & Sherrington, C.S. (1972). Reflex activity of the spinal cord. London: Oxford University Press.
- deVries, H.A. (1962). Evaluation of static stretching procedures for improvement of flexibility. Research Quarterly, 33, 222-229.
- deVries, H.A. (1986). Physiology of exercise for physical education and athletics. Dubuque: Williams C. Brown Publishers.
- Eldred, E. (1967). Functional implications of dynamic and static components of the spindle response to stretch. American Journal of Physical Medicine, 46, 129-140.
- Ekstrand, J. Gillquist, J. (1982). The frequency of muscle tightness and injuries in soccer players. The American Journal of Sportsmedicine, 10, 75-78.
- Galley, P.M. & Forster, A.L. (1982). Human movement. New York: Longman Group Limited.
- Gould, J.A. & Davies, G.J. (ed.). (1985). Orthopaedic and sports physical therapy. St. Louis : The C.V. Mosby Company.
- Gray, H. (1974). Anatomy, descriptive & Surgical. Pennsylvania: Running Press Philadelphia.

- Hartley-O'Brien, S.J. (1980). Six mobilization exercises for active range of hip flexion. Research Quarterly, 51, 625-635.
- Holland, G.J. (1968). The physiology of flexibility: A review of literature. Kinesiological Review, 49, 62-68
- Hollinshead, W.H. (1960). Functional anatomy of the limbs and back (2nd ed.) Philadelphia: W.B. Sanders.
- Hollinshead, W.H. and Jenkins, D.B. (1981). Functional anatomy of the limbs and back (5th ed.). Philadelphia: W.B Sanders.
- Holt, L.E. (1976). Scientific Stretching for Sport. Halifax: Dalhousie University Press.
- Holt, L.E, Travis, T.M. & Okita, T. (1970). Comparative study of three stretching techniques. Perceptual and Motor Skills, 31, 611-616.
- Hoover, D. (1969). P.N.F. in athletic training. National Athletic Trainers Association Journal, 4, 14.
- Houglum, P. (1975). Techniques of pnf in athletic training. National Athletic Trainers Association Journal, 10, 44-45.
- Hupperich, F.L. & Sigerseth, P.O. (1950). The specificity of flexibility in girls. Research Quarterly, 25, 53-56.
- Jones, A. (1975). Flexibility and metabolic condition. The Athletic Journal, 56, 56-57, 80-81.
- Kabat, H. (1950). The role of central facilitation in restoration of motor function in paralysis. Archives of Physical Medicine, 33, 521-533.
- Kabat, H. (1952). Studies on neuromuscular dysfunction; XV: The role of central facilitation in restoration of motor function in paralysis. Archives of Physical Medicine and Rehabilitation, 33, 521-533.

- Kingsley-Levy, C. (1979). Biology: Human Perspective. California: Good Year Publishing Company.
- Knortz, K. & Ringel, C. (1985). PNF- not just stretching. National Strength and Conditioning Associated Journal, 44, 44-45, 76.
- Knott, M. (1956). Neuromuscular facilitation in the child with central nervous system deficit. Physical Therapy, 46, 721-724.
- Knott, M. & Voll, D.E. (1968). Proprioceptive neuromuscular facilitation 2nd ed.). New York: Harper & Row.
- Kottke, F.J., Pauley, D.C., & Ptak, R.A. (1952). The rationale for prolonged stretching for correction of connective tissue. Archives of Physical Medicine and Rehabilitation, 33, 595-603.
- Kreighbaum, E, & Barthels, K.M. (1981). Biomechanics: A qualitative approach for studying human movement. Minneapolis: Burgess Publishing Company.
- Leighton, J.R. (1955). A simple objective and reliable measure of flexibility. Research Quarterly, 13, 205-216.
- Leighton, J.R. (1960). On the significance of flexibility for physical educators. Journal of Health, Physical Education and Recreation, 31, 27-28, 70.
- Leonhardt, H. (1973). Human Histology, Cytology, and Microanatomy. Chicago: Yearbook Medical Publishers, Inc.
- Markos, P.D. (1979). Ipsilateral and contralateral effects of proprioceptive neuromuscular facilitation techniques on hip motion and electromyographic activity. Physical Therapy, 59, 1366-1379.

- Medeiros, J.M., Smidt, G.L., Burmeister, L.F., & Soderberg, G.L. (1977). The influence of isometric exercise and passive stretch on hip joint motion. Physical Therapy, 57, 518-522.
- Moller, M., Ekstrand, J., Oberg, B., & Gillquist, J. (1985). Duration of stretching effect on range of motion in lower extremities. Archives of Physical Medicine and Rehabilitation, 66, 171-173.
- Monroe, R.A. & Romance, T.J. (1975). Use of leighton flexometer in the development of a short flexibility test battery. American Therapy Correction Journal, 29, 22-25.
- Moore, M.A., & Hutton, R.S. (1980). Electromyographic investigation of muscle stretching techniques. Medicine and science in sports and exercise, 12, 322-328.
- Morris, A.F. (1984). Sports Medicine: Prevention of Athletic Injuries. Iowa: William C. Brown Publishers.
- Osternig, L.R., Robertson, R., Troxel, R., Hansen, P. (1990). Differential responses to proprioceptive neuromuscular facilitation stretch techniques. Medicine & Science in Sportsmedicine, 22, 106-111.
- Perez, H. & Fumasoli, S. (1984). Benefit of proprioceptive neuromuscular facilitation on the joint mobility of youth-aged female gymnasts with correlations for rehabilitation. American Correctional Therapy Journal, 38, 142-146.
- Prentice, W.E. (1983). A comparison of static stretching and PNF stretching for improving hip joint flexibility. National Athletic Trainers Association Journal, 18, 56-59.

- Prentice, W.E. & Kooima, E.F. (1986). The use of PNF techniques in the rehabilitation of sport-related injury. National Athletic Trainers Association Journal, 21, 26-31.
- Sady, S.P., Wortman, M., & Blanke, D. (1982). Flexibility training: Ballistic, static, or proprioceptive neuromuscular facilitation? Archives of Physical Medicine and Rehabilitation, 63, 261-263.
- Sapega, A.A., Quedenfeld, T.C., Moyer, R.A., & Butler, R.A. (1981). Biophysical factors in range of motion exercise. The Physician and Sportsmedicine, 9, 57-65.
- Schmidt, R.A. (1987). Motor control and learning. Champagne, Illinois: Human Kinetics Publishers.
- Sherrington, C.A. (1947). The integrative action of the nervous system (2nd ed.). New Haven: Yale University Press.
- Smith, J.L., Hutton, R.S., & Eldred, E. (1974). Post contraction changes in sensitivity of muscle afferents to static and dynamic stretch. Brain Research, 78, 193-202.
- Sullivan, P.E., Markos, P.D., & Minor, M.D. (1982). An integrated approach to therapeutic exercise. Reston: Reston Publishing Company.
- Surburg, P.R. (1981). Neuromuscular facilitation techniques in sports-medicine. The Physician and Sportsmedicine, 9, 114-127.
- Surburg, P.R. (1977). The effect of PNF patterning upon reaction response and movement times. Physical Therapy Journal, 52, 513-517.
- Sweigard, L.E. (1974). Human movement patterns: Its ideokinetic facilitation. New York: Harper & Row Publishers, Inc.
- Tanigawa, M.C. (1972). Comparison of the hold relax procedure and passive

mobilization on increasing muscle length. Physical Therapy Journal, 52, 725-735.

Wallin, D., Ekblom, B.E., Grahn, R., Nordenborg, T. (1985). Improvement of muscle flexibility: a comparison between two techniques. The American Journal of Sportsmedicine, 13, 263-268.

Williford, H.N., & Smith, J.F. (1985). A comparison of proprioceptive neuromuscular facilitation and static stretching techniques. American Correctional Therapy Journal, 39, 30-33.

APPENDICES

APPENDIX A
CONSENT FORM

AGREEMENT TO PARTICIPATE IN RESEARCH
SAN JOSE STATE UNIVERSITY

RESPONSIBLE INVESTIGATOR: KATHRYN L. JOHNSON

TITLE OF PROTOCOL: COMPARISON OF THREE STRETCHING
TECHNIQUES TO INCREASE HIP RANGE OF MOTION

Your child is invited to participate in a research study that is investigating the optimal stretching technique for increasing hip range of motion. The results of this study should further our understanding of various stretching techniques.

I understand that

- 1) my child will be asked to participate in a flexibility program, which will occur in my scheduled physical education class, five days a week for four weeks; each session will last approximately five minutes.
- 2) the possible risks of this study are, in some cases, experiencing brief periods of muscle soreness in the hamstring area following the exercise session.
- 3) the possible benefits of this study to my child, in most cases, will be an increase in range of motion (flexibility) in the leg being tested.
- 4) the results from this study may be published, but any information from this study that can be identified with my child will remain confidential and will be disclosed only with my permission or as required by law.
- 5) I realize that in the unlikely event of a physical injury resulting from the research procedures that financial compensation for the cost of medical care is not available.
- 6) any questions about my child's participation in this study will be answered by Kathi Johnson 554-4068. Complaints about the procedures may be presented to Dr. Rod Harter 924-3015, Advisor for Graduate Studies. For questions or complaints about research subject's rights, or in the event

of research-related injury, contact Serena Stanford, Ph.D. (Associate Academic Vice President for Graduate Studies & Research) at 924-2480.

7) my consent is given voluntarily without being coerced; my child may refuse to participate in this study or in any part of this study, and I may withdraw my consent at any time, without prejudice to my relations or my child's with SJSU.

8) I have received a copy of this consent form for my file.

HAVING READ THE INFORMATION PROVIDED ABOVE, I HAVE MADE A DECISION WHETHER OR NOT MY CHILD MAY PARTICIPATE. MY SIGNATURE INDICATES THAT MY CHILD MAY PARTICIPATE AND IS WILLING TO PARTICIPATE.

DATE

PARENT'S/GUARDIAN'S SIGNATURE

PRINT CHILD'S NAME

RELATION TO CHILD

APPENDIX B

LEADER

GROUP 1: STATIC STRETCH

1. subject one- lay on your back
2. subject two- raise subject's one right leg until subject one says they feel a discomfort (left leg should be straight).
3. hold this position until the count of ten: one-one-thousand, two-one-thousand, etc.
4. relax for six seconds: one-one-thousand, two-one-thousand, etc.
5. repeat steps 2-4 two more times.
6. switch legs, repeat three (3) times.
7. switch partners.

APPENDIX C

LEADER

GROUP 2: MODIFIED HOLD RELAX

1. subject one- lay on your back.
2. subject two- raise subject ones right leg until subject one feels a discomfort, left leg should be straight.
3. subject one- push down towards the floor, subject two resists, there should be no motion, do this for 10 seconds: one-one-thousand, two-one-thousand, etc.
4. relax for six seconds- one-one-thousand, etc.
5. repeat two (2) more times.
6. switch legs, repeat steps 2-4 three times total.
7. Switch partners, repeat procedures again.

APPENDIX D

LEADER

GROUP 3: HOLD-RELAX
LEFT LEG

1. subject one- lay on your back
 2. subject two- raise subject one's left leg until subject one says they feel a discomfort (right leg should be straight)
 - hand placement- right hand on outside of thigh, left hand on ball of foot
 - position of leg- heel turned in towards body
 - foot flexed
 - leg slightly crossing body
 3. subject one- turn heel away from body, point foot down and out towards subject two
 4. hold this position until the count of five- one-one-thousand, two-one-thousand, etc.
 5. relax three seconds, one-one-thousand, etc.
 6. repeat two more times.
- new position, same leg:
7. raise left leg again until subject one says they feel a discomfort (right leg should be straight)
 - hand placement- right hand on inside of thigh, left hand cupped around heel.
 - position of leg- away from body, heel turned away from body, foot flexed.
 8. subject one- turn heel towards your body and at the same time push down.
 9. hold this position for 5 seconds, one-one-thousand,etc.
 10. rest 3 seconds, repeat two more times.
 11. switch legs, switch partners.

APPENDIX E

LEADER

GROUP 3: HOLD-RELAX
RIGHT LEG

1. subject one- lay on your back
 2. subject two- raise subject one's right leg until subject one says they feel a discomfort (left leg should be straight)
 - hand placement- left hand on outside of thigh, right hand on ball of foot
 - position of leg- heel turned in towards body
 - foot flexed
 - leg slightly crossing body
 3. subject one- turn heel away from body, point foot down and out towards subject two
 4. hold this position until the count of five- one-one-thousand, two-one-thousand, etc.
 5. relax three seconds, one-one-thousand, etc.
 6. repeat two more times.
- new position, same leg:
7. raise right leg again until subject one says they feel a discomfort (left leg should be straight)
 - hand placement- left hand on inside of thigh, right hand cupped around heel.
 - position of leg- away from body, heel turned away from body, foot flexed.
 8. subject one- turn heel towards your body and at the same time push down.
 9. hold this position for 5 seconds, one-one-thousand, etc.
 10. rest 3 seconds, repeat two more times.
 11. switch legs, switch partners.