AN ABSTRACT OF THE THESIS OF

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Title: The Comparison of the Effects of a Hamstring Strengthening Program and a Quadricep Strengthening Program on Vertical Jump and on Quadricep/Hamstring Ratios

Abstract approved: Patricia J. McSwegin, Ph.D.

This study focused on the comparison of the effects of a hamstring training program to the effects of a quadricep training program on vertical jump and on the quadricep/hamstring ratio. Fifty-two high school female students were divided into three groups: control group (CG), quadricep training group (QT), and hamstring training group (HT). The CG consisted of 16 female students who were not enrolled in a physical education class; the QT group consisted of 20 female students who were enrolled in a required physical education class, and the HT group consisted of 16 female students who had played volleyball during the 1983 season. The CG received no special training. The upper body strength program was performed three days a week for 13 weeks and was

identical for both groups. In addition, the QT group focused on a series of quadricep strength exercises, whereas the HT group did leg curls daily designed to increase hamstring strength.

The subjects were pretested and posttested on a standing vertical jump, quadricep strength, and hamstring strength as measured by a strain gauge. The best of three scores was used for statistical purposes. Differences between posttest and pretest measures were used for statistical analysis.

A one-way analysis of variance was used to compare the three groups. Omega Squared was calculated to determine any significant difference between groups. A Tukey test was administered to analyze which group was responsible for the significant difference.

Results showed that there was no significant difference between subjects who had participated in an HT program and those who had participated in the QT program in regard to vertical jump, quadricep/hamstring ratio in the right leg, or quadricep/hamstring ratio in the left leg.

A COMPARISON OF THE EFFECTS OF A HAMSTRING STRENGTHENING PROGRAM TO THE EFFECTS OF A QUADRICEP STRENGTHENING PROGRAM ON VERTICAL JUMP AND ON QUADRICEP/HAMSTRING RATIOS

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Chapter 1

INTRODUCTION

Because of the explosive nature of spiking and blocking, leg power is a critical element of volleyball skills. Therefore, it is important for volleyball coaches to examine methods of improving leg power. The present study investigated the effects of a hamstring strengthening program as compared to the effects of a traditional quadricep strengthening program on leg power as measured by vertical jump. The study also compared the ratio of quadricep strength to hamstring strength of subjects in the two training groups. The statement of the problem, the null hypothesis, assumptions of the study, purpose of the study, and significance of the study are discussed in this chapter. Limitations of the study and definitions of pertinent terms throughout the paper also are defined in this chapter.

Theoretical Formulation

The most important factor contributing to good athletic performance is strength (Klaf & Lyon, 1978). Because muscle strength is so closely related to success in athletic events, coaches are constantly searching for better methods of developing strength. Coaches who train athletes to jump are not only interested in strength development (specifically leg strength), but are even more interested in enhancing power. Strength is the foundation to all power skills. Athletes who exert the most power in the smallest period of time achieve the most success in executing a vertical jump (Scates, 1976).

Jumping ability (Scates, 1976 & Keller, 1977) is one of the basic skills a volleyball player needs to develop. The vertical jump is a result of leg power. Blocking and spiking require an explosive leg thrust in order to attain sufficient vertical height. Not only is a maximum vertical jump important, but so is the ability to be able to execute a vertical jump as effectively in the last volley of the match as was done in warm-up.

Serious volleyball players lift weights to increase the height of their vertical jump and to increase endurance (Scates, 1976 & Selznick & Valentine, 1973). The low squatting position needed in back row players has a detrimental effect upon the player's jumping ability at the net, unless the legs are thoroughly conditioned (Scates, 1976).

A good vertical jump allows the spike or block to occur at the highest point possible and allows more time for execution (Keller, 1977). The three ingredients needed to execute the spike and block (Klaf & Lyon, 1978) are arm strength, leg strength (leg strength is one component of leg power), and stamina. The leg strength requirements for the spike and block include the muscles involved in flexion and extension of the ankle, knee, and hip joints. Flexion at the knee joint involves primarily the hamstring muscle group, consisting of the biceps femoris, semimembranosus, and semitendinosus. The popliteus, though it does not actually play a role in flexion, is very important to this process also. It is the popliteus that rotates the knee, to unlock it from full extension, allowing the hamstrings to flex the knee joint. The sartorius, gracilis, and gastrocnemius also play a small role in helping the hamstring muscle group with knee flexion. Extension of the knee joint involves the quadricep muscle group, consisting of the rectus femoris, vastus medialis, vastus intermedius, and vastus lateralis. However, the hamstring muscle group also functions at the knee during extension. As the quadricep muscle group is extending the knee joint, the hamstring muscle group is also being reciprocally innervated. The hamstring muscle group assists the quadricep muscle group in the last 30^o of extension (M. Lynch, personal communication, January 14, 1984). Hip flexion is controlled by the quadriceps and hip extension is controlled by the hamstrings. Hip flexion is an extremely important movement whenever one is trying to propel the body mass vertically (Logan & McKinney, 1977). Consequently, both the hamstring and the quadricep muscle groups are important in vertical jump performance.

A commonly used method of testing leg power is the vertical jump. A study by Gray, Start, and Glencross (1962) investigated the reliability of using vertical jump as a determinant of leg power. Leg power from the Sargent jump was defined in physical science terms of work/time. The formula used was:

$$\text{Power} = \frac{w(h_1 + h_2)}{h} \sqrt{\frac{gh}{2}}$$

Eighty male college students between the age of 17 and 22 were used as subjects. Each subject was weighed and the position of his center of gravity was determined. The difference between the height of the center of gravity in a crouched position and the height of the center of gravity while the subject was standing on tip toes is h_1. The difference between the height of the center of gravity on tip toes and the height of the center of gravity at the peak of the vertical jump is h_2. The distance between the upper limits of the fingers in tip toe position and the peak of the vertical jump position is the value h.

Each subject had six attempts. The jumps were divided into two rounds of three trials. The measures obtained by two experienced observers with those of two inexperienced observers were assessed in order to determine the objectivity of the test. Inexperienced observers were defined as having no previous encounters with recording jump and reach tests. The coefficient of objectivity was found to be 0.981. The test-retest scores had a reliability of 0.985. The vertical jump has been recognized as a valid test of leg power, because of the high correlation between previous testing scores and physical activities which are believed to require leg power for successful performance. Hence, vertical jump would seem to be a sound test of leg power.

Traditionally, jumping performance has been associated with quadricep contractions. During a vertical jump it is the quadricep contraction that extends the lower leg and propels the body upward. Recently, some within the medical field (M. Lynch, personal communications, January 14, 1984) suggest that the hamstring muscle group also serves an important role in such a movement.

Usually the quadricep muscle group is responsible for hip flexion and the hamstring muscle group is responsible for hip extension. However, when flexion is done with gravity, a reversal of the usual function of the muscles occur. The posterior muscles of the hip joint (gluteus maximus and hamstring muscle group) are responsible for flexion of the hip during eccentric contraction. As a result, when a volleyball player bends at the hip and knee joints in preparation for execution of a vertical jump, the hamstrings are under a considerable amount of tension. At lift-off, the volleyball player is jumping against gravity and is using the hamstring muscle group and the gluteus maximus to extend the hip joint (Logan & McKinney, 1977). The knee joint is then extended by the quadricep muscle group. It is the stretching of the gluteus maximus and hamstring muscle groups which control hip flexion during the preparatory stage of a vertical jump and which are directly related to the amount of force that is propelled during the hip extension phase of the vertical jump (Logan & McKinney, 1977).

Traditionally, most weight programs strengthen the quadricep muscle group in order to improve vertical jump. Such weight programs often leave the hamstring muscle group untrained. The situation not only fails to increase strength in a muscle group important to the vertical jump but fosters an imbalance in strength and/or flexibility between the hamstring and quadricep muscle groups. Various injuries and postural deviations have been linked to imbalances in strength and/or flexibility between the quadricep muscle group and the hamstring muscle group (Londeree, 1981).

M. Lynch, (personal communication, January 14, 1984) studied athletes who had suffered some type of knee problem or who had undergone surgery and were involved in a rehabilitative hamstring strengthening program. These athletes showed a significant increase in their vertical jump performance after the hamstring strengthening program. Lynch believes that by strengthening the hamstrings, the quadriceps, as well as the hamstrings, will become stronger and the ratio of strength between the two will get closer to the 60:40 distribution, advocated also by Londeree (1981) and Dominguez (1979). Thus, not only does a hamstring strengthening program specifically increase hamstring strength, but it also improves the quadricep/hamstring ratio. A training method which can increase vertical jump without creating a greater imbalance between the quadriceps and the hamstrings might aid in prevention of injuries while improving jumping performance. The purpose of this study was to investigate the effects of a hamstring strengthening program as compared to the effects of a traditional quadricep strengthening program on vertical jump. The study also compared the ratio of quadricep strength to hamstring strength in the subjects of the two training groups.

The Problem

Strength training for volleyball players (Stone & Kroll, 1978) is crucial to success because strength underlies power and many volleyball skills require power. Leg power is of particular importance to volleyball players because two key skills, the spike and block, require good vertical jumping ability.

A correct understanding of the different weight training programs is essential to a coach. A coach must assess the equipment that is available and evaluate the advantages and disadvantages of the different weight training programs in order to properly select the best method. Extensive research is the only way of gaining information to appraise the equipment and/or technique. This study focused on the improvement of vertical jump performance through the strengthening of the hamstring muscle group. This study also investigated the theory that by strengthening the hamstring muscle group, the ratio of the quadricep strength to the hamstring strength would achieve a more desirable ratio, (e.g. 60:40).

Statements of the Porblem

Problem 1. Is there a significant difference in vertical jump performance between high school female students who participate in the weight training program designed to increase hamstring strength, and high school female students who participate in the weight training program designed to increase quadricep strength?

Problem 2. Is there a significant difference in the ratio of right leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program, and high school female students who participate in the traditional quadricep strengthening program?

Problem 3. Is there a significant difference in the ratio of left leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program, and high school female students who participate in the traditional quadricep strengthening program?

Statements of the Hypotheses
(Null Form)

Hypothesis 1. There is no significant difference in vertical jump performance between high school female students who participate in the weight training program designed to increase hamstring strength and high school female students who participate in the weight training program designed to increase quadricep strength.

Hypothesis 2. There is no significant difference in the ratio of right leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program and high school female students who participate in the traditional quadricep strengthening program.

Hypothesis 3. There is no significant difference in the ratio of left leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program and high school female students who participate in the traditional quadricep strengthening program.

Statistical Hypotheses:

Stated symbolically, the null hypothesis for Problem 1 is:

$$Ho{:}1 \quad \mu_{HT} = \mu_{QT}$$

while the alternate hypothesis is:

$$\mu_{HT} \neq \mu_{QT}$$

Stated symbolically, the null hypothesis for Problem 2 is:

$$Ho{:}2 \quad \mu_{HT} = \mu_{QT}$$

while the alternate hypothesis is:

$$\mu_{HT} \neq \mu_{QT}$$

Stated symbolically, the null hypothesis for Problem 3 is:

$$Ho{:}3 \quad \mu_{HT} = \mu_{QT}$$

while the alternate hypothesis is:

$$\mu_{HT} \neq \mu_{QT}$$

Assumptions of the Study

This study was designed to investigate the effects of a hamstring strengthening program as compared to the effects of a traditional quadricep strengthening program on leg power as measured by the vertical jump. It is assumed that the subjects taken from a 5A Kansas high school, are representative of all high school female students.

Another assumption concerns the vertical jump performance effort during the pretest. Each subject was directed to perform the best that she could in all areas of testing. It is assumed that the sujects exerted maximal effort on each test item.

Finally, it is assumed that both groups will improve their vertical jump performance. Experimental group one will improve vertical jump performance because their quadriceps are being strengthened directly. Experimental group two will improve vertical jump performance because the hamstring muscle has been strengthened and because the quadricep/hamstring ratio has come closer to a 60:40 distribution.

Purpose of the Study

It was the primary purpose of this study to investigate the effect hamstring strength has on vertical jump performance and on the quadricep/hamstring ratio in high school female students. One group of subjects used an isotonic weight circuit designed to increase quadricep strength and hamstring strength. The second group of subjects used a weight circuit designed to improve only hamstring strength. To evaluate vertical jump performance, subjects performed three standing vertical jump tests. To evaluate quadricep/hamstring ratio, subjects executed maximal lifts on a strain gauge. Each subject was allowed three trials for quadricep strength and three trials for hamstring strength with each leg.

Significance of the Study

Since vertical jumping ability is a critical skill to the volleyball player, coaches and trainers are constantly trying new methods to discover the best way to improve vertical jump. Most previous studies used designs which increased quadricep strength. No studies were found concerning the effect hamstring strength would have on vertical jump or on the quadricep/hamstring ratio. According to M. Lynch, (personal communication, January 14, 1984) an increase in vertical jump is brought about through a training program centered around increasing hamstring muscle strength during the rehabilitation of athletes. Could the same effect occur in healthy athletes? It was the purpose of this study to investigate the effects of a hamstring strengthening program as compared to the effects of a traditional quadricep strengthening program on vertical jump and on the quadricep/hamstring ratio.

Definitions of Terms

The following are definitions of terms which were used in this study:

Goniometer

It is a 180° protractor of plexiglass with two attached stationary arms, 15 inches long, which form any angle desired (Divitto, 1973). A goniometer is used to measure flexibility at a joint.

Hamstring

The parts of the hamstring are the biceps femoris, semimembranosus, and semitendinosus, which act on the hip joint as extensors and on the knee joint as flexors (MasConaill & Basmajian, 1977).

Isokinetic Exercise

Isokinetic exercises are those exercises which cause muscles to contract at a constant velocity against an accommodating resistance which utilizes servo-mechanism controls (deVries, 1980).

Isometric Exercise

Isometric exercises are exercises which consist of contractions in which no movement takes place. The muscle does not shorten (Coppoc, 1967).

Isotonic Exercise

Isotonic exercises consist of contractions usually employed in progressive resistance exercises. It is a contraction wherein the muscle visibly shortens (Klaf & Lyon, 1978).

Plyometric Exercise

Plyometric exercises cause a muscle that is being stretched to contract quickly. The muscle continues to lengthen while it is being contracted because the external load is greater than the internal load (Wilt, 1975).

Strain Gauge

It is a device by which the force of a muscle contraction can be measured and recorded during movement. It also limits the angular velocity of the appendages so that the velocity is constant (Asmussen, Hansen, & Lammert, 1975).

Strength

It is the ability of a muscle to exert force or the ability to work against a resistance (Klaf & Lyon, 1978).

Vertical Jump

The distance between a person standing flat footed with his dominant hand stretched upward and the maximum height a person can jump, extending his dominant hand.

Limitations of the Study

There were several limitations to this study. Subjects engaged in a wide variety of activities during the course of the study. It is feasible that these activities could affect the results of the study.

The subjects who comprised the hamstring group were all volleyball players of the 1983 volleyball season. The subjects who comprised the quadricep training group were physical education students who displayed a good attendance record prior to the start of this research project. It should be noted at this time that the subjects in the quadricep training group included girls who had participated in athletic activities such as tennis, track, basketball, and swimming as well as girls who were not engaged in athletic activities. The control group were subjects who were not currently involved in a physical education class. Subjects in the control group included athletes and non-athletes.

Chapter 2

REVIEW OF RELATED LITERATURE

Weight training has become an essential component of athletic programs. Weight training is important because it develops muscular strength, muscular endurance, and confidence. According to Blockovich (1977), when competition takes place and everything is equal, the stronger team will generally win. Blockovich believes that for most athletic events, testing and training should occur in the following areas: bench press, power clean, power curl, military press, leg press, and squats. It is interesting to note that he did include quadricep strength training, but not hamstring strength training even though an imbalance between quadricep and hamstring muscle groups has been shown to cause various injuries and postural deviations (Londeree, 1981).

Good strength in all of the extensor muscles of the hip, knee, and ankle joints is required for good jumping ability (Klaf & Lyon, 1978). By increasing one's strength through weight training, an athlete can increase his vertical jump by as much as six inches. Methods of weight training which have been proven to increase vertical jump performance are: plyometric training, use of an isokinetic jumping machine, stair running, and squats (Schakel, 1981).

This chapter includes a summary of the historical development and description of various types of weight training. This chapter also discusses research that relates to the various types of weight training programs used to increase an athlete's vertical jump, namely: isokinetic, isometric, isotonic, and plyometric weight training programs.

Historical Overview

In the 1900's weight lifting was considered a sport, not a training technique (Brubacher, 1980). Weight lifting was accepted as an Olympic event but not as a training procedure. Many coaches, who were not involved with weight lifters, believed that weight lifting was detrimental to performances of their athletes.

These coaches and athletes feared a condition called muscle boundness or muscle tightness which was supposedly caused from weight training. Muscle boundness is a loss of coordination and speed of movement due to overdevelopment of the musculature. There was no scientific evidence to ever verify development of this condition (Wilkin, 1952). However, for many years, people who were associated with athletics accepted it as truth and would not allow weight training to become a part of their conditioning program.

Though coaches and athletes did not believe in weight training as a means of conditioning, they did realize the relationship between athletic skill and strength. Educators tried to develop criteria by which to evaluate athletic ability of students. The criteria for evaluating athletes were based on strength. Rogers (1925) was the first to develop a battery of tests to evaluate the strength of students. The results were used to predict athletic ability. These tests were used for many years.

As the level of competition within athletics grew, efforts were made to develop better trained athletes through various programs. This led many to begin questioning the belief that weight training caused muscle boundness or muscle tightness. Hence, some began to use weight training as a means of improving performance.

Isotonic weight training became prominent in the late 1940's. An isotonic exercise requires the muscle to lengthen and shorten. A limb or body part is required to move and perform against resistance. An isotonic exercise involves both isotonic and isometric elements. That is, before an individual can lift a weight of 10 lbs. "isotonically", he must first build up tension of 10 lbs. "isometrically" (Jokl, 1964).

An isotonic weight training program consisted of using free weights: barbells and dumbbells. One of the first programs involved 3 sets of 10 repetitions at a weight station. The first two sets were designed to be a warm-up and the third set was designed to increase strength by overloading the muscle groups involved (Jensen & Jensen, 1978). The program was as follows:

Set I was against resistance 50% of the 10 RM's.

Set II was against resistance 75% of the 10 RM's.

Set III was against resistance 100% of the 10 RM's.

(RM = Repetition Maximum)

If an athlete's bench press repetition maximum was 80 lbs., then Set I would be 10 repetitions of 40 lbs., Set II would be 10 repetitions of 60 lbs, and Set III would be 10 repetitions of 80 lbs.

Chui (1950) was one of the first researchers to question and test the belief that weight training caused muscle boundness. His research evaluated athletic strength between those who were involved in a weight training program and those who were involved in a required physical education program. Group A, the experimental group, consisted of 23 students who met two or three times a week for one hour of isotonic weight training. Group B, the control group, consisted of 22 students who participated in a required physical education class that engaged in no weight training program. The battery of tests that were used included: body weight, standing Sargent jump, running Sargent jump, standing broad jump, 8 lb. shot-put from a stand, 12 lb. shot-put from a stand, and 60 yard sprint. The results showed that Group A made significant improvement in all six activities. Chui concluded that no muscle boundness occurred in Group A since power is developed by speed and strength.

A study similar to Chui's was done by Capen (1950). Group A consisted of 42 students who were enrolled in a weight training program. Group B consisted of 29 students who were enrolled in a conditioning class. Both groups met for 40 minutes, twice a week, for 11 weeks. The battery of tests included: right grip, left grip, chinning, dipping on parallel bars, standing broad jump, standing Sargent jump, running Sargent jump, and the 8 lb. shot-put. The results showed that Group A improved more in muscular strength and power skills. There was no significant difference in endurance gains. Capen, like Chui, concluded that weight training does not cause muscle boundness or muscle tightness.

In 1953, Hettinger and Müller, published a paper which said that great gains in strength could be made through "static tension". This is an isometric exercise (Sheeran, 1977). An isometric contraction is when a muscle contracts developing tension. There is no visible external movement because the external resistance is greater than the internal (muscle) force (Fox & Matthews, 1981). Through research, Hettinger and Müller in 1953 (Sheeran, 1977) discovered that strength could be attained by holding each contraction for six seconds at 2/3 of maximum strength.

In the early 1960's coaches and athletes used isometric training. It became popular because of several factors: first, there is no equipment needed to perform the exercise; second, a person does not need much room to execute an isometric exercise; third, isometric exercies are not time consuming; and fourth, no assistance is needed when performing the exercise (Sheeran, 1977).

Today, it is believed that one repetition done daily and held for 10 seconds at maximum effort can achieve strength gains.

However, research soon showed that isometric exercise had definite limitations (Sheeran, 1977). People with high blood pressure noticed a rapid increase in blood pressure. The intrathoracic pressure is elevated when an expiratory effort is made with the glottis closed. This occurrence, the Valsalva maneuver, is not generally seen in normal exercise. However, during isometrics this elevated intrathoracic pressure causes an increase in systolic and diastolic blood pressures (Fox & Matthews, 1981). Also, strength gains only occur at the angle at which the isometric exertion is made. Many skills are dynamic and are executed within a range of motion. An isometric exercise is static and has no noticeable movement. Therefore, by doing an isometric exercise, only one angle of the skill is strengthened. This leaves the other angles of the skill untrained. Since many athletic skills are dynamic, isometric training was not considered a good training technique.

In their search for a better method of weight training, researchers devised isokinetic weight training in the 1960's. The isokinetic program is unlike the isotonic program where the muscle must put forth a maximum effort only at the angle of pull which is the weakest. Isokinetic weight training allowed the workload to remain constant throughout the entire range of motion.

Because of this factor, automatic variable resistance, the isokinetic concept was thought to be the weight training program of the future (Sheeran, 1977). Unfortunately little research was done on isokinetic weight training due to the high cost of the equipment. The CYBEX at that time, was approximately $4,000.00 (Counsilman, 1971).

Often coaches were trying to find a training technique which would allow an athlete to gain strength faster, would use less practice time, and would strengthen muscles specifically involved in the skill. One of these coaches, Cousilman (1971), was the swimming coach at Indiana University. He read much research on isokinetic training but was searching for a more economical device than the CYBEX. A graduate student informed him that the Super Mini-Gym Isokinetic Exerciser cost only $100.00. After two years of testing, Counsilman, published the successful results of his isokinetic exercise program in which his swimmers trained on the low cost, efficient Super Mini-Gym Isokinetic Exerciser (Counsilman, 1971).

Fisher refined the Super Mini-Gym Isokinetic Exerciser into the Mini-Gym Isokinetic Leaper, model 16XB (Lapham, 1976). The format of the 16XB allows for constant maximum resistance while maintaining constant angular velocity. The 16XB trains the specific muscles involved in jumping. Because the Leaper was more economical than the CYBEX, the use of isokinetic weight training was greatly increased.

One of the more recent training methods used to increase vertical jump is plyometrics. Plyometric training was developed by coaches in the USSR (Clutch, Wilton, McGown, & Bryce, 1983). The word plyometric is derived from the Greek word plethyein (increase) and metric (measure) (Wilt, 1975). A plyometric exercise causes a muscle that is being stretched to contract quickly. While the muscle continues to lengthen it is being contracted because the external load is greater than the internal tension. This is called negative work. Plyometrics are based on the belief that an athlete can gain more power from a concentric contraction, if it is preceded by an eccentric (lengthening) contraction (Wilt, 1975). One example of a plyometric exercise is depth jumps. A depth jump allows the individual to drop from a height and upon landing, immediatly perform one type of a vertical jump (Clutch, Wilton, McGown, & Bryce, 1983). During a depth jump eccentric contraction would occur while dropping from the height. Concentric contraction would occur to bring about the immediate jump to the next height. When done properly, plyometrics cause hypertrophy and associated strength gains (deVries, 1980).

Recently, volleyball coaches have been increasing the vertical jump performance of their players through the principle of specificity. The principle of specificity implies that for vertical jump performance to increase, the athlete must practice jumping under actual conditions. Theory of specificity is based on two physiological bases: metabolic and neuromuscular (Fox & Matthew, 1981). The metabolic base takes into consideration the type of energy system being used and the cardiorespiratory system. The neuromuscular base considers the two types of muscle fibers; slow twitch and fast twitch. Researchers have found that significant increases in vertical jump occur due to the size and strength of fast twitch muscle fibers when jump training is based on speed with moderate resistance (Schakel, 1981). By performing exercises during training which involve the same muscle groups required for the actual performance, the neuromuscular pathways are trained to do the specific skill (Bertucci, 1979).

The three main types of weight training programs are isokinetic, isometric, and isotonic. A summary chart of advantages and disadvantages of these three weight training programs has been included (Appendix A) (Lamb, 1978).

Weight Training Programs

Since weight training is an accepted method of strength training, researchers have been searching for the perfect formula. This formula would include the right amount of repetitions, the right number of sets, and the proper workload to develop maximum strength and power. The next portion is directed toward examining research which pertains to various weight training methods.

The purpose of weight training is to increase strength. Muscular strength is developed through the overload principle, where the muscle is forced to work at its maximum or near maximum load (Fox, 1979). When the muscle is forced to work near maximum levels, the body adapts by increasing the diameter of the individual muscle fibers. The increase in the size of muscle fiber is developed by increasing the number and size of the myofibrils, increasing amount of protein utilized, increasing capillary density, increasing strength in connective tissue, and increasing the number of muscle fibers through longitudinal fiber splitting (Fox & Matthews, 1981). Hence, strength is gained.

A study was conducted by Ness and Sharos (1956) to investigate whether systematic weight training would improve leg strength and vertical jump. The subjects were 30 varsity basketball players. Group A was involved in a weight training program for four weeks. Group B was not involved in a formal weight training program. Measurements were taken on the following tests: Sargent jump test, leg lift, and ankle-plantar flexion strength test. In the Sargent jump test, results showed an increase of 3.23 in. in Group A while Group B had no increase. In addition, strength increase also occurred in the legs. In this study, weight training for four weeks was shown to significantly increase leg strength and vertical jump performance.

An experiment was conducted by Masley, Hairabedian, and Donaldson (1953) to determine whether increased strength gained through weight training was accompanied by an increase in muscular co-ordination and speed of movement. The experimental group consisted of 24 members of a beginning weight training class. The control volleyball group, CV, consisted of 24 members in a beginning volleyball class. The control lecture group, CL, included 15 people who attended lectures. The experimental group, X, stressed body building with moderate poundages and repetitions for eight weeks. The CV group learned basic volleyball skills and then practiced them. The CL group just attended lectures. This group's outside activities were not controlled. The results showed that weight training did increase strength in the experimental group. The results also displayed some effect on increased co-ordination and speed.

Research was conducted by Berger (1963) to find out what effects strength improvement had on vertical jump. The subjects were 89 college males who were in four activity classes. Group I did 10 repetitions of deep knee bends with a barbell resting on the shoulders. Group II did five to six repetitions of jumping squats with a barbell. Group III statically flexed the knee to 90° and 135° for eight seconds at each angle. Group IV performed 10 repetitions of the vertical jump to see if specificity is a factor in training procedures to increase vertical jump performance.

All subjects were pretested. The training was three days a week, for seven weeks. This training was followed with a posttest. It was found that dynamic training was more significant than static training.

The UCLA weight training program stresses squatting exercises in order to increase leg strength and power (Scates, 1979). The program includes squats and explosive jumping squats. The athlete squats 6-10 times with the maximum amount of weight that he can lift using good form. Once the athlete has squatted, he is encouraged to extend his legs as quickly as possible. As soon as the muscles can control the workload, more resistance is added. Males try to attain 200-300% of their body weight. Females try to attain 150-200% of their body weight.

Power is work done within a unit of time. To be powerful, one must have good strength. Strength is the basis of power and of power skills, such as the vertical jump. Hellebrandt (1958) believes that the rate at which work is done is much more important than the amount of work that is done. The faster the work can be done, the more powerful the work is performed.

McClements (1966) compared body power through measuring jumping height and body weight, using leg and thigh flexor muscles and the strength of leg and thigh extensor muscles. He also compared the effect on power of strength development of agonistic and antagonistic muscle groups. The Clark cable-tension technique was administrered to 86 college men in a physical conditioning class to determine strength in leg flexion, leg extension, thigh flexion, and thigh extension.

The men were divided into four training groups. Group I was involved in an extensor program which emphasized strength development of the leg and thigh extensor muscles and avoided exercises which strengthened leg and thigh flexion muscles. Group II was involved in a flexor program which emphasized the development of leg and thigh flexion muscles and avoided exercises which strengthened leg and thigh extension muscles. Group III was involved in a flexor-extensor program which emphasized strength development in leg and thigh flexion and extension. Group IV was involved in a normal program consisting of normal activities contained in a physical conditioning program at the university. All of the men trained for 19 weeks.

McClements found that all four groups were equally effective in increasing power of the leg and thigh muscles used in the vertical jump. The finding of no significant difference between the groups was unexpected. According to McClements, one theory that might explain this is that strength development in one set of muscles may affect an increase in the strength of the opposing set of muscles.

Baley (1966) conducted a study with 104 male college students to find out if isometric exercises improved vertical jump. The training lasted for four and one-half weeks. Group I did isometric exercises, three days a week for 30 minutes for 12 class periods. Group II met twice a week for 60 minutes for eight class periods. This group did isometric exercises as well as stretching and a mile run.

The pretest mean of Group I was 20.8 inches. The final mean of Group I was 22.1 inches. This was a mean difference of 1.3 inches at the .025 level of significance. The pretest mean of Group II was 20.2 inches. The final mean of Group II was 21.0 inches. This was a mean difference of .8 inches significant at the .10 level. The results showed that each group made a significant improvement in the final mean score. However, the mean difference scores of the two groups did not differ significantly.

In 1967, Coppoc tested the effects of isometrics on vertical jump performance of junior high boys and girls. The 94 subjects were placed in groups on the basis of their initial vertical jump. Group I performed an isometric half squat for eight seconds each day for six weeks. Group II received no supplementary isometric exercise program.

The findings indicated: (1) There was a significant improvement of the vertical jump in Groups I and II with a .01 level of significance. (2) There was no significance between the final means of the vertical jump of the two groups. (3) Seventh graders in Groups I and II did not significantly improve their vertical jump. (4) Eighth graders in Groups I and II did signficantly improve vertical jump at a .01 level of significance. (5) Girls in both groups significantly improved their vertical jump at a .01 level of significance.

Experimentation was conducted by Bangerter (1968) to analyze the vertical jump. The subjects included 112 college men divided into five groups. All groups met for three days a week, for eight weeks using progressive resistance training. Eight to twelve repetitions were done using the overload method. Group I strengthened plantar-flexors through heel raise exercises. Group II strengthened knee-extensors while seated at an exercise table. Group III strengthened hip-extensors while strapped face down on an exercise table. Group IV performed all of the above exercises. Group V was the control group and received no training. It was discovered that plantar-flexion does not significantly contribute to the vertical jump. However, knee and hip extensors or a combination of the two do significantly contribute to the vertical jump.

An experiment was conducted (Somers, 1974) to evaluate the effect that two different speeds of isokinetic weight training had on vertical jump performance. Sixty subjects were divided into three groups: control group, slow speed training group, and fast speed training group. Each subject was pretested on vertical jump performances. Group I was the slow speed training group which trained at a rate of four seconds per repetition. Group II was the fast speed training group which trained at a rate of one to one and a half seconds per repetition. Group I and II did 10 repetitions, three times a week, for six weeks. Group III was the control group and received no training. All three groups met 55 minutes a day in a required physical education class. The results showed no significant difference in improvement of vertical jump performance in either the slow speed training group or the fast speed training group.

VanOcteghen (1974) did a similar study investigating whether leg strength would be increased due to the speed of the isokinetic training program, whether vertical jump performance would increase, and whether vertical jump performance would significantly improve due to the speed of the isokinetic training. Forty-eight female volleyball players were randomly divided into either slow, fast, or control group. The experiment lasted eight weeks. Each subject was tested on an isokinetic compensator leg press machine made by Mini-Gym, Incorporated and on vertical jump.

There was a significant ($P < .05$) improvement of vertical jump scores between the two experimental groups and the control group. There was no significant difference between the two training groups. It was concluded that leg strength increases will not necessarily increase vertical jump and that the speed of the training had no effect on vertical jump performance.

In an effort to determine whether isotonic or isokinetic weight training was a better method of improving vertical jump, Brubacher (1980) conducted an experiment using 62 college students. The subjects were randomly assigned to one of two groups. Group I, isotonic group, used free weights. The isotonic group executed three sets of 20 repetitions, three times a week, for six weeks. A three to four minute rest period was allowed between sets. Group II, isokinetic group, used the Isokinetic Jumper. These subjects executed three sets of 20 repetitions, three times a week, for six weeks. This group also had a three to four minute rest between sets. All subjects were pretested and posttested on four types of vertical jumps. They were: standing two foot jump, running two foot jum, running left foot jump, and running right foot jump.

The statistical method used was the analysis of covariance at the .05 level of significance. The conclusions were that there is no significant difference in the training methods. Within the limitations of this study, the two training methods for improving vertical jump were equal.

Schakel (1981) used male athletes to compare the effects of a weight training program to the effects of a weight training program with plyometric training using ankle and vest weight drills. The men were divided into two groups. For six weeks they met six days a week for eight to nine minutes a day. The weight program for both groups included: bench press, power clean, 1/2 squat, military press, sit-ups, pull-ups, leg extension, leg curl, and use of the mini-gym leaper. In addition to the weight circuit, the experimental group did two plyometric drills. In drill 1, the subject would wear a two and one-half pound ankle weight on each ankle. He would do five sets of running in place for 30 seconds followed by 30 seconds of rest. In drill 2 the subject wore a weighted vest and performed three sets of depth jumps, 10 repetitions per set. Each set was divided by a one minute rest period. The results showed that the mean vertical jump of the control group increased 1.3 inches (from 24.9 inches to 26.2 inches). The mean vertical jump of the experimental group increased 3.0 inches (from 23.5 inches to 26.5 inches). Both of these changes are significant ($P < .01$). These results support the law of specificity and show that weight training and plyometrics enhance vertical jump.

In another experiment Clutch, Wilton, McGown, and Bryce (1983) compared the effect of weight training and plyometrics on vertical jump. The subjects were undergraduate students in a beginning weight training class. Group I did maximum vertical jumps and weights. The vertical jumps were executed in four sets of 10 repetitions, with a pause between jumps. Group II did 0.3m depth jumps and also weights. The depth jumps consisted of stepping from a box and rebounding when one's feet landed on the wrestling mat. Four sets of 10 repetitions were done. Group III did four sets of 10 repetitions of depth jumps and also did weights. Set one and three of the depth jumps were done at 0.75m and sets two and four were done at 1.10m. The weight training consisted of three sets of four to six repetitions of one-half squats.

The results of this experiment showed that all three groups had an increase in one repetition maximum squat strength, isometric knee extension strength, and in vertical jump performance. Depth jumps and weights were no more effective than regular maximum jumps. Subjects had an average increase in vertical jump of 8.40cm. These results suggest that a proper program of strength training and almost any jumping program will increase vertical jump.

In all but one of the experiments sited, the emphasis for improving vertical jump focused on strengthening the quadricep. It has been shown (Londeree, 1981) that various injuries and postural deviations are linked to imbalances in strength and/or flexibility between the quadricep and hamstring muscle groups. McClements (1966) was the only researcher to investigate the effects of a flexor (hamstring) program on vertical jump performance.

Laird (1981) investigated the quadricep/hamstring strength ratio of an intercollegiate soccer team. Twenty-three men were administered a 1 RM strength test for knee flexion and knee extension on the Universal Knee Machine. Each athlete was asked to warm-up the same way he did before practice. Three practice lifts were given. Then, each athlete tested for strength in right quadricep muscles, left quadricep muscles, right hamstring muscles, and left hamstring muscles. Resistance was initially started at five pounds. Upon completion of a good lift, five more pounds were added until maximum poundage could be lifted. Data was compared to determine quadricep-hamstring ratio, quadricep strength ratio in right and left legs, and hamstring strength ratio in right and left legs. A ratio of .62 + .05 was considered acceptable for the quadricep/hamstring ratio.

Of the 23 soccer players tested, six had acceptable quadricep/hamstring ratios in the right leg. Four players had acceptable quadricep/hamstring ratios in the left leg. No injuries were sustained in either of the groups with acceptable ratios. This data suggests a higher number of injuries based on the acceptable ratio used for quadricep/hamstring strength. The lack of injuries may be due to: flexibility levels, the fact that the athletes did not overuse their physical capabilities, or that the quadricep/hamstring strength ratio used (3:2) is not a good predictor of muscular strains.

According to Klein and Hall (1963), the hamstrings are very critical to the stability of the knee joint. Insufficient strength training within the hamstring muscle group can result in knee injuries. Therefore, care must be taken when conditioning and reconditioning leg strength and leg power to ensure that the hamstring muscle group, as well as the quadricep muscle group, receive equal consideration.

Summary

Chui (1950) and Capen (1950) showed that weight training is not associated with muscle boundness. Ness and Sharos (1956) showed that by increasing leg strength, one could increase vertical jump. Masley (1953) further showed a relationship between strength gains and the enhancement of co-ordination and speed. McClements

(1966) tested the effect of strength development of agonistic and antagonistic muscle groups and also the effect of strength development of the knee and hip flexors and extensors on power. Baleys's study (1966) showed that by doing isometric exercises, vertical jump could be increased. An analysis of the vertical jump was shown to be directly influenced by knee extensors, hip extensors, or a combination of the two (Bangerter, 1968). Two researchers (Somers, 1974 and VanOcteghen, 1974) found that vertical jump was not affected by varying the speed of weight training. Brubacher (1980) compared the effects of an isotonic weight training program to the effects of an isokinetic weight training program on vertical jump. Though both methods increased vertical jump, neither method was better. Schakel (1981) and Clutch, Wilton, McGown, and Bryce (1983) found that a weight training program with any type of jumping program would increase vertical jump.

Research regarding training to improve vertical jump clearly shows that most such training is directed toward strengthening of the quadriceps. Only two training studies were found focusing on the strengthening of the hamstring muscle group in order to improve vertical jump (McClements, 1966) and quadricep/hamstring ratio (Laird, 1981). When quadriceps are trained and the hamstrings are not, imbalances between the two cause injuries and postural deviations (Londeree, 1981). Klein and Hall (1963) emphasized the importance of strengthening quadricep and hamstring muscle groups in order to prevent an imbalance in the stability and function of the knee joint. Despite the fact that research clearly correlates quadricep muscle strength with vertical jump, it does not provide evidence of the effects of a hamstring strengthening program on vertical jump performance.

Chapter 3

METHODS AND PROCEDURES

This study focused on the effects of a hamstring strengthening program as compared to the effects of a traditional quadricep strengthening program on leg power as measured by the vertical jump. The study also compared the ratio of quadricep strength to hamstring strength of subjects in the two training groups. Female students from the physical education classes, from female students outside the physical education classes, and from the women's volleyball team were used as subjects.

Population and Sampling

Female students in a 5A high school of approximately 578 students served as subjects in this study. Volunteers were taken from students who were not currently enrolled in a physical education class, from students who were enrolled in a required physical education class, and from varsity and junior varsity volleyball players. All groups included some athletes. The control group and experimental group I had some students who were not involved in athletics. All subjects and their parents or guardian signed an Informed Consent Form (Appendix B) before taking part in the study.

Sixty-two subjects completed the pretest. Of these 62 individuals, 22 were in the control group (CG). The control group was made up of females who were not enrolled in any physical education class. Experimental group I (quadricep training group- QT) consisted of 23 females who were enrolled in a required physical education class. Experimental group II (hamstring training group, HT) consisted of 17 volleyball players who had played in the 1983 season. Sixteen subjects in the control group, 20 subjects in the experimental group I, and 16 subjects in the experimental group II completed the final tests. Due to illnesses, injuries, work schedules, and other reasons, 10 of the subjects failed to complete the program.

The type of exercise that each subject engaged in outside the program was not controlled. Those females in the experimental group II were instructed to do no notable training to strengthen the quadriceps. Subjects in experimental group I and the control group were instructed to participate in any and all activities they wanted.

Materials and Instrumentation

The testing was conducted in the wrestling room of the high school gymnasium. The weight training programs were administered in the weight room portion of the wrestling room. The subjects in the control group were pretested and posttested but received no special training.

The subjects in experimental group I were pretested and posttested. The subjects were involved in a daily stretching program (Appendix C) designed to improve flexibility. Each stretch was entered into slowly and was held for 8-10 seconds. The subjects participated in the isotonic weight program that is a part of the physical education curriculum. That weight program used free weights and a Universal weight machine. Upper body strength was also developed in this weight program. This factor, though it might have helped propel the body upward, was not emphasized in this study.

The overload principle was used. Subjects lifted workloads that were more than those normally encountered. After a period of time, the initial overload became an underload. Because of this, the resistance was systematically increased. When any subject could successfully lift a particular workload a predetermined number of repetitions, resistance was increased by five pounds. Five pound increments were chosen because the smallest weight available was two and one-half pounds. By placing a two and one-half pound weight on each side, the increment equalled five pounds. The weight circuit (Appendix D) was done three days a week for 13 weeks. A form (Appendix E) was filled out during each weight training session in order to monitor each subject's progressive resistance level.

Subjects in experimental group II did a weight training circuit (Appendix F) that involved the upper body and the hamstring muscle group. Each subject did the upper body workout three days a week for 13 weeks. Each subject did four sets of 10 repetitions on the leg curl machine daily to improve hamstring strength. The overload principle was used concerning the upper body weight stations. When a subject could do all four sets of 10 repetitions on the hamstring exercise without perceiving any muscle contraction in any muscle group besides the hamstring muscle group, she increased resistance by two and one-half pounds (M. Lynch, personal communication, January 14, 1984).

Proper technique is imperative when doing leg curls (M. Lynch, personal communication, January 14, 1984). The subject must lie prone without lifting up on her elbows. She must make a conscious effort to keep the buttocks, quadriceps, and gastrocnemius muscles relaxed. A folded towel was placed under each quadricep to help prevent the quadricep muscle group from contracting. Working one leg at a time, the subject lifted the weight 30° or six inches, whichever was least. Anything above this angle involves the use of the quadricep (Appendix J). A form (Appendix G) was filled out daily in regard to the weight being lifted on the leg curl machine. The same form was used to record upper body workouts three days a week.

The importance of maintaining flexibility was stressed. Throughout the program stretches taught were: hamstring stretch, quadricep, inside hurdle, groin stretch, and gastrocnemius/soleus stretch (Appendix H). Subjects were encouraged to do these 7-10 times a day. Each stretch was held for 8-10 seconds.

Design of the Study

This study evaluated the effect that a hamstring strengthening program had on vertical jump performance and on the quadricep/hamstring ratio. Subjects in the quadricep training group (QT) performed exercises that specifically strengthened the quadricep muscle group. Subjects in the hamstring training group (HT) performed exercises which specifically strengthened the hamstring muscle group. All subjects participated in the program for 13 weeks.

Pretesting for this study was conducted in one day. Data that were collected during the pretest included: name, birthdate, age, code number, weight, height, height of standing reach, dominant foot, three attempts at a standing vertical jump, maximum weight that could be lifted at the military press station, hamstring flexibility for right leg and left leg, three read-outs of hamstring strength per leg, and three read-outs of quadricep strength per leg. Two other areas that were discussed with each subject were the level of participation that each would be involved in during the next 13 weeks and whether the subject had had any history of previous knee injury.

Each station was demonstrated and explained the day before pretesting occurred. The researcher and co-workers administered all tests and supervised all weight training sessions. Particular care was taken to insure that the leg curl procedure was done correctly during training as well as during testing. Subjects who missed a class period which involved a weight training day made up the work before school.

Each week subjects in the QT group and the HT group received new progress report sheets that were to be filled out during each training period. Each day every subject turned the progress sheet in to the researcher. Poundage and number of repetitions per exercise were recorded daily.

The weight training programs for the QT group and the HT group were started two days after the pretest. The QT group did one set of each of the weight exercises, three times a week. The HT group did one set of weights which pertained to upper body strength three times a week and four sets of 10 repetitions on the leg curl machine daily. Both programs lasted 13 weeks. Subjects performed their weight training circuit during physical education class. Those subjects who were in the HT group and were not in a physical education class, performed their weight training circuit daily at 7:30 a.m.

At the end of the 13 week training period the subjects discontinued their weight training program. The posttest was given the day after the weight training programs were completed.

A goniometer was used to measure hamstring flexibility in each leg. The subject, in supine position, was tested for hamstring flexibility in the right leg and in the left leg. This was administrered by having the subject relax the hip joint while the tester raised the leg to the point of tension. At this point the knee was straightened and the angle of the knee joint was measured.

A strain gauge was used to measure strength in the quadricep and hamstring muscle groups. The strain gauge measures and records the force of a muscle contraction during movement (Asmussen, 1965). The score was recorded in foot-pounds. The angular velocity of the appendages are limited so that the velocity can be held constant. Quadricep strength was measured in a sitting position with the knee joint extended at an angle of 45°. Hamstring strength was measured in a prone position with the knee joint flexed at an angle of 30°.

The standing vertical jump was used as the test for measuring leg power. Vertical jump has been proven to be a good test for measuring leg power (Gray, Start, & Glencross, 1962). The vertical jump was measured by subtracting the stand and reach measurement from the measurement achieved when exerting a maximal effort from a standing position and reaching with the dominant hand.

Data Collection

The standing vertical jump was evaluated in the testing. Also, quadricep and hamstring strength were measured for each leg on a strain gauge. Three attempts were given for each area. Every score was recorded. The best effort for each test was used for statistical analysis.

On the morning of the testing program, seven to nine subjects arrived every 20 minutes for testing. In order to prepare subjects for the vigorous muscle effort required in the testing, the researcher led each group in an aerobic dance routine, which increased heart rate and increased blood circulation. Following the warm-up, subjects were led in a series of stretching exercises.

After completing the warm-up, subjects were instructed to perform their very best and were given the order in which they were to do the tests. Each testing station was monitored by an adult who had been given instructions prior to the testing time. To prevent the "Experimental Bias Effect" (Campbell & Stanley, 1963), the researcher did not administer any of the tests. The researcher led warm-up, gave instructions, and recorded test results.

Each subject began testing at the vertical jump station. First the subject's standing reach was measured. Standing reach was determined by having the subject stand flat-footed with her side against the tape measure. Her dominant hand was extended overhead. Care was taken that the shoulder girdle was perpendicular to the floor and that the arm was fully extended, in order not to alter the vertical jump performance. Height was recorded to the nearest ¼ inch.

The next step was the actual vertical jump performance. Each subject was given three attempts. Each attempt was recorded (Appendix I). The subject was not allowed to walk into the jump.

The tester was positioned on a ladder during the vertical jump test in order to more accurately evaluate the height of the vertical jump. Considerable rest was allowed between jumps in order to assure that the subject was able to give a maximum effort on each jump.

Following the vertical jump, each subject was tested for quadricep strength and hamstring strength on the strain gauge. To test quadricep strength, the subject sat on a table with foot inserted in a stirrup. The subject grasped the bottom of the table with the knee joint at an angle of 45^{o} and exerted maximum strength against the stirrup (Appendix K). Three trials were given and each trial was recorded. The best score was used for statistical analysis. This test was administered to the right and left legs.

The subject was then tested for hamstring strength. In prone position, the subject inserted a foot in a stirrup. An angle of 30^{o} (flexion) was acheived at the knee joint before the test was administered. The subject grasped the bottom of the table and exerted maximum strength (Appendix L). Three trials were given and each trial was recorded. The best score was used for statistical analysis. The same test was administered to the other leg.

Once the subject had completed the vertical jump, hamstring flexibility, quadricep strength, and hamstring strength tests; she was allowed to do the other tests in any order. The pretest was administrered on February 25, 1984. After 13 weeks of training, the posttest was administered on May 25, 1984. The prodedure used to administer the pretest and the posttest were the same.

Data Analysis

Pretest and posttest measures were taken on the same individuals from three separate groups. Quadricep/hamstring strength ratio was calculated for each leg. The difference between the two ratios (posttest-pretest) was used for statistical analysis. Differences in vertical jump performances and right and left leg quadricep/ hamstring ratios were used in order to adjust for individual differences, to adjust for differences between leg ratios, and to measure improvement. These scores were transformed to T-scores ($\overline{X}$=50, S=10) in order for the numbers to be more recognizable. The formula for calculating T-scores is:

$$X_n = \left(\frac{S_n}{S_o}\right) X_o - \left(\frac{S_n}{S_o}\right) X_n + X_o$$

o = original distribution

n = new distribution

X = raw score

S = standard deviation

This conversion did not change the shape of the distribution.

Because the design of the study used three groups, a one-way analysis of variance (ANOVA) was chosen to make specific comparisons.

The ANOVA showed whether there was any significant difference between the arrays. A one-way analysis of variance was chosen as opposed to a factorial design because of the high correlation existing between the data arrays. This type of ANOVA protects against multi-collinearity, which would affect the results of the analysis. Collinearity is a condition in which the data are closely correlated allowing for significance to be erroneously assigned to insignificant mean differences.

ω^2 (Omega Squared) was selected to measure significance. Omega was selected in preference to the F test because it is not affected by differences in group size. The formula for OMEGA is as follows:

$$\omega^2 = \frac{SS_A - (K-1)\,(MS_{S/A})}{SS_T + MS_{S/A}}$$

SS_A = sum squares treatment

K = number of groups

$MS_{S/A}$ = mean squares error

SS_T = sum squares total

A Tukey test was run to adjust for experimental error. The formula for a Tukey test is:

$$\bar{d}_T = \frac{q_T\sqrt{MS_{S/A}}}{\sqrt{n}}$$

$MS_{S/A}$ = amount of error between subjects within a group

q_T = studentized t statistic

n = sample size for each group

The Tukey test indicates those groups included in the analysis between which significant differences exist.

Chapter 4

ANALYSIS OF DATA

The purpose of this study was to compare the effects of a hamstring strengthening program with the effects of a traditional quadricep strengthening program on vertical jump performance. This study also compared the effects of a hamstring strengthening program with the effects of a traditional quadricep strengthening program on the ratio of quadricep strength to hamstring strength in the left leg and in the right leg.

SAMPLE ANALYSIS

The subjects in the study were 52 high school female students. Subjects included those female students who were not enrolled in a physical education class, female students who were enrolled in a required physical education class, and female students who had participated in the 1983 volleyball season. The control group (CG) consisted of 16 female students who were not enrolled in a physical education class. Experimental group I (QT) included 20 female students who were enrolled in a required high school physical education class. Experimental group II (HT) was comprised of 16 female students who were involved in the 1983 volleyball season.

STATISTICAL ANALYSIS

T scores ($\overline{X}$=50, S=10) were calculated on differences in raw scores between pretest and posttest vertical jump performances, quadricep/hamstring ratios in the right leg, and quadricep/hamstring ratios in the left leg. In order to ensure that the group size did not affect the outcome, ω^2 (Omega Squared) was selected to measure significance. ω^2 furnishes a relative measure of the strength of an independent variable. A Tukey test was run to locate which group was responsible for the significant difference while adjusting for experimental error.

Vertical Jump

Table 1 shows the ANOVA results of the means of the T distributions where CG=45.308, QT=53.931, and HT=49.778.

Table 1

Analysis of Variance of Differences Between Pretest and Posttest Vertical Jump Scores

Source of variation	Sum of squares	Degrees of freedom	Mean squares	ω^2
Between	662.078	2	331.039	.09
Within	4437.906	49	90.570	
Total	5099.985	51		

The ω^2 for the vertical jump equalled .09, which shows a moderately strong effect for an independent variable. To reveal which independent variable was responsible for the significance, a Tukey test was run. The Tukey test gives a quantity ($\bar{d}_T$) which tells how far the means of two groups must differ for the difference to be significant. With a $\bar{d}_T$ = 7.6715105, if $(\bar{X}n_1 - \bar{X}n_2) > \bar{d}_T$ then difference is significant. If $(\bar{X}n_1 - \bar{X}n_2) \leq \bar{d}_T$, then the difference is not significant.

Table 2

Tukey Test Results on Transformed Scores in Vertical Jump

	I	II	III
I	---	8.623006*	4.469244
II	-8.623006	---	-4.153762
III	-4.469244	4.153762	---

*a significant difference occurred between the QT group and the CG. In this Tukey test $\bar{d}_T$ = 7.6715105.

Table 2 illustrates the results of the Tukey test. The difference between $\bar{X}_{CG} - \bar{X}_{QT}$ = 8.623006, $\bar{X}_{CG} - \bar{X}_{HT}$ = 4.469244, and $\bar{X}_{QT} - \bar{X}_{HT}$ = 4.153762. Ho:1 states that there is no significant difference in vertical jump performance between high school female students who participate in the weight training program designed to increase hamstring strength and high school female students who participate in the weight training program designed to increase quadricep strength. This hypothesis was retained.

The significant difference in vertical jump was between the quadricep training group and the control group. Since $\bar{X}_{QT} - \bar{X}_{CG} > 7.6715105$, the quadricep training was significant in improving vertical jump performance as compared with the control group. This, however, is not peculiar since one assumes that strength will be gained when participating in a weight training program. Also, strength is related to the ability to execute a vertical jump.

Quadricep/Hamstring Ratio in Right Leg

Table 3 shows the ANOVA results of the means of the T distribution where CG = 49.575, QT = 49.096, and HT = 51.680.

Table 3

Analysis of Variance of Differences in Quadricep/Hamstring Ratios Between Pretest and Posttest of the Right Leg

Source of variation	Sum of squares	Degrees of freedom	Mean squares	ω^2
Between	68.227	2	34.113	-.02
Within	5031.758	49	102.689	
Total	5099.985	51		

Ho:2 states that there is no significant difference in the ratio of right leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program and high school female students who participate in the traditional quadricep strengthening program. This hypothesis was retained.

Quadricep/Hamstring Ratio in Left Leg

Table 4 shows the ANOVA results, of the means of the T distributions where CG = 51.808, QT = 49.192, and HT = 50.452

Table 4

Analysis of Variance of Differences in Quadricep/Hamstring Ratios Between Pretest and Posttest of the Left Leg

Source of variation	Sum of squares	Degrees of freedom	Mean squares	ω^2
Between	120.984	2	60.492	-.02
Within	4979.016	49	101.613	
Total	5100.0	51		

Ho:3 states that there is no significant difference in the ratio of left leg quadricep strength to hamstring strength between high school female students who participate in the hamstring strengthening program and high school female students who participate in the traditional quadricep strengthening program. This hypothesis was retained.

Chapter 5

SUMMARY, CONCLUSIONS, DISCUSSION, RECOMMENDATIONS

This study was designed to compare the effects of a hamstring training program (HT) to a quadricep training program (QT) on vertical jump, right leg quadricep/hamstring ratio, and left leg quadricep/hamstring ratio. Participants were involved in a 13 week isotonic weight program. The QT group participated in a weight program designed to increase quadricep and upper body strength. The HT group participated in a weight program designed to increase hamstring and upper body strength. Subjects were pretested and posttested on a standing vertical jump, quadricep strength in right and left legs, and hamstring strength in right and left legs, as measured by a strain guage.

CONCLUSIONS

The best score from all measurements was used for statistical purposes. The difference between pretest and posttest scores was calculated and transformed to a T score. One-way analysis of variance was used to compare the differences between the three groups. Because of the different group sizes, Omega Squared was used to measure significance. A Tukey test was administered to locate those groups in the analysis between which a significant difference existed. On the basis of the analysis, it was concluded that:

1. There was no significant difference in vertical jump performance between high school female students who participated in the weight training program designed to increase hamstring strength and high school female students who participated in the weight training program designed to increase quadricep strength.
2. There was no significant difference in the ratio of right leg quadricep strength to hamstring strength between high school female students who participated in the hamstring strengthening program and high school female students who participated in the traditional quadricep strengthening program.
3. There was no significant difference in the ratio of left leg quadricep strength to hamstring strength between high school female students who participated in the hamstring strengthening program and high school female students who participated in the traditional quadricep strengthening program.

DISCUSSION

No significant difference was found between the QT group and the HT group. There was a significant difference between the QT group and the CG.

There was a difference between the HT group and the CG, an increase but not a statistically significant increase.

Reviewing the progress reports (See Table 14) for the HT group, it was calculated that the mean increase in amount of weight lifted during leg curls was 40 lbs. This would appear to further complicate the results of this research. The subjects' workload increased by 40 lbs. and yet did not statistically significantly improve vertical jump. A vertical jump is a very complex skill which is affected by quadricep flexibility, hamstring flexibility, subject's weight, the mechanics of a vertical jump, proper motivation, and an innate ability to jump. Furthermore, it may have been a fallacy to presume that the primary purpose of the HT group was to strengthen healthy subjects' hamstrings without any notable training of the quadriceps. The subjects in the HT group, though told not to train quadriceps, were engaged in spring sports which quite likely led to an increase in quadricep strength. Therefore, as the hamstrings were being strengthened, the quadriceps were also being strengthened. Hence, the ratio could not show a significant change. It was also documented through comments and observations that subjects involved in the QT program developed soreness from time to time. However, subjects involved in the HT program developed no soreness. In addition, discomfort in the knee joints and/or low back decreased in the hamstring training group. Hamstring muscle strength is critical for normal functions as well as athletic skills because the hamstring muscle crosses the hip and knee joints.

RECOMMENDATIONS

Despite the fact that this study showed no significant improvement in vertical jump performance nor in quadricep/hamstring ratio, this researcher suggests that a training program designed to increase hamstring strength is needed in the following areas:

(1) A similar study should be done which investigates the correlation between flexibility and facilitating strength in the hamstring and quadricep muscle groups.

(2) A replication of this study should be done in which the outside activities affecting the hamstring training group are controlled more closely.

(3) One subject within the HT group was injured during the study. Therefore, a similar study should be done which screen samples on the pretest and posttest for physical injuries which might affect the results.

(4) Because the hamstring training group did not differ significantly from the quadricep training group in altering the quadricep/hamstring ratio or vertical jump performance and because the hamstring training group experienced minimal soreness, it would be suggested that coaches not only train the quadricep muscle group but also the hamstring muscle group within their conditioning program.

REFERENCES

References

Anderson, B. (1980). Stretching. Bolinas, California: Shelter Publications.

Asmussen, E., Hanson, O., & Lammert, O. (1965). "The relation between isometric and dynamic muscle strength in man". Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis, 20, 1-11.

Baley, J.A. (1966, October). "Effects of isometric exercises done with a belt upon the physical status of students in required physical education". Research Quarterly, 38, 291.

Bangerter, B.L. (1968, October). "Contributive components in the vertical jump". Research Quarterly, 39, 432-436.

Berger, R.A. (1963, December). "Effects of dynamic and static training on vertical jumping ability". Research Quarterly, 34, 419-424.

Bertucci, B. (Ed.). (1979). Championship volleyball by the experts. West Point, New York: Leisure Press.

Blockovich, J. (1977, November). "Power weight training". Scholastic Coach, 47, pp. 54+.

Brubacher, D.W. (1980). "The effects of isotonic and isokinetic weight training on vertical jump". Unpuplished master's thesis, Emporia State University, Emporia, Kansas.

Campbell, D.T. & Stanley, J.C. (1963). "Experimental and quasi-experimental designs for research on teaching". In N.L. George (Ed.). In handbook of research on teaching. Chicago: Rand McNally.

Capen, E.K. (1950, May). "The effect of systematic weight training on power, strength, and endurance". Research Quarterly, 21, 83-93.

Chui, E. (1950, October). "The effect of systematic weight training on athletic power". Research Quarterly, 21, 188-194.

Clutch, D., Wilton, M., McGown, C., & Bryce, G.R. (1983, March). "The effect of depth jumps and weight training on leg strength and vertical jump". Research Quarterly for Exercise and Sport, 54, 5-10.

Coppoc, J.H. (1967). "A study of the effect of one isometric exercise on vertical jump performance of junior high boys and girls". Unpublished master's thesis, Kansas State Teacher's College.

Counsilman, J. (1971). "New approach to strength building". Scholastic Coach, 40, pp. 50, 52, 103.

deVries, H.A. (1980). Physiology of exercise for physical education and athletics (3rd ed.). Dubuque, Iowa: William C. Brown, Co.

Divitto, C.H. (1973). "Comparison of effectiveness of isokinetic and isotonic exercise in quadriceps strengthening". Unpublished master's thesis, Kansas State Teachers College of Emporia.

Dominguez, R.H. (1979). The complete book of sports medicine. New York: Charles Scribner's Sons.

Fox, E.L. (1979). Sports physiology. Philadelphia: W.B. Saunders Company.

Fox, E.L. & Matthews, D.K. (1981). The physiological basis of physical education and athletics. Philadelphia, Pennsylvania: CBS College Publishing.

Gray, R.K., Start, K.B., & Glencross, D.J. (1962, March). "A test of leg power". Research Quarterly, 33, 44-50.

Hellebrandt, F.A. (1958, April). "Methods of muscle training: Influence of pacing". Physical Therapy Review, 38, 319-326.

Jensen, C.R. & Jensen, C. (1978, August). "Update on strength training". Scholastic Coach, 48, pp. 90-93+.

Jokl, E. (1964). Physiology of exercise. Springfield, Illinois: Charles C. Thomas.

Keller, V. (1977). United States volleyball association level I technical module. California: Val Keller.

Klaf, C.E. & Lyon, M.J. (1978). The female athlete, a coach's guide to conditioning and training. St. Louis: The C.V. Mosby Company.

Klein, K.K. & Hall, W.L. (1963). The knee in athletics. Washington D.C.: American Association for Health, Physical Education, and Recreation.

Laird, D.E. (1981, Spring). "Comparisons of quad to ham strength ratios of an intercollegiate soccer team". Athletic Training, pp. 66-67.

Lamb, D.R. (1978). Physiology of exercise. New York: MacMillan Publishing Co., Inc.

Lapham, J. (1976, February 29). "Woody Fisher only went to grade school . . . but wow!" The Kansas City Star Magazine, pp. 14.

Logan, G.A. & McKinney, W.C. (1977). Anatomic kinesiology. Dubuque, Iowa: Wm. C. Brown Company Publishers.

Londeree, B.T. (1981, September). "Strength testing". Journal of Physical Education Recreation and Dance, 52, 44-46.

MacConaill, M.A. & Basmajian, J.V. (1977). Muscles and movements a basis for human kinesiology. Huntington, New York: Robert E. Krieger.

Masley, J.W., Hairabedian, A., & Donaldson, D.N. (1953, October). "Weight training in relation to strength, speed, and co-ordination". Research Quarterly, 24, 308-315.

McClements, L.E. (1966, March). "Power relative to strength of leg and thigh muscles". Research Quarterly, 37, 71-78.

Ness, P.E. & Sharos, C.L. (1956). "The effect of weight training on leg strength and the vertical jump". Unpublished master's thesis, Smith College.

Rogers, F.R. (1925). "Physical capacity tests in the administration of physical education". Contributions to Education, 173.

Scates, A. (1979, May/June). "Volleyball (basketball) jump training at UCLA". Scholastic Coach, 48, pp. 24-25.

Scates, A.E. (1976). Winning volleyball. Boston: Allyn & Bacon, Inc.

Schakel, D.J. (1981). Volleyball fundamentals, tactics, and strategy. Boston, Massachusetts: American Press.

Selznick, G. & Valentine, T. (1973). Inside volleyball. Chicago: Henry Regnery Company.

Sheeran, T.J. (1977, August). "Contemporary strength-training modalities". Scholastic Coach, 47, pp. 50-55.

Somers, T.D. (1974). "The effects of isokinetic weight training at two speeds upon the vertical jump". Unpublished master's thesis, Kansas State Teacher's College of Emporia.

Stone, W.J. & Kroll, W.A. (1978). Sport conditioning and weight training. Boston: Allyn and Bacon, Inc.

VanOcteghan, S.L. (1973). "Two speeds of isokinetic exercise as related to the vertical jump performance of women". Unpublished doctoral dissertation, Eastern Illinois University, 1973.

Wilt, F. (1975, May). "Plyometrics - What it is, how it works". Athletic Journal, 55, pp. 77, 89-90.

APPENDIX A

Summary of Weight Training Programs
(Lamb, 1978)

SUMMARY OF WEIGHT TRAINING PROGRAMS
(Lamb, 1978)

	Isokinetic	Isometric	Isotonic
Rate of Strength Gain	Excellent	Poor	Good
Rate of Endurance Gain	Excellent	Poor	Good
Strength Gain over Range of Motion	Excellent	Poor	Good
Time per Training Session	Good	Excellent	Poor
Expense	Poor	Excellent	Good
Ease of Performance	Good	Excellent	Poor
Ease of Program Assessment	Poor	Good	Excellent
Adaptability to Specific Movement Patterns	Excellent	Poor	Good
Least Possibility of Muscle Soreness	Excellent	Good	Poor
Least Possibility of Injury	Excellent	Good	Poor
Skill Improvement	Excellent	Poor	Good

APPENDIX B

Informed Consent Form

Informed Consent Form

I, Glenda Koch, am requesting your participation in a study designed to investigate the effects of strength and flexibility training on vertical jumping ability. As a participant in the study, you will be asked to participate in one of three groups: control, Experimental Group 1, or Experimental Group 2. Results will be presented in a manner which will not allow recognition of any one particular subject. Only the primary investigator, Glenda Koch, will have access to the master list matching code numbers to names.

Controls will simply carry on their normal activities until time of retesting. Participants in Group 1 will carry out their normal physical education program until retesting, 13 weeks later. Participants in Group 2 will refrain from participating in any physical training program except for the specific training program designed to work on hamstring function. Those subjects will work out approximately twenty minutes per day five days a week for thirteen weeks prior to retesting.

The data gathered will include all of the variables which are to be measured in the program including: height, weight, hamstring flexibility, hamstring strength, quadricep strength, vertical jump, bench press, and military press. There is only a minor chance of developing an injury when taking any of these tests. Muscle soreness may occur in the upper body but is not likely to occur in the legs. Dr. Mary Lynch may help in testing procedures. There will be NO charge for this service.

The major objectives of this program are: increase vertical jump, increase hamstring flexibility, increase hamstring strength, increase quadricep strength, increase upper body strength.

Your permission to use the data described above is requested for use in conducting research for a thesis. If you have any questions concerning this program, please feel free to call Glenda Koch at 321-1870 or at home, 321-0583.

"I have read the above statement and have been fully advised of the procedures to be used in this project. I have been given sufficient opportunity to ask any questions I had concerning the procedures and possible risks involved. I understand the potential risks involved and I assume them voluntarily. I likewise understand that I can withdraw from the study at any time without being subjected to reproach."

Date ______________________ Subject ______________________

I give consent for my daughter to participate in the program described above.

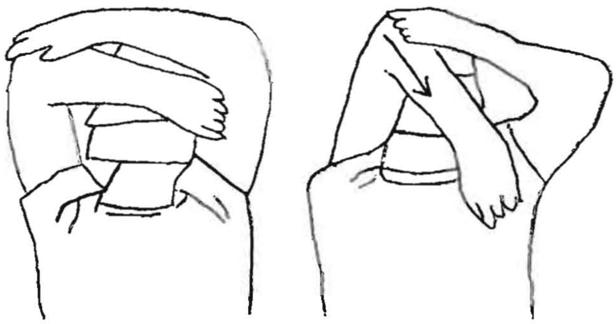
Date ______________________ Subject's Parent/Guardian ______________________

APPENDIX C

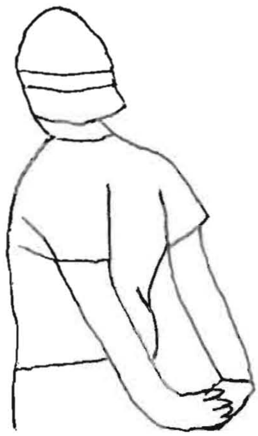
Stretching Program for Experimental Group I
(Anderson, 1980)

STRETCHING PROGRAM FOR EXPERIMENTAL GROUP I
(Anderson, 1980)

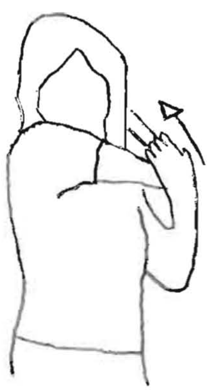
1. Triceps



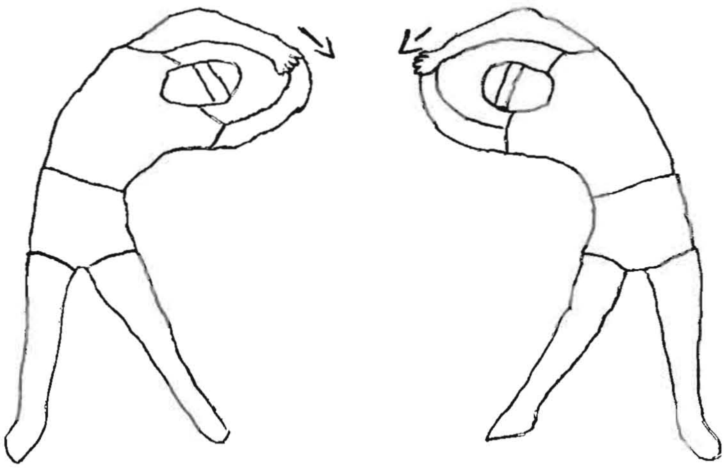
2. Pectoral



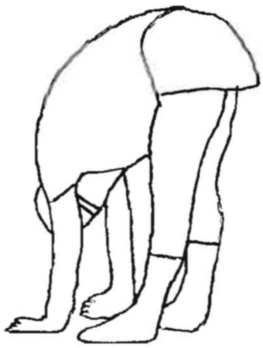
3. Shoulder



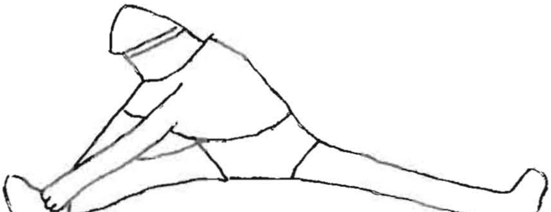
4. Side Bends



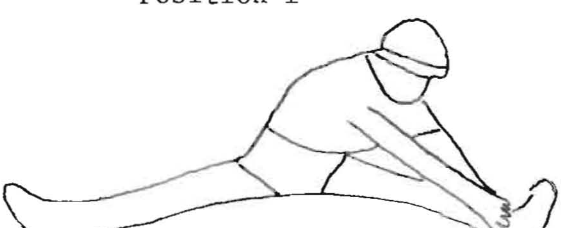
5. Standing Hamstring



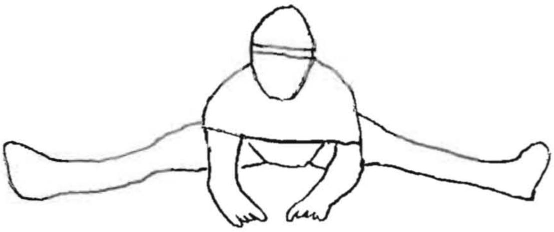
6. Straddle



Position 1

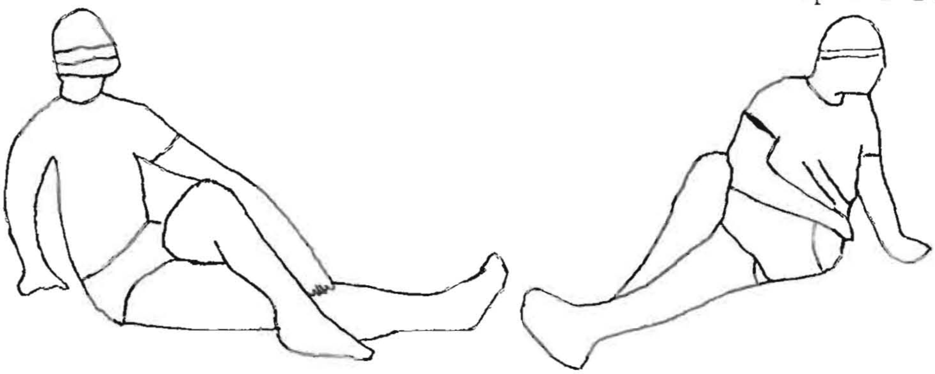


Position 2

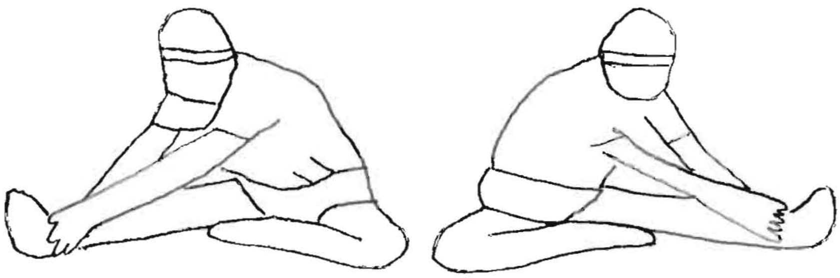


Position 3

7. Spinal Twist

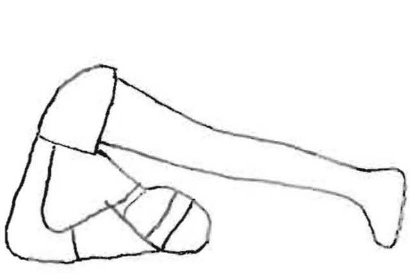


8. Inside Hurdle

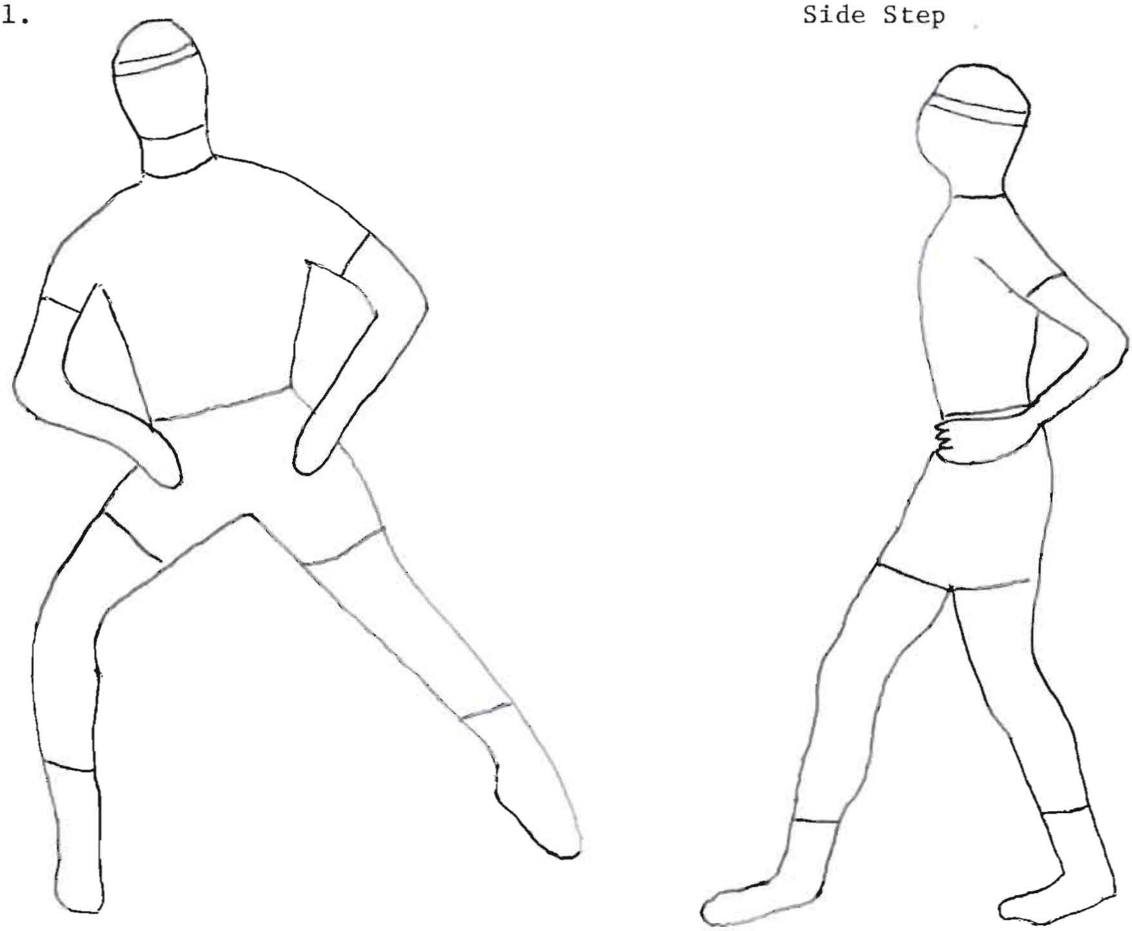


9. Quadricep

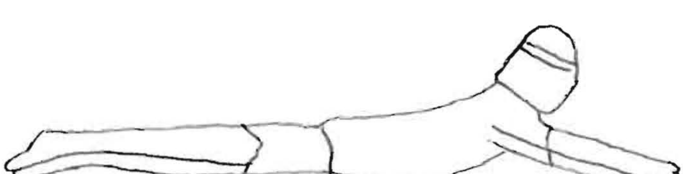
10. Pretzel Bend



11. Side Step



12. Press-Ups



APPENDIX D

Isotonic Strength Program for Experimental Group I

ISOTONIC STRENGTH PROGRAM FOR EXPERIMENTAL GROUP I

Name of Weight Station	Repetitions
Wrist Roller	2
Neck Isometrics	4 positions X 10 seconds
Flexed Arm Hang	as long as possible
Lunges	20
Leg Curls	15 (each leg)
Behind the Neck Press	12
Squats	12
Bench Press	12
Step Ups	20
Shoulder Raises	3 positions X 10
Back Hyperextension	20
Sit-Ups	20
Dorsi-Tricep Extension	12
Bicep Curls	12

APPENDIX E

Quadricep Weight Training Progress Report Form

THESIS

QUADRICEP WEIGHT TRAINING PROGRESS REPORT FORM

WEEK ____________________ CODE NUMBER ____________________

	M	T	W	T	F	S	S
WRIST ROLLER							
NECK ISOMETRICS							
FLEXED ARM HANG							
LUNGES							
LEG CURLS							
BEHIND THE NECK PRESS							
SQUAT							
BENCH PRESS							
STEP-UPS							
SHOULDER RAISES							
BACK HYPEREXTENSIONS							
SIT-UPS							
DORSI TRICEP EXTENSION							
BICEP CURL							

APPENDIX F

ISOTONIC STRENGTH PROGRAM FOR EXPERIMENTAL GROUP II

ISOTONIC STRENGTH PROGRAM FOR EXPERIMENTAL GROUP II

Upper Body

Name of Weight Station	Repetitions
Wrist Roller	2
Neck Isometrics	4 positions X 10 seconds
Flexed Arm Hang	as long as possible
Behind the Neck Press	12
Bench Press	12
Shoulder Raises	3 positions X 10
Back Hyperextension	20
Sit-Ups	20
Dorsi-Tricep Extension	12
Bicep Curls	12

Hamstring Development

Leg Curls	4 X 10, each leg

APPENDIX G

Hamstring Weight Training Progress Report Form

THESIS

HAMSTRING WEIGHT TRAINING PROGRESS REPORT FORM

WEEK ____________________ CODE NUMBER ____________________

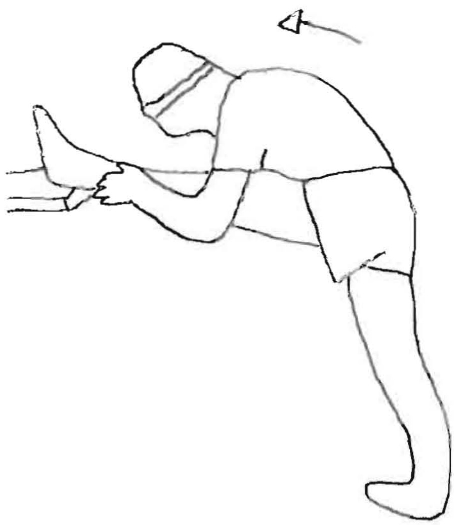
	M	T	W	T	F	S	S
LEG CURLS							
WRIST ROLLER							
FLEXED ARM HANG							
BEHIND THE NECK PRESS							
BENCH PRESS							
SHOULDER RAISES							
BACK HYPEREXTENSIONS							
SIT-UPS							
DORSI TRICEP EXTENSION							
BICEP CURLS							

APPENDIX H

Stretching Program for Experimental Group II
(Anderson, 1980)

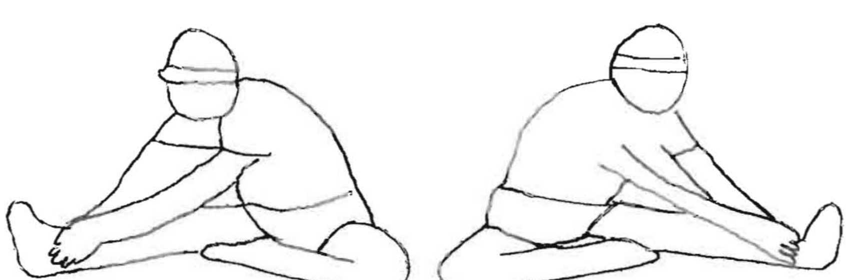
Stretching Program for Experimental Group II
(Anderson, 1980)

1. Hamstring Stretch



2. Quadricep

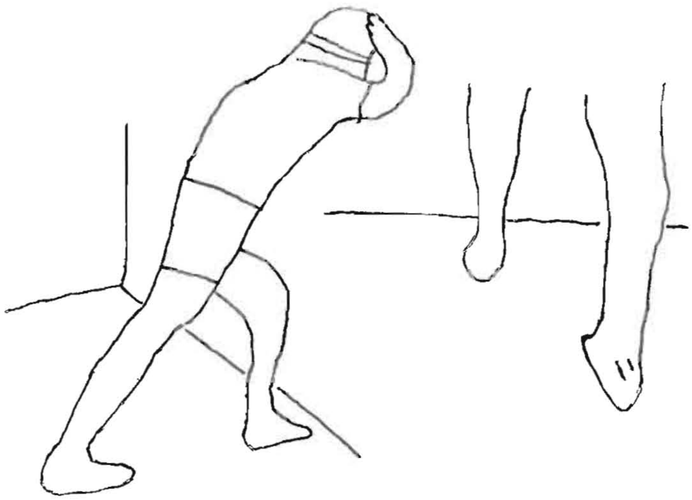
3. Inside Hurdle



4.

Groin Stretch

5.



Gastrocnemius/Soleus

APPENDIX I

Test Results Form

TEST RESULTS FORM

______TEST

______________________ BIRTHDATE

______________________ TODAY'S DATE

______________________ AGE

______________________ CODE NUMBER

________WEIGHT

_____/_____/_____VERTICAL JUMP

________HAMSTRING FLEXIBILITY

________HEIGHT

________ BENCH PRESS

R__/__/___HAMSTRING STRENGTH

L__/__/___

________HEIGHT & REACH

________MILITARY PRESS

R__/__/___QUADRICEP STRENGTH

L__/__/___

__________DOMINANT FOOT

PARTICIPATION LEVEL:

1. INVOLVED IN SPRING ATHLETICS.
2. INVOLVED IN PHYSICAL EDUCATION.
3. INVOLVED IN DANCE CLASS, AEROBICS, ETC. ON A REGULAR BASIS.
4. OCCASIONAL PHYSICAL ACTIVITY
5. NO PHYSICAL ACTIVITY
6. OTHER

HISTORY OF PREVIOUS KNEE INJURY:

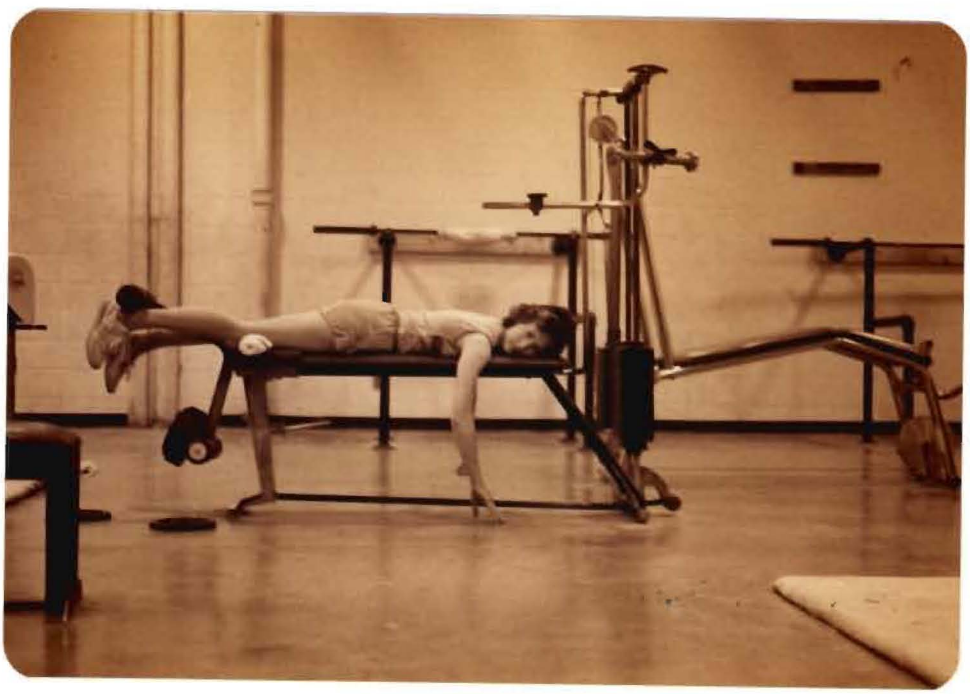
APPENDIX J

Demonstration of Leg Curl Technique

DEMONSTATION OF LEG CURL TECHNIQUE

At rest.

Performing leg curl.



APPENDIX K

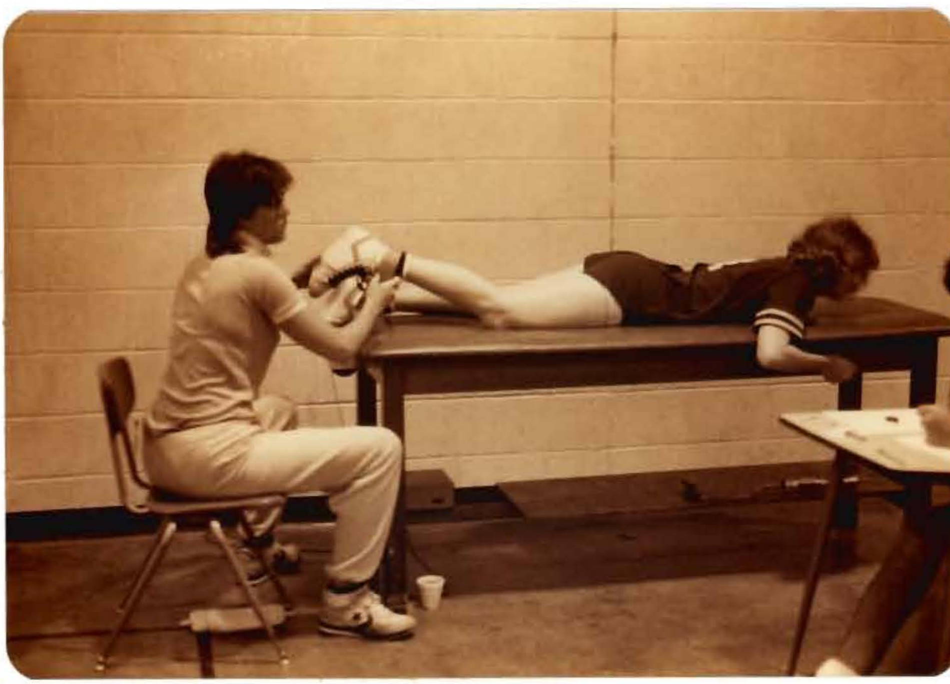
Testing of Quadricep Strength by a Strain Gauge

TESTING OF QUADRICEP STRENGTH BY A STRAIN GAUGE

APPENDIX L

Testing of Hamstring Strength by a Strain Gauge

TESTING OF HAMSTRING STRENGTH BY A STRAIN GAUGE



APPENDIX M

Tables of Raw Score Data

Table 5

Control Group Pretest and Posttest Raw Scores
Differences and T-Scores
for Vertical Jump

Subjects	Pretest	Posttest	Difference	T-Score
A	16.5	15	-1.5	29.0087
B	18.5	20.5	2.0	58.4531
C	13.5	14	.5	45.8341
D	14.5	15	.5	45.8341
E	14	14	0	41.6278
F	21.5	19	-2.5	20.596
G	16	16	0	41.6278
H	15.5	17	1.5	54.2468
I	14	15	1.0	50.0405
J	12.5	13.5	1.0	50.0405
K	15.5	17.0	1.5	54.2468
L	14	12.5	-1.5	29.0087
M	15.5	15.5	0	41.6278
N	16.5	18	1.5	54.2468
O	16	17	1.0	50.0405
P	15.5	17.5	2.0	58.4531

$\overline{x} = 45.3083$

$s = 11.062507$

Table 6

Quadricep Training Group I Pretest and Posttest
Raw Scores, Differences and T-Scores
for Vertical Jump

Subjects	Pretest	Posttest	Difference	T-Score
AA	14	15	1.0	50.0405
BB	17.5	20.5	3.0	66.8658
CC	15	16.5	1.5	54.2468
DD	14	16	2.0	58.4531
EE	18	19.5	1.5	54.2468
FF	15	15	0	41.6278
GG	14	16.5	2.5	62.6595
HH	16	18	2.0	58.4531
II	15	14.5	-.5	37.4214
JJ	13	14	1.0	50.0405
KK	13	16	3.0	66.8658
LL	13	15.5	2.5	62.6595
MM	15.5	18.5	3.0	66.8658
NN	14.5	15	.5	45.8341
OO	15.5	16	.5	45.8341
PP	15	16	1.0	50.0405
QQ	15.25	17	1.75	56.35
RR	12	13.5	1.5	54.2468
SS	10	11	1.0	50.0405
TT	14	14.5	.5	45.8341

$\overline{x} = 53.9313$

$s = 8.5301603$

Table 7

Hamstring Training Group II Pretest and Posttest
Raw Scores, Differences and T-Scores
for Vertical Jump

Subjects	Pretest	Posttest	Difference	T-Score
AAA	17	18	1.0	50.0405
BBB	14	16.5	2.5	62.6595
CCC	15.5	16.5	1.0	50.0405
DDD	16	19	3.0	66.8658
EEE	15	17	2.0	58.4531
FFF	16.5	18	1.5	54.2468
GGG	12.5	14	1.5	54.2468
HHH	16.5	17.5	1.0	50.0405
III	18	18.5	.5	45.8341
JJJ	18.5	17	-1.5	29.0087
KKK	16.5	17	.5	45.8341
LLL	14.5	15	.5	45.8341
MMM	15.5	16	.5	45.8341
NNN	16	17	1.0	50.0405
OOO	14.5	15.5	1.0	50.0405
PPP	16	15.5	- .5	37.4214

$\overline{x}$ = 49.7776

s = 9.0175198

Table 8

Control Group Right Leg Quadricep/Hamstring Ratio
Raw Scores, Differences and T-Scores

Subjects	Pretest*	Posttest*	Difference*	T-Score
A	68/39 = .574	73/43 = .589	.016	51.5102
B	93/44 = .473	77/43 = .558	.085	56.5252
C	76/51 = .671	79/50 = .633	-.038	47.6559
D	75/39 = .52	67/36 = .537	.017	51.6396
E	71/29 = .408	83/45 = .542	.134	60.0018
F	104/46 = .442	91/39 = .429	-.014	49.4091
G	74/53 = .716	66/50 = .758	.041	53.367
H	90/44 = .489	106/45 = .425	-.064	45.7724
I	78/39 = .5	81/41 = .506	.006	50.8393
J	72/43 = .597	44/42 = .955	.357	76.0649
K	29/37 = 1.276	63/42 = .667	-.609	6.6331
L	44/35 = .795	35/23 = .657	-.138	40.46
M	72/57 = .792	73/48 = .658	-.134	40.7602
N	64/39 = .609	62/40 = .645	.036	52.9666
O	60/32 = .533	57/32 = .561	.028	52.4123
P	76/42 = .553	68/44 = .647	.094	57.1792

$\bar{x}$ = 49.5748

s = 14.102161

*Rounded to nearest ten-thousandth place

Table 9

Quadricep Training Group I Right Leg Quadricep/Hamstring Ratio
Raw Scores, Differnces and T-Scores

Subjects	Pretest*	Posttest*	Difference*	T-Score
AA	78/32 = .410	69/30 = .435	.025	52.1577
BB	72/35 = .486	70/37 = .529	.042	53.4461
CC	69/27 = .391	72/31 = .431	.039	53.2156
DD	45/24 = .533	37/28 = .757	.223	66.4459
EE	75/23 = .307	74/26 = .351	.045	53.6059
FF	93/49 = .527	91/56 = .615	.089	56.7536
GG	86/36 = .419	98/46 = .469	.051	54.044
HH	69/53 = .768	88/54 = .614	-.154	39.2985
II	109/56 = .514	104/55 = .529	.015	51.4795
JJ	45/33 = .733	56/35 = .625	-.108	42.6135
KK	62/30 = .484	65/26 = .4	-.084	44.3708
LL	72/42 = .583	96/39 = .406	-.177	37.6747
MM	65/36 = .554	75/31 = .413	-.141	40.3018
NN	94/39 = .415	88/31 = .352	-.063	45.8974
OO	77/30 = .39	93/34 = .366	-.024	48.6704
PP	45/46 = 1.022	52/33 = .635	-.388	22.5513
QQ	72/33 = .458	51/32 = .627	.169	62.5448
RR	98/40 = .408	114/49 = .43	.022	51.9519
SS	74/32 = .432	74/35 = .473	.041	53.3082
TT	72/31 = .431	62/26 = .419	-.011	49.5912

$\bar{x}$ = 49.0961

s = 9.6501819

*Rounded to nearest ten-thousandth place

Table 10

Hamstring Training Group III Right Leg Quadricep/Hamstring Ratio
Raw Scores, Differences and T-Scores

Subjects	Pretest*	Posttest	Difference*	T-Score
AAA	82/58 = .707	82/55 = .671	-.037	47.7677
BBB	92/34 = .37	77/34 = .442	.072	55.5676
CCC	105/49 = .467	118/50 = .424	-.043	47.3113
DDD	102/60 = .588	89/47 = .528	-.060	46.0752
EEE	99/48 = .485	100/50 = .5	.015	51.4843
FFF	102/42 = .412	104/48 = .462	.05	53.9715
GGG	83/25 = .301	66/31 = .470	.168	62.4998
HHH	96/40 = .417	65/32 = .492	.076	55.8297
III	107/51 = .477	83/40 = .482	.005	50.776
JJJ	75/34 = .453	95/37 = .389	-.064	45.8084
KKK	92/45 = .489	94/49 = .521	.032	52.7051
LLL	92/35 = .380	97/34 = .351	-.03	48.2465
MMM	63/28 = .444	62.28 = .452	.007	50.9108
NNN	87/50 = .575	72/44 = .611	.036	53.0106
OOO	84/31 = .369	70/24 = .343	-.026	48.5144
PPP	71/33 = .465	62/34 = .548	.084	56.4013

$\bar{x}$ = 51.68

s = 4.4966856

*Rounded to nearest ten-thousandth place

Table 11

Control Group Left Leg Quadricep/Hamstring Ratio
Raw Scores, Differences and T-Scores

Subjects	Pretest*	Posttest*	Difference*	T-Score
A	60/48 = .8	65/49 = .754	-.046	46.787
B	99/44 = .444	92/37 = .402	-.042	47.0044
C	90/48 = .533	72/45 = .625	.092	54.5008
D	70/35 = .5	55/35 = .636	.136	57.0025
E	83/34 = .41	97/49 = .505	.096	54.7163
F	95/49 = .516	94/48 = .511	-.005	49.0819
G	77/47 = .610	63/49 = .778	.167	58.7389
H	86/58 = .674	110/43 = .391	-.284	33.5023
I	75/37 = .493	78/38 = .487	-.006	49.0258
J	58/38 = .655	29/39 = 1.345	.69	87.9701
K	38/36 = .947	59/42 = .712	-.236	36.1891
L	38/36 = .947	43/27 = .628	-.319	31.4901
M	94/52 = .553	78/48 = .615	.062	52.8512
N	51/38 = .745	71/39 = .549	-.196	38.4112
O	66/26 = .394	48/34 = .708	.314	66.9668
P	57/49 = .86	45/51 =1.133	.274	64.6883

$\overline{x} = 51.8079$

$s = 14.21268$

*Rounded to the nearest ten-thousandth place

Table 12

Quadricep Training Group I Left Leg Quadricep/Hamstring Ratio
Raw Scores, Differences and T-Scores

Subjects	Pretest*	Posttest*	Difference*	T-Score
AA	77/34 = .442	80/31 = .388	-.054	46.3446
BB	63/32 = .508	58/40 = .69	.182	59.541
CC	74/30 = .405	77/33 = .429	.023	50.6668
DD	40/26 = .65	44/26 = .591	-.059	46.0629
EE	58/27 = .466	59/30 = .508	.043	51.7746
FF	107/48 = .449	94/51 = .543	.094	54.6289
GG	85/29 = .341	110/45 = .409	.068	53.1714
HH	66/47 = .712	94/49 = .521	-.191	38.6887
II	90/49 = .544	100/70 = .7	.156	58.0767
JJ	43/31 = .721	48/32 = .667	-.054	46.3331
KK	55/27 = .491	66/28 = .424	-.067	45.6389
LL	69/43 = .623	87/35 = .402	-.221	37.0071
MM	59/33 = .559	70/31 = .443	-.116	42.8517
NN	83/32 = .386	85/28 = .329	-.056	46.2286
OO	73/30 = .411	69/27 = .391	-.02	48.2702
PP	49/42 = .857	65/26 = .4	-.457	23.7841
QQ	55/28 = .509	52/38 = .731	.222	61.7775
RR	103/30 = .291	125/48 = .384	.093	54.5608
SS	81/28 = .346	71/33 = .465	.119	56.0368
TT	65/33 = .508	47/18 = .383	-.125	42.3901

$\overline{x}$ = 48.1917

s = 8.8659168

*Rounded to nearest ten-thousandth place

Table 13

Hamstring Training Group II Left Leg Quadricep/Hamstring Ratio
Raw Scores, Differences and T-Scores

Subjects	Pretest*	Posttest*	Difference*	T-Score
AAA	80/41 = .513	86/37 = .430	-.082	44.7658
BBB	82/33 = .402	84/33 = .393	-.01	48.834
CCC	104/45 = .433	95/48 = .505	.073	53.432
DDD	107/47 = .439	87/41 = .471	.032	51.1619
EEE	92/41 = .446	89/39 = .438	-.007	48.9533
FFF	96/45 = .469	105/45 = .429	-.040	47.1215
GGG	76/31 = .408	53/29 = .547	.139	57.1654
HHH	78/36 = .462	67/33 = .493	.031	51.1052
III	88/48 = .545	71/39 = .549	.004	49.5852
JJJ	75/36 = .48	88/39 = .443	-.037	47.3095
KKK	95/42 = .442	80/47 = .588	.145	57.508
LLL	92/30 = .326	102/35 = .343	.017	50.3245
MMM	65/30 = .462	60/31 = .517	.055	52.4558
NNN	58/46 = .793	58/33 - .569	-.224	36.8253
OOO	88/34 = .386	65/26 = .4	.014	50.1335
PPP	68/33 = .485	54/37 = .685	.2	60.5581

$\bar{x}$ = 50.4524

s = 5.5108184

*Rounded to nearest ten-thousandth place

Table 14

Hamstring Training Group II Strength Gains Based on Amount of Weight Being Used for Leg Curls

Subjects	Starting Weight	Final Weight	Weight Difference
A	0	42.5	42.5
B	0	37.5	37.5
C	0	42.5	42.5
D	0	40	40
E	0	50	50
F	0	42.5	42.5
G	0	40	40
H	0	42.5	42.5
I	0	37.5	37.5
J	0	42.5	42.5
K	0	37.5	37.5
L	0	37.5	37.5
M	0	32.5	32.5
N	0	42.5	42.5
O	0	40	40
P	0	32.5	32.5

$\bar{x} = 40$