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The Hamstring-quadricep Strength Ratio of College-age Females

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THE HAMSTRING-QUADRICEP STRENGTH RATIO OF COLLEGE-AGE FEMALES

By

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THE HAMSTRING-QUADRICEP STRENGTH RATIO

OF COLLEGE-AGE FEMALES

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

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COMPLETED RESEARCH IN HEALTH, PHYSICAL EDUCATION AND RECREATION

South Dakota State University, Brookings, SD.

MOORE, R.G. Hamstring-quadricep strength ratio of college-age females. M.S. in Health, Physical Education and Recreation, 1982, 98 p.

Description was given of the hamstring-quadricep strength ratio (h-q ratio) of undergraduate college women (N = 188) aged 18-21. The h-q ratio was determined for each subject from results obtained isokinetically for each leg on an Orthotron apparatus. A search of the literature revealed college males of similar age had an h-q ratio of 60-65% while no ratio existed in the literature for women. The test-retest correlations (r = .874 to .922) derived in the present study showed a high reliability with correlations (r = .874 to .945) for testing found in early isokinetic studies but less than later studies (r = .927 to .977). The test-retest t's were sig at .05 for three of the four tests given. ANOVA techniques showed no sig relationships at the .05 level between age or dominant leg and the hamstring

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Thank you

Roderick G. Moore II

DEDICATION

This study is dedicated to Robert M. Stoltz, M.D., who has shown so much concern for both my professional and personal development during the past eighteen years.

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INTRODUCTION

Significance of the Study

Athletes throughout history have had various types and severity of injuries to the lower limbs. Hamstring strains have been among the most puzzling of the lower limb injuries. Many factors have been suggested as a cause for hamstring strains. Muscular imbalance, fatigue, faulty reciprocal innervation, inadequate warm-up, improper running technique, lack of flexibility and poor physical condition have been listed as factors which could lead to a hamstring injury (Klein and Allman, 1969; Klafs and Arnheim, 1973). Muscular imbalance of the upper leg, as defined by the relation of the quadricep group strength to the hamstring group strength, was investigated by Klein and Hall (1963). Klein identified a ratio between the quadricep and the hamstring muscle groups for college age males. Klein (1975) and Counsilman (1976) recognized the strength levels of the upper leg as a component of physical fitness and a factor in the improvement and maintenance of reaction time. Strength of the hamstring and the quadricep muscle groups and the ratio to each other is important to the coordination of leg movement.

A further understanding of the hamstring-quadricep strength ratio is needed to more fully understand the role it may play regarding the occurrence of hamstring injuries. Studies have been conducted concerning the ratio of the hamstring-quadricep group. These studies, however, were all done with males of various ages. Female athletes have increased in number dramatically in the past several years. There have been no studies found which determine sexual differences in leg strength ratios. Therefore, this study dealt with college-age females and the ratio between the hamstring and quadricep muscle groups of the leg.

The quadricep muscle group is the most massive muscle group in the body. Its antagonist, the hamstring group, has much less capacity for strength development. A ratio, derived through isometric tensiometer measurements, has been shown to exist between these two muscle groups for males. This ratio has apparently not been reported for college-age females. Additionally, it has not been shown that the hamstring-quadricep group ratio determined for college males is the optimal range of values needed to protect against hamstring strains in females.

Statement of the Problem

The purpose of this study was to describe the hamstring-quadricep strength ratio, as attained through isokinetic measurement, among eighteen to twenty-two year old female subjects. More specifically, the purpose of the study was to answer the following questions:

1. What is the hamstring-quadricep strength ratio of eighteen to twenty-two year old females as determined by isokinetic testing?

2. How does the hamstring-quadricep strength ratio for females, as determined in the present study, compare to the hamstring-quadricep strength ratio for males of similar age, as determined by isometric testing in previous studies?

3. Is there a significant difference between the hamstring-quadricep strength ratio and the variables age and dominant leg of the subjects?

Scope

This study was conducted during the school years of 1977-80 in the training room of the gymnasium of Valparaiso University, Indiana. The subjects (N = 188) were volunteers to announcements

made in physical education classes, dormitories and sororities for undergraduate females enrolled at Valparaiso University. The subjects were not selected as to height, weight, strength, or other anthropometrical classifications. Neither were the subjects selected as to prior athletic background. The strength measurements were read from the Orthotron apparatus, an isokinetic machine manufactured by Lumex, Incorporated, Bay Shore, New York.

Limitations

The investigator recognized the following limitations:

1. All subjects with existing knee and upper leg injuries, as determined by the preliminary history of the subject, were excluded.

2. No attempt was made to adjust body position to negate the effect of gravity; thus, gravity may affect, positively or negatively, the respective flexion and extension movements performed.

3. No attempt was made to control the activities of the subjects prior to the testing; thus, the subjects could have had various levels of

rest or activity prior to the test.

Definition of Terms

The following terms have been defined for this study:

Bilateral Muscle Strength Balance. Bilateral muscle strength balance occurs when the summation of the flexor and extensor strength measures of one leg are less than ten percent different than the flexor-extensor summation of the other leg.

Dominant Leg. The leg used to kick an object is classified as the dominant leg in this investigation.

Extension of the Knee. Extension of the knee is the movement of the lower leg in an anterior direction through the sagittal plane.

Flexion of the Knee. Flexion of the knee is the movement of the lower leg in a posterior direction through the sagittal plane.

Flexor-Extensor Ratio. The flexor-extensor ratio is also referred to as the hamstring-quadricep ratio. It is the comparison of the strength of the knee flexors and knee extensors of the same leg. For example, if the flexors (hamstring group) measured 120 foot-pounds of torque and the extensors

(Quadricep group) measured 180 foot-pounds of torque, the resultant ratio is determined by dividing the flexor torque by the extensor torque and multiplying by 100 (120/180 x 100 = 66.7%).

Hamstring Group. The hamstring group, consisting of three long muscles - the biceps femoris, semimembranosus and semitendinosus, is the flexor of the knee. The origins for the muscles are on the ischial tuberosity and the insertions are on the proximal portions of the fibula or the tibia. The biceps femoris has an extra origin, its short head, on the distal portion of the linea aspera of the femur. It inserts on the head of the fibula. The semimembranosus inserts on the posterior aspect of the medial condyle of the tibia and the semitendinosus inserts on the medial side of the knee on the shaft of the tibia.

Isokinetic Strength. The maximal muscle contraction at a constant rate of speed through a muscle's range of motion is defined as isokinetic strength. It is measured as torque and noted as foot-pounds of torque.

Isometric Strength. Isometric strength is the ability of a muscle to exert force at a given angle. It is noted as pounds of force.

Isotonic Strength. Isotonic strength is the ability of a muscle to exert force through a range of motion. It is noted as pounds of force.

Quadricep Group. The quadricep group, the extensors of the knee, include the rectus femoris, vastus lateralis, vastus medialis and the vastus intermedius muscles. The rectus femoris overlies the vastus group and has two origins. One portion arises from the anterior inferior spine of the ilium and the other arises from the posterior superior rim of the acetabulum. The vastus group inserts with the rectus femoris into the superior border of the patella which in turn inserts by means of the patellar ligament into the tibia tuberosity. The origin of the vastus group is along the shaft of the femur.

Chapter II

REVIEW OF LITERATURE

Muscle testing of the hamstring-quadricep muscle groups has been extensively researched by several authors (Klein and Hall, 1963; Burkett, 1968; Mendler, 1967; and Galloway, 1972). Most of this testing has been isometric. Researchers have been able to determine the points in the range of motion of a muscle group which exert the highest force (Clarke, 1954; Mendler, 1967; Kraus, 1956; and Krusen and Kottle, 1971). Most of the researchers have used the tensiometer testing procedures as developed by Clarke (1954). Klein and Hall (1963) and Burkett (1968) are three of the few researchers who have looked into the strength ratio of the hamstring group to the quadricep group. Recent Isokinetic literature has indicated that the hamstring-quadricep ratio has not been investigated. Research has instead been directed toward determining the uses of isokinetics as a strengthening and conditioning process (Pipes and Wilmore, 1975). Pipes and Wilmore (1975) compared the new isokinetic programs with present isotonic and isometric programs. Burkett (1968) did the

initial work with athletes to determine the relationship of the hamstring-quadricep strength ratio and its possible effect on hamstring strain susceptibility. Consequently, measurement with isokinetic devices is still in an infant stage. There is a considerable bank of knowledge on isometric testing of the lower extremity but very little material has become available concerning isokinetic testing and its possible use as a predictor of potential injury situations.

The literature is organized according to (1) strength testing methods, (2) hamstring-quadricep strength ratio and muscle injury, and (3) other factors related to muscle injury.

Strength Testing Methods

In conjunction with the development of strength testing methods, several major innovations have occurred. Strength testing started with manual assessment which yielded a subjective result (Clarke, 1954). Spring-balance testing gave better results and was followed by the Watkin-Porter Strain gauge and the Newman Myometer (Clarke, 1954). During the 1940s and early 1950s, Clarke

(1954) adapted the cable tensiometer to measure muscular strength isometrically. Clarke developed six tests with the primary consideration in each test being the position of the body. One example of these tests is the knee extension test which positioned the leg at an angle of 115 degrees. Objectivity coefficients of the tests were between .90 and .96. Protocols for these isometric tests have been used extensively for further research.

Clarke's research sought the optimal points in the respective range of motion for maximal muscular force to be applied. He concluded, as did Kraus (1956) and Krusen, Kottle and Ellwood (1971), that the greatest mechanical advantage for the tests occurred when knee extension was 115 degrees and knee flexion was 165 degrees. Later results of electromyographic studies by Bos and Blosser (1970) supported Clarke's work. Mendler (1967) found slightly different angles, 120 and 170 degrees for knee extension and flexion, respectively, to be optimal. Berger's work in 1966 differed from Mendler as he found the leg

extension force is increased as the angle of the leg increases from 105 degrees to 140 degrees of extension in the inverted leg position.

Williams and Stutzman (1959) recorded tensiometer readings at 30 intervals through flexion and extension of the knee and then plotted their findings on a "joint torque curve." The joint torque curve represented the strength levels at specific points in a muscle's range of motion. It was noted that the joint torque curve is not constant through the range of motion. This finding was in agreement with previous works which noted that the quadricep strength is greater than the hamstring strength (Clarke, 1954).

Bender and Kaplan (1966) attempted to relate isotonic strength levels through the use of isometric measurements. A relationship exists between momentum and both isometric and controlled isotonic force. Isotonic strength levels, therefore, can be measured by isometric techniques.

The pioneer work in isokinetic measurement of muscular strength was done by Glencross (1966)

in the mid-1950s. The work was not published until 1966. He developed the power lever using the formula: power = $\frac{\text{force x distance}}{\text{time}}$. This instrument was used to measure the "explosive movement of a body limb." Test-retest coefficients ranged from a low of r = .9266 to a high of r = .9772. Spearman rho scores (the proportionality of compared functions) for each leg, were slightly lower, ranging from a low of p = .8858 to a high of p = .9454. Error of variance (testor difference and time of testing differences) may have accounted for this deviation. According to Glencross, the power lever was accurate and easy to administer. This method allowed for a precise, instantaneous assessment of power. The power level was the forerunner of the present isokinetic machines.

Relationships of the parameters of isometric strength, force and isokinetic power were clarified by Moffroid et al. (1969). Later work by Coplin (1971) reinforced the work of Moffroid. The use of torque as a parameter is due to the fact that torque values obtained through isokinetic testing are independent of where on the power lever the measurements are taken. Isometric

measurements of pounds of force must consider the lever arm strength when making comparisons (Moffroid et al. 1969).

Hislop and Perrine (1967) used the term "accommodating resistance exercise" to describe how the element of acceleration is eliminated. Resistance or "load" of the isokinetic device occurs as that part of the "mechanical process of energy absorption which the apparatus performs to maintain constant speed." Specifically, energy absorption is proportional to the amount of force applied and thereby accommodates all the influencing factors.

Studies by Moffroid et al. (1969) revealed a reliability coefficient of r = .995 with a coefficient of validity of predicted-to-obtained torque movements of r = .99. The correlation of constancy of speed necessary for accommodating resistance was r = .985. Findings by Moffroid et al. were recorded during slow speeds and the plotted torque curves were the same as isometric forces at the measured angles. The highest torque values do not occur at the same point in the range of motion. When the speed of contraction

increases, not only does the maximal torque decrease, but the highest value occurs later in the range of motion and therefore changes the shape of the torque curve.

Hamstring-Quadricep Strength Ratio and Muscle Injury

Research by Klein in the late 1950s initially evaluated the hamstring-quadricep strength ratio (Klein and Hall, 1963). The ratio, according to Klein, is not constant, but varies with age. Following his research with isometric tensiometer testing and personal correspondence with Clarke, Klein concluded that 15 year old males have a 57 percent hamstring to quadricep strength ratio. Freshman and sophomore males in college had a ratio of 54 to 55 percent, and college varsity football players (n = 537) had a ratio of 60 percent. Later work by Klein (1975) has shown high school level males to have a ratio of 50 percent, and college level males to have a 60 to 65 percent ratio. The number of participants in each study above was noted except for the college football players.

Mendler (1967) conducted a study of the hamstring-quadricep strength ratio with a series

of six male, (age not stated), three month rehabilitation cases and found a 60 percent ratio. Ryan (1962) and Klafs and Arnheim (1973), after a review of the current literature, expressed the opinion that the hamstring group should be 60 percent of the strength of the quadricep group. They did not specify age or sex.

Tensiometer measurements by Klein (1963) and later by Burkett (1968) revealed significant strength differences between the injured and uninjured legs. Galloway (1973) concluded that thigh muscle strains may be related to an imbalance in knee flexor strength. If a marked strength difference between knee flexors is a significant factor in muscle injury, it would seem plausible that, based on these differences of the knee flexors, predictions could be made as to those athletes who might be injured at a later date. However, Galloway is referring to significant differences in bilateral hamstring strength levels and does not discuss the hamstring-quadricep ratio in this regard.

Other Factors Related to Muscle Injury

An imbalance in bilateral leg strength of

more than ten percent has been recognized as a primary factor of muscle injuries. Klein and Hall (1969) found that, of 537 football players, 79.5 percent of those injured suffered knee injuries to their weaker leg. All subjects were administered isometric strength tests prior to the football season. It was discovered that the injured leg was shown to have a hamstring-quadricep strength ratio which was 9.8 percent weaker than the uninjured side when measured with tensiometer.

Burkett (1968) investigated leg strength imbalance among members (n = 37) of the San Diego professional football team and thirty track athletes. He concluded that hamstring strains occurred more frequently, seventeen of seventeen, in the weaker leg.

Klein and Allman (1969) and Burkett (1968) appear to be the only studies which make any statements concerning lower extremity muscular strength imbalance. Many authors have used the results of Klein and Burkett. It is now common practice in rehabilitation of leg injuries to strengthen the hamstring-quadricep strength ratio of the injured leg until it is within ten percent of the uninjured leg before an athlete is allowed to return to competition.

Additional factors related to leg muscle injuries have been suggested. Klafs and Arnheim (1973) have theorized that faculty postural alignment, fatigue, poor form in exercise and a lack of conditioning may contribute to the incidence of injury. Ryan and Allman (1974) stated that movement speed, slow reaction time, uncoordinated muscle activity, lack of flexibility, loss of balance, loss of strength, lack of endurance, and loss of concentration can contribute to injury. Neilson and Jensen (1972) saw the hamstring-quadricep mechanism not just as the ability to apply force but as a functional whole derived by a combination of forces of the agonistic muscles, the mechanical ratio of the body lever of the parts involved and the ability to coordinate the actions of the antagonistic muscles with the actions of the agonists.

Warm-up, as stated by several authors, is a potential factor in hamstring strains. DeVries (1974) concluded that the studies have shown that warm-up is of benefit if it is done properly. A general body warm-up is found to be the only type which improved strength performance. A specific area warm-up had no effect on subsequent performance. Klafs and Arnheim (1973) stated that

warm-up increased general body and deep muscle temperature. This fact plus the increased flexibility of ligaments and related tissue aids in injury prevention.

Burkhardt (1976) has used a series of proprioceptive neuromuscular facilitation (PNF) exercises as part of the warm-up regimen before football practices and games during 1974 and 1975. Utilizing this protocol, no reportable leg strains occurred during the season. This protocol was used by the Valparaiso University football team during the 1976 season. The number of upper leg strains in the 1975 season was twenty-eight while the total was two during the 1976 season (Moore and Rehm, 1976).

Summary

Research which has been conducted with the hamstring-quadricep muscle groups has been isometric and concerned with males. The investigator has not located any research which has dealth with female subjects. Isokinetic instrumentation has given researchers a new approach to the analysis of muscle capabilities. Klein and Burkett were

the only studies which dealt with the hamstring-quadricep strength ratio with any number of subjects. Klein's work has prompted this investigation of the hamstring-quadricep strength ratio in college-age females.

Chapter III

METHODS AND PROCEDURES

The purpose of this study was to determine the hamstring-quadricep strength ratio of eighteen to twenty-two year old female subjects at Valparaiso University. The methods and procedures for collection of the data are described in this chapter under the headings: Organization of the Study; Source of the Data; and Collection of the Data.

Organization of the Study

The Orthotron machine, an isokinetic measuring device, was manufactured by Lumex Incorporated, Bay Shore, New York. The machine was purchased by Valparaiso University in August, 1976. Mr. Ron Modjeski, sales representative for Lumex Incorporated, was present initially to handle any technical problems with the apparatus. Four other testers were used. They received an explanation of the study, the protocol to be followed, and were trained in the setup and use of the Orthotron. The Orthotron was checked periodically by the Lumex representative and the present researcher to insure the accuracy of

the arm speed of thirty degrees per second. Calibration checks are listed in Appendix A.

The testing commenced September 1, 1977, and was concluded on May 14, 1980. One hundred and eighty-eight subjects were tested on twenty-four testing dates. The dates and subjects tested on each date are included in Appendix B.

Prior to the initiation of testing, each subject was given an explanation of the present study (Appendix C). The subject was measured and a history of athletic activities and prior injuries was taken (Appendix D). Instructions on the protocol to be followed were given to familiarize each subject with the testing apparatus (Appendix E).

Source of the Data

Candidates for this study were volunteers from the female population of Valparaiso University. Subjects were tested on an appointment basis during the day or evening. Table I shows the physical characteristics of the subjects. The mean age for all subjects was 19.2 years with a range of 18.0 to 21.9 years. The overall group

Table I

Physical Characteristics

of Subjects (N = 188)

	$\bar{X}$	Range
Age (yrs)	19.2	18.0 - 21.9
Height (cm)	167.3	153.0 - 185.0
Weight (kg)	59.3	45.0 - 82.0
Athletic Experience (yrs)	2.25	0.0 - 7.0
Dominant Leg - Right	172	
Dominant Leg - Left	16	

mean for height was 167.3 centimeters with a range of 153.0 to 185.0 centimeters. The group mean weight was 59.3 kilograms with a range of 45.0 to 82.0 kilograms. The right leg was dominant in 172 subjects and the left leg was dominant in 16 subjects. The overall mean for years of athletic experience was 2.25 years with a range of 0.0 to 7.0 years.

Collection of the Data

The subjects were given an explanation of the present study. A personal history and a series of measurements were taken of each subject. The history and measurements included height, weight, age, birthday, dominant leg, and athletic experience on both the interscholastic and intercollegiate levels. A sample of the history form is included in Appendix F. The athletic experience guide is included in Appendix G.

Each subject was tested on the Orthotron. Warm-up consisted of three submaximal repititions of extension and flexion. Two maximal sets of three repititions of extension and flexion were then performed with thirty seconds of rest between sets. Each subject started with the right leg. The subject switched to the opposite side and repeated the test protocol. Maximum torque readings of each set of each leg for both extension and flexion were recorded from the dial arms to the nearest five foot-pounds. (Appendices H and I and Plate #3 - Appendix E).

Chapter IV

ANALYSIS AND DISCUSSION OF RESULTS

The purpose of this study was to describe the hamstring-quadricep strength ratio as attained through isokinetic measurement among eighteen to twenty-two year old female subjects. This chapter presents the analysis of data collected from 188 female subjects of Valparaiso University between 1977 and 1980. In addition to the hamstring-quadricep strength ratio, the legs were compared to each other and to the variables of age and dominant leg for any significant levels of correlation. This chapter has been organized according to (1) analysis of data, (2) reliability and reproducibility of the data, (3) representative values of the tests, (4) relationships among variables, and (5) discussion of results.

Analysis of Data

The data obtained in the testing procedures were analyzed with the Statistical Package for the Social Sciences (SPSS) at South Dakota State University to give overall and grouped means, standard deviations, standard error of the means

and ranges for the variables (Table II). An analysis of variance (ANOVA) technique was subsequently run to compare age and dominant leg with the means of each muscle group tested. Additionally, an ANOVA technique was used to analyze the hamstring-quadricep strength ratios obtained for each leg and the difference in bilateral muscular strength balance is determined by the ratio differences of paired legs. The test-retest reliability was determined through the Pearson Product-Moment correlation technique to determine the correlation coefficient between test 1 and test 2 for each leg. The dependent t-test was used to determine whether significant differences were found between the means of test 1 and test 2. Finally a Pearson Product-Moment correlation matrix was constructed to give the interrelationships of all the variables tested. Age and dominant leg were also included in the matrix to determine their association with isokinetic strength.

Reliability and Reproducibility of the Data

Two tests were administered to each leg. Each test consisted of one set of three repititions

TABLE II

$\bar{X}$, SD, $SE_{\bar{x}}$, CV AND RANGE REPRESENTATIVE VALUES OF THE TOTAL (N = 188)

	$\bar{X}$	SD	$SE_{\bar{x}}$	CV	Range
Height (cm)	167.26	6.17	0.45	3.69	153.0 - 185.0
Weight (kg)	59.30	6.63	0.48	11.18	45.0 - 82.0
Left Hamstring[a]	110.04	26.91	1.96	24.45	57.5 - 247.5
Right Hamstring[a]	111.53	28.31	2.07	25.38	55.0 - 235.0
Left Quadricep[a]	169.43	31.26	2.28	18.45	95.0 - 262.5
Right Quadricep[a]	178.79	35.61	2.60	19.92	85.0 - 287.5
Ratio Left H-Q[b]	65.17	10.97	0.80	16.83	44.1 - 107.6
Ratio Right H-Q[b]	62.81	11.83	0.86	18.83	37.0 - 111.0
Ratio Percent Difference	7.58	6.07	0.44	80.08	0.0 - 32.6
Years Experience[c]	2.25	2.14	0.16	95.11	0.0 - 7.0

[a] recorded in foot-pounds of torque

[b] ratio is determined by dividing hamstring strength mean by quadricep strength mean

[c] number of years of participation in interscholastic and intercollegiate sports

of flexion and extension at a speed of thirty degrees per second. A thirty second rest was given between tests for each leg. The mean, standard deviation, standard error of the mean, coefficient of variability and range for each test are shown in Table III. The test-retest reliabilities and reproducibilities were determined through the use of the Pearson Product-Moment Correlation and the t-test, respectively (Tables IV and V). The test-retest t-ratios of 4.23 for the left hamstring, 3.87 for the right hamstring, and 3.22 for the left quadricep were all significant at the .05 level. The right quadricep test-retest t-ratio of 0.74 was not significantly different. The correlation coefficients ranged from a low of $r = .874$ for the right hamstring tests to a high of $r = .922$ for the left quadricep tests. The correlation coefficients were less than Glencross (1966) determined ($r = .927$ to $r = .977$) but the coefficients were very similar to the values ($r = .886$ to $r = .945$) which Glencross initially found for the isokinetic testing done with the forerunner of the Orthotron.

Representative Values of the Tests

The representative values of the mean,

TABLE III

DESCRIPTIVE DATA OF TRIALS 1 AND 2 OF THE

ISOKINETIC FLEXION-EXTENSION TEST[a]

	$\bar{X}$	SD	$SE_{\bar{x}}$	CV	Range
T1[b] Left Hamstring	108.01	27.93	2.04	25.86	55 - 250
T2[c] Left Hamstring	112.07	27.48	2.00	24.52	55 - 245
T1 Right Hamstring	109.47	28.80	2.10	26.31	55 - 230
T2 Right Hamstring	113.62	29.70	2.17	26.14	60 - 240
T1 Left Quadricep	170.90	33.14	2.42	19.39	90 - 275
T2 Left Quadricep	167.90	30.55	2.23	18.20	100 - 255
T1 Right Quadricep	178.35	38.24	2.79	21.44	70 - 295
T2 Right Quadricep	179.23	34.73	2.53	19.38	80 - 280

[a]expressed in foot-pounds of torque

[b]Trial 1

[c]Trial 2

TABLE IV

TEST-RESULT RELIABILITY AND REPRODUCIBILITY OF THE ISOKINETIC FLEXION-EXTENSION TEST[a] (N = 188)

	Trial 1		Trial 2					
	$\bar{X}_1$	SD_1	$\bar{X}_2$	SD_2	$\bar{X}_\Delta$	$SE_{\bar{X}_\Delta}$	t-ratio	r
L[b] Hamstring	108.01	27.93	112.07	27.48	4.07	0.96	4.23[d]	.887
R[c] Hamstring	109.47	28.80	113.62	29.80	4.15	1.07	3.87[d]	.874
L Quadricep	170.90	33.14	167.90	30.55	3.00	0.93	3.22[d]	.922
R Quadricep	178.35	38.24	179.23	34.73	0.88	1.19	0.74	.905

[a] expressed in foot-pounds of torque

[b] Left

[c] Right

[d] Significant at $p < .05$

TABLE V

INTER-CORRELATION MATRIX FOR

REPRESENTATIVE $\bar{X}$'s, AGE AND DOMINANT LEG

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	L HAM 1[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.	L HAM 2[a]	.89	-	-	-	-	-	-	-	-	-	-	-	-	-
3.	L HAM AVE[a]	.97	.97	-	-	-	-	-	-	-	-	-	-	-	-
4.	L QUAD 1[b]	.70	.70	.72	-	-	-	-	-	-	-	-	-	-	-
5.	L QUAD 2[b]	.67	.70	.70	.92	-	-	-	-	-	-	-	-	-	-
6.	L QUAD AVE[b]	.70	.71[d]	.73	.98	.98	-	-	-	-	-	-	-	-	-
7.	R HAM 1[a]	.80	.73	.79	.62[e]	.59	.62	-	-	-	-	-	-	-	-
8.	R HAM 2[a]	.88	.81	.87	.66	.63	.66	.87	-	-	-	-	-	-	-
9.	R HAM AVE[a]	.86	.79	.85	.66	.63	.66	.97	.97	-	-	-	-	-	-
10.	R QUAD 1[b]	.69	.68	.70	.88	.83	.87	.67	.67	.69	-	-	-	-	-
11.	R QUAD 2[b]	.70	.69	.72	.88	.86	.89	.63	.69	.68	.90	-	-	-	-
12.	R QUAD AVE[b]	.71	.70	.73	.90	.86	.90	.67	.70	.70	.08	.97	-	-	-
13.	AGE	.07	.05	.06	-.03	-.02	-.03	.15	-.07	.11	.00	-.02	-.01	-	-
14.	DOM LEG[c]	.05	.04	.04	.09	.10	.10	.08	.09	.09	.05	.04	.04	.05	-

[a] hamstring

[b] quadricep

[c] dominant leg

[d] $r = .70$ is significant at $p < .01$

[e] $r = .62$ is significant at $p < .05$

standard deviation, standard error of the mean, coefficient of variability and range for the total group of subjects (N = 188) and by age groups (18, 19, 20, 21) are contained in Tables II (page 27) and VI through X. The average of the two trials for each muscle group tested was used as the representative value of the mean. The other total and grouped means were determined in the same manner. The mean height for the total group (N = 188) was 167.26 centimeters. The eighteen year old group (n = 64) had a mean height of 165.70 centimeters; the nineteen year olds (n = 57) had a mean height of 168.16 centimeters; the twenty year olds (n = 35) had a mean height of 167.26 centimeters; and the twenty-one year old group had a mean height of 168.22 centimeters. The mean weight of the total group was 59.3 kilograms while the eighteen year old group was 57.75 kilograms; the nineteen year old group was 60.74 kilograms; the twenty year old group was 58.40 kilograms; and the twenty-one year old group was 58.81 kilograms. The mean foot-pound measurement for the total group's left hamstring was 110.04 foot-pounds and the left hamstring measures for the age groups (18, 19, 20, 21)

TABLE VI

$\bar{X}$, SD, $SE_{\bar{X}}$, CV, AND RANGE REPRESENTATIVE VALUES BY AGE GROUP OF 18 YEAR OLDS (N = 64)

	$\bar{X}$	SD	$SE_{\bar{X}}$	CV	RANGE
Height (cm)	165.70	6.01	0.75	3.63	154.0 - 180.0
Weight (kg)	57.75	6.66	0.83	11.53	45.0 - 82.0
Left Hamstring[a]	106.02	23.30	2.91	21.98	57.5 - 162.5
Right Hamstring[a]	106.88	21.93	2.74	20.52	62.5 - 170.0
Left Quadricep[a]	167.54	28.57	3.57	17.05	112.5 - 250.0
Right Quadricep[a]	178.06	31.89	3.99	17.91	110.0 - 287.5
Left Ratio H-Q[b]	63.56	10.83	1.35	17.04	46.0 - 94.1
Right Ratio H-Q[b]	60.09	9.81	1.23	16.33	41.0 - 84.0
Ratio Difference (%)	7.98	5.80	0.73	72.68	0.0 - 22.3
Years Experience[c]	2.03	1.86	0.23	91.62	0.0 - 5.0

[a] recorded in foot-pounds of torque

[b] ratio is determined by dividing hamstring strength mean by quadricep strength mean

[c] number of years of participation in interscholastic and intercollegiate sports

TABLE VII

$\bar{X}$, SD, $SE_{\bar{X}}$, CV AND RANGE REPRESENTATIVE VALUES BY AGE GROUP OF 19 YEAR OLDS (N = 57)

	$\bar{X}$	SD	$SE_{\bar{X}}$	CV	Range
Height	168.16	6.55	0.87	3.90	153.0 - 184.0
Weight (kg)	60.74	7.02	0.93	11.56	46.0 - 77.0
Left Hamstring[a]	113.64	28.82	3.82	25.36	65.0 - 190.0
Right Hamstring[a]	112.11	32.07	4.25	28.61	60.0 - 215.0
Left Quadricep[a]	175.53	32.94	4.36	18.77	105.0 - 262.5
Right Quadricep[a]	185.00	39.96	5.29	21.60	85.0 - 270.0
Ratio Left H-Q[b]	64.73	10.56	1.40	16.31	44.1 - 95.2
Ratio Right H-Q[b]	61.46	11.41	1.51	18.56	37.0 - 111.0
Ratio Difference (%)	7.07	6.05	0.80	85.57	0.0 - 29.2
Years Experience[c]	2.39	2.12	0.28	88.70	0.0 - 6.0

[a] recorded in foot-pounds of torque

[b] ratio is determined by dividing hamstring strength mean by quadricep strength mean

[c] number of years of participation in interscholastic and intercollegiate sports

TABLE VIII

$\bar{X}$, SD, $SE_{\bar{X}}$, CV AND RANGE REPRESENTATIVE VALUES BY AGE GROUP OF 20 YEAR OLDS (N = 35)

	$\bar{X}$	SD	$SE_{\bar{X}}$	CV	Range
Height (cm)	167.26	5.86	0.99	3.50	155.0 - 185.0
Weight (kg)	58.40	6.39	1.08	10.94	48.0 - 75.0
Left Hamstring[a]	110.43	31.40	5.31	28.43	62.5 - 247.5
Right Hamstring[a]	116.43	32.26	5.45	27.71	70.0 - 235.0
Left Quadricep[a]	165.57	25.40	4.29	15.34	110.0 - 230.0
Right Quadricep[a]	175.64	28.87	4.88	16.43	110.0 - 250.0
Ratio Left H-Q[b]	66.47	12.33	2.09	18.55	50.0 - 107.6
Ratio Right H-Q[b]	66.20	15.94	2.69	24.08	42.0 - 110.0
Ratio Difference (%)	8.40	7.02	1.19	83.57	0.4 - 32.5
Years Experience	2.51	2.29	0.39	91.24	0.0 - 7.0

[a] recorded in foot-pounds of torque

[b] ratio is determined by dividing hamstring strength mean by quadricep strength mean

[c] number of years of participation in interscholastic and intercollegiate sports

TABLE IX

$\bar{X}$, SD, $SE_{\bar{X}}$, CV AND RANGE REPRESENTATIVE VALUES BY AGE GROUP OF 21 YEAR OLDS (N = 32)

	$\bar{X}$	SD	$SE_{\bar{X}}$	CV	Range
Height (cm)	168.22	5.92	1.05	3.52	155.0 - 178.0
Weight (kg)	58.81	5.93	1.05	10.08	48.0 - 71.0
Left Hamstring[a]	111.25	24.98	4.42	22.45	72.5 - 167.5
Right Hamstring[a]	114.45	27.88	4.93	24.36	55.0 - 165.0
Left Quadricep[a]	166.56	38.28	6.77	22.98	95.0 - 247.5
Right Quadricep[a]	178.59	41.92	7.41	23.47	90.0 - 255.0
Ratio Left H-Q[b]	67.75	10.24	1.81	15.11	50.0 - 87.0
Ratio Right H-Q[b]	64.31	10.08	1.78	15.67	45.0 - 87.0
Ratio Difference (%)	6.79	5.62	0.99	82.77	0.0 - 18.3
Years Experience	2.16	2.57	0.45	118.98	0.0 - 7.0

[a] recorded in foot-pounds of torque

[b] ratio is determined by dividing hamstring strength mean by quadricep strength mean

[c] number of years of participation in interscholastic and intercollegiate sports

TABLE X

REPRESENTATIVE MEAN VALUES BY AGE GROUPS

AGE	18	19	20	21	Total
n	64	57	35	32	188
Height (cm)	165.70	168.16	167.26	168.22	167.26
Weight (kg)	57.75	60.74	58.40	58.81	59.30
Left Hamstring[a]	106.02	113.64	110.43	111.25	110.04
Right Hamstring[a]	106.88	112.11	116.43	114.45	111.53
Left Quadricep[a]	167.54	175.53	165.57	166.56	169.43
Right Quadricep[a]	178.06	185.0	175.64	178.59	178.79
Ratio Left H-Q[b]	63.56	64.73	66.47	67.75	65.17
Ratio Right H-Q[b]	60.09	61.46	66.20	64.31	62.36
Ratio Difference[c]	7.98	7.07	8.40	6.97	7.58

[a] expressed as foot-pounds of torque

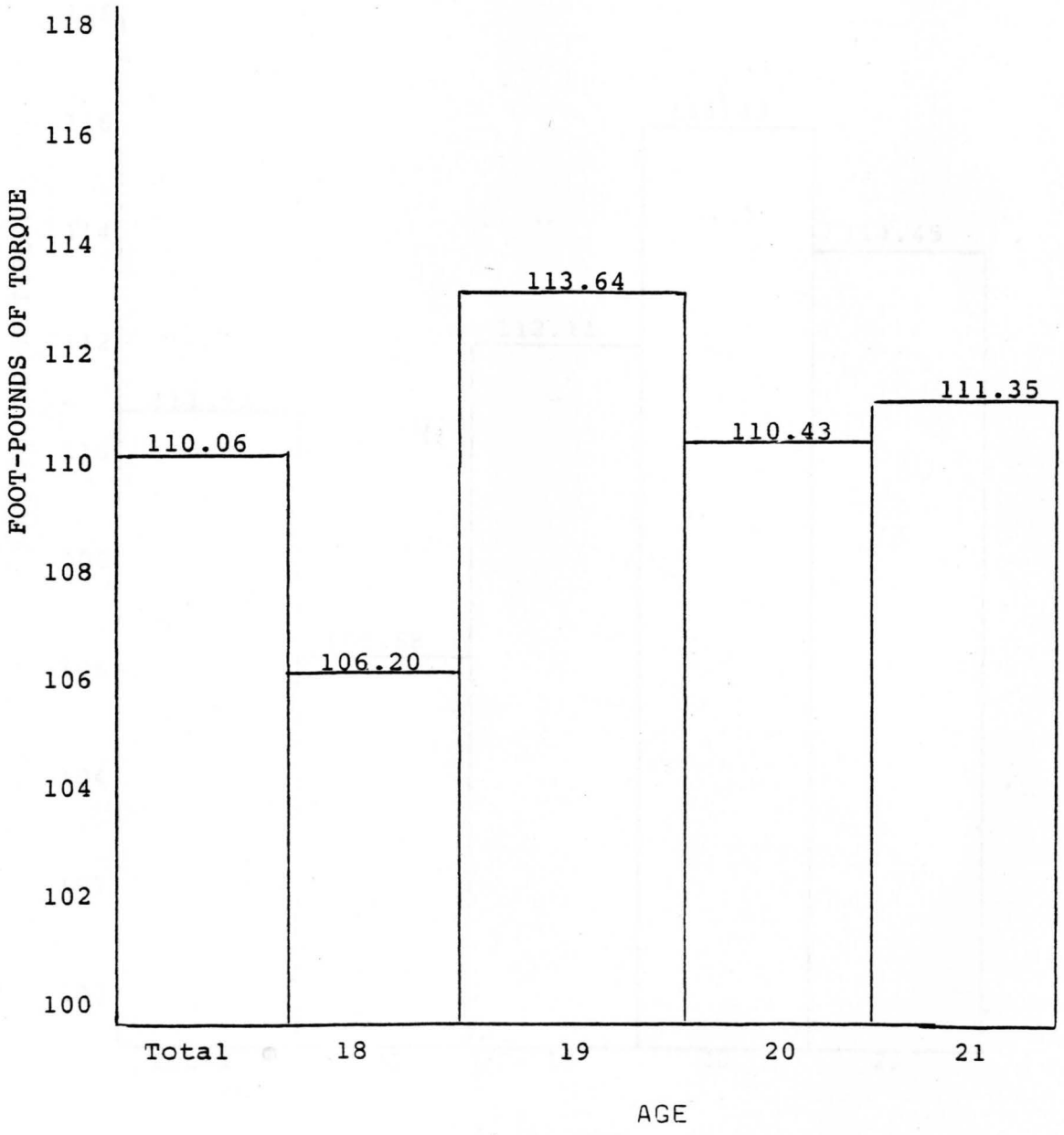
[b] H-Q = hamstring-quadricep

[c] difference between left and right hamstring-quadricep ratios - expressed as a percent

were 106.02, 113.64, 110.43 and 111.25 foot-pounds, respectively (Graph I). The total group mean for the right hamstring was 111.53 foot-pounds while the age group (18, 19, 20, 21) means for the right hamstring were 106.88, 112.11, 116.43 and 114.45 foot-pounds, respectively (Graph II). The total group mean for the left quadricep was 169.43 foot-pounds with the age group (18, 19, 20, 21) means being 167.54, 175.53, 165.57 and 166.56 foot-pounds, respectively (Graph III). The total group mean for the right quadricep was 178.79 foot-pounds with the age group (18, 19, 20, 21) means being 178.06, 185.0, 175.64 and 178.59 foot-pounds, respectively (Graph IV). The strength level of the hamstring group moved progressively closer to that of the quadricep muscle group as the age increased. For example, at age eighteen the left hamstring-quadricep ratio was 63.56 (106.02 ÷ 167.54 x 100) and the right ratio was 60.09. The nineteen year old age group had a ratio of 64.73 for the left hamstring-quadricep strength ratio and 61.46 for the right side. The resultant ratios for twenty year olds was 66.47 on the left and 66.20 on the right. The ratios for twenty-one year olds was

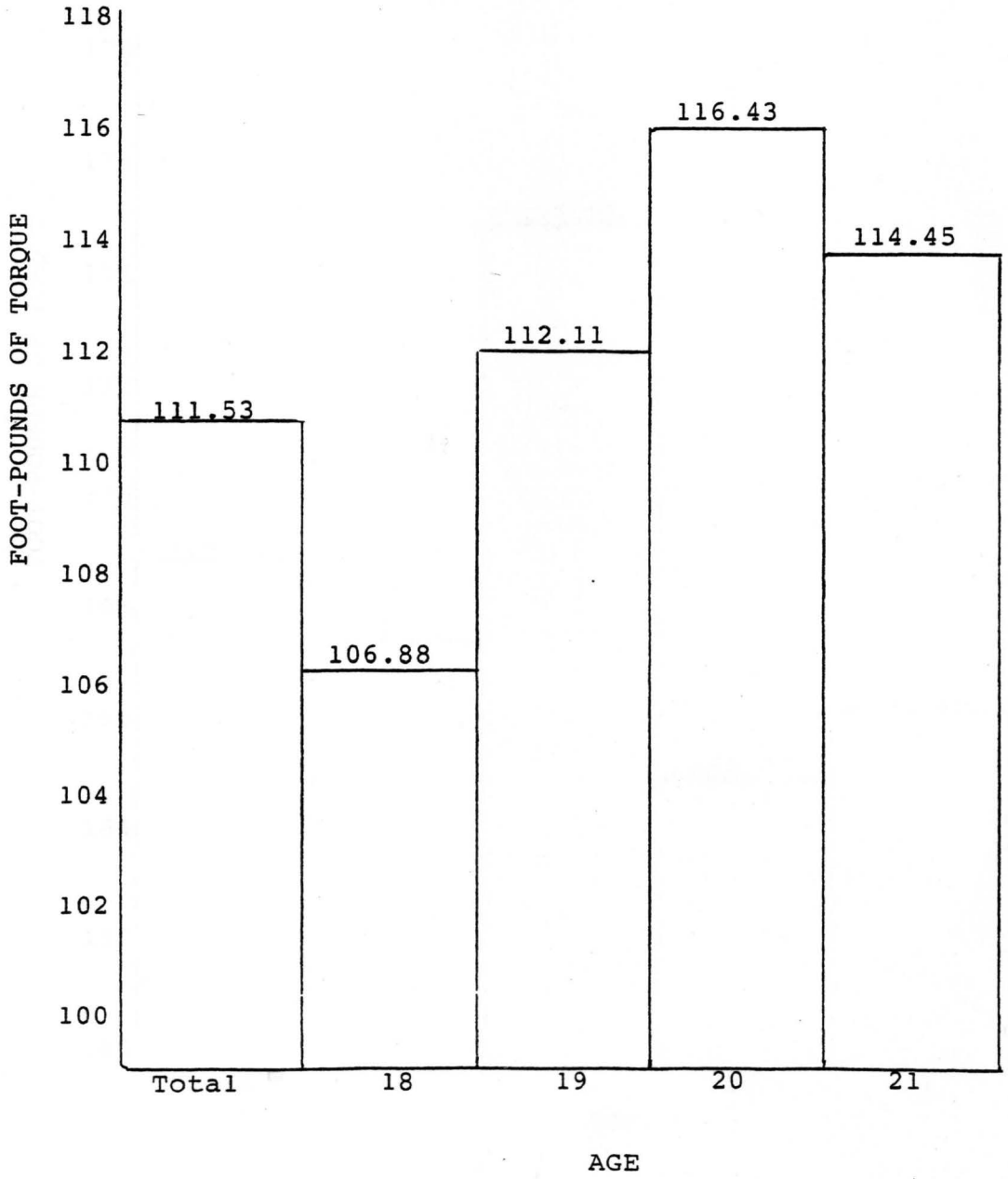
GRAPH I

LEFT HAMSTRING STRENGTH COMPARISON FOR TOTAL GROUP AND BY AGE (18, 19, 20, 21)



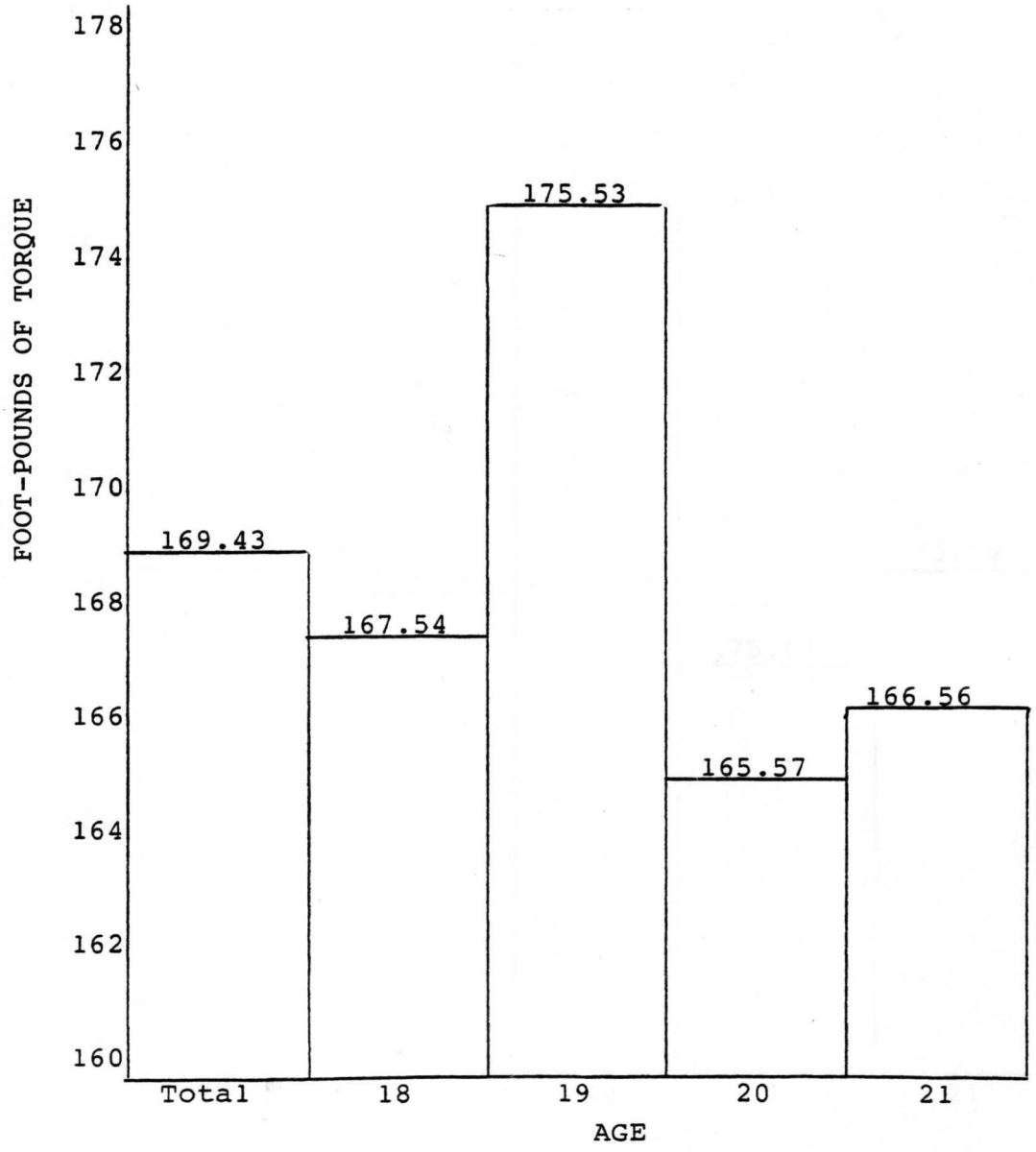
GRAPH II

RIGHT HAMSTRING STRENGTH COMPARISON FOR TOTAL GROUP AND BY AGE (18, 19, 20, 21)



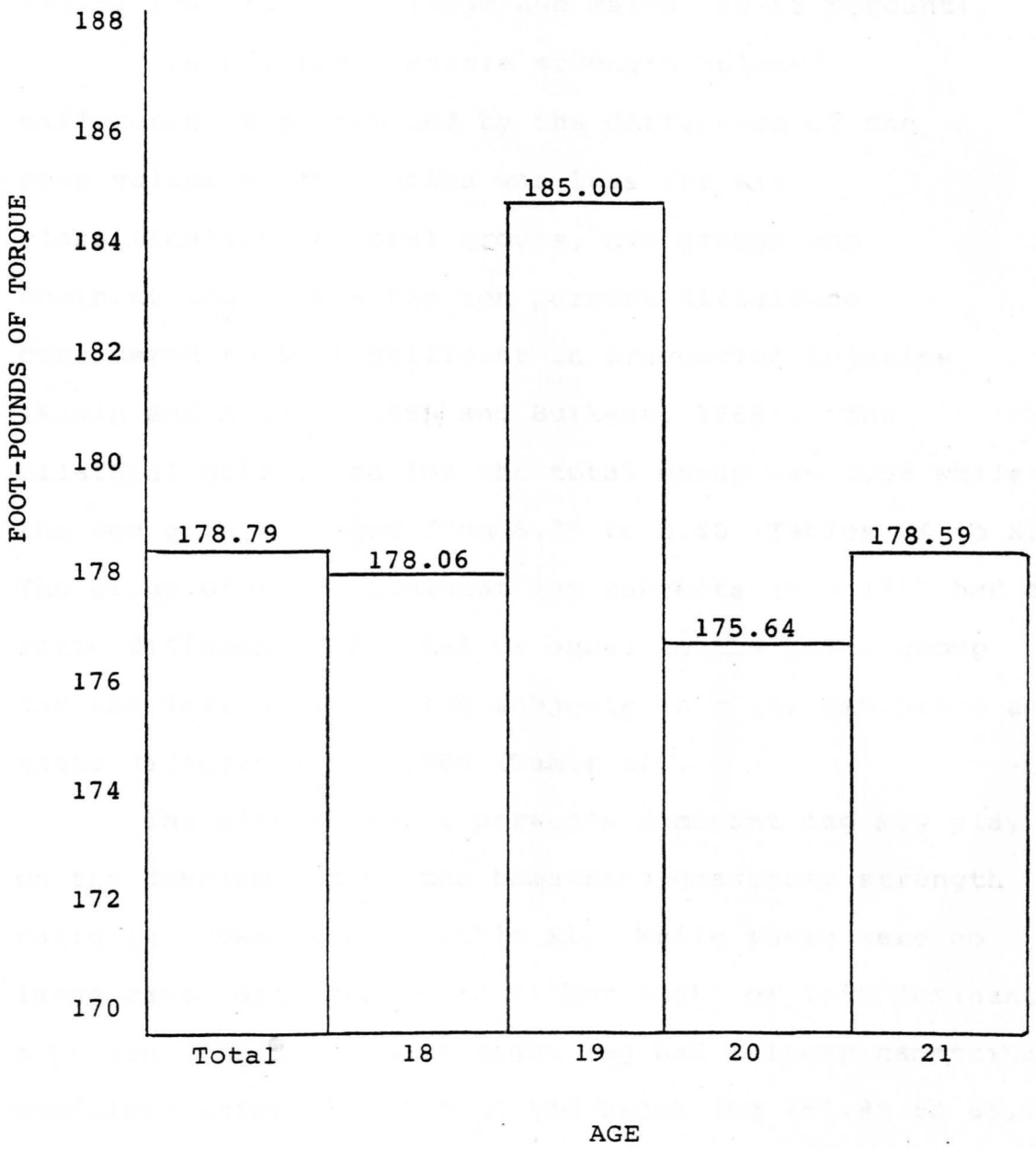
GRAPH III

LEFT QUADRICEP STRENGTH COMPARISON FOR TOTAL GROUP AND BY AGE (18, 19, 20, 21)



GRAPH IV

RIGHT QUADRICEP STRENGTH COMPARISON FOR TOTAL GROUP AND BY AGE (18, 19, 20, 21)



67.75 and 64.31 on the right. This last ratio of 64.31 was the lone exception in the study of downward ratio movement as the age increased. The hamstring-quadricep strength ratio for the total group (62-65 percent) was very similar to Klein's (1975) results for college age males (60-65 percent).

The bilateral muscle strength balance difference as determined by the difference of the mean values of the ratios was less for all classifications - total groups, age groups and dominant leg - than the ten percent difference considered to be significant in preventing injuries (Klein and Allman, 1969 and Burkett, 1968). The bilateral difference for the total group was 7.58 while the age groups ranged from 6.75 to 8.40 (Tables VI to X). The group of right dominant leg subjects (n = 171) had a ratio difference of 7.58% or equal to the total group and the left dominant leg subjects (n = 16) exhibited a ratio difference of 7.96% (Table XI).

The effect that a person's dominant leg may play on the development of the hamstring-quadricep strength ratio is shown also in Table XI. While there were no large ratio differences in either right or left dominance, a person with a dominant right leg had a lower hamstring-quadricep strength ratio in the right leg (61.95 to 65.20).

TABLE XI

MEAN VALUES BY DOMINANT LEG

Dominant Leg	Right	Left
n	171	16
Age (yrs)	19.71	19.38
Height (cm)	167.21	167.94
Weight (kg)	59.28	59.63
Left Hamstring (ft-lbs)	109.37	115.63
Right Hamstring (ft-lbs)	110.48	121.41
Left Quadricep (ft-lbs)	168.24	181.09
Right Quadricep (ft-lbs)	178.21	184.53
Ratio Left Hamstring-Quadricep	65.20	64.44
Ratio Right Hamstring-Quadricep	61.95	66.25
Ratio Difference (%)	7.58	7.96
Years Experience	2.23	2.44

The person with a dominant left leg also had a lower hamstring-quadricep strength ratio for the dominant leg (64.44 to 66.25). In addition to this, the mean level of foot-pounds to torque was greater in the right dominant leg for both the hamstring (110.48 to 109.39) and the quadricep (178.21 to 168.23). However, in the left dominant leg, the hamstring-quadricep strength ratio was similar to the right dominant leg ratio but the torque levels were greater in the right leg for both the hamstring (121.41 to 115.63) and the quadricep (184.53 to 181.09).

Relationships Among Variables

In Table V (page 31) are listed the correlation coefficients between the test variables (left hamstring trials 1 and 2 and average; left quadricep trials 1 and 2 and average; right hamstring trials 1 and 2 and average; right quadricep trials 1 and 2 and average) and the anthropometric variables of age and dominant leg. The correlations between age and dominant leg with any of the other variables were very low (-.01 to .15). The correlations between the hamstring and quadricep trials and averages (Table V) ranged from moderately high (r = .59)

to high (r = .90). The correlation coefficients were higher for the same muscle groups (quadricep to quadricep) than for opposite muscle groups (hamstring to quadricep). The quadricep to quadricep correlation coefficients between right and left legs were quite high (r = .83 to r = .88) while the hamstring-quadricep correlations were considerably lower (r = .59 to r = .70). The correlations for the trial averages were very similar to the individual trials just discussed. The same muscle group averages (left quadricep to right quadricep) exhibited high correlations (r = .85 and r = .90) while the correlations for opposite muscle group averages (left hamstring to right quadricep) were considerably lower (r = .66 to r = .73).

The analysis of variance (ANOVA) technique showed no significant relationships at the .05 level between the hamstring muscle group, the quadricep muscle group, or the hamstring-quadricep strength ratio of each leg with the variables of age and dominant leg. The F ratios ranged from a low of 0.118 to a high of 2.533 which were all below the levels needed to show significant relationships at the .05 level (Tables XII to XVII).

TABLE XII

ANALYSIS OF VARIANCE OF LEFT HAMSTRING

BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Square	F - ratio
Total	186	134775.688	724.600	
Main Effects	4	2045.704	511.426	0.702
Age	3	1473.511	491.170	0.674
Dominant Leg	1	380.143	380.143	0.522

TABLE XIII

ANALYSIS OF VARIANCE OF LEFT QUADRICEP

BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Squares	F - ratio
Total	186	182350.563	980.379	
Main Effects	4	4980.180	1245.045	1.289
Age	3	2559.471	853.157	0.883
Dominant Leg	1	2031.116	2031.116	2.103

TABLE XIV

ANALYSIS OF VARIANCE OF RATIO OF LEFT HAMSTRING-QUADRICEP GROUP BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Square	F - ratio
Total	186	22454.371	120.722	
Main Effects	4	469.706	117.427	0.963
Age	3	461.427	153.809	1.261
Dominant Leg	1	14.349	14.349	0.118

TABLE XV

ANALYSIS OF VARIANCE OF RIGHT HAMSTRING BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Square	F - ratio
Total	186	149420.938	803.338	
Main Effects	4	3996.931	999.233	1.257
Age	3	2251.022	750.341	0.944
Dominant Leg	1	1496.711	1496.711	1.883

TABLE XVI

ANALYSIS OF VARIANCE OR RIGHT QUADRICEP

BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Squares	F - ratio
Total	186	237065.063	1274.543	
Main Effects	4	1309.072	327.268	0.253
Age	3	723.458	241.153	0.186
Dominant Leg	1	496.481	496.481	0.384

TABLE XVII

ANALYSIS OF VARIANCE OF RATIO OF RIGHT

HAMSTRING-QUADRICEP GROUP BY AGE AND DOMINANT LEG

Source of Variation	df	Sum of Squares	Mean Square	F - ratio
Total	186	25992.891	139.747	
Main Effects	4	1288.003	322.001	2.414
Age	3	1013.443	337.814	2.533
Dominant Leg	1	245.629	245.629	1.842

Discussion of Results

There is a large amount of literature available concerning muscle testing. However, a paucity of material exists concerning the strength levels and the ratios derived from testing the hamstring and quadricep muscle groups. The material that does exist is concerned only with males and no information exists concerning college-age female strength levels and the resultant ratios between the hamstring and quadricep muscle groups. With the increase in female participation in sports and the concomitant increase to conditioning and strength programs, some insight must be gained of what is normal for this age group. Within the limitations of this study, it was found that the overall hamstring-quadricep strength ratio for college-age females (62-65 percent) was very similar to that found previously by Klein and Hall (1963) for college-age males (60-65 percent).

The results showed a tendency for the hamstring-quadricep strength ratio to increase (60 to 67 percent) as age increases. One exception was noted among the age groups as

ratios of the right leg decreased between the twentieth and twenty-first year. This possibly could be ascribed to the small sample for each of the age groups.

There were no significant correlations with the variables of age and leg dominance. All analysis of variance tests and correlation coefficients obtained from the Pearson Product-Moment matrix between the variables of age and dominant leg and the muscle groups tested closely approached zero. While there was the tendency for the hamstring-quadricep strength ratio to increase with age, there were no significant relationships established. The tendency of the ratio to increase with age was similar to the findings by Klein and Hall (1963) between high school and college males. The interaction between leg dominance and the hamstring-quadricep strength ratio appeared to be negligible. Part of this could be explained by the continuing controversy as to which should be considered the dominant leg - the support leg or the active leg.

The correlation coefficients obtained between the tests of the same respective hamstring and quadricep muscle groups showed a high correlation ($r = .874$ to $r = .922$) which indicated that isokinetic testing is a reliable method of testing muscular strength (Table IV, page 30). The correlation coefficient also showed a high relationship between the mean of the two trials of each muscle group and the individual trial ($r = .97$ to $r = .98$). This correlation exhibited a high degree of reproducibility between the tests. The reliability and reproducibility of isokinetic testing performed in the present study adds further evidence to previous studies by Glencross (1966) and Moffroid et al. (1969), that the Orthotron apparatus is an accurate means for the measurement of muscular strength.

The difference of the mean values derived from the comparison of the right and left hamstring-quadricep strength ratios was 7.58 percent. This percentage is less than the ten percent difference presently in use as a guideline for predicting return to activity

following an injury. While the range of the ratio differences went as high as 8.40 percent in one age group, the average difference percentage of 7.58 shows that it is not unreasonable to demand an injured player to work on rehabilitation and remain away from competition until the ten percent difference level, or less, is reached.

Chapter V
SUMMARY, FINDINGS, AND RECOMMENDATIONS

Summary

The purpose of this study was to describe the hamstring-quadricep strength ratio for college-age females.

One hundred and eighty-eight subjects from the undergraduate female population of Valparaiso University, Indiana volunteered to participate in the study. The history of each subject included height, weight, age, dominant leg, birthday and the number of years of athletic experience on the high school and college or university level.

The testing consisted of two sets of three repititions for each leg on the Orthotron apparatus. Thirty seconds rest was given between the sets for each leg. A repetition consisted of both an extension and flexion phase. The maximum torque achieved in each set was recorded. The testing was conducted on twenty-four dates between September 7, 1977 and May 14, 1980.

The statistical analysis used to determine reliability of the tests included paired t-tests

and the Pearson Product-Moment correlation technique. Analysis of variance (ANOVA) techniques and the Pearson Product-Moment correlation techniques were used to determine any relationships between the means of the tested body parts - the hamstring and quadricep muscle groups of each leg - and the variables of age and dominant leg.

Findings of the Study

The findings of the study were as follows:

1. The Orthotron isokinetic testing apparatus was a reliable means of assessing muscular strength levels for the hamstring and quadricep muscle groups. The correlation coefficients and paired t-test ratios derived showed a high test-retest reliability and reproducibility with the coefficients and t-ratios similar to previous studies.

2. The hamstring-quadricep strength ratio for college-age females (62-65 percent) was very similar to that found in previous studies by isometric testing for college-age males (60-65 percent).

3. There were no significant differences between age and the hamstring-quadricep strength ratio.

4. There were no significant differences between dominant leg and the hamstring-quadricep strength ratio regardless of age.

5. The percent difference between the mean values of the hamstring-quadricep strength ratio of the respective legs was less than the ten percent difference of the legs used to measure whether competition may be resumed after the rehabilitation of an injury.

6. The results showed no significant statistical relationship between the increase of the hamstring-quadricep strength ratio and an increase in age.

7. There was a very high correlation between the means of the respective trials of the hamstring and quadricep muscle groups and the individual trials ($r = .97$ to $r = .98$).

8. There was a high correlation between the trials of the same respective hamstring and quadricep muscle groups ($r = .874$ to $r = .922$).

Conclusions

As a result of this study the following conclusions were reached:

1. The hamstring-quadricep strength ratio of eighteen to twenty-two year old females, as determined through isokinetic testing, was 62-65 percent.

2. The hamstring-quadricep strength ratio for females, ages 18 to 21, was very similar to the same ratio for males of similar ages (60-65 percent) as determined by isometric testing in prior studies.

3. There was no significant difference between the hamstring-quadricep strength ratio and the variables of age and dominant leg of the subjects.

Recommendations

As a result of this study the following recommendations are made:

1. A similar study be conducted with fourteen to seventeen year old females to determine if any progression of the hamstring-quadricep strength ratio is present as a tendency

was seen in the present study for the hamstring-quadricep strength ratio to increase with age.

2. A similar study be conducted with both genders on the Orthotron apparatus to verify the similarities of the genders. This study would confirm the use of isokinetic testing as an accurate means of muscular strength assessment and verify the previous isometric studies.

3. A study be conducted with female athletes to determine incidence of injury to the quadricep and hamstring muscle groups relative to the existing hamstring-quadricep strength ratio of those athletes. This study could help to establish norms to look for in pre-season screening of athletes, possible rehabilitation work or goals, and analyze the results of conditioning programs.

4. A study be conducted with both genders to determine if the hamstring-quadricep strength ratio is similar to the hamstring-quadricep power ratio. The hamstring-quadricep power (power = speed x time) ratio can be measured isokinetically and very little research information exists on the

power of the various muscle groups of the body or any resultant ratios. This research could aid to develop optimum conditioning programs for specific body areas.

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APPENDIX A

CALIBRATION OF ORTHOTRON

Date	Person Calibrating	Condition
8-27-77	Ron Modjeski	Reset
3- 7-78	Rod Moore	Good
10-15-79	Ron Modjeski	Good
2-18-80	Rod Moore	Good
4- 9-80	Rod Moore	Good
5- 2-80	Rod Moore	Good

Procedure:

The speed of the lever arm at 30 degrees per second was checked against a stop watch. If the calibration was correct, it would take three seconds ($\pm$ .05 seconds) to manually take the lever arm through a complete range of motion (180°).

APPENDIX B

TESTING DATES AND SUBJECTS TESTED

Date	Number Tested
9- 1-77	2
9- 2-77	1
9- 6-77	3
9- 7-77	1
9-26-77	2
9-28-77	2
3- 7-78	2
10-15-79	2
2-18-80	5
2-19-80	16
2-20-80	3
2-21-80	14
2-24-80	8
4- 9-80	20
4-10-80	1
4-28-80	27
4-29-80	27
4-30-80	36
5- 1-80	4
5- 2-80	4
5- 5-80	1
5- 6-80	4
5-13-80	2
5-14-80	1
Total	188

APPENDIX C

EXPLANATION OF TESTING PROCEDURE

The following explanation was given to the subjects prior to history-taking or testing to acquaint the subjects with the purpose of the testing:

The study is designed to investigate the strength ratio which exists between the hamstring muscle group located in the back of the upper leg and the quadricep muscle group located on the front of the upper leg. Your legs will be tested by performing two sets of three repetitions each on both sides of the Orthotron. A repetition includes both extension (pushing up) of the lower leg and flexion (pulling down) of the lower leg.

APPENDIX D

RAW DATA - HISTORY

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
001	18.7	Right	170.2	65.0	4
002	18.0	Right	170.2	70.9	4
003	18.2	Right	161.9	67.7	4
004	21.6	Right	170.2	60.0	4
005	21.8	Left	176.5	62.7	7
006	21.2	Right	170.8	59.1	5
007	20.2	Right	163.8	66.1	7
008	21.3	Right	170.2	59.1	7
009	18.9	Right	165.7	65.9	5
010	20.2	Right	164.5	57.3	6
011	19.5	Right	177.8	66.8	4
012	19.7	Right	172.7	68.2	6
013	20.9	Right	163.8	56.8	4
014	20.3	Right	161.3	57.3	5
015	19.2	Right	165.1	56.8	3
016	18.8	Right	165.1	56.8	1

[a]expressed in years

[b]measured in centimeters

[c]measured in kilograms

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
017	19.8	Right	170.2	56.8	5
018	21.8	Right	167.6	51.8	0
019	18.6	Right	162.6	59.1	0
020	20.5	Right	167.6	57.7	4
021	18.9	Right	162.6	59.1	0
022	18.8	Right	180.3	56.8	4
023	19.0	Left	168.9	56.8	3
024	18.5	Right	165.1	53.6	0
025	18.1	Right	157.5	56.4	0
026	18.5	Right	175.3	52.3	0
027	19.4	Right	162.6	54.6	2
028	18.5	Right	160.0	59.1	0
029	18.4	Right	170.2	63.6	1
030	20.5	Right	167.6	54.6	4
031	18.9	Right	172.7	72.7	5
032	18.7	Right	172.7	59.1	0
033	18.6	Right	167.6	54.6	4

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
034	20.1	Right	163.2	56.4	6
035	20.4	Left	167.6	59.1	4
036	19.0	Left	184.2	72.7	5
037	20.7	Right	165.1	59.1	1
038	20.3	Right	157.5	48.6	1
039	19.9	Right	170.2	63.6	3
040	18.2	Right	162.6	53.2	4
041	19.4	Right	175.3	68.2	6
042	19.3	Right	168.9	63.6	3
043	20.6	Right	170.2	63.6	7
044	19.4	Right	157.5	50.0	0
045	19.6	Right	162.6	50.0	4
046	20.0	Left	163.8	59.1	0
047	21.0	Right	172.7	56.8	0
048	18.9	Right	174.0	62.7	2
049	18.7	Right	172.7	53.6	3
050	18.9	Right	162.6	65.9	5

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
051	18.6	Right	157.5	45.9	1
052	21.1	Right	165.1	56.4	7
053	19.0	Right	182.9	77.3	5
054	19.8	Right	175.3	63.6	4
055	18.6	Right	167.6	61.4	4
056	19.8	Right	172.7	62.7	2
057	18.6	Right	160.0	63.6	3
058	19.7	Right	162.6	59.1	0
059	18.9	Right	162.6	50.0	3
060	20.9	Right	167.6	50.0	0
061	19.5	Left	167.6	57.7	5
062	19.0	Right	169.6	65.9	5
063	19.1	Right	160.0	50.9	2
064	19.2	Left	165.1	58.6	4
065	19.2	Right	170.2	61.4	2
066	18.6	Right	167.6	56.8	1
067	19.1	Right	170.2	59.1	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
068	19.4	Right	170.2	63.6	0
069	18.7	Right	157.5	52.7	0
070	18.1	Right	167.0	54.6	3
071	20.9	Right	172.7	61.4	3
072	19.8	Right	165.1	49.6	2
073	19.8	Right	165.1	58.2	4
074	19.4	Right	168.9	56.8	0
075	21.3	Right	162.6	53.6	0
076	19.1	Right	163.8	63.6	2
077	18.8	Left	166.4	55.0	0
078	19.6	Right	168.9	56.8	2
079	19.9	Right	160.0	61.4	0
080	20.1	Right	171.5	59.1	2
081	18.6	Right	160.0	54.6	2
082	20.9	Right	166.4	53.2	0
083	20.2	Right	172.7	52.3	3
084	21.1	Right	167.6	54.6	3

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
085	18.5	Right	175.3	56.8	5
086	21.4	Left	167.6	61.4	6
087	19.1	Left	167.6	54.6	0
088	18.7	Right	159.4	50.0	5
089	18.9	Right	154.9	47.7	0
090	21.2	Right	171.5	63.6	3
091	18.6	Right	177.8	61.4	3
092	19.2	Right	168.9	62.7	2
093	19.3	Right	172.1	62.3	4
094	21.9	Right	170.2	66.8	0
095	20.1	Right	172.7	64.6	1
096	18.7	Right	165.1	50.0	0
097	19.5	Right	167.6	75.0	0
098	20.3	Right	162.6	65.9	0
099	21.6	Left	160.0	63.6	0
100	19.2	Left	167.6	56.8	0
101	19.2	Right	160.0	51.4	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
102	20.5	Right	162.6	50.0	0
103	18.9	Right	168.9	54.1	0
104	---	---	---	---	---
105	---	---	---	---	---
106	18.5	Right	167.6	65.9	1
107	18.1	Right	164.5	61.4	1
108	18.9	Left	162.6	63.6	2
109	19.8	Right	153.0	45.9	6
110	19.9	Right	158.8	51.8	2
111	19.9	Right	177.8	68.2	6
112	18.7	Right	154.3	55.5	2
113	19.1	Right	170.2	62.7	3
114	18.9	Right	169.6	81.8	0
115	21.4	Right	173.4	55.9	3
116	19.1	Right	176.5	65.9	3
117	19.0	Right	168.9	57.7	0
118	18.9	Right	165.1	50.0	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
119	19.9	Right	174.0	59.1	1
120	19.3	Left	165.1	52.3	3
121	20.3	Left	163.8	56.8	0
122	20.8	Right	175.3	63.6	1
123	20.1	Right	175.3	59.1	3
124	21.7	Right	175.3	63.6	1
125	19.2	Right	161.9	53.2	5
126	18.5	Right	165.1	52.3	0
127	18.8	Right	160.0	53.6	4
128	19.4	Right	177.8	72.7	4
129	19.0	Right	166.4	61.4	0
130	18.7	Right	163.2	59.1	0
131	18.7	Right	153.7	56.8	0
132	18.5	Right	158.8	58.2	5
133	21.5	Right	172.7	61.4	1
134	19.9	Right	166.4	60.5	0
135	18.8	Right	160.0	61.4	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
136	19.1	Right	154.3	52.3	0
137	18.6	Right	167.0	52.3	1
138	19.0	Right	164.5	47.7	0
139	18.6	Right	168.3	62.3	2
140	19.2	Right	162.6	62.7	0
141	18.6	Right	168.9	61.4	4
142	18.7	Right	165.1	60.0	3
143	20.1	Right	165.1	52.3	4
144	21.0	Right	169.6	51.8	2
145	19.7	Right	165.1	69.6	0
146	18.8	Right	162.6	63.6	2
147	18.7	Right	167.6	62.7	4
148	20.8	Right	165.1	63.6	0
149	18.9	Right	162.6	44.6	0
150	18.3	Right	175.3	65.9	2
151	19.7	Right	170.2	68.2	3
152	21.6	Right	154.9	61.4	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
153	20.8	Right	167.6	65.9	0
154	19.8	Right	165.1	63.6	0
155	18.5	Left	170.2	60.9	0
156	18.8	Right	165.1	56.8	0
157	21.0	Right	177.8	70.5	0
158	21.9	Right	154.9	47.7	0
159	18.9	Right	175.3	68.2	5
160	20.9	Right	172.7	55.9	3
161	20.3	Right	167.0	52.3	2
162	19.1	Right	172.7	68.2	0
163	18.3	Right	165.1	52.3	3
164	18.7	Right	177.8	62.7	0
165	18.4	Right	158.8	54.6	2
166	19.3	Right	172.7	63.6	0
167	18.9	Right	170.2	65.9	5
168	20.8	Right	170.2	59.1	1
169	20.9	Right	170.2	70.5	0

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
170	18.9	Right	160.0	57.7	2
171	18.7	Right	172.7	61.4	4
172	21.9	Right	167.6	58.2	0
173	20.5	Right	167.6	54.6	1
174	20.4	Right	154.9	47.7	3
175	21.9	Right	172.7	68.2	0
176	21.9	Right	171.5	65.0	0
177	21.0	Right	165.7	52.3	2
178	21.1	Right	158.8	47.7	0
179	20.5	Right	170.2	63.6	4
180	21.3	Right	167.6	49.1	0
181	20.9	Right	154.9	50.0	1
182	21.4	Right	175.3	68.2	2
183	19.1	Right	179.7	68.2	5
184	20.7	Right	185.4	75.0	7
185	21.6	Right	162.6	59.1	6
186	19.8	Right	158.8	63.6	6

APPENDIX D - Continued

ID NO	AGE[a]	DOMINANT LEG	HEIGHT[b]	WEIGHT[c]	YEARS OF ATHLETIC EXPERIENCE
187	21.7	Right	157.5	55.9	4
188	21.9	Right	167.6	59.1	0
189	21.7	Right	168.9	54.6	0
190	21.5	Right	170.2	60.9	6

APPENDIX E

TEST PROTOCOL

The maximum strength levels of the quadricep and hamstring muscle groups is the best of each of two sets of three repetitions each. Both legs are tested.

PROCEDURE

Have the subject sit on the left side of the Orthotron. Attach the lower leg strap and pad and the upper leg strap. (See Figure 2 for pad and strap placement).

Check the alignment of the knee with the axis of the lever arm. The top of the lever arm should be in the approximate middle of the knee joint.

Set the machine at 30 degrees per second. (2½ on the scale).

Instruct the subject to hold the handles of the chair and to keep the back against the back of the chair.

Instruct the subject to perform three submaximal repetitions to become acquainted with the action of the machine and to warm-up.

Re-set the dial arms.

Instruct the subject to perform a set of three repetitions as hard as possible in both directions.

Record maximum scores of flexion and extension.

APPENDIX E - Continued

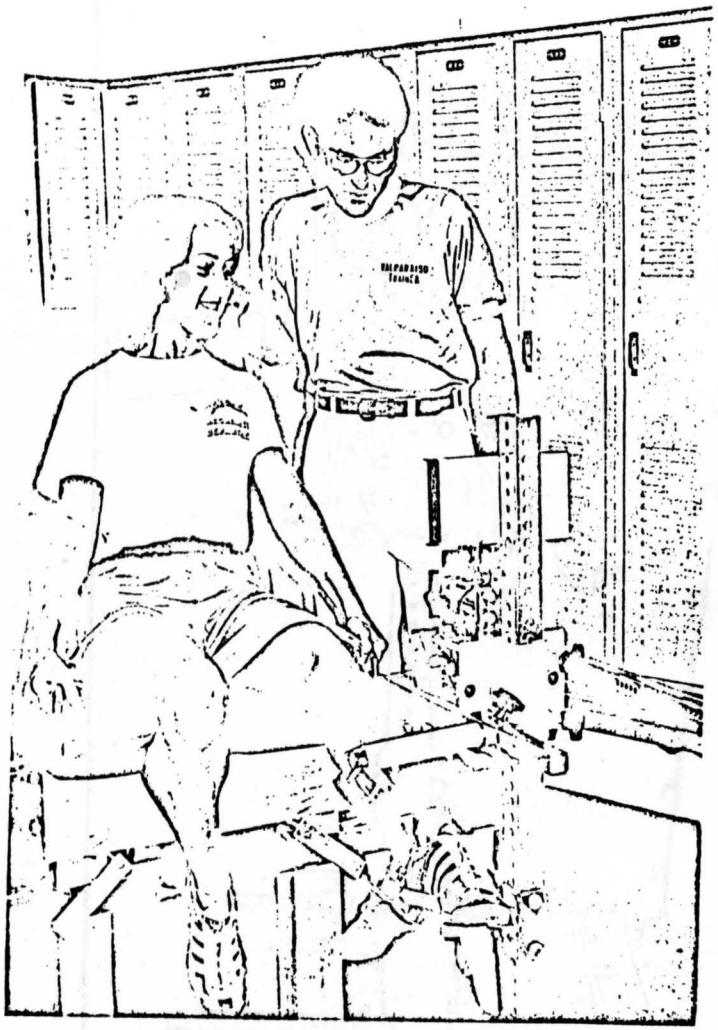
Rest for thirty seconds and re-set the dial arms.

Instruct subject to perform second set of three repetitions.

Record maximum scores for second set.

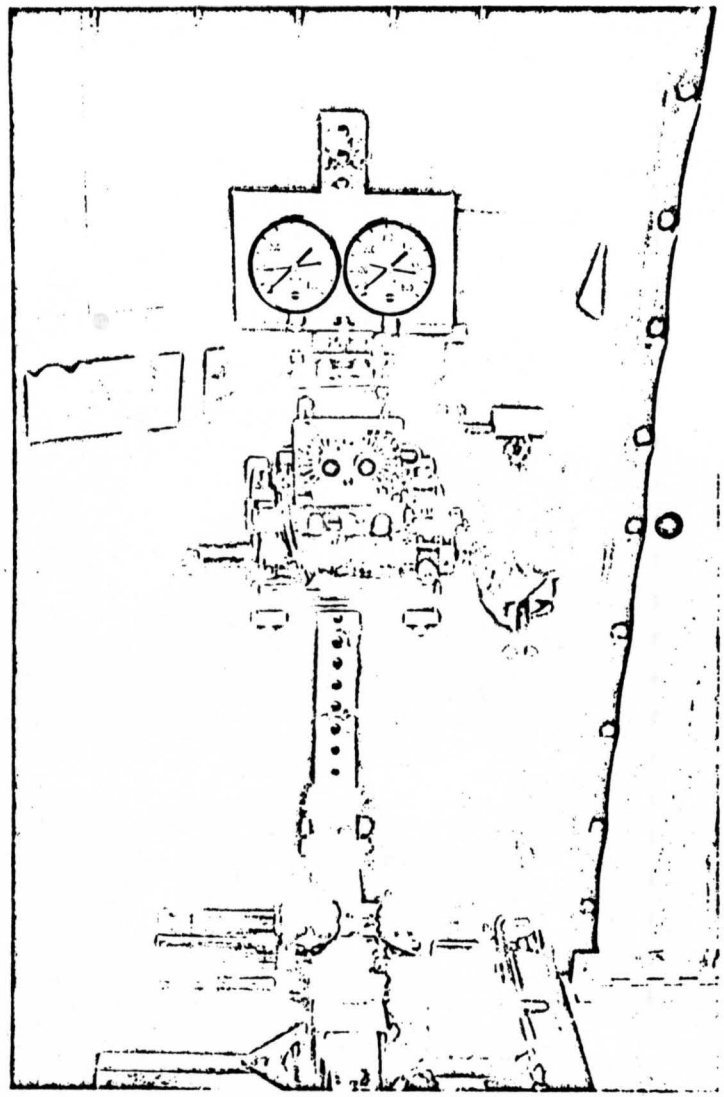
Change to other side of Orthotron and repeat above steps.

Thank the subject when test is completed.



ORTHOTRON TESTING - Subject in Middle of Extension Phase

ORTHOTRON TESTING - Finish of Flexion Phase and Start of Extension Phase



Front-View - ORTHOTRON

APPENDIX F

HISTORY FORM

NAME: _____ ID NO: _____

AGE: _____ BIRTHDAY: _____ DOMINANT LEG: LEFT ___
RIGHT ___

HEIGHT: _____ WEIGHT: _____

HISTORY: HIGH SCHOOL
SPORTS _____

LEVEL OF PARTICIPATION: _____

KNEE AND LEG INJURIES: _____

COLLEGE

SPORTS: _____

LEVEL OF PARTICIPATION: _____

KNEE AND LEG INJURIES: _____

- -

APPENDIX G

ATHLETIC ACTIVITY GUIDE

LEVEL OF PARTICIPATION:	VARSITY	V (1-4)
	JUNIOR VARSITY:	JV (1-4)

INDEX OF SPORTS:	BADMINTON	BD
	BASKETBALL	BA
	BOWLING	BO
	CHEERLEADER	CL
	CROSS COUNTRY	CC
	FIELD HOCKEY	FH
	GOLF	GO
	GYMNASTICS	GY
	SOCCER	SC
	SOFTBALL	SB
	SWIMMING	SW
	SYNCHRONIZED SWIMMING	SS
	TENNIS	TE
	TRACK	TR
	VOLLEYBALL	VB

APPENDIX H

SAMPLE RECORDING FORM

ORTHOTRON TESTING INFORMATION

ID NO	L-HAM	L-HAM	$\bar{X}$	L-QUAD	L-QUAD	$\bar{X}$	RATIO	R-HAM	R-HAM	$\bar{X}$	R-QUAD	R-QUAD	$\bar{X}$	RATIO	DIFF

APPENDIX I

RAW DATA - TEST RESULTS[a]

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
001	130	120	125	210	190	200	62.5	100	110	105	200	210	205	51.2	11.3
002	95	80	87.5	180	190	185	47.3	105	100	102.5	210	190	200	51.3	4.0
003	100	140	120	220	230	225	53.3	140	110	125	200	200	200	62.5	9.2
004	120	120	120	190	165	177.5	67.6	170	135	152.5	220	210	215	70.9	3.3
005	145	155	150	240	255	247.5	60.6	155	155	155	255	255	255	60.8	0.2
006	130	130	130	230	240	235	55.3	120	100	110	230	230	230	47.8	7.5
007	120	120	120	195	220	212.5	56.5	125	120	122.5	200	140	220	55.7	0.8
008	130	130	130	220	200	210	61.9	120	140	130	250	250	250	52.0	9.9
009	135	130	132.5	210	230	220	60.2	150	190	170	250	220	235	72.3	12.1
010	120	120	120	175	180	177.5	67.6	110	110	110	210	190	200	55.0	12.6
011	150	150	150	240	230	235	63.8	140	130	135	230	220	225	60.0	3.8
012	135	125	130	190	180	185	70.3	95	105	100	185	180	182.5	54.8	15.4
013	90	85	87.5	150	150	150	58.3	90	100	95	135	150	142.5	66.7	8.4
014	160	135	147.5	190	190	190	77.6	170	155	162.5	150	145	147.5	110.2	32.6
015	130	140	135	190	185	187.5	72.0	125	140	132.5	185	190	187.5	70.7	1.3

[a]all readings are in foot-pounds of torque

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
016	120	130	125	150	150	150	83.3	125	135	130	170	165	167.5	77.6	5.7
017	120	130	125	170	185	177.5	70.4	120	140	130	140	200	170	76.5	6.1
018	110	120	115	145	140	142.5	80.7	105	110	107.5	125	140	132.5	81.1	0.4
019	120	120	120	120	135	127.5	94.1	115	125	120	150	160	155	77.4	16.7
020	120	135	127.5	170	160	165	77.3	160	160	160	180	175	177.5	90.1	12.8
021	80	80	80	160	165	162.5	49.2	80	60	70	150	165	157.5	44.4	4.8
022	115	100	107.5	190	195	192.5	55.8	120	130	125	190	195	192.5	64.9	9.1
023	120	145	132.5	160	195	177.5	74.7	95	115	105	175	180	177.5	59.2	15.5
024	95	135	115	165	170	167.5	68.7	115	110	122.5	190	185	187.5	60.0	8.7
025	70	55	62.5	115	120	117.5	53.2	95	80	87.5	130	120	125	70.0	16.8
026	75	80	77.5	135	130	132.5	58.5	55	85	70.0	140	195	167.5	41.8	16.7
027	120	110	115	180	175	177.5	64.8	110	105	107.5	175	185	180	59.7	5.1
028	80	100	90	155	150	152.5	59.0	75	95	85	140	155	147.5	57.6	1.4
029	120	120	120	170	185	177.5	67.6	95	120	107.5	200	205	202.5	53.1	14.5
030	105	120	112.5	190	170	180	62.5	90	90	90	220	200	210	42.9	19.6

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
031	160	155	157.5	260	240	250	63.0	140	150	145	295	280	287.5	50.4	12.6
032	110	130	120	150	160	155	77.4	105	90	97.5	175	170	172.5	56.5	20.9
033	90	80	87.5	155	160	157.5	55.6	110	115	112.5	175	185	180	62.5	6.9
034	115	100	107.5	190	180	185	58.1	160	145	152.5	210	205	207.5	73.5	15.4
035	115	100	107.5	190	180	185	58.1	140	140	140	205	190	197.5	70.9	12.8
036	185	160	172.5	250	210	230	75.0	170	205	187.5	270	260	265	70.8	4.2
037	90	105	97.5	195	185	190	51.3	85	90	87.5	195	195	195	44.9	6.4
038	80	90	85	145	135	140	60.7	75	85	80	150	145	147.5	54.2	6.5
039	90	120	105	165	185	175	60.0	110	115	112.5	180	180	180	62.5	2.5
040	105	105	105	160	155	157.5	66.7	105	115	110	185	185	185	59.5	7.2
041	160	160	160	210	185	197.5	81.0	155	175	165	220	225	222.5	74.2	6.8
042	110	90	100	180	175	177.5	56.3	115	120	117.5	200	190	195	60.3	4.0
043	110	110	110	170	165	167.5	65.7	110	125	117.5	185	190	187.5	62.7	3.0
044	85	110	92.5	130	145	137.5	67.3	95	95	95	140	140	140	67.9	0.6
045	75	85	80	120	120	120	66.7	60	80	70	115	120	117.5	59.6	7.1

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
046	120	100	110	180	170	175	62.9	130	135	132.5	165	155	160	82.8	19.9
047	130	100	115	165	160	162.5	70.8	105	140	122.5	170	175	172.5	71.0	0.2
048	120	130	125	185	185	185	67.6	90	105	97.5	170	200	185	52.7	14.9
049	145	150	147.5	195	185	190	77.6	105	130	117.5	205	220	212.5	55.3	22.3
050	135	125	140	200	200	200	65.0	130	145	137.5	190	205	197.5	69.6	4.6
051	105	100	102.5	135	135	135	75.9	115	115	115	145	150	147.5	78.0	2.1
052	140	140	140	205	195	200	70.0	110	135	122.5	215	205	210	58.3	11.7
053	120	140	130	215	230	222,5	58.4	90	115	102.5	215	245	230	44.6	13.8
054	95	120	107.5	160	165	162.5	66.2	60	75	67.5	190	175	182.5	37.0	29.2
055	120	150	135	195	205	200	67.5	110	120	115	185	170	177.5	64.8	2.7
056	115	125	120	200	190	195	61.5	120	120	120	205	205	205	58.5	3.0
057	115	120	117.5	210	190	200	58.8	130	120	125	225	215	220	56.8	2.0
058	125	120	122.5	190	195	192.5	63.6	105	90	97.5	215	200	207.5	47.0	16.6
059	105	115	110	160	150	155	71.0	130	95	112.5	175	155	165	68.2	2.8
060	95	100	97.5	180	175	177.5	54.9	90	105	97.5	200	200	200	48.8	6.1

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
061	130	120	125	195	185	190	65.8	150	150	150	205	195	200	75.0	9.2
062	110	100	105	205	205	205	51.2	160	155	157.5	230	225	227.5	69.2	18.0
063	90	85	87.5	150	140	145	60.3	70	85	77.5	110	150	130	59.6	0.7
064	80	90	85	160	170	165	51.5	90	90	90	145	145	145	62.1	11.3
065	90	95	92.5	115	115	115	80.4	80	90	85	120	115	117.5	72.3	8.1
066	100	110	105	155	150	152.5	68.9	90	120	105	175	175	175	60.0	8.9
067	135	125	130	205	195	200	65.0	120	125	122.5	200	200	200	61.3	3.7
068	135	120	127.5	185	180	182.5	69.9	130	120	125	200	185	192.5	64.9	5.0
069	70	80	75	105	120	112.5	66.7	90	95	92.5	130	130	130	71.2	4.5
070	80	80	80	145	150	147.5	54.2	95	85	90	165	140	152.5	59.0	4.8
071	100	120	110	165	155	160	68.8	120	120	120	165	170	167.5	71.6	2.8
072	90	105	97.5	135	135	135	72.2	90	95	92.5	150	145	147.5	62.7	9.5
073	85	85	85	170	180	175	48.6	75	85	80	145	160	152.5	52.5	3.9
074	80	95	87.5	140	140	140	62.5	85	95	90	140	150	145	62.1	0.4
075	75	70	72.5	140	150	145	50.0	75	70	72.5	135	140	137.5	52.7	2.7

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
076	130	120	125	150	165	157.5	79.4	120	110	115	155	130	142.5	80.7	1.3
077	90	100	95	140	140	140	67.9	90	90	90	135	125	130	69.2	1.3
078	130	135	132.5	170	165	167.5	79.1	115	105	110	190	180	185	59.5	19.6
079	115	115	115	215	200	207.5	55.4	125	115	120	215	205	210	56.0	0.6
080	115	105	110	170	160	165	66.7	130	135	132.5	185	180	182.5	72.6	5.9
081	100	95	97.5	155	140	147.5	66.1	100	115	107.5	165	165	165	65.2	0.9
082	115	110	112.5	155	150	152.5	73.8	110	110	110	160	155	157.5	69.8	4.0
083	125	130	127.5	175	165	170	75.0	125	140	132.5	185	180	182.5	72.6	2.6
084	105	115	110	175	170	172.5	63.8	105	120	112.5	205	205	205	54.9	8.9
085	170	150	160	200	200	200	80.0	160	175	167.5	215	215	215	77.9	2.1
086	130	140	135	165	170	167.5	80.6	120	130	125	170	165	167.5	74.6	6.0
087	85	100	92.5	170	155	162.5	56.9	85	90	87.5	180	170	175	50.0	6.9
088	85	90	87.5	150	150	150	58.3	95	100	97.5	150	150	150	65.0	6.7
089	105	105	105	135	140	137.5	76.4	110	110	110	155	145	150	73.3	3.1
090	120	130	125	195	200	197.5	63.3	120	120	125	220	220	220	56.8	6.5

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
091	115	125	120	200	195	197.5	60.8	100	115	107.5	210	200	205	52.4	8.4
092	130	105	117.5	175	165	170	69.1	120	125	122.5	180	175	177.5	69.0	0.1
093	120	125	122.5	165	170	167.5	73.1	105	115	110	180	185	182.5	60.3	12.8
094	90	105	97.5	185	175	180	54.2	90	105	97.5	180	180	180	54.2	0.0
095	85	95	90	150	155	152.5	59.0	90	90	90	140	155	147.5	61.0	2.0
096	80	85	82.5	135	130	132.5	62.3	90	95	92.5	115	105	110	84.1	21.8
097	60	70	65	145	135	140	46.4	60	60	60	100	125	112.5	53.3	6.9
098	115	130	122.5	190	170	180	68.1	120	120	120	205	200	202.5	59.3	8.8
099	120	125	122.5	125	200	207.5	59.0	145	145	145	205	300	202.5	71.6	12.6
100	120	125	122.5	185	180	182.5	67.1	125	130	127.5	185	185	185	68.9	1.8
101	75	90	82.5	145	150	147.5	55.9	80	95	87.5	140	140	140	62.5	6.6
102	70	80	75	155	145	150	50.0	65	85	75	145	150	147.5	50.9	0.9
103	55	60	57.5	135	115	125	46.0	60	65	62.5	110	120	115	54.4	8.4
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
106	70	90	80	160	185	172.5	46.4	70	80	75	135	155	145	51.7	5.3
107	100	105	102.5	185	155	170	60.3	105	105	105	160	185	172.5	60.9	0.6
108	110	110	110	205	195	200	55.0	95	110	102.5	195	215	205	50.0	5.0
109	100	100	100	95	115	105	95.2	85	105	95	70	100	85	111.8	16.6
110	95	105	100	160	140	150	66.7	100	100	100	165	155	160	62.5	4.2
111	180	200	190	255	250	252.5	75.3	200	230	215	265	270	267.5	80.4	5.1
112	80	85	82.5	165	160	162.5	50.8	85	90	87.5	160	165	162.5	53.9	3.1
113	100	105	102.5	195	195	195	52.6	110	120	115	210	200	205	56.1	3.5
114	125	130	127.5	200	195	197.5	64.6	120	130	125	215	225	220	56.8	7.8
115	85	95	140	155	147.5		61.0	80	80	80	125	160	142.5	56.1	4.9
116	180	185	182.5	275	250	262.5	69.5	180	175	177.5	270	270	270	65.7	3.8
117	120	120	120	210	215	212.5	56.5	130	130	130	240	220	230	56.5	0.0
118	90	100	95	150	150	150	63.3	90	90	90	180	170	175	51.4	11.9
119	130	170	150	200	185	192.5	77.9	130	145	137.5	200	210	205	67.1	10.8
120	110	105	107.5	190	180	185	58.1	120	120	120	180	180	180	66.7	8.6

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
121	90	105	97.5	105	115	110	88.6	105	100	102.5	95	125	110	93.2	4.6
122	100	120	110	210	190	200	55.0	105	90	97.5	195	190	192.5	50.7	4.3
123	90	100	95	165	155	160	59.4	110	115	112.5	185	175	180	62.5	3.1
124	165	150	157.5	230	210	220	71.6	170	160	165	235	230	232.5	71.0	0.6
125	95	95	95	170	160	165	57.6	115	105	110	195	185	190	57.9	0.3
126	110	100	105	155	145	150	70.0	115	105	110	160	150	155	71.0	1.0
127	80	95	87.5	170	175	172.5	50.7	80	75	77.5	170	170	170	45.6	5.1
128	145	180	162.5	215	200	207.5	78.3	165	145	155	290	220	255	60.8	17.5
129	80	80	80	180	170	175	45.7	75	85	80	180	175	177.5	45.1	0.6
130	85	100	92.5	180	175	177.5	52.1	90	95	92.5	180	200	190	48.7	3.4
131	120	130	125	180	170	175	71.4	100	130	115	200	185	192.5	59.7	11.7
132	100	105	102.5	160	190	175	58.6	115	110	112.5	215	190	202.5	55.6	3.0
133	120	120	120	165	170	167.5	71.6	140	135	137.5	185	200	192.5	71.4	0.2
134	70	65	67.5	140	130	135	50.0	80	85	82.5	145	145	145	56.9	6.9
135	90	75	82.5	160	150	155	53.2	85	105	95	190	210	200	47.5	5.7

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
136	70	80	75	115	125	120	62.5	85	75	80	135	130	132.5	60.4	2.1
137	110	110	110	170	160	165	66.7	110	110	110	180	160	170	64.7	2.0
138	90	85	87.5	150	147.5		59.3	75	85	80	140	170	155	51.6	7.7
139	165	160	162.5	205	180	192.5	84.4	140	155	147.5	215	225	220	67.1	17.3
140	105	100	102.5	150	160	155	66.1	105	100	102.5	180	160	170	60.3	5.8
141	135	155	145	170	150	160	90.6	135	150	142.5	175	175	175	81.4	9.2
142	80	90	85	150	120	135	63.0	95	85	90	165	165	165	54.6	8.4
143	65	60	62.5	95	130	112.5	55.6	85	70	77.5	155	160	157.5	49.2	6.4
144	85	90	87.5	120	105	112.5	77.8	95	85	90	155	135	145	62.1	15.7
145	55	75	65	150	145	147.5	44.1	65	65	65	120	135	127.5	51.0	6.9
146	80	80	80	150	160	155	51.6	70	80	75	140	140	140	53.6	2.0
147	90	85	87.5	125	110	117.5	74.5	80	85	82.5	115	140	127.5	64.7	9.8
148	105	95	100	160	140	150	66.7	115	120	117.5	185	165	175	67.1	0.4
149	90	95	92.5	120	120	120	77.1	65	85	75	115	130	122.5	61.2	15.9
150	120	120	120	165	170	167.5	71.6	110	125	117.5	175	120	192.5	61.0	10.6

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
151	110	110	110	200	175	187.5	58.7	80	110	95	200	185	192.5	49.4	9.3
152	85	80	82.5	150	140	145	56.9	90	85	87.5	140	145	142.5	61.4	4.5
153	70	80	75	155	145	150	50.0	60	80	70	135	140	137.5	50.9	0.9
154	75	85	80	165	170	167.5	47.8	60	70	65	155	165	160	40.6	7.2
155	75	95	85	170	175	172.5	49.3	80	85	82.5	195	200	197.5	41.8	7.5
156	75	80	77.5	150	135	142.5	54.4	100	90	95	165	150	157.5	60.3	5.9
157	120	135	127.5	200	120	205	62.2	120	140	130	225	195	120	65.0	2.8
158	75	90	82.5	105	110	107.5	76.7	50	60	55	100	80	90	61.1	15.6
159	130	120	125	200	190	195	64.1	110	120	115	195	210	202.5	56.8	7.3
160	90	110	100	130	125	127.5	78.4	130	100	115	150	170	160	71.9	6.5
161	100	110	105	130	145	137.5	76.4	120	120	125	125	160	142.5	87.7	11.3
162	100	120	110	190	165	177.5	62.0	105	125	115	205	195	200	57.5	4.5
163	105	105	105	205	195	200	52.5	95	115	105	190	210	200	52.5	0.0
164	90	75	82.5	180	170	175	47.1	135	130	132.5	195	205	200	66.3	19.2
165	120	120	120	185	160	172.5	69.6	120	115	117.5	170	165	167.5	70.2	0.6

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
166	130	135	132.5	175	155	165	80.3	130	135	132.5	180	170	175	75.7	4.6
167	120	150	135	200	195	197.5	68.4	80	130	105	200	205	202.5	51.9	16.5
168	115	110	112.5	170	165	167.5	67.2	100	100	100	200	200	200	50.0	17.2
169	105	105	105	170	160	165	63.6	120	125	122.5	160	160	160	76.6	13.0
170	110	100	105	160	165	162.5	64.6	110	120	115	200	190	195	59.0	5.6
171	100	120	110	195	200	197.5	55.7	145	110	127.5	200	200	200	63.8	8.1
172	70	80	75	115	135	125	60.0	100	70	85	145	150	147.5	57.6	2.4
173	100	110	105	140	150	145	72.4	130	100	115	180	150	165	69.7	2.7
174	80	85	82.5	150	155	152.5	54.1	80	60	70	150	140	145	48.3	5.8
175	90	70	80	90	110	95	84.2	110	100	105	120	140	130	80.8	3.4
176	100	100	100	165	155	160	62.5	120	100	110	190	170	180	61.1	1.4
177	100	130	115	210	190	200	57.5	140	110	125	225	205	215	58.1	0.6
178	90	110	100	115	130	122.5	81.6	90	105	97.5	125	135	130	75.0	6.6
179	175	175	175	200	190	195	89.7	130	175	152.5	190	225	207.5	73.5	16.2
180	70	75	72.5	125	135	130	55.8	65	65	65	140	155	142.5	45.6	10.2

APPENDIX I - Continued

ID NO	LEFT HAM	LEFT HAM	$\bar{X}$	LEFT QUAD	LEFT QUAD	$\bar{X}$	RATIO	RIGHT HAM	RIGHT HAM	$\bar{X}$	RIGHT QUAD	RIGHT QUAD	$\bar{X}$	RATIO	RATIO DIFF.
181	110	120	115	170	165	167.5	68.7	130	140	135	195	175	185	73.0	4.3
182	185	150	167.5	195	190	192.5	87.0	150	170	160	230	220	225	71.1	15.9
183	150	180	165	235	230	232.5	71.0	170	170	170	230	245	237.5	71.6	0.6
184	250	245	247.5	220	240	230	107.6	230	240	235	240	260	250	94.0	13.6
185	105	120	112.5	165	160	162.5	69.2	135	145	140	160	160	160	87.5	18.3
186	120	115	117.5	170	155	162.5	72.3	115	115	115	200	200	200	57.5	14.8
187	120	135	127.5	170	155	162.5	78.5	130	125	127.5	190	190	190	67.1	11.4
188	80	95	87.5	140	155	147.5	59.3	120	105	112.5	150	155	152.5	73.8	14.5
189	105	80	92.5	110	110	110	84.1	85	80	82.5	110	120	115	71.7	12.4
190	115	125	120	180	165	172.5	72.7	125	135	130	195	195	195	66.7	6.0