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I am submitting herewith a thesis written by Nickolas Mazis entitled "Stretching in Hamstring Muscle Flexibility: Active Isolated VS Static." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

Wendell Liemohn, Major Professor

We have read this thesis
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Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

Stretching in Hamstring Muscle Flexibility: Active Isolated vs Static

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

Nickolas Mazis

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ABSTRACT

Numerous studies have advocated the importance of flexibility as a main component of physical conditioning and fitness. Decreased hamstring muscle flexibility is related with a higher incidence of hamstring strains, as well as general dysfunction syndromes of the low back. Several stretching techniques have been developed such a static stretching (SS), proprioceptive neuromuscular facilitation (PNF), ballistic stretching, and active isolated stretching (AIS). The purpose of the present study was to determine if AIS was effective as SS in improving hamstring muscle ROM. Thirty male and female students, ranging in age from 18 to 25 years, volunteered to participate in this study. The subjects were stratified randomly and assigned to three experimental groups, SS, AIS, and control. The subject's hamstring flexibility was measured with a goniometer. The subjects were stretched at a rate of 3 days a week for a total of 9-treatments over a 3-week period. The selected stretching techniques produced significant pretest to posttest increases in both the non-dominant (trained) and the dominant (untrained) legs ($p<0.0001$). Sheffe' post hoc analysis revealed that AIS group improved significantly more than SS group. Females were significantly more flexible than males ($p<0.0001$), but no significant gender differences were seen in the level of improvement ($p>0.05$). Posttraining results revealed that the AIS group significantly increased the degree of asymmetry between the non-dominant (trained) and dominant (untrained) legs when compared to the same data for the control group ($p<0.02$).

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CHAPTER 1

INTRODUCTION

Flexibility has been defined as the total range of motion (ROM) possible at a particular joint or series of joints in functional combination (Borms, 1984). Numerous studies have advocated the importance of flexibility as a main component of physical conditioning and fitness, while decreased flexibility is related with impaired general physical condition (Beaulieu, 1981). A common aspect of physical training is to stretch the muscle tendon complex; various stretching techniques have been developed and successfully applied to different body areas to achieve this objective. In sports medicine stretching has been used to prevent or decrease the incidence of musculotendinous injuries while in rehabilitation stretching has been recommended to regain ROM, minimize and alleviate muscle soreness, or even as a way to create feelings of well being (Bandy and Irion, 1994; Beaulieu, 1981). In addition, studies have shown that an adequate amount of flexibility contributes to the enhancement of athletic performance (Taylor, et al., 1990).

Hamstring flexibility has been described as a key component of general fitness and health. If an individual's hamstring muscles are of inadequate length his/her ability to perform functional activities may be altered. These muscles play an important role in both the effectiveness and the efficiency of basic human movement. Moreover, it is believed that hamstring shortness is often related to disorders of the lumbar spine, general dysfunction syndromes of the low back, contractures resulting from deficits of the central nervous system, and sport related injuries (Gajdosik, 1991).

During running and sprinting events, great amounts of force are applied to the musculotendinous structures of the lower extremity, and especially to the hamstring muscle group (Worrell, et al., 1994). Results of various studies have revealed that there

is a relationship between hamstring flexibility and hamstring injury, since it appeared that hamstring-injured subjects were less flexible than non-injured ones (Liemohn, 1978; Worrell et al., 1994). In addition, it has been suggested that the development of low back pain (LBP) may be associated with hamstring tightness (Liemohn, 1996; Wehrenbert and Costello, 1983). Short hamstring muscles rotate the pelvis posteriorly; this places more tension on the hamstrings and makes them more vulnerable to injury (Liemohn, 1993a; Li et al., 1996).

The techniques used to improve flexibility include active and passive stretching; they are designed to improve active or passive ROM, respectively. However, passive stretching such as propriceptive neuromuscular facilitation usually requires the assistance of another person, and when done improperly, it is possible to stretch the muscles and tendons beyond their limits and cause injury (Borms, 1984). There are four general techniques used to improve flexibility and they may be summarized as follows:

- Static Stretching (SS). This involves a slow progressive stretch torque and maintenance of the muscle in a lengthened position.
- Proprioceptive Neuromuscular Facilitation (PNF). This induces a muscle's relaxation so that it can be stretched through spinal reflexes, such as reciprocal and/or autogenic inhibition.
- Ballistic Stretching. This involves jerking or bouncing movements, with the force of the bouncing stretching the muscle,
- Active Isolated Stretching (AIS). This may relax the muscle that is about to be stretched through reciprocal inhibition and because of the shortness of each stretching period.

Several research studies have tried to determine which technique has the greater effect on flexibility. The majority of the literature states that the ballistic procedure is the least desirable technique due to the high incidence of injury. PNF and static stretching procedures have been compared frequently (Lucas, 1984; Osternig et al., 1990; Sady et al., 1982). When these techniques have been compared, most researchers found that PNF

technique was superior to static stretch. However, Moore and Hutton (1980), and Osternig et al. (1990), found that PNF produced more EMG activity than static stretching during the stretching period in addition to producing greater increases in ROM. This was somewhat of a surprise, for the success of PNF has been predicated on the assumption that it induced relaxation in the target muscle due to reciprocal and/or autogenic inhibition. It should be pointed out that those studies were conducted by obtaining results of only single treatment sessions; however, this should not affect the results.

On the other hand, Condon and Hutton (1987) and Godges et al., (1993) did not find differences between static stretching and PNF in ROM improvement. Sullivan et al. (1992) compared PNF to static stretching under two conditions, namely with the pelvis either anteriorly or posteriorly rotated. They concluded that the position of the pelvis was more important than stretching method used for increasing hamstring muscle length.

PNF exercises are typically designed as partner stretches, and if done incorrectly may cause injury (Borms, 1984). Because SS does not have this liability, and because a partner is not necessary, it is often the preferred method of improving flexibility.

Although non-research reports support the use of AIS (Matheny, 1995; Warldron, 1994; Lee, 1997), research supporting its efficacy is lacking. Moreover, it utilizes aspects of static stretching as well as PNF, and can be done without the need of a second person.

The purpose of this study was to determine if AIS was as effective as SS in improving hamstring muscle ROM in normally active male and female university students who participated in a nine session treatment program over a period of three weeks.

CHAPTER 2

RELATED LITERATURE

In this chapter several areas pertinent to this research will be reviewed. These include the applied physiology of stretching, including the role of reflexes, the lengthening of connective tissue, anatomical considerations, a description of ROM-improvement protocols, practical considerations of stretching programs, and a review of efficacy studies.

Applied Physiology of Stretching

The structural unit of skeletal muscle is the muscle fiber which is a long cylindrical cell, and is wrapped and separated from its neighboring fibers by its connective tissue covering, the endomysium. Fibers are organized into bundles encased by another connective tissue covering, the perimysium. The entire muscle is surrounded by still another connective tissue covering, the epimysium. Each muscle fiber is composed of a large number of smaller functional units called myofibrils that are the contractile elements of muscle. Within each myofibril there are sarcomeres, the functional unit of a muscle fiber, that gives the muscle the ability to contract or relax (Nordin and Frankel, 1989).

Myosin and actin are the contractile proteins which form cross bridges in the sarcomere. The relative movement of the actin and myosin filaments results in shortening or lengthening of the muscle. When the cross bridges lengthen the muscle stretches, and when they shorten the muscle shortens or contracts (McArdle, Katch & Katch, 1996).

The structures that surround, connect and stabilize the joins of the musculoskeletal system are the tendons, the ligaments, and the joint capsules. The role of the ligaments and joint capsules is to provide stability, guide and prevent excessive motion, while the

role of tendons is to attach the muscle to the bone and transmit forces. The noncontractile tissue which is located in those three principal structures and limits range of motion consists of collagen, elastin, and ground substance (Nordin and Frankel, 1989).

Muscle spindles and Golgi tendon organs (GTO) are specialized sensory receptors located in the muscles and tendons that provide information about muscle length and tension, as well as, their rate of change. The muscle spindles provide sensory information concerning the changes in muscle length and tension. The muscle spindles are uniform shaped, composed of intrafusal fibers that lie parallel to extrafusal fibers. Spindles are served by three types of nerve fibers, annulospiral sensory endings, flower-spray sensory endings, and gamma efferent fibers. The function of muscle spindles is to detect and respond to changes in the length of extrafusal muscle fiber (McArdle, Katch & Katch, 1996).

The GTO are connected in series within the tendons near the junction of the muscle. Their function is to protect the muscle from an excessive load that can result in injury, by bringing about a reflex inhibition of the muscles they supply. The GTO responds to both stretching and contracting. Thus, it can prevent overstressing the muscle tissue and protect it from too much tension caused either by active contraction or by lengthening.

The viscoelastic behavior of biologic materials is depicted by a spring-dashpot model adopted from engineering. The spring represents the ability of elastic materials to reverse themselves to their original length. The dash-pot is analogous to a hydraulic piston; however, in biologic tissues such as tendon, it represents the displacement of intracellular viscous fluids that provide the resistance to movement. Due to its viscoelasticity, the lengthening of connective tissue can be achieved easier with a low force of long duration than with a high force of short duration (Liemohn, 1993a).

Myotatic Reflexes

The function of the stretch reflex mechanism is to protect the muscle from being overstretched. When a muscle is stretched the intrafusal fibers are lengthened, thus activating the stretch reflex mechanism which causes a contraction of the stretched muscle. Depending on the amount and rate of the stretching, the stretch reflex mechanism responds, creating a proportional amount and rate of contraction. However, the stretch reflex responds only to stretching (Borms, 1984; Beaulieu, 1981).

Stretch of Connective Tissue

In order to move voluntarily body segments, muscles must work together as a team. Muscles antagonistic to contracting muscles should adequately lengthen to allow this movement. If the antagonistic muscles do not have sufficient length, ROM is impaired. The tendon and its associated connective tissue are usually the major components that preclude ROM, and increase resistance to the actual movement (Liemohn, 1993a).

The force applied on a tissue is called stress, while the resisting force is called strain. A longitudinal strain of tissues is called tension. In the literature there are three zones related to connective tissue lengthening. In the toe phase (elastic) region a tension-stress results in a lengthening of the connective tissue but without breaking any chemical bonds. If it is stretched less than one second the viscoelastic tendon tissue returns to its original length as soon as the tension force is released. If it is held for periods of time longer than one second, the viscoelastic tendon tissue demonstrates its plasticity and may increase in length. However, if the stress placed on the tissue is too great, irreversible damage can occur e.g., macro-failure. However, if any viscoelastic material is stretched safely below this point and then held at its new length, the stress required to hold it at that length decreases; the reduction in stretching force required is called stress relaxation (Liemohn, 1993a).

Hamstring Anatomy and Function

The hamstring muscle group consists of the biceps femoris, semitendinosis, and semimembranosus muscles. The biceps femoris is composed of two heads; the long head portion attaches to the sacrotuberous ligament and the posterior aspect of the ischial tuberosity; the short head originates from the femur at the lateral lip of the linear aspera, the proximal two-thirds of the suprocondylar line, and the lateral intramuscular septum. Both the long and the short head pass distally to insert on the lateral side of the head of the fibula, the lateral condyle of the tibia, and the deep fascia of the lower leg. While the long head is innervated by the tibial portion of the sciatic nerve, the short head is innervated by the peroneal portion. The medial hamstrings consist of the semitendinosis and the semimembranosous muscles. The semitendinosis has the same origin with the long head of the biceps femoris from the ischial tuberosity. It inserts proximally into the medial surface of the tibia and the deep fascia of the lower leg and distally to form a member of the pes anserinus with the gracilis and sartorious. The semimembranosus originates through a tendon from the ischial tuberosity proximal and medial to the biceps femoris and the semitendinosis, and inserts into the medial-posterior aspect of the tibia. The semitendinosis and semimembranosus muscles are innervated by the tibial portion of the sciatic nerve (Gray, 1985; Schulthies, 1987).

A complete gait cycle is described as heel strike to heel strike of the same leg. In walking one limb is always in contact with the ground; however, during running this is not apt to happen. The period which no limb is in contact with the ground is called float; this period increases with higher running speeds. Hence, in running and sprinting the muscles of the lower extremity are required to contract faster and absorb greater forces in a short period of time. In walking, the hamstrings are active functionally at the end of the swing phase (foot flat), and contract eccentrically to control knee extension. During heel strike phase they stabilize and initiate flexion of the knee. In running, the hamstrings function

is activated during the last third of the swing phase and before foot contact for hip extension and knee flexion (Worrell and Perrin, 1992). In addition, the hamstrings are directly antagonistic to the quadriceps during the first 160 to 165 degrees of leg extension. However, during the last few degrees of knee-joint extension the hamstrings increase the diminishing effectiveness of the quadriceps and assume a paradoxical extensory action immediately after foot strike (Liemohn, 1978).

Methods of Increasing Flexibility

Numerous stretching techniques have been developed to increase flexibility. These regimens are designed to improve passive and/or active range of motion. Active methods include rapid, smooth rhythmical or slow movements ended in a short rebound movement aimed gradually and progressively by an increase in joint motion. Passive methods often require the assistance of a second party or can be performed with one's own body weight. However, there is a possible risk of injury and therefore, should be applied cautiously (Beaulieu, 1981; Borms, 1984). The four most popular stretching techniques used today include:

1) **Ballistic or Dynamic Stretching.** These protocols are performed with jerking or bouncing movements, and the force of the bouncing stretches the muscles. There is an enormous tension applied to the muscles compared with the other techniques as a result of the quick and forceful bouncing that creates a great amount of stretch reflex contraction against the stretch. This method is most often performed in plyometric training with competitive athletes whose events include ballistic elements. However, this is the least desirable stretching technique due to the high risk of injury for most individuals. Thus, it is not recommended for rehabilitation purposes and for the majority of the population (Beaulieu, 1981; Sady et al., 1982; Borms, 1984; Moore and Hutton, 1980).

2) **Static Stretching.** This refers to the procedure where the muscle-tendon complex is lengthened to the point of slight discomfort and then held at that position for 10 to 60 seconds. The literature indicates that static stretching produces the least amount of tension in the target muscle, while it appears to be more effective on passive ROM than active ROM (Borms, 1984; Bandy and Irion, 1994; Magnusson et al., 1995).

3) **Proprioceptive Neuromuscular Facilitation (PNF).** In this method relaxation is induced in the muscle to be stretched through spinal reflexes. The target muscle group is contracted for about 5-15 seconds against resistance after the limb is at end - ROM, this theoretically produces autogenic inhibition. Then the limb is moved beyond this point passively by a second party or with active contraction followed by passive assistance. If active contraction is employed, reciprocal inhibition should be enhanced. In PNF cases an experienced assistant is required to administer those techniques (Taylor et al., 1990; Bandy and Irion, 1994; Beaulieu, 1981).

4) **Active Isolated Stretching.** This refers to the method where a muscle or muscle group is first isolated and then stretched by contraction of the antagonist of the target muscle; this movement is done slowly. After active end-ROM is reached, movement is assisted further by pulling on the limb with the hand and/or a rope to the point of light irritation; this is held for up to 2-seconds and then the limb is returned to the starting position and rested for 2-seconds (Warldron, 1994; Lee, 1997; Matheny, 1995).

Practical Aspects of Stretching: Duration, Pelvic Position and Warm-up

In several studies the magnitude and duration of stretching that is necessary to exert the best results has been investigated. The literature indicates that small loads over long periods are more effective in producing stress relaxation than large loads over shorter periods. This is because the time-rate dependency of connective tissue lengthens in proportion to the magnitude of the load applied (Smith, 1994). Taylor et al. (1990) found

that the greatest amount of stress relaxation occurs during the initial 12-18 seconds of stretch with no other significant increases in length beyond this period. However, this study used an animal model, hence it might not be totally applicable to humans.

Bandy and Irion (1994) investigated the length of time that the hamstring muscles should be placed in a sustained stretched position. They concluded that 15 seconds was no more effective than no stretching, and that the most effective duration was one of 30 seconds. These authors did not find significant differences by increasing the duration of stretching from 30 to 60 seconds. The results of this study contradict findings of previous research which suggest that a 15 second stretch might be as effective as 2 minutes (Madding, 1987; Wiktorsson et al., 1983). However, it should be noted that the results that Bandy and Irion found were based on a change in ROM across a 6 week period instead of in a single treatment session that the other studies used.

Sullivan et al. (1992) compared static stretch and PNF hamstring stretching techniques under two conditions, namely while maintaining the pelvis in either an anterior or a posterior rotated position. They found that pelvic position had more influence on ROM gain than type of training (i.e., SS or PNF). An anterior pelvic tilt position evidently placed the hamstrings in maximal stretch and thus was the most beneficial stretching position for either of the two stretching techniques. The findings revealed in this study were also supported by Gajdosik (1991) who reported significant increases in hamstring flexibility by keeping the pelvis in anterior rotation.

Musculoskeletal injuries such as muscle strains and tears are very common and account for approximately half of all injuries in sports (Garrett et al., 1984). A warm-up period often precedes the actual event in order to improve performance and reduce the incidence of injury by elevating body temperature, increasing dissociation of oxygen from hemoglobin and myoglobin, altering muscular blood flow, and increasing the sensitivity of nerve receptor and nerve impulses (Safran, 1988; Mechelen et al., 1980; Watson and Lindsay, 1993; Shellock and Prentice, 1985).

Some research suggests that stretching is not affected by the use of warm-up prior to the actual stretching task. Cornelious and Hands (1992) as well as Sapega et al. (1981) did not find that by increased heat with stretching will result in superior flexibility performance than stretch exercises alone. On the other hand, structural weakening which occurs during stretching can be reduced by warming-up (Hubley et al., 1984; Schulthies, 1987; Shellock and Prentice, 1985). Therefore, it is preferable for a minimal warm-up to precede stretching tests, for even if it does not affect the actual flexibility scores, the incidence of injury will be reduced.

Review of Other Studies of Stretching Techniques

Numerous studies have tried to compare PNF to SS and determine with is the most effective in increasing flexibility/ROM. Medeiros (1977) found slight differences in flexibility when he compared PNF to SS and PNF appeared to be slightly superior. Sady et al. (1982) also concluded that PNF increased flexibility more than SS. The same results were reported by Tanigawa (1972), Moore and Hutton (1980), and Osternig et al. (1990). The two latter studies also indicated that PNF tended to produce significantly greater ROM although in some treatment sessions SS produced more ROM. Finally, Etnyre and Abraham (1986), Hartley-O'Brien (1980), Holt et al. (1970) supported the superiority of PNF over SS.

However, the superior results that some of those studies showed can be attributed to factors other than the actual stretching regimens (Lucas and Koslow, 1984). Tanigawa (1972) chose an alpha level of .10, while the amount of time used for each session was different in each study, varying from 2 minutes (Holt et al., 1970; Tanigawa, 1972) to 10 minutes (Hartley-O'Brien, 1980). The total treatment time also varied from 18 minutes (Holt et al., 1970) to 90 minutes (Hartley-O'Brien, 1980).

Some of the literature indicates that PNF is not superior to SS and suggests that those two methods do not differ in their effectiveness. Condon and Hutton (1987), stated that PNF was as effective as SS, while Sullivan et al. (1992) concluded that there was not significant difference between SS and PNF in their research paradigm. The latter authors concluded that pelvic position was more important that the actual stretching technique. Because PNF often requires the assistance of a second party, SS is more applicable and easier to do.

The AIS protocol is considered to be a relatively new technique often performed by dancers, martial arts enthusiasts, and track and field athletes (Lee, 1997). Traditional stretching is based on extending a limb and then leaning into it. AIS is dynamic and pain-free. The muscle which is about to be stretched should first be isolated and relaxed, then its antagonistic muscle is contracted until active end-ROM is reached. Immediately after each stretch the limb is brought passively to the point of light irritation and held for two seconds. The attraction of AIS is that it allows a deeper and gradual stretch since the muscle is pushed gently a little further than it wants (Matheny, 1995; Warldron, 1994; Lee, 1997). This short stretch period (i.e., 2-sec) is somewhat supported by Moore and Hutton (1980) and Osternig et al. (1980). The latter investigators found that in SS protocols in which the stretch was held more than 10 seconds, there was a reflex contraction in the target muscle that could theoretically impede ROM gains.

Summary

Some of the literature supports that static stretching has advantages of improving flexibility/ROM since ballistic stretching and PNF can place the muscle and tendons at high risk of injury and/or often require the assistance of a second party. However, although the use of active isolated stretching has been encouraged, no research was found that compared its outcomes to other stretching techniques.

CHAPTER 3

METHODS

Description of Subjects

A total of 30 (15 male students and 15 female students) from the University of Tennessee, Knoxville volunteered to participate in this study. All of these individuals were normally active, and they performed cardiovascular training (eg., swimming, jogging) two to four times a week for 30 to 50 minutes. They were stratified randomly and assigned to three experimental groups. Ten subjects were assigned to the static stretching group, 10 subjects to the active isolated group, and 10 subjects to the control group. Subjects were asked not to alter their regular physical activity patterns during the course of the study.

This study was approved by the University of Tennessee, Knoxville Institutional Review of Research Involving Human Subjects. All subjects were asked to sign an informed consent form prior to any procedure.

Measurement Procedures

Flexibility of the hamstring muscles was measured with a goniometer. Bandy and Irion (1994), found a test-retest reliability of 0.98 using the goniometer in their ROM study. The goniometer is often the instrument of choice in measuring ROM (Borms et al., 1987; Webright et al., 1997).

Markers were placed on the joint centers of the hip, the knee, and the ankle while, a knee brace was applied to hold the knee of the tested leg in passive extension. To eliminate pelvic movement that could probably affect the reliability of straight leg raise (SLR) test, the non-testing leg was stabilized to the testing table by a belt applied to the

thigh. After a 3-minute warm-up (jogging), each subject completed a series of three active SLR with each leg and the mean values were recorded.

Pretest measurements were taken two days before the stretching program began, while the post-test evaluation occurred two days after the completion of the training sessions. Prior to any test or training sessions, subjects were warmed up by a 3-minute light jogging activity. Their dominant leg was determined by asking them to kick a ball. For this study the non-dominant leg was selected to be trained.

Procedures

The rationale for selecting a nine treatment session protocol was based upon Sullivan et al. (1992) findings. These researchers found that an eight treatment session was an adequate time for improving the flexibility of the hamstring muscles.

The subjects of the two experimental treatment groups were instructed by the principal investigator (PI) on how to perform the assigned technique on the first day of stretching. The treatment groups stretched three days a week, Monday, Wednesday, Friday, for three weeks (9 treatments); the PI directed their programs on each of these days.

Data from the pre and posttest hamstring-flexibility testing were gathered using the active SLR test. Gajdosik (1991) and Borms et al., (1987) state that it is a common clinical test for assessing hamstring length and can be used to examine the effectiveness of exercise programs. Additionally, various studies have used the active SLR test to evaluate static stretching techniques in improving hamstring flexibility and length (Godges et al., 1989; Medeiros, 1977).

Active Isolated Stretching (AIS) Training Protocol

The subjects met with the investigator for each training session. Subjects of the AIS group assumed the supine position with their dominant leg bent at the hip and the knee joints and with their non-dominant foot flat on the floor. They looped a rope around the arch of the non-dominant foot and then straightened their non-dominant leg by contracting their quadriceps and locked their knee. Using the hip joint flexors they lifted their non-dominant leg as far as active ROM would permit; this movement was done slowly. Immediately on reaching end ROM of active hip-joint flexion, they assisted the movement with the rope to their end ROM. They held this position for 2 seconds and then returned their leg to the floor; this procedure was repeated 14 times at each training session. Following this procedure the total length of stretch at end-ROM was 30 seconds.

Static Stretch (SS) Training Protocol

According to Sullivan et al., (1992) the anterior pelvic tilt position is the most beneficial for improving hamstring ROM when the SS protocol is used. Each subject of the SS group was instructed to stand facing a chair with their heel of the non-dominant leg resting on the edge of the chair seat, while maintaining the standing leg perpendicular to the chair. In the Sullivan et al. (1992) study, each subject stood facing a padded table with one heel resting on the edge of the table at approximately 90° of hip flexion. However, this was not feasible in the present study since many subjects did not have adequate hamstring flexibility or height to assume this position.

Subjects were asked to keep their hands on their hips, keep their head in a neutral position, and look straight forward, keeping the stretched leg fully extended, and to extend their cervical, thoracic, and lumbar spines, and to retract their scapulae. They were then requested to flex their trunks forward until they perceived a hamstring tightness without pain. They held this stretch at end-ROM for 30 seconds. Bandy and Irion (1994) also used

a 30 second stretch and found it to be better or at least effective as stretches of 15 and 60 seconds.

Data Analysis

Intraclass correlation (ICC) coefficiencies were calculated to determine intraester reliability of the measurement protocol. A MANOVA was used to evaluate the initial differences in demographic characteristics among the three groups. Two MANOVA's were used to determine significant differences in flexibility improvement and asymmetry from pre-training to post-training data. Scheffe's post hoc tests were conducted in the presence of significant effects. The alpha level was set at 0.05 for each MANOVA.

CHAPTER 4

RESULTS

The demographic characteristics of the subjects are presented in Table 1. All subjects were stratified randomly, and assigned to either the SS, AIS, or control group.

Test Reliability

The results of the reliability study revealed that the intratester ICC was 0.997 for the dominant leg while, the intratester ICC for the non-dominant leg was 0.952. A MANOVA 3x3 (weight, height, age) was used to evaluate the initial differences in demographic characteristics among the three groups.

Demographic Variables

The MANOVA conducted on the demographic characteristics revealed no significant differences among the three groups. ($F [2, 29] = 0.02$; $F [2, 29] = 1.77$; $F [2,29] = 0.04$, $p>0.05$).

Dependent Measures

Two MANOVA's 4x3x2 (pretraining dominant x pretraining non-dominant x posttraining dominant x posttraining non-dominant, and dominant improvement x non-dominant improvement x pretraining asymmetry x posttraining asymmetry) were also used to determine significant differences in flexibility improvement and asymmetry from pretraining to post-training. The results were compared based on group and sex differences. There were no significant differences on pretraining flexibility between groups. Females were found to be significantly more flexible than males for both legs ($p<0.0001$).

Table 1. Demographic characteristics of subjects

		Age (years)		Height (cm)		Weight (kgm)	
	N	M	SD	M	SD	M	SD
C	10	22	2.44	1.75	0.62	74.12	8.23
SS	10	21.8	2.2	1.74	0.56	72.77	8.34
AIS	10	21.7	2.26	1.77	0.58	73.76	8.12

C = control group
SS = static stretch group
AIS = active isolated stretch group

Results of the MANOVA evaluating the efficacy of the flexibility training techniques used indicated that both training groups significantly improved their flexibility from pretest to posttest (dominant leg F [5, 29] = 30.08; non-dominant leg F [5, 29] = 74.49, $p<0.0001$) (Figure 1). There were no significant differences in improvement between males and females ($p>0.05$). For the non-dominant leg the improvement for the AIS group was 6.13 +/- 1.13 deg increase; the improvement for the SS group was and 3.31 +/- 0.21 deg increase.

Scheffe' post hoc analysis revealed that active isolated stretching group improved significantly more than static stretch group. Average pretest to post test improvement in dominant leg hamstring flexibility was also greater for the active isolated group (1.39 +/- 0.26) than the improvement for the static stretch group (0.59 +/- 0.21). Mean pretest and posttest values are presented in Table 2.

A MANOVA was used to evaluate the degrees of asymmetry (difference in flexibility between dominant and non-dominant leg). Pretraining data indicated no significant differences between legs among the three groups (F [2, 29] = 0. 22; $p>0.05$). Posttraining results revealed that only the active isolated group was significantly different from the control group (F [2, 29] = 4.20, $p>0.02$) (Figure 2). No significant differences were indicated in degrees of asymmetry between males and females in pretest and posttest data ($p>0.05$).

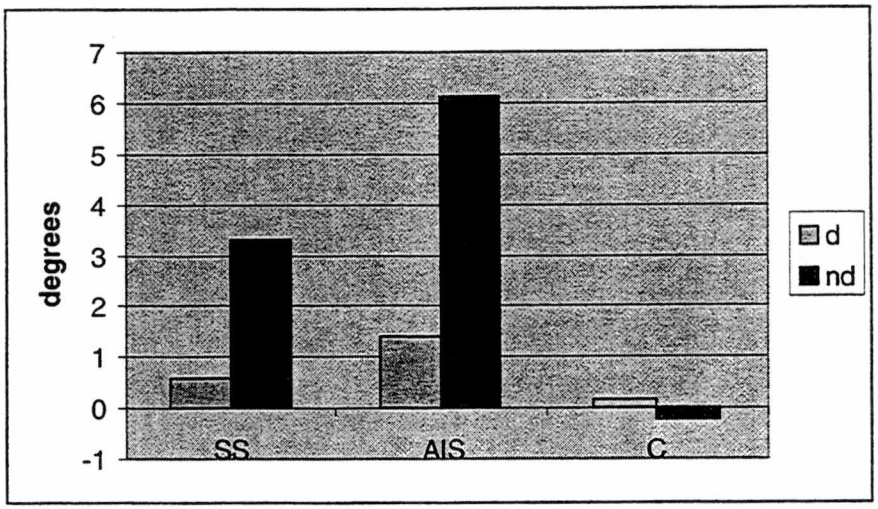


Figure 1. Average improvement in dominant (d) and non-dominant (nd) leg flexibility

Table 2. Pretest to posttest improvement

		Non-Dominant		Dominant	
	N	Pretest	Posttest	Pretest	Posttest
C	10	86.2	86.59	87.71	87.86
SS	10	90.78	94.09	91.26	91.85
AIS	10	90.17	96.3	91.72	93.11

C = control group
SS = static stretch group
AIS = active isolated group
*All scores are in degrees

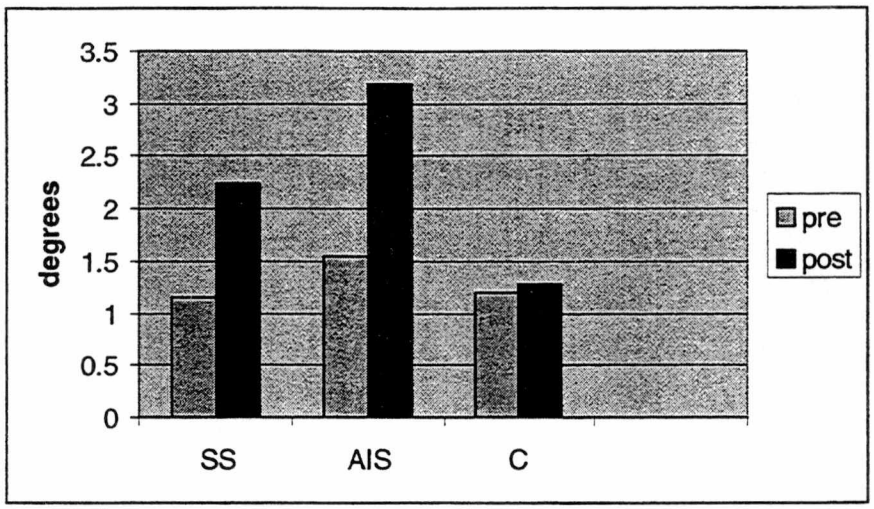


Figure 2. Asymmetry from pretraining to posttraining

CHAPTER 5

DISCUSSION

Stretching Technique Differences

Although both training groups showed a significant improvement in ROM, active isolated stretching (AIS) appeared to be significantly more effective in improving flexibility than the static stretch (SS) protocol in this investigation. The AIS group experienced an average pretraining to posttraining improvement of 2.82 deg higher than SS group (i.e., 6.13 vs. 3.31 degrees). There are several possible reasons for this. In AIS a voluntary contraction by the hip flexors and the quadriceps precede the actual hamstring stretching; this should facilitate reciprocal inhibition of the hamstrings during the stretch phase. In addition, the duration of the actual stretch in AIS is short (2 sec). As was previously discussed, PNF and SS held for longer periods of time result in increased levels of EMG activity in the muscle group being stretched. As postulated by Mattes (1990), a stretch held for 2-seconds or less is perhaps not of sufficient length to reach the threshold of the flower-spray receptors of the muscle spindle.

Another factor that may have contributed to the significant higher improvement of the AIS group over the SS group is the morphology of the SLR test used as the pre and post treatment measure. This test is active in nature and is somewhat similar to the actual performance of the AIS technique. In both this SLR test and AIS, the subjects had to actively raise their leg to the maximum point that they could. However, in the SS no similar movement takes place.

Sex Differences

In the present study, females were significantly more flexible than males. The pretraining data indicated that the females in this investigation had a mean average of 11.53 deg and 10.59 deg greater flexibility for their dominant and non-dominant legs, respectively, than did the males. Males of the two training groups showed a greater improvement; however, this difference was not significant. Hence, the significant difference between males and females was maintained after the training sessions. These findings are supported from other studies that investigated flexibility differences between males and females (Kiber et al., 1989; Bell and Hoshizaki, 1981; Smith and Miller, 1985; Docherty and Bell, 1985).

Asymmetry

Anatomical variabilities and asymmetries are developed during growth and determined by genetical and environmental factors. The influence of heredity predetermines the preferred side of the body for several basic motor functions, while environmental sources exert facilitating or inhibitory pressures upon the use of each limb results in the development of asymmetries in anthropometric measurements such as strength and flexibility (Liemohn, 1978; Agre et al., 1988). Various studies have investigated the relationship between asymmetric musculoskeletal flexibility and injury. Agre et al., (1987) studying the characteristics of professional ice hockey players, found a mean side-to-side difference of 4.5 deg using the SLR test. Vagenas and Hoshizaki (1991) concluded that long distance runners exhibited significant lower extremity asymmetries; they stated that functional variations are related to the etiology of injuries. Especially for the hamstring muscles potential asymmetries may predispose the leg to asymmetrical absorbing mechanisms resulting to injury; this concept is supported by Liemohn (1978). The latter author investigating possible causes related to hamstring

injuries in runners, concluded that there is a host of factors including asymmetry that either singly or synergistically predispose one to hamstring strains.

In the present study pretraining data revealed that all the groups had limb-to-limb differences in flexibility of 1.55, 1.20 and 1.15 for the AIS, C, and SS groups, respectively. After the compliance of the training sessions, only the AIS group increased significantly the degrees of asymmetry. Posttraining data revealed that subjects of AIS increased their hamstring asymmetry by 3.19 deg. Due to the potential risk of injury which is supported by many studies in case of functional variations, subjects were notified of these differences and flexibility regimen was provided to correct those abnormalities in their musculoskeletal profile.

Neural Transfer

Another interesting finding of this study was the significant improvement of the dominant leg (non-trained) of the two treatment groups. Sullivan et al. (1992) found no transfer or learning between the two legs. The results of their study revealed that stretching a muscle on one side did not affect contralateral muscle flexibility. However, in the present study subjects showed an improvement of their nontrained limb of 1.39 deg and 0.59 deg for the AIS and SS group respectively. The phenomenon of cross-transfer, the ability for exercise of one limb to cause an increase in strength of the contralateral unexercised limb, has been suggested by various studies.

Kannus et al., (1992) investigating the effect of one legged exercise on the strength, power and endurance of the contralateral leg concluded that there is a cross education effect from the trained limb to the untrained one. Hamstring muscles of the untrained leg showed an improvement of 36%, 58%, and 43% respectively for the parameters mentioned above. The authors stated that especially in the hamstring muscles the better the improvement in the trained side the better the effect in the untrained side. The

mechanism for that cross-education results from both diffusion of motor impulses and tonic postular reflexes arising in and acting on the extremity, which are modulated by reflex mechanisms situated in the brain stem. During training not only the trained limb but also the untrained one receives motor impulses from the motor cortex of the brain (Kannus et al., 1992).

Grady and Saxena (1991) investigated the optimal amount of time necessary to provide an adequate stretch flexibility for the gastrocnemius muscle found that the contralateral limb that the subjects did not stretch showed an increase in flexibility in 11 of 25 (44%) of the subjects. The phenomenon of cross transfer could be applicable and useful to the prevention of deterioration of muscle function during immobilization. Maintenance of flexibility has been employed to avoid the deleterious effects of immobilization on joint musculature and its function (Grady and Saxena, 1991). However the incidence of developing asymmetries should be considered, therefore, further research work is needed to investigate the cross-education effect.

CHAPTER 6

SUMMARY OF FINDINGS

Conclusions

The results of this study demonstrated that both hamstring stretching techniques produced significant pretest to posttest improvements in flexibility/ROM over the training period of nine sessions. However, the AIS group improved significantly more than SS group in both the non-dominant (trained) and the dominant (non-trained) legs, increasing significantly the degrees of asymmetry compared to the control group. The reciprocal inhibition and the shortness of each stretching cycle used in the AIS protocol may have relaxed the hamstring muscles more than the slow progressive torque and maintenance of the muscle in a lengthened position as used in SS. Females were found to be more flexible than males but no significant gender differences were seen in the level of improvement. Finally, although the dominant leg was not trained, both treatment groups improved significantly suggesting a neural transfer or learning.

Recommendations

The sample used in this study was one of convenience; this research could be conducted with subjects of different demographic background. The morphology of the SLR test that is active in nature and similar to the AIS technique, might have contributed to the significant higher improvement of the AIS group over the SS group. Therefore, future

studies should try to evaluate and compare the effectiveness of the AIS protocol to other stretching techniques using different tests.

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VITA

Nickolas Mazis was born in Athens, Greece on January 21, 1973. He attended schools in the public educational system of Greece, where he graduated from Polycladic High school of Athens in May, 1990. He entered the University of Athens during September 1990 where in February 1995 he received the Bachelor of Science in Physical Education. He entered the Master's program in Exercise Science at the University of Tennessee, Knoxville in August of 1996, officially receiving the Master's degree in May, 1998. He has been a member of the swimming national team of Greece, while in August of 1995 he competed at the World University Games in Fukuoka, Japan with the water polo national team of his country.