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THE EFFECTS OF INCREASING HAMSTRING FLEXIBILITY
ON PEAK QUADRICEPS TORQUE IN
COLLEGE-AGE FEMALES

BY
MARK LOREN AMUNDSON

A thesis submitted in partial fulfillment
of the requirements for the degree
Master of Science
Major in Health, Physical Education, and Recreation
South Dakota State University
1987
THE EFFECTS OF INCREASING HAMSTRING FLEXIBILITY
ON PEAK QUADRICEPS TORQUE IN
COLLEGE-AGE FEMALES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Jack Ewing, Associate Professor, Thesis Advisor and HPER Graduate Coordinator

Dr. James E. Lidstone, Assistant Professor, HPER Research Coordinator

Dr. Harry Forsyth, Professor and Head, Department of HPER
DEDICATION

This thesis is dedicated to my wife Margaret and my son Daniel. Without their love, sacrifice, continual support, and positive attitude this thesis would not have been possible.
ACKNOWLEDGEMENTS

The author thanks Dr. Jack Ewing for his many hours of assistance, expertise, enthusiasm, and friendship throughout the completion of this thesis. Thanks to Dr. Jim Lidstone for his part in stimulating an interest in research, and for his guidance in the statistical analyses related to this thesis. The author also thanks Dr. Jim Booher and Barb Moran for their moral support and helpful suggestions during the completion of this thesis. A very special thanks is extended to Dr. Loren and Mavis Amundson, the parents of the author, for their loving support and continued commitment to the education of this author.
Amundson, M. L. *The effects of increasing hamstring flexibility on peak quadriceps torque in college-age females.* Master of Science, 1987, 85 p. (J. L. Ewing)

The purpose of this investigation was to determine if increasing hamstring flexibility elicited a significant increase in peak quadriceps torque in college-age females. Fifteen college-age females, mean age $18.93 \pm 0.77$ years, volunteered as subjects for the study. Each subject was pretested and posttested for hamstring flexibility and peak quadriceps torque (Orthotron II set at 60 degrees per second). All subjects completed an eight week treatment program consisting of 10 repetitions of proprioceptive neuromuscular facilitation stretching for the right hamstring muscles, done three times per week, with the left leg used as a control leg. Hamstring flexibility was measured utilizing a Leighton Flexometer, an aluminum hinged device strapped to the lateral side of the leg, and passive straight leg raising. The mean change in flexibility from pretest to posttest on the right leg was $+8.71 \pm 2.73$ degrees and $+0.21 \pm 1.33$ degrees on the left leg. The mean peak torque on the right leg increased $10.31 \pm 15.91$ foot pounds from pretest to posttest while the left leg increased $0.55 \pm 14.56$ degrees. The mean change in the angle at which the peak quadriceps torque occurred from pretest to posttest was $-1.51 \pm 5.12$ degrees for the right
leg and $-0.13 \pm 4.10$ degrees on the left leg. Using paired t-tests a significant difference ($p < 0.05$) was found in hamstring flexibility between the right and left legs from pretest to posttest. No significant differences were seen in peak quadriceps torque or the angle at which peak torque occurred from pretest to posttest between the right and left legs. Increasing hamstring flexibility does not seem to significantly affect peak quadriceps torque or the angle at which peak torque occurs.
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CHAPTER I

INTRODUCTION

Free, unrestricted movement, is dependent upon normal joint connective tissue mobility and contractile tissue flexibility. Cureton (1941) and Flint (1963) pointed out that a certain level of flexibility is important to every person regardless of their age or activity level. Physical education and physical therapy experts have long believed that flexibility is one of the most important aspects of a conditioning program. Klafs and Arnheim (1977) stated that persons who are flexible are generally thought to be able to use their bodies more effectively and efficiently. Not only is flexibility believed to improve efficiency, it is also believed to aid in the prevention of injuries. As a person becomes more flexible the chance of injury to the connective and contractile tissues of the body lessons (Klafs & Arnheim, 1977). Holland (1968) proposed that there is an optimal level of flexibility. Too much flexibility endangers the supporting ligaments and connec-tive tissue while too little flexibility may cause harm to the contractile muscle tissue.

American researchers became increasingly interested in studying flexibility when the demand for physically fit
soldiers increased with the onset of World War II (Kendall & Kendall, 1949; Hupprich & Sigerseth, 1950; McCue, 1953). Until the early 1970’s static and dynamic stretching were used for the development of flexibility. Static stretching has been defined by deVries (1962) as, "a method involving a held position with no movement, slow or fast, in which the body segments to be stretched are locked into a position of greatest possible length" (p.223). He defined ballistic stretching as "a method involving quick movements characterized by quick jerks and pulls upon the body segments to be stretched" (p.223). In the 1950’s and early 1960’s the majority of the flexibility research compared static and ballistic stretching techniques (deVries, 1962; Riddle, 1956).

Although the concept of proprioceptive neuromuscular facilitation (PNF) was developed in the middle 1960’s it was not until the early 1970’s that researchers began comparing PNF stretching techniques with static and ballistic techniques. Proprioceptive neuromuscular facilitation has been defined by Knott and Voss (1968) as "methods of promoting or hastening the response of the neuromuscular mechanism through stimulation of the proprioceptors" (p.4). Tanigawa (1972), Moore and Hutton (1980), and Prentice (1983), all reported that PNF stretching techniques were superior to static and ballistic stretches while Lucas and Koslow (1984) found no significant
difference between the three techniques. Physical therapists and athletic trainers generally concur that PNF stretching is the method of choice for increasing flexibility.

Strength is one of many factors which can be critical to athletic performance and the performance of various tasks. Strength is important when lifting objects of significant weight, when jumping, running, or when attempting to move the body against significant resistance. Over the years strength has been quantified in many different manners. Since the introduction of the principle of isokinetic muscle contraction by Thistle, Hislop, Moffroid, and Lowman in 1967 many studies have been completed examining maximum dynamic strength measured isokinetically (Gilliam, Sady, Freedson & Villanacci, 1979; Holmes & Alderink, 1984; Dibrezzo, Gench, Hinson, & King, 1984).

The isokinetic device which has been most widely used and is considered state-of-the-art is the Cybex II (Lumex, Inc.). The Cybex II is a device which consists of an electromechanical apparatus that keeps limb motion at a constant, preselected velocity. Force applied by a subject is met by an equal resistance and the force applied is recorded as torque. Normative values for peak quadriceps and hamstring torque, hamstring/quadriceps torque ratios and other related data have been gathered (Holmes & Alderink, 1984; Miyashita & Kanehisa, 1979; Rankin & Thompson,
1983). Peak torque has often been utilized by researchers as representing strength.

The literature provides very little data regarding the relationship between flexibility and strength. The only study found addressing this topic was by Wiktorsson-Moller, Oberg, Ekstrand, and Gillquist (1983). They looked at the effects of warm up, massage, and stretching on range of motion and strength in the lower extremity. Their results indicated that stretching significantly \( p < 0.05 \) increased range of motion and found that massage decreased lower extremity strength. It was determined that stretching and warm-up had no effect on strength.

It has been the observation of this author, through the practice of physical therapy, that in fact a relationship may exist between flexibility and strength. Numerous young, active females with varying degrees of degeneration of the patello-femoral joint, known as chondromalacia patella, were treated by this investigator. Each patient was instructed in an exercise program of hamstring flexibility and quadriceps strengthening. Both exercises have been thought to be important rehabilitative activities for the treatment of chondromalacia. Many patients reported improvements in their symptoms following a four to eight week exercise program. A certain number of patients who admitted to completing only the hamstring stretching portion of the rehabilitation program also found relief
between the right and left legs following an eight week program of PNF stretching for the right hamstring muscles.

Definition of Terms

Ballistic Stretch: A stretch which involves quick movements characterized by quick jerks and pulls upon the body segment being stretched (devries, 1962).

Chondromalacia Patellae: A degenerative process that results in a softening (degeneration) of the articular surface of the patella (Booher & Thibodeau, 1985).

College-age Female: For the present study, a college-age female is one who was 18 to 22 years in age and was not competing on a varsity athletic team and was not in an organized stretching or strengthening program at the time of the study.

Hamstring Flexibility: The number of degrees of flexion which can be achieved at the hip joint with the knee held in an extended position (McCue, 1953). In the present study hamstring flexibility was defined as the average of the last three trials of passive straight leg raising with the knee fully extended.
**Hold Relax Stretching Technique:** A passive flexion of the leg with the knee extended to a point of perceived stretch, followed by a five second isometric contraction of the hamstring muscles, followed by a five second relaxation period (Surburg, 1981).

**Isokinetic Exercise:** A form of resistive exercise which utilizes an electromechanical device to keep limb motion at a constant, predetermined velocity. Any effort applied encounters an equal counterforce so that a maximal effort elicits a maximal resistance (Moffroid et al., 1969).

**Orthotron II:** An isolated joint, reciprocal, isokinetic system used for rehabilitation, exercise, and testing of the ankle, knee, hip, and shoulder (Lumex, Inc.).

**Passive Straight Leg Raise:** A technique used to test hamstring flexibility where the hip of the subject is flexed, with the knee fully extended, until a limitation of movement is perceived (Tanigawa, 1972). In the present study the subject's hip was flexed, with the knee extended and the non test leg stabilized over the edge of a plinth, until the pointer on an aluminum hinged device deviated from the center line by two millimeters.
Peak Quadriceps Torque: The greatest single force, acting about an axis of rotation, produced by the quadriceps muscle during knee extension (Moffroid et al., 1969). In the present study it was the single greatest torque, in foot pounds, produced by the quadriceps muscle during three maximal repetitions at 60 degrees per second of knee extension on the Orthotron II.

Plinth: A padded table for a patient to sit or lie on while performing therapeutic exercises (Dorland’s Medical Dictionary, 1974)

Proprioceptive Neuromuscular Facilitation: A method of developing flexibility where the response of the neuro-muscular mechanisms are enhanced through stimulation of the proprioceptors (Knott & Voss, 1968).

Static Stretch: A stretch which involves holding a position with no movement, slow or fast, in which the body segments being stretched are locked in a position of greatest possible length (deVries, 1962).
Assumptions

The following assumptions were made by the researcher for this study.

1. It was assumed that all efforts put forth by each subject during peak torque measurement were maximal efforts.
2. It was assumed that all subjects strictly adhered to the requirement that the left leg was not to be stretched during the duration of the study.
3. It was assumed that all subjects strictly adhered to the requirement that no strength training was to be undertaken during the duration of the study.

Limitations

A limitation of the present study was that the Orthotron II was used as the isokinetic device to measure peak quadriceps torque as opposed to the state-of-the-art Cybex II device. The Orthotron II is a hydraulically braked device while the Cybex II is an electromechanically braked device. Although the method of braking differs there is no evidence to indicate that a variable error will result from the use of the Orthotron II.
Scope of the Study

Fifteen college-age females, age 18 to 22 years, who were enrolled in a physical education lifetime activities class at South Dakota State University volunteered as subjects for this investigation. All subjects completed a familiarization session, a pretest, and a posttest for hamstring flexibility and peak quadriceps torque. Each subject also completed an eight week treatment program consisting of 10 repetitions of PNF stretching. All 10 stretches were completed three times per week on the right leg with the left leg used as a control. All testing was conducted by the investigator in the Human Performance Lab and Rehabilitation Room at South Dakota State University during the spring semester of 1986.

Significance of the Study

Sports medicine authorities consider flexibility to be a major aspect of conditioning. Mathews, Shaw, and Bohhew (1957) and Mathews, Shaw, and Woods (1959) have completed studies which indicate that increasing flexibility can decrease the amount of injuries. It is also contended that increasing flexibility contributes to better athletic performance. Klafs and Arnheim (1977) state that:
with more flexibility the runner can increase his stride, the hurdler can effect a more economical flight and the swimmer can produce a better leg kick and more efficient arm stroke. The gymnast, the wrestler, and various other athletes are all dependent to a large degree upon good flexibility (p.73).

There has been very little empirical research done to support Klafs and Arnheim's statement. Therefore, this study was undertaken to determine if increasing hamstring flexibility has an effect on peak quadriceps torque in college-age females. If peak torque is enhanced by increasing hamstring flexibility perhaps persons involved in activities that require maximum quadriceps effort may improve their effectiveness in those activities through appropriate flexibility exercises. In addition, very little research has been completed on the mechanisms associated with flexibility. The results of this study could enhance our understanding of these mechanisms.
CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the published scientific literature related to this investigation. It includes a review of literature pertaining to flexibility and isokinetic strength measurement. For organizational purposes the material reviewed under each of the major headings is further subdivided where appropriate. A summary of the literature review is provided at the end of the chapter.

Flexibility

General Considerations

Flexibility has been defined in several different ways. Mathews, Shaw and Bohhew (1957) defined flexibility as "the range of joint motion" (p. 352) while McCue's (1953) definition was "the amount of movement which can be achieved through the use of a group of articulations" (p.316). A current definition of flexibility provided by Arnheim (1985) is "the range of movement of a specific joint or groups of joints influenced by the associated bones and bony structures and the physiological characteristics of the muscles, tendons, ligaments, and the various other collagenous tissues surrounding the joint" (p. 91).
As early as 1941, Cureton wrote of the merits of flexibility. He included flexibility along with strength, endurance, power, speed, and skill as factors that need to be considered when discussing total body performance. It has been pointed out by physical medicine and rehabilitation specialists that the development and maintenance of normal flexibility is important. Arnheim (1985) stated that "in general, the flexible athlete, is less injury prone and more likely to perform optimally when compared to the inflexible athlete" (p. 91). This statement was supported by the work of Cureton (1941). He stated that in 1932, flexibility measurements were taken on Japanese and American swimmers, as well as a group of college competitive swimmers of the same age group. The results of the measurements were that the Japanese swimmers, who broke the world 880 yard relay record, averaged 31.3 percent better on trunk flexion than the American relay team members. The American Olympic athletes were found to be, on the average, 11.4 percent more flexible in ankle flexion and 7.7 percent more flexible in trunk flexion when compared to the American college competitive swimmers. Cureton concluded that an increased amount of flexibility significantly enhanced the performance in swimmers.

There are many anatomical and physiological factors which affect flexibility. Johns and Wright (1962) measured the relative contributions of skin, muscle, tendons, and
joint capsule to the total stiffness in the wrist joint of cats. Their findings demonstrated that the joint capsule contributed 47 percent of the total resistance to mid-range joint movement while passive muscle motion accounted for 41 percent. Tendons and skin contributed 10 percent and two percent, respectively. In regards to the muscle’s role in limiting joint motion, Holland (1968) pointed out that the myotatic reflex may be a limiting factor during stretching. The myotatic reflex is a phenomenon where receptor organs (the muscle spindles) are excited within a muscle when it experiences an unanticipated stretch. Due to this excitation a contraction takes place which in turn may limit flexibility. Although the contribution of the myotic reflex to limitation of range of motion has not been demonstrated it should be considered as a contributing factor.

Hupprich and Sigerseth (1950) conducted a study using 300 females, age 6 to 18 years. The purpose of their investigation was to determine if flexibility in young females was a general factor or one that was joint specific. In addition they wanted to determine if the flexibility of females changes as they advance in age. Flexibility measurements, using the Leighton flexometer, were taken on the right elbow, wrist, shoulder, ankle, hip, and knee joints for all subjects. The six year old group demonstrated a mean thigh flexion of $111.78 \pm 9.24$ degrees
One arm of the goniometer is stabilized while the other arm moves with the body segment. A direct reading is taken from the goniometer, and this reading is the actual joint range of motion (Hsieh, Walker, & Gillis, 1983). The protractor goniometer is widely used today by therapists and trainers. The shortcomings of the goniometer are that it is difficult to correctly align with the axis of motion and it is difficult to stabilize while moving the body segment. The protractor part of the apparatus is sometimes hard to read and is not exact. Zankel (1951) introduced the photogoniometer as a new method of measuring joint range of motion. It consisted of a goniometer, divided into five degree segments, projected upon the patient so the center of the goniometer circle is focused over the joint’s axis of rotation. The desired body part is moved and a reading is taken from the projected image.

Leighton (1955) introduced a more sophisticated device to measure range of motion. The "Leighton Flexometer", as it was named, consists of a weighted 360 degree dial and a weighted pointer which are mounted in a case. The dial and pointer are free moving and controlled by gravity. There are locking devices for both the dial and the pointer which will prevent all movements at any given point. The flexometer is commonly strapped to the body segment being measured. The dial is locked in the zero position, the body segment is moved to the desired position, and the
pointer is then locked in position. The direct reading of
the dial is the range of motion, in degrees, which has
taken place. Leighton (1955) reported reliability coeffi-
cients ranging from .913 to .996 for 30 different measure-
ments taken using the flexometer.

Along with various devices to measure flexibility,
researchers have assessed flexibility by isolating the
desired joints and muscles in various positions. Sady,
Wortman, and Blanke (1982), examining flexibility measure-
ment techniques, determined hamstring flexibility using a
flexometer with the subjects in a supine position on a
table. The test leg, with the flexometer strapped to the
lateral aspect of the leg, was actively raised as much as
possible while the non-test leg remained in contact with
the table. The amount of hamstring flexibility was
measured in degrees of hip flexion. Another study using
the flexometer was completed by Gajdorik and Lusin (1983).
The purpose of their study was to examine intratester
reliability in a test designed to measure hamstring
tightness. Gajdorik and Lusin positioned their subjects in
a supine position on a table with the non-test leg strapped
to the table across the thigh. A second strap was placed
across the anterior superior iliac spines to stabilize the
pelvis. The flexometer was placed on the lower leg and
secured by two elastic straps. The subjects actively
flexed the hip to 90 degrees with the knee in a flexed
position, which placed the thigh in contact with a fixed metal wire. The knee was extended until a feeling of mild resistance in the posterior knee was felt. The degree of knee flexion was read from the flexometer and this value was the amount of hamstring tightness for each subject. Hunter, Etchison and Halpern (1985) used a similar technique but measured the amount of active knee flexion with a standard protractor goniometer.

Passive straight leg raising has been a popular method of evaluating hamstring flexibility. Moore and Hutton (1980) positioned their subjects supine on a wooden bench with a brace applied to hold the knee in complete extension. A wall pulley system was applied to the brace so the hip was flexed by the downward movement of the weights. The angle of hip flexion was recorded for each subject. Hsieh, Walker and Gillis (1983) and Bohannon (1982) also used the weighted pulley system of passive straight leg raising, however, Bohannon evaluated the degree of hip motion using cinematography as opposed to more standard methods. Prentice (1983) and Agre and Baxter (1981) both implemented passive straight leg raising in their studies using the tester to passively elevate the leg. They also measured the angle of hip flexion using a goniometer.

Tanigawa (1972) introduced an alternate technique for measuring hamstring flexibility. Initially, Tanigawa obtained three anthropometric measurements. The length of
for trunk flexion, trunk extension, and shoulder elevation before and after the training sessions. The results showed that the static stretching group had a mean improvement of 1.84 inches in trunk flexion, 2.62 inches in trunk extension, and 1.66 inches in shoulder elevation. The ballistic group demonstrated a mean improvement of 1.6 inches in trunk flexion, 4.38 inches in trunk extension, and 2.16 inches in shoulder elevation. The improvements in all measurements, for both groups, were significant at the 0.01 level while the mean differences between the groups were not significant at the 0.05 level. The conclusions drawn by DeVries were that, both static and ballistic stretching improved flexibility significantly and that neither method was more effective than the other in improving flexibility.

Two separate studies were conducted which compared the three techniques of stretching. Sady et al., (1982) tested college-age males for flexibility of the shoulder, trunk and hamstring muscles while Lucas and Koslow (1984) studied college-age females using the hamstring/gastrocnemius muscles. Each investigation assigned subjects into ballistic, static and PNF groups. Sady, et al., (1982) also used a control group whereas Lucas and Koslow (1984) did not. Each research project implemented a pretest posttest design and carried out the specified treatments three days per week for six weeks. Lucas and Koslow (1984) used a sit and reach apparatus to assess hamstring/gastrocnemius
flexibility and found that the static group increased from a mean of \(26.98 \pm 5.22\) centimeters on the pretest to \(29.88 \pm 4.10\) centimeters on the posttest. The dynamic group had a mean value of \(27.66 \pm 7.27\) centimeters in the pretest and \(30.37 \pm 5.60\) centimeters in the posttest while the PNF group went from a pretest mean of \(26.91 \pm 5.12\) centimeters to a posttest mean value of \(30.24 \pm 4.30\) centimeters.

Statistical analyses revealed that there was a significant change from the pretest to the posttest for all groups (\(p < 0.05\)). Lucas and Koslow found that all three methods of flexibility training produced significant beneficial changes but no method was superior. The investigation by Sady et al. (1982) implemented the Leighton flexometer as the measurement device. After finding a significant \(F\) value for the method using the analysis of variance a post hoc analysis of the data showed that the only significant difference among methods of stretching occurred between the PNF group (\(M = 10.6\) degrees) and the control group (\(M = 3.4\) degrees).

Even though recent studies have compared all three flexibility techniques, the ballistic or bounce stretch technique is not being utilized by most flexibility experts. The reasons for this, as DeVries (1962) points out, are that with ballistic stretching there is a greater danger of tissue damage from overstretching, there is a higher energy demand, and there is an increased chance of
muscle soreness following stretching. Prentice (1983) conducted a study to determine if static stretching or PNF stretching was more effective in improving flexibility about the hip joint. Forty six males and females, age 18 to 34 years, were assigned to a static stretching group or a PNF stretching group for a 10 week treatment program which concentrated on flexibility and cardiovascular endurance. Each subject followed a specific stretching program three days per week, on the right leg, while the left leg was used as a control. Pre and post treatment measurements of hip flexion were taken using a standard 360 degree goniometer. The static stretching group showed a mean improvement of 8.86 degrees on the right leg and 3.30 degrees on the left leg from pretest to posttest while the PNF group demonstrated a mean improvement of 12.04 degrees on the right leg and 3.52 degrees on the left. The analysis of variance indicated that both groups improved significantly from pretest to posttest and the PNF group improved significantly more than the static group. Prentice concluded that static and PNF stretching were both effective techniques for improving hip flexibility and that PNF stretching was superior to static stretching for improving flexibility at the hip.

Tanigawa conducted a similar investigation using 30 males, age 20 to 48 years. He used a control group as well as a PNF group and a passive mobilization (static stretch)
group. He stretched all subjects two times per week for three weeks and followed that by one week without stretching. The results obtained by Tanigawa showed that the PNF group improved in passive straight leg raising ability from a mean of 35.2 degrees the first day to a mean of 51.1 degrees at the end of the three weeks. The passive mobilization group improved from a mean of 32.1 degrees to 39.2 degrees during the same time period. The control group had a mean flexibility the first day of 35.6 degrees and a mean flexibility of 37.0 degrees at the end of the three weeks. At the end of the entire four weeks the PNF group showed a mean improvement of 9.7 degrees while the passive mobilization group improved 1.8 degrees and the control group increased their straight leg raising by 0.1 degrees. Analysis of variance indicated that both the passive mobilization group and the PNF group significantly improved ($p < 0.01$) in passive straight leg raising ability compared to the control group and that the increase by the PNF group was significantly greater than that of the passive mobilization group. Tanigawa concluded that passive mobilization and PNF stretching increased the ability to passively raise the leg and that PNF stretching was superior to passive mobilization in producing an increase in passive straight leg raising.

Moore and Hutton (1980) took a different approach to evaluating muscle stretching techniques. These
investigators used electromyography (EMG) to determine relative levels of relaxation during the application of static and PNF procedures. Twenty-three females, age 17 to 23 years, who had been involved in gymnastics for six years or longer were used as subjects. All subjects were placed in a supine position on a table with a knee brace placed on the leg to ensure passive extension of the knee joint. A pulley system was applied to the ankle which brought the leg into 90 degrees of passive hip flexion with the knee extended. Surface electrodes were placed on the rectus femoris muscle and the semitendinosus muscle and a ground electrode was placed proximal to the lateral malleolus. Following practice sessions all subjects performed three trials of static hamstring stretching, contract relax hamstring stretching, and contract relax with agonist contraction hamstring stretching. EMG activity was quantified after each trial and statistical analyses was performed on the data. The findings indicated that the greatest EMG activity for most subjects occurred during the stretch phase of the contract relax with agonist contraction stretch. The contract relax with agonist contraction stretch also increased the range of motion to a greater extent than did any other method. Moore and Hutton concluded that "full muscle relaxation was not imperative for effective stretching of muscle" (p. 327).

Proprioceptive neuromuscular facilitation (PNF) as a
Stretching technique has increased in popularity during the past 15 to 20 years. It has been used by physical therapists in the rehabilitation of nervous system disorders and by athletic trainers for injury prevention and warm-up. A survey of 111 athletic trainers from across the United States was completed by Surburg (1981). The trainers were surveyed about their use of PNF and the areas of the body they treated with the technique. The results pointed out that PNF techniques were used most often to treat knee injuries (70%) and hip injuries (65%). Trainers used PNF techniques 64 percent of the time to treat shoulder injuries, 52 percent of the time for neck and ankle injuries and 49 percent of the time for elbow and wrist injuries. Of the seven facilitation techniques described by Surburg (1981) the hold relax technique was most often utilized (23%) for hamstring injuries followed by the contract relax technique (21%).

In an article that synthesizes much of the literature related to techniques of increasing flexibility, Surburg (1983) stated that research comparing stretching techniques does not reflect a clear picture concerning the superiority of a given technique.

**Normative Data for Hamstring Flexibility**

A variety of equipment and techniques have been used
to provide data regarding flexibility of the hamstring muscles. Hupprich and Sigerseth (1950) took 12 different flexibility measurements in females age 6 to 18 years using the techniques described by Leighton (1955). The mean thigh flexion measurement in 100 females 18 years of age was $105.40 \pm 10.95$ degrees. In 1953 McCue studied 130 college women and measured the right side of the body. The Leighton flexometer and the techniques described by Leighton were used during the study. McCue found the mean hip flexion to be $104.62 \pm 10.68$ degrees. Tanigawa (1972) implemented a different technique to measure the degree to which 30 males, age 20 to 48 years, could passively raise the right leg. The examiner stabilized the non-test leg over the edge of a plinth and passively raised the right leg, with the knee extended, until the subject expressed the perception of tension in the posterior thigh or knee. The mean pretest degree of passive straight leg raising was 35.2 degrees for the PNF group, 32.1 degrees for the passive mobilization group, and 35.6 degrees for the control group. Sady et al. (1982) measured 43 male college students for shoulder, hamstring, and trunk flexibility. The hamstring flexibility measurement was taken with the Leighton flexometer strapped to the lateral thigh and the subjects in a supine position with both legs completely extended. The right hip joint was actively flexed as far as possible while the left leg remained in contact with the
plinth. The mean flexibility measurement was 84 ± 11.7 degrees. Gajdorsik and Lusin (1983) measured hamstring flexibility in 15 males, age 18 to 26 years, while Hunter, Etchison, and Halpern (1985) used 2,774 males and females age 12 to 18 years. Both studies used a technique which maintained the hip in 90 degrees of flexion while in the supine position. The test knee was actively extended until a feeling of tightness developed in the posterior thigh or knee area. The flexibility value was determined to be the degree of knee flexion present once the point of tightness was reached. Gajdorsik and Lusin (1983) reported the mean degree of knee flexion as 37.60 ± 16.73 degrees while Hunter et al. (1985) found the mean degree of knee flexion to be 18.0 degrees in 18 year old males and 16.0 degrees in 18 year old females.

Relationship of Strength and Flexibility

Wiktorsson-Moller, Oberg, Ekstrand, and Gillquist (1983) completed the only study identified which examined the relationship of strength and flexibility. The purpose of the investigation was to study the effects of warm up, massage, and stretching, on range of motion and strength in the lower extremity. Eight males volunteered as subjects, their hip flexion, hip extension, hip abduction, knee flexion, and ankle dorsiflexion with the knee flexed and
straight were measured with a flexometer. Quadriceps and hamstring strength was measured using the Cybex II dynamometer at 30 and 180 degrees per second. The warm up consisted of riding a bicycle ergometer for 15 minutes at a load of 50 watts while the massage was administered by a professional masseur to the major muscles of the lower extremity. The stretching was carried out on all major muscles or muscle groups of the lower extremity and consisted of placing each muscle in a position of maximal stretch, followed by a four to six second isometric contraction, followed by a two second relaxation period. The muscle was then put on maximal stretch once again and the process was repeated five times for each muscle or muscle group. Four separate treatment sessions were completed on each subject with 48 hours of rest between sessions. The first session consisted of measurement of range of motion and quadriceps and hamstring strength followed by general warm up followed by remeasurement of range of motion and strength. The second session consisted of identical measurements with a treatment of warm up and massage between the measurements of range of motion and strength. The treatment in the third session was massage alone, with range of motion and strength measurements taken before and after the treatment. The final treatment session consisted of general warm up and stretching. The results indicated that with the treatment of warm up only
there was a significant increase \( (p < 0.02) \) in ankle dorsiflexion with the knee straight. All other range of motion measurements were not significantly affected. The treatment of massage only caused a significant increase \( (p < 0.005) \) in ankle dorsiflexion with the knee bent and straight (10-12%). With warm up and massage ankle dorsiflexion, with the knee bent \( (p < 0.002) \) and straight \( (p < 0.005) \), were significantly increased while a significant decrease was noted in hip extension at the 0.05 level of significance. Warm up and stretching elicited a significant increase \( (p < 0.02) \) in range of motion of all muscle groups tested with the largest increase (31%) being in ankle dorsiflexion with the knee flexed. A significant decrease \( (p < 0.02) \) was seen in hamstring strength at 180 degrees per second and at 30 degrees per second following massage only. The quadriceps muscle showed a significant decrease \( (p < 0.05) \) in isometric strength following massage only. No significant change was seen in quadriceps torque following the warm up and stretching treatment. At 30 degrees per second the mean initial torque was 262 ± 7.6 Newton meters and following the warm up and stretching the mean quadriceps torque was 257 ± 8.9 Newton meters. The authors concluded stretching was superior to other methods for increasing flexibility and stretching did not significantly increase strength in the lower extremity muscles.
Isokinetic Exercise

General Considerations

Isokinetic exercise is a relatively new method of resistive exercise. Unlike isotonic exercise, which measures dynamic strength by assessing the greatest weight that can be moved through the full range of motion one time, isokinetic exercise measures dynamic strength at every point in the range of motion. Rather than the isotonic strength being the strength that relates to the weakest point in the range of motion, isokinetic strength is the strength which takes place at the strongest point in the range of motion (Elliot, 1978). Moffroid, Whipple, Hofkosh, Lowman and Thistle (1969) state that:

isokinetic exercise is made possible by an electro-mechanical device which keeps limb motion at a constant, predetermined velocity. Any effort applied encounters an equal counterforce. Increased muscular output produces increased resistance rather than increased acceleration, as would occur in a gravity loaded system of resistive exercise. Hence, the resistance developed is in proportion to the amount of muscle force exerted, and a maximal effort can be experienced, as if a maximal load were being applied at all points throughout the arc of motion (p. 735).

The Cybex II isokinetic dynamometer is the most widely used isokinetic exercise device. Since its development in 1970, the Cybex has been used for testing strength, pre-season screening, injury evaluation, and rehabilitation. While the knee has been the most widely tested joint, the Cybex can theoretically evaluate every major
muscle group in the body (Elliot, 1978). The Cybex is adjustable so that the anatomical axis of the joint being measured is aligned with the machine's axis of rotation. Because of this adaptability, the Cybex not only has the ability to measure peak torque but also can measure range of motion.

Normative Data

Over the past decade a significant body of research has been completed using the Cybex apparatus. Researchers have attempted to develop normative data for peak quadriceps and hamstring torque and hamstring/quadriceps strength ratios. They have also studied the isokinetic torque levels as they relate to gender, body size, body weight, sport, and performance.

Rankin and Thompson (1983) studied female college athletes for the purpose of determining hamstring/quadriceps ratios for athletes in various sports. The peak hamstring/quadriceps ratio at 60 degrees per second ranged from .5762 for track jumpers to .6984 for cross country runners. In a study of 241 females, age 18 to 28 years, Dibrezzo, Gench, Hinson and King (1985) used the Cybex II dynamometer, set at 60 degrees per second, to measure the peak hamstring/quadriceps ratio. The results showed the mean peak hamstring/quadriceps torque ratio to be .536. In
a similar study, Holmes and Alderink (1984) used 17 male and 32 female high school students as subjects. The purpose of the investigation was to determine the peak hamstring/quadriceps ratio at 60 degrees per second. They found the value for 18 year old females to be .57.

Researchers have also examined the ratio of peak quadriceps torque per pound of body weight. Rankin and Thompson (1983) found the ratios in female college athletes to range from .6715 foot pounds per pound of body weight to .8851 foot pounds per pound of body weight. Morris, Lussier, Bell and Dooley (1983) conducted a similar study using 12 male varsity cross country runners as subjects. The purpose was to measure the strength of the knee flexors and extensors and provide data on the peak quadriceps torque per pound of body weight for cross country runners. The results of the study showed the mean peak torque per pound of body weight to be .93 foot pounds per pound of body weight.

Studies have also been completed which have looked at the effects of age on peak torque values. Thomas (1984) tested 97 healthy, females, age 20 to 61 years, for the purpose of determining the effects of age and body size on isokinetic torque. The results of the zero order correlation for torque versus age were -0.44 for knee flexion and -0.37 for knee extension. Both of these values were significant at the 0.05 level. Thomas concluded that an
increase in age causes a decrease in torque output for the quadriceps and hamstring muscles. Miyashita and Kanehisa (1979) completed a study designed to investigate the peak quadriceps torque and its relationship to age, sex, and performance. Using 569 males and females, age 13 to 17 years, they measured the peak quadriceps torque at 210 degrees per second. The mean peak torque of the 13 year old males was $65.0 \pm 18.48$ Newton meters while the 17 year old males recorded a mean peak torque of $114.4 \pm 20.62$ Newton meters. The 13 year old females had a mean peak torque of $53.3 \pm 13.51$ Newton meters and the 17 year old female's mean peak torque was $71.1 \pm 16.57$ Newton meters. Statistically significant ($p < 0.05$) changes were seen in peak torque from age 13 to 14 years, 14 to 15 years, and 15 to 16 years in the males and age 13 to 14 years in the females. The conclusions of the study were that peak quadriceps torque increased linearly with age for males from age 13 to 17 years while peak torque remained constant for females 14 to 17 years.

Variable test speeds are often used when doing research with isokinetic exercise equipment. Many researchers have concerned themselves with identifying differences in torque levels and torque ratios at various speeds. Wyatt and Edwards (1981) studied 50 male and 50 female non-athletes for the purpose of measuring peak torque of the knee extensors and flexors at 60, 180 and 300
degrees per second. They found the peak quadriceps torque for females to be $80 \pm 14$ foot pounds at 60 degrees per second, $58 \pm 10$ foot pounds at 180 degrees per second, and $38 \pm 8$ foot pounds at 300 degrees per second. Significant differences ($p < 0.01$) were found between the different test speeds. In addition the quadriceps muscle produced greater torques than the hamstring muscles at all test speeds. They concluded that as the speed increases the peak torque of the knee extensors decreases. Holmes and Alderink (1984) and Thomas (1984) also studied peak quadriceps torque at various speeds. Holmes and Alderink found the mean peak torque to be $100.19 \pm 15.57$ foot pounds at 60 degrees per second and $56.71 \pm 11.45$ foot pounds at 180 degrees per second for female students. Thomas found the peak torque of the knee extensors at 60 degrees per second to be $65.5 \pm 14.3$ foot pounds and $23.3 \pm 5.8$ foot pounds at 240 degrees per second for female subjects. Both studies concluded that as the test speed increases the peak quadriceps torque deceases.
Angle of Peak Quadriceps Torque

The only study identified which focused on the angle at which the peak quadriceps torque occurred was completed by Hart, Stobbe, Till, and Plummer (1984). They studied seven males, age 20 to 32 years, using the Cybex II dynamometer to assess peak quadriceps torque and the angle at which it occurred. At a speed of 30 degrees per second and a starting position of 100 degrees of knee flexion, subject number three demonstrated a peak torque of 360 Newton meters at an angle of 60 degrees of knee flexion. The leg was considered to be in zero degrees of knee flexion when it was completely extended and subject number three was considered to be representative of the subjects.

Summary

Flexibility has been recognized as a facet of total body fitness for many years. Physical educators and rehabilitation specialists feel that it is essential for persons to obtain and maintain a certain level of flexibility. Researchers have identified that muscle tissue accounts for a portion of the resistance to movement, and by increasing the length of muscle tissue you can improve movement patterns. Through research it has been identified that girls tend to be more flexible than boys and that at a certain age flexibility starts to diminish and continues to
decrease with age. Length of body segments, body fat, and body mass have been found to have no significant influence on flexibility. Limited research has also concluded that there is no significant relationship between flexibility and strength in lower extremity muscles. The large majority of investigators agree that flexibility is specific for each joint and not a general condition of the body.

An interest in quantifying flexibility has been present since the onset of flexibility exercises. The first technique used was visual comparison. This was a very crude and inaccurate method. An advance in accuracy occurred with the use of the protractor goniometer and the photogoniometer which are two similar devices used in measuring range of motion. The protractor goniometer is still widely used today. In 1955 the "Leighton Flexometer" was introduced. This device uses a 360 degree dial and a weighted pointer, both of which are controlled by gravity. The research has produced reliability coefficients of .911 to .996 with this apparatus. Some studies have implemented anthropometric measurements and mathematical equations to obtain flexibility measurements. No matter which technique is used researchers agree that the most important aspect of flexibility measurement is the precise implementation of the technique.

The ballistic or bounce stretch, the static or
prolonged stretch, and the PNF stretch are the three main stretching techniques identified in the literature. Much time has been spent comparing the three techniques and evaluating which is most effective. Ballistic stretching has been omitted by experts due to the increased chance of injury during stretching. The results of the studies that have compared static and PNF techniques are varied. The majority of the researchers have concluded that the PNF technique is the most effective but this is not an unanimous choice. More research needs to be completed before one stretching technique is universally accepted.

In the past 20 years the concept of isokinetic exercise has been introduced and adopted by sports medicine and rehabilitation experts throughout the country. Isokinetic exercise is a type of resistive exercise that incorporates the concepts of accommodating resistance and constant speed. The Cybe x was the first isokinetic exercise apparatus available and remains the most widely used piece of isokinetic equipment to date. Researchers have used the Cybe x to study peak torque levels and hamstring/quadriiceps ratios for many different groups of people. The relationship of these values to gender, age, body size, body weight, and performance have also been studied. Some general conclusions have been drawn from the completed research using the Cybe x. The hamstring/quadriiceps ratio increases as the test speed increases and the
peak quadriceps torque is generally greater than the peak hamstring torque at any test speed. A significant amount of research has been completed on the development of normative data for strength and flexibility. Studies have used subjects of different age and sex and have used numerous techniques to gather the data. For hamstring flexibility in the supine position with the hip flexed to 90 degrees, females display a range from 11 to 16 degrees of knee flexion while males range from 18 to 29 degrees. These values have been shown to increase with age.

The Cybex dynamometer has been widely used in the development of normative strength data. When using the Cybex strength is defined as peak torque and is recorded in foot pounds. The mean peak torque of the quadriceps muscle has been found to range from 79 to 97 foot pounds in various studies while the range of peak torque values has been reported from 39 to 168 foot pounds for females.
CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to examine the effects of increasing hamstring flexibility on peak quadriceps torque in college-age females. This chapter includes a description of the subjects, the techniques used in assessing hamstring flexibility and peak torque, an explanation of the training protocol and the statistical analyses which were performed.

Subjects

Fifteen female college students, age 18 to 22 years (M = 18.93 ± 0.77 years), from South Dakota State University volunteered as subjects for this investigation. All subjects were enrolled in a physical education lifetime activities class. No volunteers were accepted if they competed on any varsity athletic team or participated in an organized flexibility or strengthening program during the time of the study. Descriptive statistics on the subjects are contained in Table 1. The mean height of the subjects was 65.06 ± 1.83 inches (165.6 ± 4.65 centimeters) and the mean weight was 130.53 ± 14.94 pounds (59.33 ± 6.79 kilograms). Each subject was required to sign an informed
<table>
<thead>
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<th>Characteristic</th>
<th>M</th>
<th>SD</th>
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<td>Age (years)</td>
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<td>0.77</td>
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<tr>
<td>Height</td>
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<td></td>
</tr>
<tr>
<td>inches</td>
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<td></td>
</tr>
<tr>
<td>pounds</td>
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<td>14.94</td>
</tr>
<tr>
<td>kilograms</td>
<td>59.33</td>
<td>6.79</td>
</tr>
</tbody>
</table>
consent form prior to the initiation of the investigation (appendix A).

Testing Methodology

Flexibility Measurement

The accurate quantification of hamstring flexibility is a difficult task and the literature available to date does not support any one technique as being superior. The present investigation used a modification of the techniques described by Sady, Wortman, and Blanke (1982) and Prentice (1983) in an attempt to more accurately assess hamstring flexibility.

A familiarization session was conducted with each subject which began with a five minute warm-up session on a Schwinn Air-Dyne exercise bicycle, using only the legs, at a setting of 1.5 on the load indicator which is approximately equal to 75 watts. Following the warm-up session an explanation of the procedures used to measure hamstring flexibility was given.

The subject was positioned in a supine position on a standard padded plinth with the knees fully extended and the arms by her sides. The investigator identified the joint line of the knee through palpation and clearly marked the joint line with a felt pen (vertical line). The breadth of the knee was measured with a standard wooden
caliper and a dot was placed on the vertical line at exactly one half the breadth of the knee. This dot indicated the axis of motion for the knee joint. The greater trochanter of the femur was then palpated and marked. The breadth of the thigh was measured with a caliper at the level of the greater trochanter and the height of the greater trochanter was recorded. The lateral edge of the fibula just proximal to the lateral malleolus was palpated and clearly marked.

A single axis aluminum device 60.96 centimeters in length and 2.54 centimeters wide was constructed and a metal pointer was glued and taped to the exact center of the device (Figure 1). The device was held on the leg so the axis of the device and the knee axis were in alignment. The upper shaft of the aluminum device was aligned with the greater trochanter and secured with adhesive tape snugly around the leg just proximal to the patella and at the superior end of the hinged device. In a similar fashion the lower end of the aluminum apparatus was aligned with the mark on the distal fibula and taped just distal to the patella and at the inferior end of the device. Proper alignment was then evaluated in complete extension, flexion, and throughout the range of motion.

A Leighton flexometer was firmly attached to the lateral thigh with a strap and positioned in a manner such as to keep the face of the flexometer parallel to the
FIGURE 1

Flexibility Measurement: Starting Position
FIGURE 2
Flexibility Measurement: End Position
sagittal plane in which the leg was to be raised. The subject was asked to slide to the end of the plinth and allow both lower legs to hang freely over the edge of the plinth. The non-test leg was stabilized in this position behind a strap which was attached to the legs of the plinth. A stabilization strap was also placed around the subject and plinth at the level of the superior pelvis in order to further prevent the pelvis from rotating. The lower test leg was then passively extended by the investigator and held in complete extension. The entire leg was raised until the aluminum hinged device was parallel to the floor, which was assured by placing a small level on the upper shaft of the hinged device. Once parallel, the calibrated dial of the flexometer was locked in the zero position. The investigator passively raised the entire leg in the sagittal plane while giving the subject verbal encouragement to relax as much as possible. The leg was raised until the metal pointer deviated from the center line of the device by two millimeters at which time the pointer dial on the flexometer was locked and the value on the flexometer was read and recorded (Figure 2). This procedure was repeated six times on each leg and the average of the last three trials was recorded as the hamstring flexibility value. A second flexibility testing session was completed with each subject in the same manner two days later. If the hamstring flexibility value on the
torque voltages and adds the variable of time. The Isoscan software program provides the researcher with a multitude of potential data but this investigation chose to examine only the absolute torque and position values.

The literature is virtually void of research done using the Orthotron II. This may be due to the relative newness of the Orthotron II and the fact that the Orthotron II needs to be modified before it is capable of carrying out quality research. Much research has been carried out utilizing the Cybex II but due to its high cost and lack of availability the Orthotron II was used in the present study.

Pilot Study

Because of the lack of research using the Orthotron II a pilot study was conducted, prior to the major investigation, to determine the reliability of the Orthotron II/Isoscan system. Fifteen graduate students and faculty members from the Department of HPER of South Dakota State University participated in the pilot study. Each subject warmed up on the Schwinn Air-Dyne exercise bicycle for five minutes, at 75 watts, prior to being tested on the Orthotron II. Each subject was seated on the Orthotron II so that the popliteal fossa of the knee just touched the seat. A pelvic stabilization strap was snugly placed around the
waist and a thigh strap was placed over the right leg at midthigh level. The input shaft of the accumulator was aligned with the axis of the knee joint and the shin pad was placed just superior to a line between the malleoli. Each subject received an explanation of the Orthotron II and the concepts of isokinetic exercise. Following the explanation each subject completed five submaximal contractions of the knee extensors and flexors at 60 degrees per second, then rested for two minutes. During the rest the subjects were instructed that they should give a maximal effort throughout the entire test. When the investigator gave the "begin" command each subject completed three maximal contractions of the knee extensors and flexors with the Orthotron II set at 60 degrees per second with the investigator providing zealous verbal encouragement. A two minute rest was allowed and followed by a second set of contractions identical to the first. The peak quadriceps torque was recorded for each subject from each set of three contractions. Two days later the subjects completed a testing session identical to that of the first day. Statistical analyses were carried out on the data in order to calculate reliability coefficients. The reliability coefficient for comparing Day 1/Trial 1 with Day 1/Trial 2 was .98 (p < 0.001) while the coefficient for comparing Day 1/Trial 1 with Day 2/Trial 1 was .97 (p < 0.001). A reliability coefficient of .99 (p < 0.001) was calculated
for the comparison of Day 2/Trial 1 with Day 2/Trial 2. A comparison of Day 1/Trial 2 with Day 2/Trial 2 yielded a coefficient of .98 ($p < 0.001$) (Tables 2 & 3). The conclusion drawn from these results was that the Orthotron II is a reliable device for measuring peak quadriceps torque at 60 degrees per second.

**Peak Torque Measurement**

The protocol for the measurement of peak quadriceps torque is much more well defined in the literature than the measurement of hamstring flexibility. This investigation utilized suggestions from numerous studies in the development of the present testing protocol.

Prior to initiation of the familiarization session for peak torque measurement the Orthotron II was calibrated and the speed was set at 60 degrees per second using the Isoscan calibration and speed setting routines. The speed of 60 degrees per second was calibrated by setting the clockwise and counterclockwise dials on the accuator of the Orthotron II to a setting of two and then actively moving the lever arm through the entire motion. The dials were adjusted following each trial according to the speed registered on the computer until the dials were set for 60 degrees per second. The torque was calibrated by hanging a 100 pound weight on the lever arm, set at 12 inches, and
## TABLE 2

**PILOT STUDY**
**Descriptive Statistics**
*(N = 15)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Peak Torque (foot-pounds)</th>
<th>Standard Deviation</th>
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<tbody>
<tr>
<td>D1T1</td>
<td>236.49</td>
<td>57.55</td>
</tr>
<tr>
<td>D1T2</td>
<td>231.63</td>
<td>58.31</td>
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<tr>
<td>D2T1</td>
<td>234.94</td>
<td>61.34</td>
</tr>
<tr>
<td>D2T2</td>
<td>237.21</td>
<td>62.10</td>
</tr>
</tbody>
</table>

D1T1 - Day One Trial One  
D1T2 - Day One Trial Two  
D2T1 - Day Two Trial One  
D2T2 - Day Two Trial Two
### TABLE 3

**PILOT STUDY**  
Reliability Analysis  
(N = 15)

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>p</th>
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<tbody>
<tr>
<td>D1T1/D1T2</td>
<td>.9770</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>D1T1/D2T1</td>
<td>.9719</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>D2T1/D2T2</td>
<td>.9915</td>
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</tr>
<tr>
<td>D1T2/D2T2</td>
<td>.9780</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

D1T1- Day One Trial One  
D1T2- Day One Trial Two  
D2T1- Day Two Trial One  
D2T2- Day Two Trial Two
verifying that the torque reading was zero when the lever arm was in the horizontal position. Torque and speed setting calibration was carried out prior to each day of testing.

The familiarization session began with each subject completing a five minute warm up on the Schwinn Air-Dyne exercise bicycle at a load of 1.5 (75 watts), using the legs only. The investigator then positioned each subject in a seated position on the Orthotron II so that the popliteal fossa of the knee was touching the seat. The backrest was then moved forward so that the subject was in a comfortable position. The backrest on the Orthotron II is similar to that of the Cybex II in that it is positioned approximately 20 degrees from vertical which is the recommended position for testing the knee extensors and flexors (Dibrezzo et al., 1985; Holmes & Alderink, 1984). The distance, in inches, that the backrest was pulled forward was recorded for each subject to insure a similar alignment in subsequent testing. The axis of the accuator was aligned with the anatomical axis of rotation of the knee and the position was recorded. Stabilization of the subject was conducted as described by Dibrezzo et al., (1985). A pelvic stabilization strap was placed around the waist and secured to the Orthotron II while a thigh stabilization strap was placed at midthigh to maintain proper alignment of the knee axis with the axis of the
accumulator. The length of the lever arm was set so the bottom of the shin pad was in contact with the tibia just proximal to a line between the malleoli. The strap on the shin pad was securely tightened around the distal lower leg. Instructions regarding the Orthotron II and isokinetic exercise were given to each subject.

Following the instructions, the subjects grasped the handgrips firmly and completed five submaximal contractions of the knee extensors and flexors with the Orthotron II set at 60 degrees per second. A one minute rest period followed and all subjects were informed of the starting commands of the test. The test consisted of three maximal contractions of the knee extensors and flexors, at 60 degrees per second, with boisterous verbal encouragement offered by the investigator. The data from each subject was saved on a floppy disk. Following removal of the stabilization straps the subject was asked to move off the Orthotron II while the accumulator was positioned for the opposite leg. Following the repositioning of the Orthotron II, each subject was given a two minute rest period. The procedure was then repeated in an identical manner for the opposite leg. The order of right and left leg testing was randomly assigned. A pretest and a posttest session was carried out on each subject in identical fashion to the familiarization session.
Flexibility Training

Enhancing a person's flexibility can be achieved in a variety of ways. The three techniques most often cited are ballistic, static, and proprioceptive neuromuscular facilitation (PNF) stretching. This investigation chose the PNF technique, due to the results found in the literature, which indicated that PNF is the most effective technique for increasing flexibility. A variety of stretching techniques have been identified as being PNF. This study used an adaptation of the hold-relax technique described by Sady et al. (1982). They described the PNF stretch as having a partner take the hamstring muscle to a point of stretch, followed by a five second isometric contraction of the stretched muscle, followed by a relaxation phase in which the muscle is once again passively stretched by the attendant.

In the present investigation each subject was assigned a partner who remained with them throughout the study. A familiarization session was conducted with all subjects with an explanation and demonstration of the specific technique used to increase hamstring flexibility. The session began with five minutes of brisk walking to increase deep muscle temperature of up the subjects prior to being stretched. One half of the subjects were then positioned supine on a padded mat while their partners
knelt beside their right leg. The right leg of the subject in the supine position was placed on the shoulder of the partner in a manner that put the heel of the leg in a comfortable position. The leg was then passively raised by the partner until the subject noted a tight feeling in the posterior thigh or knee area. At that point the stretch was held for a period of five seconds. The stretch was followed by a five second isometric contraction of the hamstring muscles in the stretched position. The leg was then relaxed for five seconds. This sequence was repeated nine more times without the leg ever being lowered from the partner's shoulder. The subject and the partner then changed positions in order to stretch the right leg of the partner. The length of the stretches, contractions, and relaxation periods was controlled by an audio tape which was produced by the investigator. This tape included properly timed five second intervals for the required 10 repetitions. The tape was rewound for the second group of subjects. Only the right leg was stretched and the left leg was used as the control leg. Using the left leg as a control insured the investigator of controlling for intra-subject variability, such as illness or fatigue, which may have been present during the pretest or posttest sessions. All subjects were treated three times per week for eight weeks. Each treatment session was conducted by the investigator and the audio tape, all subjects were
stretched during the same sessions and if the subjects missed more than three sessions they were disqualified. No subject was disqualified due to absences, five subjects missed two sessions, and six subjects attended all sessions.

Statistical Analyses

The variables analyzed in this investigation were hamstring flexibility, peak quadriceps torque, and the angle at which the peak torque occurred. The hamstring flexibility value was determined in degrees and was calculated by taking the average of the last three trials. The peak quadriceps torque for each subject was found using the raw data portion of the Isoscan program. The specific repetition in which the peak torque occurred was determined by examining the graph of torque versus time. A printout of the raw data, from the specified repetition, was obtained and the peak torque was identified as well as the angle at which that torque occurred. If the peak torque took place at more than one angle the last angle at which it occurred was used as the appropriate angle value.

The purpose of the statistical analyses was to determine if hamstring flexibility was significantly increased by PNF stretching and then to determine if hamstring flexibility had an effect on peak quadriceps torque. Descriptive statistics, including the mean,
standard deviation, maximum and minimum values, and the range were determined for position, peak torque, and flexibility of the right and left legs for the pretest and posttest. The difference between the pretest and posttest was also calculated for position, peak torque, and flexibility of the right and left legs.

The statistical analyses performed, using the SPSS-X computer program, were paired t-tests on the group differences. To calculate the group differences the pretest mean was subtracted from the posttest mean for each variable. The t-tests were completed on the variables of right and left angle change, right and left peak torque change, and right and left flexibility change. The 0.05 level of significance was established by the investigator.
CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the results and discussion of this study which examined the effects of hamstring flexibility on peak quadriceps torque in college females. The chapter includes descriptive statistics of the subjects and the variables of hamstring flexibility, peak quadriceps torque, and the angle at which the peak torque occurred. It also includes the results of the paired t-tests which were completed on the group differences. The chapter concludes with a discussion of the results and how they compare with the results of previous investigations.

Results

Flexibility

Table 4 presents the descriptive statistics for hamstring flexibility while Figure 3 provides a graphic depiction of the means. The pretest mean hamstring flexibility value was $49.26 \pm 5.08$ degrees on the right leg and $48.29 \pm 3.97$ degrees on the left leg. After stretching the right leg three times per week for eight weeks the posttest mean hamstring flexibility on the right leg was
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<td>57.97 ± 5.57</td>
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57.97 ± 5.57 degrees while the non-stretched left leg had a mean flexibility of 48.50 ± 4.08 degrees. The maximum flexibility demonstrated in the pretest was 57.00 degrees on the right leg and 54.70 degrees on the left leg. Following the eight week treatment period the maximum flexibility measurement recorded on the right leg was 65.60 degrees and 54.00 degrees on the left. The minimum flexibility value recorded on the right leg during the pretest was 42.30 degrees while the minimum value on the left leg was 41.00 degrees. The minimum values in the posttest were 48.60 degrees on the test leg and 42.60 degrees on the control leg. The mean flexibility group difference, from pretest to posttest, for the right leg was +8.71 ± 2.73 degrees and +0.21 ± 1.33 degrees for the left leg. A paired t-test on the differences showed a probability of 0.001 (Table 5). The conclusion drawn from the paired t-test result was that the right leg showed a significant (p < 0.05) increase in flexibility from the pretest to posttest when compared to the left leg change.

**Peak Torque**

The descriptive statistics for peak quadriceps torque are presented in Table 6 and Figure 4 provides a graphic presentation of the means. The mean peak quadriceps torque value for the pretest on the right leg was 124.22 ± 24.94
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* t-test compared change in right leg to change in left leg.
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<td>130.87 ± 30.69</td>
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Figure 4
Peak Torque

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Right Leg | Left Leg

Pretest | Posttest
foot pounds while the left leg pretest value was
130.87 + 30.69 foot pounds. Following eight weeks of
stretching the right leg, doing 10 repetitions of the hold
relax PNF technique three days per week, the posttest peak
torque value was 134.53 + 19.90 foot pounds on the right
leg and 131.41 + 24.67 foot pounds on the left leg. The
maximum peak torque recorded for the right leg pretest was
177.80 foot pounds and for the right leg posttest was
169.60 foot pounds. The peak maximum torque for the
pretest on the left leg was 196.30 foot pounds while the
maximum posttest left peak torque was 176.80 foot pounds.
Minimum peak torque levels in the pretest were 93.50 foot
pounds on the right leg and 88.70 foot pounds on the left
leg. The minimum posttest peak torques were 96.40 foot
pounds on the right and 98.20 foot pounds on the left. The
mean right leg change, following flexibility training, was
found to be +10.31 + 15.91 foot pounds while the left leg,
which was not stretched, had a group mean peak torque
change of +0.55 + 14.56 foot pounds. A paired t-test on the
group change between the right and left legs was conducted
(Table 5). The probability was found to be 0.061 from
which it was concluded that the change in peak quadriceps
torque from pretest to posttest on the treated right leg
was not significantly different (p < 0.05) than the change
seen in the left leg.
Peak Torque Angle

The mean angle at which the peak quadriceps torque occurred varied only slightly from pretest to posttest in both the right and left legs. Table 7 contains a summary of the descriptive statistics for the angle at which peak torque occurred and Figure 5 shows the means graphically. The mean angle of the right leg during the pretest was 27.74 ± 4.36 degrees while the mean angle of the left leg during the pretest was 26.13 ± 2.81 degrees. The mean angle for the right leg during the pretest was 27.74 ± 4.36 degrees while the mean angle of the left leg during the pretest was 26.13 ± 2.81 degrees. The mean angles for the right and left legs in the posttest were 26.23 ± 2.85 degrees and 26.00 ± 4.50 degrees, respectively. The mean angle change from the pretest to the posttest was -1.51 ± 5.12 degrees on the right leg and was -0.13 ± 4.10 degrees on the left leg. The highest angle values recorded for the pretest were 34.70 degrees on the right leg and 30.0 degrees on the left leg. The highest posttest angle for the right leg was 30.90 degrees and 33.50 degrees for the left. The minimum angle values obtained for the right and left legs during the pretest were 18.80 degrees and 20.60 degrees, respectively, while the posttest yielded minimum angle values of 21.20 degrees and 16.80 degrees for the the right and left legs. A paired t-test on the group
difference between the right and left leg for the angle at
which peak torque occurred was completed and a probability
of 0.396 was found (Table 5). The 0.05 level of signifi-
cance was chosen by the investigator for all analyses.
Thus, there was no significant difference seen in the angle
at which peak torque occurred between the right and left
legs.

The results of the statistical analyses point out that
hamstring flexibility is significantly increased in college-
age females when a program of PNF stretching is completed
three times per week for eight weeks. The analyses also
points out that the angle at which the peak quadriceps
torque took place was not significantly changed by increas-
ing hamstring flexibility.

Discussion

The present investigation supported the findings of
Wiktorsson-Moller, Oberg, Ekstrand, and Gillquist (1983) in
regards to the relationship of flexibility and strength in
the lower extremity. Wiktorsson-Moller, et al. reported
that following warm up on a bicycle ergometer and PNF
stretching there was a significant increase in flexibility
of the muscles of the lower extremity but there was no
increase in strength of the quadriceps muscle. The present
study also showed a significant increase (p < 0.05) in
### TABLE 7

Descriptive Statistics for Angle (degrees) at which Peak Torque Occurred (N = 15)

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<td><strong>Pretest</strong></td>
<td>27.74 ± 4.36</td>
<td>26.13 ± 2.81</td>
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<tr>
<td><strong>Posttest</strong></td>
<td>26.23 ± 2.85</td>
<td>26.00 ± 4.50</td>
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<tr>
<td><strong>Difference</strong></td>
<td>-1.51 ± 5.12</td>
<td>-0.13 ± 4.10</td>
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<td><strong>Maximum Value</strong></td>
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<tr>
<td>Pretest</td>
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<tr>
<td><strong>Range</strong></td>
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<tr>
<td>Pretest</td>
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<td>Posttest</td>
<td>9.70</td>
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Figure 5
Angle of Peak Torque

![Bar graph showing angle of peak torque for right and left legs, comparing pretest and posttest results.](image-url)
hamstring flexibility following PNF stretching and found no significant increases ($p = 0.061$) in peak quadriceps torque following the same stretching period.

The absolute values of hamstring flexibility found in the present study are not comparable to those of studies reported in the literature due to the present study's unique method of measuring flexibility. The increase in hamstring flexibility with PNF stretching in the present study (8.71 degrees) is similar to that reported by other investigators. Sady, Wortman, and Blanke (1982) conducted a study to determine if static, ballistic, or PNF stretching was most beneficial. The PNF group increased their mean hamstring flexibility by 9.4 degrees over a six week period of time. Tanigawa (1972) reported a mean gain in hamstring flexibility of 9.7 degrees in 30 males who were stretched over a four week period. Prentice (1983) also reported similar findings when studying 46 males and females to determine the effectiveness of PNF and static stretching on hip joint flexibility. The PNF stretching group showed a mean hamstring flexibility increase of 12.04 degrees when stretched three times per week for 10 weeks.

Numerous investigations have examined absolute peak torque of the quadriceps for various populations. A study by Thomas in 1984 looked at the peak quadriceps torque, at 60 degrees per second, of adult females ranging in age from 20 to 61 years. He reported that the mean peak torque of
the left leg was 65.5 ± 14.3 foot pounds. Holmes and Alderink (1984) studied high school age males and females. The mean peak torque of the quadriceps muscles, tested at 60 degrees per second, for the high school age females was 100.19 ± 15.57 foot pounds for the dominant leg and 99.68 ± 16.0 foot pounds for the nondominant leg. Two hundred and forty one females, age 18 to 28 years were tested by Dibrezzo, Gench, Hinson and King (1985) for peak torque at 60 degrees per second. They found the mean peak torque to be 96.47 ± 20.38 foot pounds. The highest value obtained was 168.09 foot pounds and the lowest value was 39.59 foot pounds. All of these studies found mean peak torques that were lower than those found in the present investigation (right leg = 124.22 ± 24.94 foot pounds, left leg = 130.87 ± 30.69 foot pounds). One reason for the difference in mean peak quadriceps torque might have been that the college-age female subjects used in the present investigation had a higher level of fitness at the onset of the study. A higher level of fitness, of which strength is one component, may lead to higher initial peak torque values. The study completed by Thomas included subjects who were much older than the subjects in this study. The literature indicates that peak quadriceps torque decreases with age and this may be one reason for the lower mean peak torques reported by Thomas. Dibrezzo, et al. (1985) reported a very wide range of peak torque values with the lowest value
being 39.59 foot pounds. This value is considerably lower than any reported in this study and may have affected the mean peak torque value reported by Dibrezzo, et al.

Only one study has been identified which has focused on the angle at which peak quadriceps torque occurs at. Hart, Stobbe, Till and Plummer (1984), gathered data on the position at which the peak torque occurred. Seven subjects were tested at 30 degrees per second on the Cybex II starting at different positions in the range of motion. Those subjects starting at 100 degrees of knee flexion demonstrated that the mean peak torque took place at 60 degrees of knee flexion. Complete knee extension was considered to be zero degrees of knee flexion. This finding is very similar to the value obtained in this investigation, where zero degrees was assigned to 90 degrees of knee flexion (right leg = 27.74 ± 4.36 degrees, left leg = 26.13 ± 2.81 degrees). The fact that the point at which the peak quadriceps torque took place did not change significantly, even in the face of a significant increase in hamstring flexibility, indicates that this variable is independent of hamstring flexibility and appears to remain relatively constant.

The present investigation supported the previous research done on flexibility. It found that PNF stretching does significantly improve hamstring flexibility. The absolute mean peak quadriceps torques recorded were higher
than reported in previous studies. Possible explanations for this were, a higher initial level of fitness of the subjects in the present investigation, and a lower mean age and narrower range of ages in the present study compared to earlier completed studies.
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The present study was completed for the purpose of determining if increasing hamstring flexibility affects the peak quadriceps torque of college-age females (N = 15). Each subject participated in a familiarization session for peak quadriceps torque measurement, hamstring flexibility measurement, and hamstring stretching techniques. All subjects completed a pretest and posttest for peak quadriceps torque and hamstring flexibility on the right and left legs.

The peak torque test consisted of a five minute warm-up on the Schwinn Air-Dyne exercise bicycle prior to being placed on the Orthotron II. Once stabilized with a pelvic belt, a midthigh strap and a strap around the distal lower leg each subject completed five submaximal contractions of the knee extensors and flexors at 60 degrees per second. Following a one minute rest period, each subject completed three maximal contractions of the knee extensors and flexors with strong verbal encouragement provided by the investigator. The peak quadriceps torque was recorded from
the three trials. An identical test was performed on the opposite leg with a short rest period between legs with the order being randomly assigned.

A pretest for hamstring flexibility was conducted for each subject. The test began with a five minute warm up on the Schwinn Air-Dyne exercise bicycle. Each subject was placed supine on a padded plinth with the knees completely extended and the arms by the side. An aluminum hinged indicator device was placed on the leg and securely attached with adhesive tape. A flexometer was strapped to the lateral thigh and each subject's non-test leg and pelvis were stabilized. The extended leg was held parallel with the ground while the calibrated dial of the flexometer was locked in position. The leg was then passively raised until the metal pointer deviated from the center line by two millimeters. At that time the pointer dial of the flexometer was locked and the flexibility reading recorded. The procedure was repeated five more times on the same leg with the average of the last three trials recorded as the flexibility value. The same procedure was repeated on the opposite leg following a few minute rest period. The order of flexibility testing on each leg was randomly assigned.

Each treatment session started with a five minute warm up consisting of brisk walking. One half of the subjects laid supine on a mat while their designated partners knelt beside their right legs. The right leg was placed on the
shoulder of the kneeling partner and passively raised keeping the knee in an extended position. The leg was raised until a feeling of stretch was perceived in the posterior thigh or knee area. At that point the stretch was held for five seconds followed by a five second isometric contraction of the hamstring muscles while in the stretched position. The leg was relaxed slightly for five seconds and then placed in a position of stretch again. The procedure was repeated a total of 10 times. After 10 repetitions the subjects and partners changed places and the other half of the subjects were stretched in an identical manner. All portions of the stretching sequence were controlled by an audio tape produced by the investigator. The treatment sessions took place three times per week for a period of eight weeks. All subjects attended each session and were allowed no more than three absences before being eliminated from the study. Posttest sessions were completed for peak quadriceps torque and hamstring flexibility measurement following the end of the treatment program.

Descriptive statistics on the subject's age, height, and weight were calculated. The mean, standard deviation, difference, maximum value, minimum value, and range were calculated for the peak torque, hamstring flexibility, and angle at which peak torque occurred for right and left legs for both pretests and posttests. Paired t-tests were
carried out on the group changes between the right and left legs for the angle at which peak torque occurred, peak quadriceps torque, and hamstring flexibility to determine if there was a significant difference in the amount of change that took place. A significant \( p < 0.05 \) difference was observed in the change of flexibility in the right leg compared to the left leg. The right leg was significantly more flexible than the left leg following an eight week treatment program of PNF stretching. No significant difference was found between the right and left leg change for the angle at which the peak torque occurred or for the peak quadriceps torque.

Conclusions

One conclusion of the present investigation was that PNF stretching, done three times per week for eight weeks, significantly increased hamstring flexibility in college-age females. A second conclusion of this investigation was that no significant difference was seen in absolute peak quadriceps torque following the treatment program. The final conclusion of the present study was that the angle at which the peak quadriceps torque occurred did not significantly change from pretest to posttest.

These conclusions support the previous research done with regards to flexibility in that the present
investigation also found a significant increase in hamstring flexibility following eight weeks of PNF stretching. The results of the present study refute the author's original theory that an increase in flexibility in the agonist muscle group may significantly affect strength in the antagonist muscle group. Increasing hamstring flexibility had no significant effect on peak quadriceps torque.

**Recommendations for Further Study**

The present study utilized a unique method of flexibility measurement. One recommendation for further investigation would be to complete subsequent studies using the technique of flexibility measurement described in the present research. A second recommendation would be to conduct a similar study using college-age males as subjects. This modification would provide information as to the affects of gender on peak torque and flexibility as well as address the relationship of flexibility and strength in males. To further examine the relationship between strength and flexibility a study similar to the present one with three groups of subjects could be carried out. One group would experience training in the same manner as the present study (flexibility), another group would train for strength development, and the third group would experience both flexibility and strength training.
This design would help to identify whether flexibility training does contribute to peak torque generation.
Bibliography


Appendix A

SUBJECT INFORMED CONSENT FORM

I, ____________________________, state that I am between the ages of 18 and 22 years and am of my own will participating in the research being conducted by Mark L. Amundson.

I understand that I cannot be a member of any varsity athletic team at South Dakota State University and cannot be participating in weight lifting or stretching activities on a regular individual basis or as a member of any organized class.

I have been informed the purpose of the investigation is to determine the effects of flexibility on peak quadriceps torque.

I realize the project involves a pretest and posttest session as well as treatment sessions three days per week for seven weeks. The test sessions involve collecting data on hamstring flexibility and peak quadriceps torque and the treatment sessions involve a specific stretching program to increase hamstring flexibility.

I acknowledge that I have been informed that, upon request, I will be furnished with my results as well as how my test results compare to the other subjects.

I acknowledge that I have been informed of the testing
procedures and the possible risks associated with being a subject. I understand that if I do not participate in the pretest and posttest and/or if I miss more than three treatment sessions I will be withdrawn from the study. I realize that I may withdraw from the research project at anytime. I have read and comprehend the above statements and freely volunteer to participate in the research project.

SIGNATURE OF SUBJECT ________________________________

SIGNATURE OF RESEARCHER ______________________________

DATE ____________________
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(A) - The angle in degrees at which peak torque occurred
(B) - The peak torque in foot pounds generated by the quadriceps muscle
(C) - The number of degrees of hamstring flexibility