A COMPARISON OF SIX METHODS OF STRETCH
ON THE PASSIVE RANGE OF HIP FLEXION

by

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ABSTRACT

A theoretical model stating that one must decrease resistance in a target area (area to be stretched) or increase the ability to overcome that resistance (strength) in order to positively alter range of joint movement was designed and an experiment set up to begin testing this model. It was discussed that there are two distinct ranges of joint movement: PASSIVE being that range attained with the aid of some external force (a partner or gravity) and ACTIVE being that range attained by voluntary muscle contraction. It was also discussed that most methods of stretching could likewise be classified as either ACTIVE METHODS or PASSIVE METHODS.

It was the purpose of this study to research the effects of six methods of stretch on the passive range of right hip flexion of 119 volunteer college women. Approximately 20 subjects were randomly assigned to each one of seven treatment groups. All subjects were measured before treatments were initiated and after treatments had ceased at the end of the study. Six of the groups were each assigned to a stretching regimen which was practiced in a lab ten minutes a day, three days a week for three weeks. All subjects, including the control group, were tested pre and post treatment on the first day of each week.

The methods that were tested were divided into active methods in which the subject actively mobilized their
leg (Active P.N.F. and Spring Stretch); passive methods in which the partner mobilized the subjects leg (Relaxation, Passive P.N.F. and Prolonged Stretch); and a combination method in which the partner mobilized the subjects leg and then the subject actively tried to maintain the range attained (Passive Lift-Active Hold).

All treatment groups showed a significant increase in their range of hip flexion though the mean increase of the treatment groups was significantly greater than the mean increase of the control group. The three passive methods (Relaxation, Passive P.N.F. and Prolonged Stretch) and the combination method (Passive Lift-Active Hold) were all equally effective in increasing passive range (only 1.3° between highest and lowest). The mean gain of the three passive methods was significantly greater than the mean gain of the two active methods.
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This study represents one half of a larger dual study conducted by Keith W. Russell and Sandra J. Hartley. These experimenters pooled their subjects and aided each other in data collection. They also shared a common committee and experimental design, but each drew different data from the experiment and each wrote a separate thesis.
ACKNOWLEDGEMENTS

A very special thank-you is extended to Sandra Hartley who, in the difficult position of co-researcher, proved that the pooling of efforts and knowledge can indeed be beneficial and rewarding.
CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Flexibility is an area of study that receives little attention considering its importance. It has been described by Johnson et al. (1975) as one of the four qualities basic to physical fitness (along with circulo-respiratory capacity, muscular endurance and strength). Its importance is also alluded to by other authors such as de Vries (1974:432) who points out that "...graceful movement in walking and running are unlikely without it." Davis, Logan and McKinney (1965) postulate that injury prevention would ensue development of optimum ranges of flexibility, while other authors such as Cureton and Morehouse are credited by de Vries (1974) as being proponents of the importance of flexibility in general fitness.

Lack of adequate flexibility is a concern of some researchers in that it can often presage medical problems such as lower back pain (Kraus and Hirchland, 1954; Johnson et al., 1966). Kraus and Raab (1961) credit poor flexibility as being directly related to the general tension syndrome (residual neuromuscular tension) and again to lower back pain. On this subject of medical problems, de Vries (1974:432) states:

...maintenance of good joint mobility prevents or to a large extent relieves the aches and pains that grow more common with increasing age.
and that "... stretching aids in relief of acute muscular distress in athletes."

It is on this subject of flexibility for athletes that this study is directed. That is, flexibility as it pertains to athletes and sport and most particular the sport of gymnastics, in which good flexibility is clearly one of the most important physical attributes necessary for success. It now appears, mainly through Leighton's studies (1960), that each sport demonstrates particular movement patterns that manifest themselves in particular flexibility patterns unique to that sport and that:

... it may not be possible to develop skills to a high degree without laying the groundwork of a proper flexibility pattern for the skill. (Leighton, 1960:70)

Thus it appears that flexibility can, indeed, help the athlete achieve greater success. Below is a list of some of the advantages an athlete can expect to enjoy by possessing optimal flexibility:

1. The possibility of mastering skills that are dependent on a certain range of joint movement, (walkovers in gymnastics).
2. Less resistance to movement, thus greater movement efficiency.
3. Prevention of soft tissue damage due to limited range of movement.
4. Increased amplitude thus enhancement of aesthetic impression and perceived ease of movement.
5. Mechanical advantages:
a. Greater range over which to apply force, (shoulder hyperextension in volleyball spike).
b. Placing the body in a position such as to facilitate application of forces, (wrist and hip flexibility needed for straight arm press to handstand in gymnastics).

The advantages enjoyed by flexible athletes are numerous yet relatively few studies have been conducted in the area and those completed have been intermittent and, in most cases, unrelated to each other. Even the terms of reference for the area are not yet clearly established. The term flexibility itself, for example, implies only flexion (Holland, 1968), and it has only been through common usage that this term has come to be associated with maximum range of joint movement. The terms "amplitude", "range", and "joint excursion" are all used rather interchangeably. As Holland (1968:58), stated: and Clarke (1975:1) reiterated:

There appears to be little agreement with regards to the definition and limits of so-called normal flexibility, and what constitutes hypo- or hyper-flexible joint range of motion.

This lack of uniformity and established terms of reference is also apparent with respect to the methods by which joint range can be increased. There is no unanimity as to which methods are best, and little research has been conducted on the effects of various methods.

Little is known about the minimum requirement for producing gains on flexibility. (Johnson et al., 1975:102)
The question of which methods are most advantageous for improving range of motion has received very little attention. (de Vries, 1974:436)

Most researchers have compared one method against another. No where in the literature is there a comprehensive comparison of four or more methods. Methods such as static stretch and spring stretch (ballistic) have been compared by Weber and Kraus (1949), Logan and Egstrom (1961) and de Vries (1962). The consensus of opinions is that both methods are equally effective but that the spring stretch methods are more likely to cause soft tissue injury. Since dancers utilize "controlled spring stretching" continuously and are generally considered to be the epitome of flexible performers, it is desirable to study these two methods still further.

Incorporated in many of the prolonged stretching methods is an element of mental and/or physical relaxation. Williams (1968) compared static stretch with a relaxation method and found the static stretch method increased range significantly over the relaxation method. The stretching periods, however, were only 10 seconds in length and Bates (1971) found that 10 seconds was not sufficient stretching time to elicit a significant change in range of movement. Also, Rathbone (1959) suggested improving flexibility using relaxation techniques and Bates (1974) suggested using "cybernetic or mind-set" techniques to enhance flexibility. Neither of these authors advanced any experimental data to back up their claims and thus it appears desirable to investigate this area further.
E.N.F. (proprioceptive neuromuscular facilitation) techniques for increasing ranges of joint movement are now widely used in rehabilitation medicine and in sport. Tanigawa (1972) and Holt et al. (1970) have researched these methods, but their stretching techniques differed and they did not compare a P.N.F. method with many other methods. Again, it is desirable to investigate this area in more detail.

Finally, a method that is fairly commonly used in the sport of gymnastics is the passive lift-active hold method, which has not yet been experimentally compared to other methods.

It was therefore the intent of this study to compare these various methods and to advance standardized terminology (see definitions). In addition, the lack of a theoretical model in the area of flexibility is recognized and one is developed. That model is described below:

To increase the amplitude of a joint, one of two events must occur. Firstly, the resistance to the movement must be decreased and/or secondly, the force (strength) required to overcome the resistance must be increased. These will be termed the MECHANICAL OBJECTIVES. In order to attain these mechanical objectives, certain PHYSIOLOGICAL CONDITIONS, such as elongating the connective tissue or loading the muscle must be met. These physiological conditions, in turn, are met by utilizing certain COURSES OF ACTION or certain physical or psychological techniques. Figure 1 schematically illustrates the model.
### MECHANICAL OBJECTIVES

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**Figure 1.** Schematic Representation of Theoretical Model.
The Problem

The purpose of this study is to compare the effects of six methods of stretching on reducing the resistance to passive hip flexion and thus begin testing the aforementioned theoretical model.

Sub Problem 1

To determine if any one of the experimental methods exceeds the others in increasing passive range.

Sub Problem 2

To determine if passive methods increase passive range better than active methods.
Definitions

Flexibility. A broad descriptive term which refers to that physical component describing the ease and the extent of movement in a given joint.

Amplitude. A specific term meaning the total angular displacement of a body segment around a given joint. For example: maximum extension to maximum flexion of the leg.

Range. The maximum angular displacement of a body segment in one direction only. For example: range of hip flexion, range of arm extension. This term must be further qualified into active range and passive range.

(1) Active Range is that range achieved by voluntary muscle contraction. If the contraction is very strong and results in the limb being quickly propelled to an end point, then the range is termed fast or dynamic active range. (Momentum is a contributing factor). If the contraction is slow and held at the end point, then the range is termed slow or static active range. These two terms can be logically shortened to simply static and dynamic ranges.

(2) Passive Range is that range achieved by utilizing some external force such as gravity or a partner's assistance. This range represents the maximum limits of a joint.

Passive Stretching Methods. Those methods in which a partner applies a force to the limb.
**Active Stretching Methods.** Those methods in which the limb is mobilized by its own muscle contractions.

**The Hypotheses**

1. Passive stretching methods result in a greater improvement in passive range than do active methods.  
   **Rationale:** The limb is mobilized through a far greater range with passive methods.

2. The "relaxation" method results in a greater improvement in passive range than do other passive methods.  
   **Rationale:** There should be an optimum increase not only in soft tissue extensibility due to stretch, but also in muscle extensibility due to decreased reflexive muscle contraction.

**Delimitations**

1. The study was conducted over a four week period using 119 female physical education students from the University of British Columbia.

2. Only the right hip was exercised and tested for hip flexion.

3. Only the effects of the exercise on the passive range was studied. For the effects on active range see Hartley (1976).

**Limitations**

1. No attempt was made to regulate activities outside the study other than to ask subjects not to purposely stretch the hip extensors during the course of the experiment. Subjects exercised under the supervision of the
experimenter but were mobilized by a partner. There was some variability in the skill displayed by these partners.

3. Extremely flexible subjects were not eliminated from the study yet they had very little potential for improvement.

4. Subjects were taken from physical education activity classes and it could be expected that some of their increase in range of movement was due to these classes.

**Significance of the Study**

A thorough review of the literature indicates that there is a need to clarify the differences among stretching methods in their effect on active and passive ranges. Indeed, no study to date has distinguished between these two ranges in their measurements. Also, to date there has not been a study utilizing or comparing more than three methods of stretching. Many studies are vague in terms of equalizing the time spent actually stretching by each method and the time resting. All exercise and rest time are equated in this study. This is one of the few studies that has not introduced experimenter bias by having the experimenter manually manipulate subjects in either the exercise or the testing sessions.

Most studies in the past have stabilized the leg and achieved hip flexion by rotating the hip around the head of the femur (thus using abdominal contractions to bend forward, as in the sit and reach tests and the standing toe touch tests (Wells and Dillon, 1952; Fieldman, 1968). In this study hip flexion was tested by rotating the leg
in the acetabulum and thus requiring the use of the rectus femoris and iliopsoas muscles.

It is hoped that this study, by comparing all of the most commonly used stretching methods, will give both the therapist and the physical educator more information by which to select their exercise battery.
CHAPTER II

REVIEW OF RELATED LITERATURE

This chapter will be organized under the following headings:

FLEXIBILITY DEFINED
TISSUE RESPONSES TO STRETCH
METHODS OF INCREASING FLEXIBILITY
METHODS OF MEASURING FLEXIBILITY
RELATIONSHIP OF FLEXIBILITY TO OTHER FACTORS.

FLEXIBILITY DEFINED

Sigerseth (1965; 88) reports that the term flexibility is derived from the Latin "bilis" meaning capability and "flectere" meaning to bend. This origin is reflected in the typical dictionary definition which invariably describes flexibility as ease of flexion or ease of bending. Despite this dictionary definition and the original meaning of the word, authors persist in referring to flexibility as the range of joint movement. (Holt, 1971; de Vries, 1974; Johnson et al, 1974; Clarke, 1975).

Leighton (1960; 27) gave a more expanded definition than is usual:

The potential and existing ranges of such movement have come to be called "flexibility" of the body and its various parts.
Common practice has established the use of the term with reference to range of movement only, although by its nature the term might apply to many other factors of movement such as muscle viscosity.

Holland (1968:49) further criticizes the common usage of the term flexibility:

...it should be noted that the term flexibility implies just flexion and therefore should be considered a misnomer and replaced with a more appropriate designation.

He did not, however, suggest a more appropriate term.

Since flexibility or range of joint movement is generally agreed to be a highly joint-specific factor (Hupperich and Sigerseth, 1950; Leighton, 1960; Harris, 1969) and since there is even little relationship between flexion and extension of the same joint (Dickinson, 1968) it appears pointless to continue defining flexibility as "the range of joint movement". Fleishman (1961) found through factor analytic studies that there were two factors involved in so-called flexibility. One, "extent flexibility", was the ability to extend or stretch a body part as far as possible in various directions (referred to in the study as range). The other factor was referred to as "dynamic flexibility" and was to do with the ability to perform repeated movements (ease of movement). The term "flexibility" is perhaps best thought of as the ability or ease in flexing or extending and is synonymous with the term suppleness.

The actual total angular displacement of a joint is best referred to as "amplitude" (Glanville and Kreezer, 1937) while the actual angular displacement in a given direction is
suggested by the present study to best be referred to as "range", for example, range of hip flexion or range of shoulder abduction. (see definitions)

Finally, if we define flexibility as a general term and range as the actual angular displacement in a given direction, then we must consider range as being either actively or passively attained. (Barnett, Davies, 1962). That is, active range is the range attained with voluntary muscle contraction and passive range is the range attained with the aid of some external force.

TISSUE RESPONSES TO STRETCH

If flexibility is to be enhanced, that is, the range of movement in some joint increased, then changes must take place in the soft tissue surrounding that joint. The typical synovial joint consists of two, cartilage covered bone ends which are surrounded by a fibrous capsule and anchored together by various ligaments. Passing over the joint and attaching at close proximity to it are tendons of various muscles. The interior aspect of the joint (inside the capsule) contains a fluid that is secreted by the synovial membrane which lines the capsule.

The amplitude of movement exhibited by a given joint is "... determined by the geometry of the bone surfaces and the constraints on bone movement imposed by the fibrous capsule, the ligaments and the muscle-tendon connections" (Boudreau and Tsuchitani, 1973:123). A look at each of these tissue's
response to stretch will follow these few definitions.

"Any physical deformation of matter caused by any kind of load acting on it." is how Frost (1973:40) describes the term "strain". He goes on to discuss the term "mechanical stress" as being "the resistance of the intermolecular bonds in a substance to physical deformation by externally applied forces (Frost 1973:34). These two terms "mechanical stress" and "strain" are important in accurately describing the response of various tissues to stretch. Mechanical stress, then, is the tissues' resistance to different strains, be they:

a) tension strain which is elongation or stretch, b) compression strain which is shortening or squashing or, c) shear strain which is a cutting or tearing strain. This paper deals only with tension strain.

Elasticity and plasticity (Wright and Johns, 1959; Remington, 1957) are terms used for tension strain at a cellular level. The former refers to the ability of fibers to be elongated and then to return to their original length. The latter refers to the ability of fibers to be elongated but not to return to original length.

1. **FIBROUS CONNECTIVE TISSUE**: The joint capsule, ligaments, tendons and the investing sheaths of muscle fibers (endomysium, perimysium, epimysium) are all basically composed of the same material with similar basic functions and mechanical as well as biological properties (Frost, 1973). This material, fibrous connective tissue, consists of elastin fibers, reticulin fibers and collagen fibers with the most
abundant being the fibrous, crystalline protein, collagen. It is collagen which supplies the "strength and rigidity in tension . . ." (Frost, 1973:238). That is, collagen has great capacity to maintain its original dimension under tension strain. The following are three properties of collagen fibers as outlined by Frost (1972):

a. Great strength to tension loads aligned parallel to the long axis of the fiber.

b. Ability to align individual fiber bundles parallel with tension loads and thus produce (1) thread-like or rope like structures (tendons, ligaments), (2) fabric-like structures (interosseous membrane, fascial sheaths, etc.

c. Ability to adapt and match their size (thus their strength) with tension loads they characteristically carry.

In addition to the above, living fibrous connective tissue also displays the following properties: (Smith, 1954; Frost, 1973).

a. Ligament and tendon can be temporarily stretched and return to their original length (20% stretch in the case of ligament and 10% stretch in the case of tendon. (Frost, 1973: 241).

b. Stretch hypertrophy is a property of tendon and ligament whereby regular, intermittent stretch causes collagen tissue to hypertrophy, until the resulting increase in strength eliminates elongation at that tension.

c. Stretch-creep is a property of tendon and ligament whereby constant gentle tension results in non-elastic yet non
From the preceding it can be seen that the fibrous connective tissue responds to tension strain (stretch) first by elongating slightly, then by exhibiting a slow adaptation (over time) to the force being applied (creep) resulting in a permanent elongation.

2. MUSCLE TISSUE: Muscle can be elongated up to double its resting length and return to normal without any apparent damaging effects. It is, therefore, an elastic tissue closely resembling rubber. (Remington, 1957). Besides being able to temporarily stretch, it also has the ability to permanently increase length as evidenced in normal growth. As the bones grow, so must the muscle and this is accomplished by adding new sarcomeres serially to the ends of existing myofibrils (Goldspink, 1972).

This serial addition of sarcomeres has also been shown to occur in muscles that have been immobilized in an elongated position for several weeks (Tabary et al., 1972). Conversely, a reduction in the number of sarcomeres has been shown in muscles that have been immobilized in a shortened position, (Williams and Goldspink, 1971; Tabary et al., 1972).

It appears then, that increased range can be attributed to both fibrous connective tissue elongation (creep) and muscle elongation (serial addition of sarcomeres). These physiological responses to stretch have been considered, however, in absence of any reference to the nervous system. The following section will therefore deal with the innervation of the afore-
mentioned tissues and the physiological responses to stretch which result.

3. **NEUROMUSCULAR RESPONSES TO STRETCH**: There are two main considerations when studying the neuromuscular response to stretch: a. the response of the muscle spindle to stretch and b. the influence of the spindle prior to stretch. A brief description of the structure and mechanisms of the neuromuscular spindle will first be reported.

Imbedded in skeletal muscle (extrafusal fibers) are the neuromuscular spindles which are fluid filled capsules, (2 x 20 m.m.) enclosing 2 to 10 specialized muscle fibers called intrafusal fibers (Ganong, 1973). These intrafusal fibers are contractile at their poles but not contractile in the center portion where there are many nuclei. There are two kinds of afferent innervation leaving these spindles: the primary afferent (Ia) neurons originate in "annulospiral endings" in the central nuclear regions and the secondary afferents (II) originate in "flower-spray endings" in the polar contractile regions (Olkowski and Manocha, 1972).

When the muscle in which the spindle is embedded is stretched, likewise the spindle is stretched thus eliciting a discharge from the annulospiral and flower-spray receptors and sending impulses along the Ia and II neurons. While primary afferents signal both rate of stretch (phasic or dynamic) and length of stretch (tonic or static), the secondary afferents signal only tonic stretch (Ganong, 1973).

In addition to the above mentioned afferent fibers,
there are 7-25 efferent neurons innervating each intrafusal spindle. For the most part, these are gamma motor neurons and they evoke contraction of the polar ends of the intrafusal fibers, which in turn causes stretch of the nuclear area and the resultant excitation of the stretch receptors in that area (Matthews, 1964; Polak, 1970).

Returning to the main consideration, that of neuromuscular response to stretch, let us consider a. the response of the spindle to stretch.

As a skeletal muscle is lengthened, the spindles signal this lengthening by firing phasically or tonically or both. The impulses are carried via the afferent neurons to the spinal cord where they excite motor neurons of the extrafusal fibers of the same muscle. That is, there is a monosynaptic pathway between the intrafusal and the extrafusal fibers of the same muscle and:

When stimulated by stretch of its endings, the primary afferent neuron fires signals into the central nervous system which evoke a contraction just sufficient to relieve the stretch. (Gardner and O'Connell (1972:200))

The frequency of firing is related directly to the velocity of stretch. When stretching ceases, the frequency drops to a lower level appropriate to the new length. Thus fast or "ballistic" (spring) stretch will induce a greater reflexive contraction of the muscle being stretched than will slow-prolonged stretch.

The second consideration to be discussed under neuromuscular response to stretch is b. the influence of the
spindle prior to stretch. Since the intrafusal fibers are supplied with efferent innervation, it is possible to pre set their length. This pre setting is done via the gamma motor neurons and is called "gamma bias". It is the gamma bias mechanism which allows spindle sensitivity to be continuously maintained. For example, if a limb is passively moved so as to shorten a given muscle, the spindle would subsequently be ineffective at registering stretch until the original length was surpassed. The gamma outflow, however, causes contraction of the intrafusal fibers thus "taking up the slack" and re-establishing spindle sensitivity. This is the so called "shortening reaction". A similar "lengthening reaction" occurs when a muscle is stretched. At first the stretching causes a reflexive contraction (myotatic reflex) but as the gamma bias is re set at this new length, the Ia discharge returns to the resting rate. (Gardner and O'Connell, 1972). It is important to note that resistance to stretch can occur even if the muscle is in a shortened position.

Since these gamma motor neurons inter-connect with higher centers (Granit et. al., 1955) the influence of volition is important to increasing range of movement. Impulse traffic from higher brain centres impinges on both the alpha motor neurons (to extrafusal fibers) and the gamma motor neurons. It would seem that, if alpha motor neurons are inhibited (as in muscle quiescence, Basmajian, 1973) and if gamma bias is "set" at the very limit of myofibril extensibility, then maximum range will result. If, on the other hand, gamma bias is
set so that there is still considerable myofilament overlap and/or if there is not complete inhibition of the extrafusal fibers, then there will not be maximum elongation. In the sedentary individual who never moves his/her limbs through a full range of movement, the "habitual" limit of gamma bias set may well be less than the "physiological" stretch limit.

4. NEURO-TENDINOUS RESPONSE TO STRETCH: In the neuro-muscular response to stretch, the myotatic reflex causes a muscle to contract when it is stretched. The opposite is true of the tendon or inverse myotatic reflex (autogenic inhibition). As the tendon is stretched, receptors called golgi tendon organs fire in response to this stretch.

Golgi tendon organs may be excited by strong passive stretch but are much less sensitive than the muscle spindles. They are, however, highly sensitive to the stretch imposed upon them by the contraction of the muscle in which they lie. (Gardner and O'Connell, 1972:207).

Ganong (1973) explains that there is little response from the golgi tendon organ to passive stretch because the more elastic muscle fibres take up much of the stretch. During contraction, however, the tendons are quickly stretched with the concomitant firing from the golgi tendon organ. An example of this reflex is the sudden release of muscle contraction that can be seen during arm wrestling (Gardner and O'Connell, 1972)

5. NEURO-CAPSULAR RESPONSE TO STRETCH: The joint capsule, skin and ligaments are all supplied with sensory receptors, some of which are slowly adapting (sensitive only to position) and some are fast adapting (sensitive to movement).
As a limb is being mobilized and stretching of these tissues is taking place, there is the resultant outflow of afferent impulses, which as well as register kinesthetic sensations also influence some of the reflexes mentioned previously.

Since the afferent neurons of these joint receptors interconnect at the spinal cord with interneurons of broad distribution, their influence is more diffuse than that of muscle proprioceptors. (Gardner and O'Connell, 1972: 210).

METHODS OF INCREASING FLEXIBILITY

One of the earliest written accounts of the benefits and techniques of increasing flexibility was written in 1589 by St. Archange Tuccaro - "Dialogue on the Acrobatics of Jumping" (cited by Holland, 1968). Many studies have subsequently been performed and it is now well known that the modifiability of flexibility is easily demonstrated. In fact, many methods have proven to positively alter flexibility. (Billig, 1951; Weber and Kraus, 1949; McCue, 1952; Riddle, 1956; de Vries, 1962; Fieldman, 1966; Bates, 1971; Liverman, 1970; Norman, 1970). The methods that have been studied can be generally grouped under the following headings: 1. Static (passive), 2. Spring (ballistic), 3. Relaxation and/or Mindset, 4. P.N.F. (proprioceptive neuromuscular facilitation).

1. and 2. **Passive Stretch and Spring Stretch.** Weber and Kraus (1949) compared spring and passive stretch and found the former to be slightly better. Other studies, however, found both methods to be equally effective (de Vries, 1962; Logan...
and Egstrom, 1961). These latter two studies plus others (Young, 1950; Stafford and Kelly, 1958; Rathborne, 1959; Bates, 1971) have expressed a concern over the potential danger of the spring stretch methods. It is the consensus of opinions that if the two methods are similarly effective, then the passive methods should be chosen because of the reduced likelihood of injury.

3. Relaxation Methods, that is, passive methods in conjunction with some form of relaxation training, have been used for many years in yoga training though no controlled research comparing the effectiveness of yoga relaxation training and other methods for gaining flexibility have been published. It seems, however, intuitively plausible that relaxation will be beneficial to enhancing flexibility for several reasons. One, the gamma bias will "be set longer" than if some movement is anticipated. Two, resistance to stretch will be less, due to muscle quiescence "... electromyographic studies have clearly demonstrated that voluntary muscle can be completely relaxed by a small effort of the will", (Basmajian, 1973:259).

Both Rathbone (1943) and Scott (see Williams 1968:4) have stated that the ability to relax muscles surrounding a joint should increase range of movement at that joint. Relaxation methods such as Jacobsen's Progressive Relaxation (1938, 1967) and Shultz's Autogenic Therapy (Shultz and Luthe, 1969; Jencks, 1973, 1974) have not been thoroughly studied as to their effectiveness in increasing range of joint motion.
One study by Van Anne (1962) did show small positive correlations between increased flexibility of ankle, hip and shoulder with decreased residual tension of the gastrocnemius, biceps femoris and pectoralis major muscles. Yet another study, however, by Williams (1968) showed that static stretching alone was better than progressive relaxation and progressive relaxation plus static stretch. She did not, however, state whether the progressive relaxation training was done before, during or after the stretching procedure. The relationship between relaxation and stretching to increase range of joint movement is in need of further research.

Also under the category of relaxation methods is the "mind-set" or "cybernetic stretch" suggested by Bates (1974). Although no experimental work has been done on this area until this study, it again seems a plausible method. By training the mind (Psychocybernetics, Maltz, 1970) to imagine a position of elongation greater than is normally possible, one should be able to exert a volition or cerebral influence over lower motor neurons (such as gamma efferents to muscle spindles) thus manipulating a gamma bias or gamma set which in turn will determine at what point the myotatic reflex is elicited.

There have recently been many experiments in the area of biofeedback (Brown, 1975) that clearly demonstrate our ability to override or have volitional control over many so called "visceral" functions. It seems possible that many persons are, in fact, well within their physiological limits when they reach an "end-point" in joint range. Instead, they have
reached a limit determined by gamma bias and that it is possible to extend that limit by volition or mind-set.

4. **P.N.F. Methods.** Neuromuscular facilitation refers to techniques which will facilitate or enhance the ability of muscles to contract or to relax. Three techniques or principles of facilitation were first established by Sherrington in 1898. These were (Griffin, 1974):

a. **Immediate induction** - agonists and synergists are facilitated to contract at the beginning of a movement.

b. **Reciprocal innervation** - antagonists are inhibited from contracting at the beginning and during a movement.

c. **Successive induction** - antagonists are facilitated to contract at the end of a movement.

**Proprioceptive neuromuscular facilitation** refers more specifically to:

... promoting or hastening the response of the neuromuscular mechanisms through stimulation of the proprioceptors. (Knott and Voss in Tanigawa, 1972:725)

Gellhorn (1949) experimentally demonstrated proprioceptive facilitation in several techniques:

a. Resistance increases the response of muscle to voluntary contraction.

The effects seem to be based on the interaction of the proprioceptive impulses with those elicited by cortical stimulation, resulting in an increased number of discharging motor units (Gellhorn, 1949:35).

b. Stretch of a muscle prior to voluntary contraction
facilitates that contraction (also Cavagna et al, 1971).

c. Stimulation and excitation of reflexes will facilitate voluntary contraction of the same muscle group.

In addition to Sherrington's and Gellhorn's experimental work, and the clinical work of Kabat (1952) which all support P.N.F. techniques, Knutsson (1973) also mentions post contraction depression which is the depression of the stretch reflex for about 4 seconds after a contraction (starting 1 to 2 seconds after end of contraction).

Although utilized mainly for therapeutic work in muscle strengthening, P.N.F. methods have also been studied with respect to increasing joint range of movement. Holt, Travis and Okita (1970) compared one P.N.F. method (described as "active P.N.F." in appendix of this study) with spring stretch and passive stretch and found that the P.N.F. method they used resulted in increases of nearly three times that of the other two methods (which each had very similar results).

Tanigawa (1972) utilized a different P.N.F. method (described as "Passive P.N.F." in appendix of this study) and compared it with a passive stretch method. The P.N.F. method resulted in 5.4 times greater gain in range.

Holt (no date) published a book, *Scientific Stretching for Sport* in which he describes a method which is, in effect, a combination of passive P.N.F. and active P.N.F. Again, more experimental work is needed to determine exactly which methods are best suited to which conditions.
METHODS OF MEASURING FLEXIBILITY

Many unique and innovative methods have been developed for measuring the range of joint movement. These methods have been reported in other reviews by Wiechec and Krusen, 1939; Darcus and Salter, 1953; Leighton, 1954; Moore, 1959; Dickinson, 1963; and Clarke, 1975. The most common method used in present day rehabilitation medicine and in research prior to 1955 was the protractor goniometer. In 1955, Leighton introduced a pendulum goniometer which has become known as the Leighton Flexometer, and which has become very widely used in research. More recently, an electrogoniometer (elgon) has been developed and is becoming increasingly popular as a research instrument for measuring dynamic range (Adrian et al., 1965).

THE RELATIONSHIP OF FLEXIBILITY TO OTHER FACTORS

1. Age and Sex
2. Morphological and anthropometrical variables
3. Warm-up
4. Posture
5. Performance
6. Retention
7. Adaptive shortening

1. **AGE AND SEX**: Generally, flexibility declines with age (Wright and Johns, 1959; Sigerseth, 1965; Downie, 1970). The pattern of decline differs somewhat between males and females and between different age groups. With respect to males, Forbes (1950) studied 400 boys from 10-18 years of age
and found that the boys generally lost flexibility up to and through adolescence and then gained until age 18. Leighton (1954, 1956) found little change between boys of 6 to 10 years of age but then noted a steady downward trend from 10 to 18. He suggested (1960) that specific, habitual patterns of movement were more important than age with respect to changes in flexibility. Odgers (1969) studied 6-13 year old males and found a gradual increase until age 12 and then a decline at adolescence (13). He found 11 and 12 year olds to be the most flexible and 6-9 year olds to be the least flexible. The only consistent trend seems to be a decrease in flexibility during the adolescent growth spurt.

With respect to females, Hupprich and Sigerseth (1950) studied 6, 9, 12, 15 and 18 year olds and found a general increase from 6 to 12 years old and then a decline. Leighton (1960) compared his data on adolescent males with the data of Hupprich and Sigerseth on adolescent females and found that during their respective growth spurts the males generally decreased while the females stayed the same. Downie (1965, 1970) found that 6-10 year old girls generally showed no change, while 10 year olds increased in approximately half of their tests while remaining the same in the other half. The 12 year olds showed similar trends towards increased flexibility. Thus, unlike males, there does not appear to be any sharp decline during the adolescent growth spurt.

Several studies have compared males and females and of these, the greatest majority concluded that females were more
flexible than males at any given age (Phillips et al., 1955; Buxton, 1957; Kirchner and Glines, 1957; Shaffer, 1959). Some studies, however, did not corroborate these findings. Forbes (1950) found that at age 12, girls had greater range of movement in more joints than did boys, but that the reverse was true at age 18. Kendall and Kendall (1948) using two tests (toe touch and forehead to knees in sitting position) found that at age 5, 98 percent of the boys and 86 percent of the girls could perform the toe touch. Beginning at age 6 however, there was a sharp decline in this percentage and by age 12 only 30 percent of each sex could perform the test. The forehead-to-knee test produced opposite results with the number of girls successful at age 5 being 15 percent and boys being only 5 percent. This percentage did not change appreciably through to age 17.

Whether the difference between males and females or between ages are biological or environmental in nature is not clear. It does seem clear, however, that inactivity in the form of restricted joint movement does promote decreased range of movement in those joints. Akeson (1961) established that restricted joints lose mucopolysaccharides and as a result there is more "cross linkage" of collagen fibers and thus less elasticity. The patterns witnessed above may, in fact, be as Leighton (1960) pointed out; due to the different movement patterns which are characteristic of a given age or sex.
2. MORPHOLOGICAL AND ANTHROPOMETRICAL VARIABLES: After Kraus and Hirschland (1954) reported the comparison of fitness levels between American and European children, there were several "schools of thought" as to the cause of these differences. Inactivity, as mentioned previously, was certainly one possibility but so were possible population differences such as stature and size. Many studies followed the Kraus and Hirschland report and a great many of these looked at the fitness item which caused greatest failures in American children - flexibility. McCue, (1952), Perbix, (1954), Lauback and McConville, (1966) all studied the relationship between flexibility and somatotype and all concurred that there was no significant relationship. Tyrance (1958), however, studied the extremes of the three somatotypes and found a slight trend towards the endomorphs being more flexible. Likewise, Shaffer (1962, cited by Clarke, 1975) reported that tall overweight subjects were most flexible while short under and overweight subjects were least flexible.

With respect to anthropomorphic measurements, again the consensus of opinions is that there is no significant relationship with flexibility (Mathews, Shaw and Bohnen, 1957; Mathews, Shaw and Woods, 1959; Lauback and McConville, 1966; Harvey and Scott, 1967; Dinkheller, 1969). Two studies that do indicate significant relationships between anthropomorphic measurements and flexibility are Bröer and Galles (1958) and Wear (1963).

3. WARM-UP: Range of joint movement can be increased by warm-up in the form of practice trials (Lukes, 1954; Rochelle,
1960; Fieldman, 1966). Angle (1963) reported that a general warm-up in the form of relaxed riding on a bicycle ergometer resulted in an increase in the range of most joints studied. Warm-up in the form of heat application has been found by some investigators to likewise enhance range of movement (Wear, 1963; Wehr, 1964; Frey, 1970; Lehman et al., 1970; Grobaker, 1974). The effect of cold application, however, has not yet been researched sufficiently to allow a definitive statement. Frey (1970) and Grobaker (1974) found cold application to have no significant effect while Hol't (1971) claimed that the application of ice enhanced range of movement. Wear (1963), on the other hand, claimed that cooling a joint decreased the range of movement.

4. POSTURE: Several studies have looked at the relationship of posture and flexibility and once again the collective results indicate little or no relationship (Coppock, 1958; Flint, 1963, 1964; Hutchins, 1965).

5. PERFORMANCE: The various performance factors will be considered under the following subsections:
   a. Motor Fitness
   b. Physical Activity Patterns
   c. Strength
      a. Motor fitness items (running, jumping, throwing, etc.) have been studied with respect to flexibility and the results have been contradictory. McCue (1953), and Odgers (1969)
both reported that the superior groups of performers on their respective motor fitness tests were also the groups exhibiting the best ranges of movement (particularly trunk and hip flexion/extension). Dintiman (1964) found stretching exercises improved performance times on the 50 yard sprint. Other researchers, however, have reported contrary findings. Nelson (1960) and de Vries (1963) both found no significant difference in running times after stretching exercises while Davies (1957) and Burley (1961) each reported low correlations between motor fitness items and flexibility measurements. Also under the division of motor performance, Norman (1970) could not prove that velocity of knee extension could be increased by enhancing the extensibility of muscles crossing the knee joint.

b. **Physical activity patterns** such as would be expected from extensive participation in specific activities (employment or sport) result in unique patterns of joint flexibility (Kingsley, 1952; Bennet, 1956; Leighton, 1957a, 1957b; Villa, 1958; Bateman, 1962; Sterner, 1963; Leighton, 1960; Shaw, 1968; Denk, 1971; Ruhl, 1972). A summary of the findings of several of the above mentioned studies can be found in Clarke (1975).

c. **Strength training** and its effect on flexibility is yet another area in which there still is divided opinion amongst researchers. Studies by Massey and Chaudet (1956) and Chapman (1971) showed decreases in range of movement as a result of strength training. Wickstrom (1963),
Brigham (1963) and Gardner (1963) all reported no significant changes in range of movement after strength training. Tucker (1963) reported an overall increase in the amplitude of the shoulder joint but no significance was reported in any single range while other studies actually reported increases in range of movement following strength training (Taylor, 1928 - cited in Forbes, 1950; Wilson, 1945; Wickstrom, 1963). The latter investigator reported that after heavy strength training, flexibility changes were extremely varied with a trend for those starting with poorest flexibility to make largest gains and vice versa. In a similar area, Liverman (1970) found that there was no significant decrease in the explosive powers of the leg following a 6 week stretching regimen which significantly increased range of movement.

It would appear from the preceding that strength training done through a full range of movement has little chance of causing a decrease in range and that one's state of flexibility prior to beginning strength training may be of some importance.

6. RETENTION: The retention of newly attained ranges of movement following training has received relatively little research attention. Hansen (1962) studied the lasting effect of a single regimen of stretching and concluded that:

... an initial gain after stretching by all subjects lasting for three hours followed by a gradual decrease in mean score values. The critical decline seems to occur between three and twenty-four hours after stretching but is greatest in magnitude between the six and twenty-four hour period.
McCue (1953) reported that changes brought about by stretching exercises persist for up to eight weeks, while Bates (1971) concluded that the rate of loss depends on the amount of time spent stretching at each exercise period (60 seconds per day, five days a week for three weeks was better than 10 seconds, 30 seconds, 90 seconds and 120 seconds). Both Bates and Kingsley (1952) state that improvement is more dramatic in those subjects starting with lower ranges of movement.

7. **ADAPTIVE SHORTENING**: Decreasing the range of movement around a joint can also occur. Lockhart (1972) relates as to how adaptive shortening or "passive insufficiency" can occur in muscles by simply wearing shoes which have high heels. There is an adaptive, permanent shortening of the gastrocnemius and soleus muscles.

Another situation which can cause a reduction in range of movement is brought about by excessive residual muscle tension. Van Anne (1962) found small negative correlations between decreases in muscle residual tension and increases in joint ranges of movement. Increasing age has been mentioned earlier as yet another factor that contributes to decreasing flexibility. Similarly, inactivity with its resultant lack of movement of limbs through their full ranges, could cause adaptive shortening of the soft tissues around joints (Goldspink, 1972; Lockhart, 1972; Tabary et al., 1972).
CHAPTER III

METHODS AND PROCEDURES

Subjects

The sample consisted of 119 female subjects enrolled in Physical Education at the University of British Columbia. Their mean age was 20.19 years, their mean height was 1.65 metres and their mean weight was 60.15 kilograms. All subjects were first paired with another girl in the same class then these pairs were randomly assigned to one of seven groups (six treatment groups and one control group). The experiment ran from mid January to mid February, 1976.

Time of Exercise and Duration of Study

Each subject received five minutes of exercise, three times each week for three weeks. In addition, there was one testing day at the beginning and end, thus summing to eleven days spread over four weeks. Exercise was always done under the supervision of the experimenter between 8:00 a.m. and 6:30 p.m. All methods consisted of sixty seconds of exercise followed by sixty seconds of rest, then sixty seconds exercise etc., for a total time of ten minutes.
Space, Personnel and Equipment

The exercising area consisted of a flat carpeted surface on which the subjects laid supine. While being tested, each subject had her left leg anchored to the floor by means of a strap placed proximal to the knee. The right leg was held straight by the use of a padded 3" x 18" x 3/8" plywood splint firmly fastened to the anterior aspect of the leg (the middle of the splint juxtaposition to the patella). All straps were made secure by the use of strips of 2" wide velcro.

All measurements were taken by the experimenter and all exercise assistance was done by partners who kept time by the use of a large sweep-hand timer. Exercise rhythm and timing was further facilitated by the use of an audible electronic metronome calibrated to one beat per second.

A Leighton Flexometer, with 2" wide velcro glued to the back, was easily applied to the strap on the lateral side of the right leg splint. The Flexometer was set at zero when each subject was lying supine. This instrument has a test retest reliability of greater than .90 (Leighton, 1955).

Test Procedures and Instructions

Days 1 and 11 were strictly measurement days. Subjects wore gymnastics leotards or track suits and were first tested for active range and then passive range. This testing order was maintained throughout the experiment because it was felt that active range measurements would not affect
Plates 1 and 2: Exercise Session in Progress
Plate 3: Exercise Session showing clock and metronome

Plate 4: Demonstration of Flexometer Placement
passive range measurements but that the converse was not true. On each of the testing days, the subject laid supine with the left leg anchored and the right leg held straight by the use of the splint. The flexometer was attached and set at zero, and the subject was asked to slowly raise her right leg as far as possible and hold it there. A reading on the Flexometer was taken as soon as an end point was reached. For the passive measurement, the partner was instructed to mobilize the subject's leg by grasping it behind the heel and calf and slowly raise it until an end point was attained (subject indicated when pain-free range had been reached). No warm-ups were allowed and only one measurement was taken for each range. A correlation matrix was calculated to determine the reliability of taking one measure as compared to taking three measurements. Seventeen subjects were used and the lowest $r$ attained was .93 between a first and a third measurement. Thus it was decided to use only the one measurement.

After measurements were taken on day 1, subjects were instructed and allowed to practice their randomly assigned method. Practice was limited to learning the techniques of the method and the assisting. Hand-outs were given explaining the techniques and the rationale behind their particular methods. The subjects then met three times a week for three weeks. On days 4, 7 and 10 they were measured before and after exercise using the same sequence as day 1 and 11. Figure 2 is an outline of the sequence of exercise.
Specific Procedures for each Treatment Group

A detailed description of each method can be seen in the APPENDIX. The following is an account of the specific procedures used for each treatment group:

1. Control: This group was measured on days 1, 4, 7, 10, 11. They did not appear on the other days.

2. Passive Lift-Active Hold: The subject's leg was raised by the partner to the end point and held there for 6 seconds, then it was released and the subject tried to hold it at that point by contracting the hip flexors again for 6 seconds. This procedure was repeated 5 times in the 60 seconds and then the partners changed positions.

3. Active P.N.F.: The subject actively lifted right leg and held it at the end point for 6 seconds. The partner held the leg at that point while the subject exerted a maximum contraction of the hip extensors (isometric contraction) for 6 seconds. The subject then actively held the leg for

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Figure 2. Exercise Sequence for all Pairs of Subjects.
another 6 seconds, followed by a 6 second isometric contraction etc. for a total of 60 seconds before the partners changed places.

4. Spring Stretch and Hold (ballistic): Subjects did not need a partner for this method. Starting at 45 degrees, the right leg was swung to its maximum range 4 times and then held at the end point for 6 seconds. This procedure was repeated 6 times in the minute after which the subject rested for 60 seconds before repeating the sequence.

Note: This method is often referred to as "ballistic stretch" in the literature. This investigator does not wish to perpetuate this term since "ballistic" refers to a projectile separated from its source of energy.

5. Relaxation: The subject's right leg was passively lifted to its maximum range and held there for 60 seconds. During this time, the subject practised relaxation and "mind-set", which was a technique of mentally imagining themselves in a position of much greater stretch than they were capable. For example, they were shown a very flexible girl and told to "imagine" themselves to be able to achieve the same range.

6. Passive P.N.F.: The subject's right leg was passively lifted to its maximum range and held there for 6 seconds. The partner then resisted (held the leg firm in that position) while the subject contracted the hip extensors maximally for 6 seconds. This procedure was repeated 5 times in the 60 seconds then the partners changed positions.
7. Prolonged Stretch: The subject's leg was passively lifted to its maximum range and held there for 60 seconds. The partners then changed positions.

Experimental Design

A 7x5 randomized group, factorial design with repeated measures on the second factor was used. The two independent variables were A: the treatment factor containing 7 levels and B: the time factor containing 5 levels. The dependent variable was the measurement of passive range. The treatment factor was the six stretching methods and the control group, while the time factor was the 5 measurement days. Days 1 and 11 constituted pre experiment and post experiment measurements, while days 4, 7 and 10 constituted pre exercise and post exercise measurements on a given day. It was hoped that days 1 and 11 comparison would indicate the success of each method while days 4, 7 and 10 comparison would indicate trends of improvement. Each treatment cell contained between 15 and 20 subjects. Figure 3 is a schematic diagram of the experimental design.

Statistical Treatment

A multivariate analysis of variance was used and pre-planned orthogonal comparisons were set up to test the hypotheses. The contrasts were designed so as to compare:

1. The control versus all treatment methods.
2. The combination method (passive lift-active hold) versus all the other treatment methods.
3. Active methods versus passive methods.

4. One active method versus the other active method.  
   (Active P.N.F. versus spring stretch).

5. The relaxation method versus the other two passive  
   methods. (passive P.N.F. and prolonged stretch).

6. One passive method versus the other passive method.  
   (Passive P.N.F. versus prolonged stretch).

Figure 4 shows the pre-planned orthogonal contrasts  
and Table 1 shows the coefficients for the contrasts. This  
statistical treatment utilized the computer programme  
MULTIVARIANCE-VERSION 4-JUNE, 1968-by J.D. Finn.
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</tr>
<tr>
<td>Prolonged Stretch</td>
<td></td>
<td></td>
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<td>N=18</td>
<td></td>
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<td></td>
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</tbody>
</table>

Figure 3. Schematic Diagram of Experimental Design
A=Treatments  B=time
Table 1. Coefficients for the 6 Pre-Planned Orthogonal Contrasts.

<table>
<thead>
<tr>
<th></th>
<th>+6</th>
<th>-1</th>
<th>-1</th>
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<td>0</td>
<td>3</td>
<td>3</td>
<td>-2</td>
<td>-2</td>
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</tbody>
</table>

Figure 4. Pre-Planned Orthogonal Contrasts Used to Test the Hypotheses.
CHAPTER IV

RESULTS AND DISCUSSION

The results are reported in three subdivisions: overall effects; trends of improvement and pre-experiment versus post-experiment differences.

Overall Effects

Table 2 lists the means from all testing sessions and Figure 5 graphs these means.

Table 2. Means for Treatment Groups at each Testing Session (in degrees)

<table>
<thead>
<tr>
<th>Treatment Method</th>
<th>Day 1</th>
<th>Day 4</th>
<th>Day 7</th>
<th>Day 10</th>
<th>Day 11</th>
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<tbody>
<tr>
<td>1. Control</td>
<td>107.4</td>
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<td>114.9</td>
<td>118.5</td>
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<tr>
<td>2. Pas Lift Act Hold</td>
<td>101.3</td>
<td>113.3</td>
<td>119.0</td>
<td>122.9</td>
<td>129.0</td>
</tr>
<tr>
<td>3. Active P.N.F</td>
<td>95.5</td>
<td>104.6</td>
<td>109.6</td>
<td>113.4</td>
<td>115.4</td>
</tr>
<tr>
<td>4. Spring Stretch</td>
<td>101.9</td>
<td>110.3</td>
<td>115.3</td>
<td>117.3</td>
<td>124.8</td>
</tr>
<tr>
<td>5. Relaxation</td>
<td>100.6</td>
<td>112.5</td>
<td>120.3</td>
<td>123.5</td>
<td>127.5</td>
</tr>
<tr>
<td>6. Passive P.N.F</td>
<td>103.5</td>
<td>113.4</td>
<td>120.4</td>
<td>125.8</td>
<td>130.9</td>
</tr>
<tr>
<td>7. Prolonged Stretch</td>
<td>108.1</td>
<td>115.1</td>
<td>122.7</td>
<td>129.3</td>
<td>134.6</td>
</tr>
<tr>
<td>Post Exercise</td>
<td></td>
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<td></td>
<td></td>
</tr>
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<td>115.9</td>
<td>115.7</td>
<td>119.5</td>
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<td></td>
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<tr>
<td>2. Pas Lift Act Hold</td>
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<td>125.9</td>
<td>132.3</td>
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<tr>
<td>3. Active P.N.F</td>
<td>110.6</td>
<td>115.2</td>
<td>118.4</td>
<td></td>
<td></td>
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<tr>
<td>4. Spring Stretch</td>
<td>117.3</td>
<td>120.9</td>
<td>126.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Relaxation</td>
<td>122.5</td>
<td>122.3</td>
<td>129.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Passive P.N.F</td>
<td>123.6</td>
<td>127.4</td>
<td>133.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Prolonged Stretch</td>
<td>125.2</td>
<td>132.4</td>
<td>134.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. Means for Treatment Groups at each Testing Session
Trends of Improvement

All groups showed an increase in passive range. The experimental groups, however, showed significantly greater day to day improvements than did the control group (multivariate $F = 4.34$, $P = .0002$). The only exception to this trend was between days 7 and 10 where the control groups displayed gains equal to those of the mean of the experimental groups. Table 3 displays these trends.

Table 3. ANOVA Table for Helmert Contrast: Control Versus Experimental

<table>
<thead>
<tr>
<th>Test Days</th>
<th>Univariate F</th>
<th>$P$ less than</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 versus 4, 7, 10, 11</td>
<td>12.91</td>
<td>0.0005</td>
</tr>
<tr>
<td>4 versus 7, 10, 11</td>
<td>14.59</td>
<td>0.0003</td>
</tr>
<tr>
<td>7 versus 10 and 11</td>
<td>1.91</td>
<td>0.17</td>
</tr>
<tr>
<td>10 versus 11</td>
<td>4.69</td>
<td>0.03</td>
</tr>
</tbody>
</table>

As can be seen from Table 4, the greatest improvement occurred between days 1 and 4, and although the control group plateaued between days 4 and 7 and again between days 10 and 11, the experimental groups showed no signs of plateauing (see Figure 6).
Table 4. Means for Ranges Attained on Pre Exercise Measurements for the Control Groups versus the 6 Experimental Groups

<table>
<thead>
<tr>
<th>Test Day</th>
<th>Means for Control Group</th>
<th>Means for Experimental Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>107.35°</td>
<td>101.84°</td>
</tr>
<tr>
<td>4</td>
<td>114.18°</td>
<td>111.54°</td>
</tr>
<tr>
<td>7</td>
<td>114.94°</td>
<td>117.88°</td>
</tr>
<tr>
<td>10</td>
<td>118.47°</td>
<td>122.01°</td>
</tr>
<tr>
<td>11</td>
<td>118.71°</td>
<td>127.03°</td>
</tr>
</tbody>
</table>

Figure 6. Graph of Means for Ranges Attained on Pre Exercise Measurements for the control group versus the 6 Experimental Groups
With respect to the passive methods versus the active methods, the groups training under passive methods showed significantly greater ranges on all days with the exception of day 1. Table 5 demonstrates this trend.

Table 5. Means and Multivariate F for Active Versus Passive Methods.

<table>
<thead>
<tr>
<th>Test Day</th>
<th>x for active methods</th>
<th>x for passive methods</th>
<th>Univariate F</th>
<th>P less than</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>98.7°</td>
<td>104.1°</td>
<td>2.29</td>
<td>0.13</td>
</tr>
<tr>
<td>Day 4</td>
<td>107.5°</td>
<td>113.7°</td>
<td>3.69</td>
<td>0.06</td>
</tr>
<tr>
<td>Day 7</td>
<td>112.5°</td>
<td>121.1°</td>
<td>6.35</td>
<td>0.01</td>
</tr>
<tr>
<td>Day 10</td>
<td>115.4°</td>
<td>126.2°</td>
<td>11.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Day 11</td>
<td>120.1°</td>
<td>131.0°</td>
<td>11.39</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Figure 7 and Table 6 show there is also a definite trend for the increase within a given day, that is pre exercise compared to post exercise measurement, to be greater than the increase between pre exercise measurements of that same day and pre exercise measurements of the subsequent testing day, even though the latter measurement followed three treatment days.
Figure 7. Trends of Improvement
Table 6. Mean Increases in Range on Testing Days and Between Testing Days for all groups

<table>
<thead>
<tr>
<th>Mean Increases pre and post Exercise</th>
<th>Mean Increases Between Testing Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Day 4</td>
<td>Between Days 1,4</td>
</tr>
<tr>
<td>7.8°</td>
<td>9.3°</td>
</tr>
<tr>
<td>On Day 7</td>
<td>Between Days 4,7</td>
</tr>
<tr>
<td>5.4°</td>
<td>5.8°</td>
</tr>
<tr>
<td>On Day 10</td>
<td>Between Days 7,10</td>
</tr>
<tr>
<td>6.0°</td>
<td>4.0°</td>
</tr>
<tr>
<td></td>
<td>Between Days 10,11</td>
</tr>
<tr>
<td></td>
<td>4.3°</td>
</tr>
</tbody>
</table>

Pre Experiment and Post Experiment Differences

All methods, except Prolonged Stretch, achieved the greatest range on the post exercise measurement of day 10. It was, however, the day 11 measurement (no warm-up) that was compared with the day 1 measurement to calculate the mean increase in range. Table 7 lists the pre experiment versus post experiment differences. The control group gained significantly less ($F=25.79, P<.0001$) than the mean of the 6 treatment groups. The active methods showed significantly lower ($F=5.9, P<0.01$) mean increase in range than did passive methods, which as a group showed uniform mean increases of 26.9° for Relaxation; 27.4° for Passive P.N.F. and 26.4° for Prolonged Stretch. Passive Lift-Active Hold showed the greatest mean improvement with 27.7°. There was no significant difference between the Relaxation method and the mean of the other two passive methods.
Table 7. Pre Experiment (day 1) and Post Experiment (day 11) Differences.

<table>
<thead>
<tr>
<th>1. Control</th>
<th>11.4°</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Passive Lift-Active Hold</td>
<td>27.7°</td>
</tr>
<tr>
<td>3. Active P.N.F.</td>
<td>19.9°</td>
</tr>
<tr>
<td>4. Spring Stretch</td>
<td>22.9°</td>
</tr>
<tr>
<td>5. Relaxation</td>
<td>26.9°</td>
</tr>
<tr>
<td>6. Passive P.N.F.</td>
<td>27.4°</td>
</tr>
<tr>
<td>7. Prolonged Stretch</td>
<td>26.4°</td>
</tr>
</tbody>
</table>

Discussion

It appears from this study that a substantial increase in passive range can be easily and quickly acquired. Five, 60 second stretching periods, 3 times per week for three weeks resulted in 30% of the subjects in the treatment groups (30 out of 101 girls) increasing their range 30° or more. This increase could, in part, be attributed to their concomitant participation in activity courses although the control group had a mean increase of only 11.4°, much of which could be attributed to the fact that they were measured 8 times. As was seen in Figure 6, all methods except Prolonged Stretch showed a gradual tapering in the amount of gain between each testing session. The decrease in amount of gains was not substantial enough, however, to suggest that further exercise would not result in further gains. Quite the contrary, the decreases may well have been motivational in nature since 4 of the 7 groups showed an upswing on the last day of testing. (Hawthorne Effect).
It is interesting to note in Table 6 the positive effect that the exercise sessions had on the post exercise scores. The fact that the differences were greater between pre-post scores on day 7 and day 10 than between pre scores after three days of exercising (between days 4 and 7, between days 7 and 10), suggests that there is a neuromuscular warm-up effect (gamma bias resetting or habituation of the spindle firing) or that there is physical lengthening of the connective tissue. The fact that the increase is so quick (after only 5 minutes of exercise) and that only a portion of it persists, indicates that neuromuscular mechanisms are probably the dominant factors.

The difference between active and passive methods could, in part, be attributed to the fact that the passive methods maintain a position of maximum stretch for the full 60 seconds. The active methods alternate between maximum stretch and some facilitatory technique. This latter condition was, however, also true of Passive Lift-Active Hold which was the method showing the greatest improvement.

The three passive methods did not differ significantly from each other between pre and post experiment scores. Although the Relaxation and Passive Lift-Active Hold methods showed the greatest initial improvements of all methods (12° between days 1 and 4) the Prolonged Stretch method showed the least plateau effect.

With respect to the hypotheses, one was substantiated and the other was not. The first hypothesis that passive methods would show a better increase in passive range than
would active methods was accepted. It was found in the other half of this study (Hartley, 1976) that the converse was not true, active methods did not give a better increase in active range over passive methods. In fact, the passive method Relaxation gave the greatest increase in active range. The second hypothesis that the Relaxation method would be better than the other passive methods was rejected.

It is noteworthy that the results of this study are in direct opposition to those of Holt et al. (1970) who found that Active P.N.F. was the best of three studied, (a static, a dynamic and a P.N.F. method). In this study, Active P,N,F. was the least successful method, as it was in Hartley's study. The reason for these opposite results may be attributed to the difference in exercise time and rest time. Holt et al. had their subjects rest for 10 seconds after every 20 seconds of stretch (repeated 4 times). Tanigawa (1972) found that a passive P.N.F. method (hold-relax) resulted in a greater gain in passive range than did a passive stretch. This study does not support that finding and again it may be attributed to the fact that the subjects in Tanigawa's study were stretched for only 7 seconds at a time then rested for 5 seconds, (repeated 4 times).

It appears that P.N.F. methods develop a greater range than static stretching methods when the exercise period is short but when the exercise periods are increased up to at least one minute duration then the static methods (Prolonged Stretch and Relaxation) equal or surpass the P.N.F. methods.
in both active and passive range. The difference between the results of the two P.N.F. methods utilized in this study was conspicuous and further research between these and other "facilitation" techniques is warranted. In his book Scientific Stretching for Sport, Holt describes a P.N.F. method that is essentially the same as the Active P.N.F. method used in this study except that the partner aids with "slight pressure" on the active lift phase. It would seem that this is a combination of active and passive and should be compared with the other methods.

The Passive Lift-Active Hold method improved most for passive range and was ranked second for active range (see Hartley, 1976). It is easier to administer than the P.N.F. methods and requires less teaching than does the relaxation method. The reason for this method's success can perhaps be attributed to the fact that it is 1) a passive method thus stretching is occurring at maximum range and 2) the active hold phase elicits reciprocal inhibition of the hip extensors that may facilitate lessening the myotatic reflex when passive stretch is again applied. At this point it is appropriate to conjecture that a passive stretching technique such as Prolonged Stretch combined with an active contraction of the hip flexors (to elicit reciprocal inhibition) would result in maximum stretch and maximum relaxation of the target area.
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Flexibility is an area of study that has received relatively little attention and has still no universally accepted terms of reference or theoretical model. In addition, there has so far been no comprehensive study of many of the methods that are commonly used to increase joint amplitude. It was the purpose of this study to forward standard terminology (see definitions) and a theoretical model as well as to conduct an experiment that tested the effect of six different stretching methods on passive range of hip flexion.

The theoretical model stated that one must decrease resistance in a target area (area to be stretched) or increase the ability to overcome that resistance (strength) in order to positively alter flexibility. Several physiological conditions which would allow for these above objectives were listed as well as several courses of action which would satisfy the physiological conditions.

A sample of 119 university aged females were paired and randomly assigned to one of seven groups (6 treatment groups and 1 control group). They were measured on day 1, and then exercised 3 days a week for 3 weeks and measured
again on day 11. In addition, measurements were taken before and after exercise on days 4, 7 and 10. All measurements were taken by the experimenter using a Leighton Flexometer.

The methods that were tested were divided into: active methods in which the subject actively mobilized their leg (Active P.N.F. and Spring Stretch); passive methods in which the partner mobilized the subjects leg (Relaxation, Passive P.N.F. and Prolonged Stretch); and a combination method in which the partner mobilized the subjects leg and then the subject actively tried to maintain the range attained (Passive Lift-Active Hold).

Statistical treatment consisted of a multivariate analysis of variance with pre planned orthogonal contrasts, and the results were reported as: overall effects; trends of improvement and pre experiment versus post experiment differences.

Conclusions

1. Substantial increases in range of hip flexion are easily and quickly achieved.

2. All methods studied resulted in significant increases over the control group.

3. The passive methods employed in this study were significantly better than the active methods used.

4. Further study is necessary to differentiate between the effects of the different P.N.F. techniques that are presently used in sport and therapy.
5. The three passive methods (Relaxation, Passive P.N.F. and Prolonged Stretch) and the combination method (Passive Lift-Active Hold) were all equally effective in increasing passive range (only $1.3^\circ$ between highest and lowest).

6. The relaxation method appears to have more potential than was determined by this study. Accentuating a "mind-set" approach instead of a relaxation approach may result in greater gains.
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Denk, G.M.  

DeVries, H.A.  

DeVries, H.A.  

DeVries, H.A.  

Dickinson, R.V.  

Dickinson, R.V.  

Dinkheller, A.L.B.  

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Downie, P.D.  

Downie, P.D.  
Fieldman, H.

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Frey, H.J.

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Wright, V. and Johns, R.J.

Young, D.
APPENDIX A

INDIVIDUAL RAW SCORES

**Group 1 - CONTROL**

**Flexibility in degrees**

<table>
<thead>
<tr>
<th>NO.</th>
<th>ACT</th>
<th>PAS</th>
<th>ACT</th>
<th>PAS</th>
<th>ACT</th>
<th>PAS</th>
<th>ACT</th>
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<td>136</td>
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<tr>
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Group 6 - PASSIVE PNF
Group 7 - PROLONGED STRETCH

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APPENDIX B

INTERPRETATION OF PHYSIOLOGICAL MECHANISMS UNDERLYING THE SIX METHODS

All of the following methods are assumed to have an effect on the lengthening of soft tissue. However, each method has a unique approach to the problem of increasing range of motion.

Prolonged Stretch:

It is well known that the myotatic reflex declines over time. The prolonged position of stretch is thought to introduce fatigue and/or accommodation in the tonic stretch receptors. In prolonged stretch, the phasic component of the myotatic response is effectively eliminated and thus the reflex to contract the stretched muscle is potentially reduced.

Relaxation and Prolonged Stretch

It can be reasoned that the ability of muscle fibres to lengthen is dependent upon their state of relaxation. Mindset techniques as well as progressive relaxation deal with this goal in terms of tension awareness. If a relaxed state can be induced in combination with the prolonged stretch exercise, the following is expected:

1. Reduction of the myotatic reflex due to accommodation
2. Voluntary inhibition of the reflex due to tension awareness
3. Later onset of the reflex due to gamma bias accomplished by mind-set.

**Passive PNF**

The physiological bases for this method is that the soft tissue undergoing passive lengthening will undergo even greater stretch, particularly at the tendinous junctions, during the isometric extensor contraction phase. The maximal extensor contraction also facilitates the relaxation of the extensors when they cease contraction.

**Active PNF**

The physiological bases for the Active PNF method appear to be:

a) facilitation of flexor contraction following extensor contraction (successive induction)

b) facilitation of extensor relaxation due to inhibition of the stretch reflex following extensor contraction

c) facilitation of extensor relaxation due to the contribution of the tendon reflex (inverse myotatic reflex).

**Ballistic**

The rationale for "ballistic and hold" is that the "hold" introduces a quality of control at the joint limit that may prevent tissue damage which has been a concern with this method. The dynamics of this activity allows it to contribute to flexor strength and fast lengthening action of the extensors as is required for sport movements.
Passive Lift and Active Hold

This method not only employs the passive lengthening of the extensors, but is thought to facilitate reciprocal inhibition (relaxation) of the extensors by active contraction of the flexors when the hip flexors (iliopsoas and rectus femoris) are actively called upon in terms of strength to hold the leg in a position of maximal extension.
APPENDIX C
INSTRUCTIONAL SHEETS ON THE METHODS

NAME..........................

The group that you have been assigned to in this experiment is called the CONTROL GROUP.

Basically this means that you will not be active in terms of exercising but that you will be a full participant in terms of all measurements to be made. In this sense you will be part of a group that act as a "standard" that will be used as a performance comparison for the exercise groups. For this reason, it is very important that you do not take specific action to mobilize or strengthen the right leg in hip flexion over the next four weeks. It is appropriate that you continue with your normal activities as usual.

As a control group member, you will be required to attend only the measuring sessions (Days 1, 4, 7, 10, 11). This means that if we are meeting three times a week with your class or group, then you will be required on the same day of the week for four weeks, and then also on the next class day right after that.

NAME..........................

The stretching method that you have been assigned to is called Passive Lift and Active Hold. Please read the following instructions carefully prior to practicing with your partner.
INSTRUCTIONS FOR PASSIVE LIFT, ACTIVE HOLD METHOD

1. While lying on your back, just relax and let your partner raise your right leg slowly. The left leg remains on the floor with the knee extended, and it is important to keep the right leg straight throughout the exercises. Over a six second period, the partner will take your leg to the limit of your pain-free range (i.e. a position of stretch that you can maintain for the remainder of the six seconds) and will support the leg in the position where you say "stop."

2. After the six second mobilization of the leg, the partner will slowly release her support on the leg and it is then up to you to hold the leg in the position where it is released. If the leg slips back a little, try very hard to stop it as soon as you can. Actively hold your leg this way for six seconds.

3. On the next six second interval, the partner will give you support again, and move you slowly to at least your original position of limitation. If it is possible to go further than before, let your leg be moved to a new position before you say "stop."

4. The procedure is continued with the passive lift and active hold phases alternating every six seconds, a total of five times in one minute. After one minute the subject changes over to assist the partner in her stretch. The exercise will take place in ten minutes (5 minutes exercise, 5 minutes rest).

ASSISTING PARTNER

The partner stands facing the subject on the platform that stabilizes the subject's left leg. Taking hold
behind the subject's right ankle, the partner slowly elevates the leg. The knee can be supported also if it is bending. The leg is to be mobilized to the limit of the subject's pain-free range in the 6 second interval. The partner then releases pressure on the leg very gradually so that the subject can maintain that position on her own for 6 seconds.

The partner then resumes her position supporting the ankle (and knee if necessary) and mobilizes the leg to its original position (if the leg has slipped back), or to a new range in the next six second interval.

All movements in passive stretching are slow and gentle since the subject will be working at her end-point most of the time. Remember that your assistance is primarily to maintain the end-point position of the leg so that the subject can rest there at least part of the time; mobilizing the subject's leg to a new passive position will not be possible every time, especially as she approaches her maximum range.

The whole procedure will take 10 minutes (5 minutes of exercise and 5 minutes of rest alternating in one minute intervals). It is recommended that you go easy on the first day.

The stretching method that you have been assigned to is called the **ACTIVE PNF** method (proprioceptive neuro-muscular facilitation). Please read the following instructions **carefully** prior to practicing with your partner.
INSTRUCTIONS FOR ACTIVE PNF METHOD

1. While lying on your back, you will first be required to slowly lift your right leg upward, keeping it straight, directly pulling it toward your face as hard as you possibly can. The left leg remains stabilized on the floor during the exercise with the knee extended. You will have six seconds to lift the leg and hold it in its maximal position. Your partner will then step in and support your stretching leg for the next six second phase.

2. Next, you will gradually try to push your leg back down to the floor as hard as you can, and this will be an isometric contraction (i.e. the partner will resist the down movement) for six seconds.

3. You now lift your leg again, to a new position if possible, or at least maintain your present position for six seconds.

4. This alternating lift and isometric push-down are repeated until one minute is up (five times each per minute). Then you can rest your leg and assist your partner for the next 60 seconds. Altogether you will be exercising for five minutes and resting for five minutes. It is recommended that you go easy on the first day.

ASSISTING PARTNER

The partner is positioned so that she serves as an immovable object when the subject commences to exercise. She will stand facing the subject on the platform that stabilizes the subject's left leg. The partner must be prepared to resist the downward force when the subject is in the push-down phase. She does this by bracing her legs,
slightly flexed, and supports the back of the ankle with her hands or shoulder. The partner must resist completely all movement downward in order to make the subject's contraction isometric.

In the six second lift up phase, the partner does not assist the subject, but follows the movement and prepares for the next isometric contraction down from the new end-point. There are five resistive down phases in a one minute period, and the total exercise will take ten minutes (five minutes exercise and five minutes resting in alternating oneminute intervals).

NAME..........................

The stretching method that you have been assigned to is called the BALLISTIC AND HOLD method. Please read the following instructions carefully prior to practicing with your partner.

INSTRUCTIONS FOR BALLISTIC AND HOLD METHOD

1. While lying on your back, raise your right leg directly forward to approximately a 45 degree angle and use this position as a starting point for the exercise. The exercise is called "ballistic" but a better description of what we want you to do is "a controlled bounce." You can use the momentum of your leg swing to gain flexibility if you swing your leg in a controlled way at and past your original end-point. You are required to swing the right leg upward from the elevated starting position four times up and down. It is recommended that you go easy until you know where your end-point is, and then try to surpass your limit gradually.
with gentle momentum. On the fourth swing, you go up to the end-point and hold the leg there without bouncing back for six seconds. Try your best not to let the leg drop from that end-point.

2. After the leg hold, the leg is moved back to the 45 degree angle once more and you proceed with the four leg swings upward again. Altogether the ballistic swings and the hold are repeated six times in one minute. In total the exercise will take five minutes, alternating with five one minute rest intervals.

The left leg is kept extended and stabilized on the floor while the right leg is kept straight during the activity. Go as far as you with a straight leg, and take it easy on the first day.

NAME

The stretching method that you have been assigned to is called the RELAXATION method. Actually you and your partner will follow the same physical instructions as the PROLONGED STRETCH group, but in addition, there will be some "thinking" processes attached to your method. Please read the following instructions carefully prior to practicing with your partner.

INSTRUCTIONS FOR RELAXATION METHOD

This method has not been researched and your understanding of it is most important. Firstly, it involves a "mind-set" or a mental picture of the goal you are aiming for. Once you can visualize what you want to do, you can
better inhibit or over-ride reflexes that are preventing you from achieving this goal.

For example, when you stretch a limb past its usual 
(everyday) range, the muscle has a built in reflex that says, "Whoa! You are stretching me further than I usually go, so I'm letting you know." This is called the myotatic reflex. In effect, the muscle being stretched will actually contract or tighten when normal range is exceeded! You are then trying to stretch a contracted muscle and the tightness and pain are due to the fact that you have reached the physiological limit of stretch. If you could "inhibit" or over-ride this myotatic reflex, you could move your limb much further.

To do this, you first need a mental picture of where you want to be, and then you need to concentrate very hard on this picture when you stretch. You are concentrating on relaxing the stretched muscle and the more you relax, the less pain you will feel because the muscle will stop contracting. This is of course what is done in some yoga methods minus the scientific jargon.

It must be appreciated that in hip flexion there is no anatomical reason why you cannot be "very flexible." In fact, inactivity is the prime reason for lack of flexibility. Make sure that you do not allow your partner to stretch you so much that you are really uncomfortable. You cannot possibly "relax" if this occurs. Instead, have your partner stop just as you feel a tightness behind the leg and then "concentrate" on relaxing the muscle being stretched. As you relax, tightness will subside and you can have the partner increase the stretch. Remember this method calls for more "mental effort" than physical, and you must CONCENTRATE on your desired goal and on RELAXING the stretched muscle.
The stretching method that you have been assigned to is called the PASSIVE PNF method (proprioceptive neuro-muscular facilitation). Please read the following instructions carefully prior to practicing with your partner.

INSTRUCTIONS FOR PASSIVE PNF METHOD

1. While lying on your back, just relax your right leg and let your partner raise it slowly. The left leg remains stabilized on the floor with the knee extended and the right leg must remain straight throughout the exercise. Over a six second period, the partner will take your leg to the limit of your pain-free range (i.e. a position which you can tolerate for several seconds) and will support the leg in the position where you say "stop."

2. When the six seconds are up the partner will say "push" and you will then gradually try to push your leg back down to the floor as hard as you can against your partner's resistance. This is a six second effort and should be a maximal isometric contraction (as hard as you can with no movement occurring).

3. You can relax your right leg on the next six seconds, so that the partner can gently take your leg into the stretch again. At the limit of your pain-free range you again say "stop" and let her hold your leg at that position, keeping the leg straight. You may find that following each isometric push down that you can be passively moved to a slightly greater range each time (five stretches, five push downs in one minute). You will be active for five minutes altogether with five minutes of rest intervals. Take it easy on your first day.
ASSISTING PARTNER

The partner is positioned facing the subject so that she serves as an immovable object when the subject commences to exercise. She will be standing on the platform that stabilizes the subject's left leg.

Taking hold behind the subject's right ankle, the partner slowly elevates the leg directly upward through the subject's pain-free range. At the limit, the subject says "stop" and the partner holds the leg in this maximal position keeping the leg straight if necessary by holding above the knee with one hand and behind the ankle with the other.

After the six second period allotted to the above movement, the partner prepares to resist the downward leg push of the subject. In order to stop all movement downward and make the contraction an isometric one, the partner braces her legs slightly flexed while supporting the ankle with her hands or shoulder. The partner must take care that the subject's leg is mobilized in direct line with the body, and at no time should there be twisting of the hips.

NAME

The stretching method that you have been assigned to is called the PROLONGED STRETCH method. Please read the following instructions carefully prior to practicing with your partner.

INSTRUCTIONS FOR PROLONGED STRETCH METHOD

1. While lying on your back, just relax and let your partner raise your right leg slowly. The left leg remains stabilized on the floor with the knee extended, and it is
important to keep the right leg straight throughout the exercise. The partner will take your leg to the limit of your pain-free range (i.e. a position of stretch that you can maintain for a minute) and will support the leg in the position where you say "stop." If you have misjudged the position and experience discomfort, you can ask your partner to ease off a little until you are in a more comfortable position.

2. The stretch position is held by your partner (passively on your part) for one minute. After the minute, you change over with your partner and mobilize her right leg in the same way. Altogether you will be exercising five minutes and resting five minutes.

ASSISTING PARTNER

The partner stands facing the subject on the platform that stabilizes the subject's left leg. Taking hold behind the subject's right ankle, the partner slowly elevates the leg to the limit of the subject's pain-free range. The partner holds the right leg in its maximal position, keeping it straight if necessary by holding above the knee and behind the ankle for the minute period. The subject then lowers the leg. Take care to insure that the leg is mobilized in direct line with the body. It is recommended that all subjects go easy on the first day.