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An Investigation Into Isokinetic Normative Data of the Quadriceps and Hamstrings Muscles of Males and Females, Ages 36 Through 40

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This Thesis submitted by Renee L. Rud Mabey in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

Chairperson

This Thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

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TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

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ABSTRACT

Isokinetic exercise is a valid, reliable, and objective method of evaluating and improving muscle fitness. It is utilized in rehabilitation, athletics, and research. A common isokinetic tool is the Cybex II Isokinetic System®.

To be of maximal value, an instrument requires normative data specific to the population it was designed to test and train. This study establishes (selected) normative data for the quadriceps and hamstrings muscles of males and females ages 36 through 40.

Sixty adults, meeting specific age, medical, and activity requirements were tested on the Cybex II System. Reciprocal contractions of the quadriceps and hamstrings were performed at 60°/s, 180°/s, and 300°/s angular velocities. Peak torque measurements were measured, recorded, and then analyzed according to acceptable statistical methods.

The following results were obtained: Peak torque values for women were 49 to 58 percent of those for men. Mean peak torque values and T-scale scores were calculated for both sexes, both muscle groups, all velocities. No significant differences were found in torque values between kick dominant and nondominant lower extremities. Significant differences were found between torque dominant and nondominant muscle groups for both men and women; the difference was within 15 percent at 300°/s, and within 10 percent at the remaining velocities. The hamstrings to quadriceps ratio was 0.62 at 60°/s, 0.72 at 180°/s,

and 0.84 at 300°/s, and similar for males and females. Peak torque decreased with increasing velocity, but the percentage change varied between muscle groups and between sexes. The rate of tension development identified also varied between muscle groups and between males and females.

The isokinetic normative data, and the interrelationships established, will be useful in rehabilitative medicine when a "normal" contralateral limb is not physically or functionally available for comparative measurement; data will assist in goal setting and charting of progress. It will also assist in providing an age continuum of normative data so that age related changes in these muscle fitness components may be quantified.

CHAPTER I

INTRODUCTION

Isokinetic exercise, first introduced in the 1960's (Hislop and Perrine 1967) is recognized as a valid, reliable, and objective method of evaluating and improving muscle fitness. It is utilized in rehabilitative medicine, as a training/testing device for athletics, and as a scientific tool for research (Goslin and Charteris 1979).

To be of maximal value in testing and treatment, an instrument requires normative data; goals can then be set and progress charted. However, because isokinetic equipment is adaptable for testing and training of multiple muscle functions, multiple muscle groups, and individuals of a wide age range, the establishment of normative data is incomplete.

Nature of the Study

Isokinetic literally means "same speed." During isokinetic exercise, as a muscle contracts, the angular velocity of the responding limb segment is held constant. Because of this fixed speed, any increase in muscular effort produces an increase in muscular tension or force. Isokinetic devices apply resistance equal to the force generated. Isokinetic exercise has thus been called an "accommodating resistance exercise" (Thistle, Hislop, Moffroid, and Lowman 1967).

Isokinetic equipment assists in evaluating and improving muscular strength, endurance, power, and rate of tension development (Isolated

Joint . . . 1980). Strength is determined by a muscle's ability to generate tension or force. When a force acts about an axis of rotation, at a perpendicular distance from a joint, it is defined as torque. Isokinetic muscle strength is quantified as torque in foot-pounds. Torque measurements are necessary for calculations of endurance, work, power, and the rate of tension development.

Muscular endurance is the ability of the muscle to maintain high levels of performance. It is measured as the number of repetitions performed before a preset level of fatigue is noted (as measured by decreasing torque values). It can also be quantified as a ratio; specifically, it is the ratio of work performed during later repetitions to work performed at initial repetitions.

Work is traditionally defined as force times distance. During the angular displacement of isokinetic exercise, work equals torque (in foot-pounds) times two pi times the distance of the arc traveled (in degrees). In isokinetic exercise, power is the total work performed divided by the contraction time.

During functional activities, it often becomes necessary to generate tension quickly. The time rate of tension development is a function of neurological efficiency and muscular power (Isolated Joint . . . 1980). The rate of tension development is the rate of torque measured at 0.2 seconds to the peak torque developed; measurements will be obtained during a 60 degree per second angular velocity.

Evaluations of and training for muscle fitness can be performed at an infinite number of angular velocities. Angular velocity, the speed at which a limb segment moves about an axis of rotation, is measured in degrees per second (°/s). Static and dynamic exercise can be performed on isokinetic equipment, as the velocity selected can range from 0°/s to 300°/s.

Isokinetic exercise equipment can be adapted to multiple muscle groups, acting on multiple joints. It can be applied to the following functions: shoulder abduction/adduction, extension/flexion, horizontal abduction/adduction, internal/external rotation; elbow extension/flexion; forearm and wrist pronation/supination, extension/flexion; hip abduction/adduction, extension/flexion, internal/external rotation; knee extension/flexion, tibial internal/external rotation; ankle plantarflexion/dorsiflexion, and inversion/eversion.

Of the above joints and muscle groups, isokinetic equipment is most frequently utilized to evaluate the integrity of the knee joint, and to test and train its corresponding musculature. The primary muscle groups acting upon the knee are the quadriceps and hamstrings. The quadriceps extends the knee; the hamstrings flexes the knee. The strength, endurance, power, and rate of tension development of quadriceps and hamstrings are important measures for normal ambulation (walking, jogging, running, stair climbing, transfers) and in the prevention of knee injuries. Proper muscle fitness ratios between muscle groups and between extremities is also necessary.

Isokinetic equipment has proven useful for children and adults of all ages. However, most isokinetic data available today have been gathered at isometric or slow angular velocities; most researchers have studied human subjects who were less than 35 years old or from a select population. Isokinetic equipment allows for testing and training at faster limb velocities; and even though isometric and isotonic studies have shown changes in muscle performance with increasing age, only four isokinetic studies dealing with adults over age 35 were found; none included both males and females, an age continuum, and higher angular velocities.

This study established normative torque data for an older population, including the norms for high velocity muscle contraction. Specifically: 1) The peak torque values for the quadriceps and hamstrings muscles at 60°/s, 180°/s, and 300°/s were identified, for males and females, ages 36 through 40. Peak torque values were quantified in regard to kick dominant and nondominant lower extremities. 2) The absolute and percentage differences in peak torque between torque dominant and torque nondominant muscle groups were quantified. 3) The hamstrings to quadriceps torque ratio was given for all velocities. 4) The changes in peak torque with increasing velocity were given. 5) The rate of tension development was quantified (torque at 0.2 seconds, 60°/s) in absolute and relative terms.

Review of Literature

Instrumentation

The Cybex II Isokinetic System®* included an electrogoniometer and a dynamometer, with a duo-channel recording giving a continuous printout of the curve of range of motion, and the peak torque developed across the range of motion (Elliott 1978). The validity and reliability of the unit for measuring torque, work, range of motion (at 72°/s or less), power, and speed has been previously established (Moffroid, et al. 1969); the coefficients of validity and reliability identified

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*Cybex Division of Lumex, Inc., 2100 Smithtown Ave., Ronkonkoma, NY 11779.

ranged from r = 0.946 to r = 0.999. Molnar and Alexander (1973) found the isokinetic device to be "applicable and reliable" for children ages 5 through 15. Their test-retest reliability values were not significantly different at the $p < 0.01$ level of significance.

Isokinetic Exercise

Many of the advantages of isokinetic exercise are evident from an understanding of work physiology and isokinetic equipment. Other practical advantages become apparent with usage of the system. The advantages of isokinetic procedures are as follows:

Both static and dynamic muscle testing and training can be performed on the same device. Isokinetic exercise can be performed at varying speeds, thus greater specificity of exercise is achieved with this method than with conventional exercise.

With isometric resistive exercise, maximal tension is produced at a given angle only, and isometric training produces strength gains specific to the given joint angle (Pipes and Wilmore 1976). Isokinetic exercise produces changes in strength throughout the full range of motion.

Isotonic exercise, with a fixed resistance and variable speed, produces less work than isokinetic exercise, as the muscle must be loaded for the weakest point in its range. At stronger points, only a percentage of maximal tension is utilized with the given load. With isotonic strength training, gains made are not as great, nor are they made as quickly as with isokinetic exercise (Pipes and Wilmore 1975; Pipes and Wilmore 1976; Johnson 1980). Other researchers (DeLateur, Lehmann, Warren, Stonebridge, Funita, Cokelet, and Egbert 1972) found isotonic and isokinetic exercise equally effective in increasing muscle strength; however, their criterion measure utilized for strength was the number of repetitions performed.

Isokinetic speed adjustments can be made to match the speed of performance. With isotonic exercise, the limb speed rarely exceeds 60°/s, which is inadequate for training of "time critical" muscle tension. Functional movements occur faster than 60°/s, and some athletic performances require speeds exceeding 200°/s (Pipes and Wilmore 1975). Thorstensson, Grimby, and Karlsson (1976) recorded a maximal knee extension velocity of 687°/s. Isokinetic equipment is available to test/train at a 300°/s maximal velocity.

With motor performance testing (vertical jump, softball throw, 40 yard dash, two-handed sitting shotput, and standing long jump), isotonic training produced no improvement in scores. Isokinetic slow velocity training produced improvement in three tests; high velocity training enhanced scores in all but the standing long jump (Pipes and Wilmore 1975). Improvements in motor performance were also found by Von Oteghen (1975) in testing vertical jump ability following slow and fast speed isokinetic training.

Isokinetic training has proved superior to isotonic procedures in regard to anthropometric measures. Pipes and Wilmore (1975) identified a reduction in body fat and increased muscle mass following high velocity isokinetic exercise.

Both the agonist and the antagonist muscle groups can be exercised maximally, with no change in the position of the subject or of the equipment (Use of . . . 1975).

The concentric contraction of muscle during isokinetic exercise is followed by a passive recovery. No eccentric contraction occurs; the muscle soreness and associated weakness of a lengthening contraction is not present (Talag 1973; Pipes and Wilmore 1975).

If a person applies less torque force to the lever arm than that which is allowed for by the speed of contraction, no resistance is encountered. This avoids injury during testing or training; if muscular torque is suddenly decreased due to pain or weakness, no weight is left to fall on the limb (Elliott 1978).

During isokinetic exercise "no traction loading is placed on the ligaments or joints since the resistance is passively concentric" (Use of . . . 1975). Joint integrity is protected.

Motivation is provided for the subject, as he can visualize the gauge indicating his performance and strive for an improved tracing (Thistle, et al. 1967). Kenihan and Oakes (1981) state isokinetic equipment has "great patient acceptance and therefore compliance with treatment is excellent."

Torque curve printouts will show variations of strength in specific ranges due to weakness or pain from joint or muscle injury, congenital defects, tremor, or spasticity. Thus a more comprehensive evaluation is achieved (Thistle, et al. 1967; Use of . . . 1975).

The endurance capacity of the muscle is objectively and accurately determined isokinetically with less risk of injury. The subject performs a "perfect decreasing set"; he is always working at a maximum for each repetition or throughout the hold. And, as with strength testing/training, endurance factors can be specific to isometric, slow velocity, or high velocity performances.

Isokinetic exercise records are precise and permanent; they are acceptable in court. During personal injury settlements, they objectively classify the extent of disability and the capacity to function. Also, malingering and other deliberate submaximal efforts are identified; as the torque curve is spread out with increased paper speeds, reproduction of the exact curve (slope, shape, and peak values) of submaximal effort is impossible (Farmer 1979).

Only one disadvantage was identified. Isokinetic exercise at this time does not test eccentric muscle strength, an important criterion of joint stabilization. If the resistance to stretch could be measured, it could possibly be used as a predictor of injury and a preventative prescription for exercise given (Elliott 1978).

Normative Data

Generalized studies of normative data concern the establishment of peak torque values, the relationships of dominant and nondominant extremities and muscle groups, the relationship between agonist and antagonist muscle groups, the effects of velocity on peak torque, and the effects of aging on peak torque. Specific normative data which follow will be limited to the quadriceps and hamstrings muscles of adults and muscle fitness components of strength.

Dynamic isokinetic torque values will be less than isometric torque values. As contraction velocities increase, torque decreases (Rodgers and Berger 1974; Thorstensson, et al. 1976; Knapik and Ramos 1980; Scudder 1980; Murray, Gardner, Mollinger, and Sepic 1980). As the speed of contraction increases, maximal torque values tend to occur later in the range of motion cycle (Moffroid, Whipple, Hofkosh, Lowman, and Thistle 1969; Osternig 1975; Thorstensson, et al. 1976; Scudder 1980).

A significant difference is noted between strength values of the torque dominant and nondominant muscle groups (Goslin and Charteris 1979). Other researchers found significant differences between dominant and nondominant limbs when dominance is determined by hand dominance (Carter, et al. 1982). A significant difference may or may not be present between kick dominant and nondominant lower extremities; differences appear dependent upon the population tested (Wyatt and Edwards 1981; Mabey 1984).

Several researchers (Moffroid, et al. 1969; Carter, et al. 1982; Wyatt and Edwards 1981) have studied the hamstrings to quadriceps ratio. Generally, at slower speeds, the knee flexor torque is half that of the extensor torque. As the velocity of contraction increases, the ratio approaches unity.

Conventional exercise techniques have shown that, with aging, there is a degeneration of maximal muscle tension capability. There is an estimated 20 percent loss between the ages of 25 and 60 years; the largest percentage of decrease occurring after age 45 (Astrand 1977, page 123). Murray, Baldwin, Gardner, Sepic, and Downs (1977), using isokinetic equipment at 0°/s and three knee joint positions, supported this. Larsson, Grimby, and Karlsson (1979) found isometric and isokinetic values to increase up to the third decade of life, remain constant to the fifth decade, and then decrease with increasing age; their study involved males only at isokinetic velocities equal to or less than 180°/s. Murray, et al. (1980) found significantly different torque values (0°/s and 36°/s) between young men (ages 20 to 35 years) and older men (ages 50 to 65 and 70 to 86); no significant difference was found in torque values between the older groups. Johnson (1982) found younger women (ages 20 to 29) had higher isometric and dynamic (10 rpm) torque outputs than older women (ages 50 to 80).

In addition to the peak torque values established for the age groups noted above, Carter, et al. (1982) established torque data for males and females, 20 to 35 years of age, at 60°/s and 180°/s velocities. Wyatt and Edwards (1981) established data for 60, 180, and 300°/s contractions for a population 25 to 34 years of age. Molnar and Alexander (1974) developed standards for children ages 7 through 15 at 30°/s.

In summary, although many studies were found concerning isokinetic exercise, and quadriceps/hamstrings isokinetic data, only a few articles were found concerning norms for older adults, of both sexes, for a wide range of limb velocities. This study hopes to partially fulfill these areas of need.

CHAPTER II

PROCEDURES

Approval to perform this study was given initially by the Master's Advisory Committee, via the thesis outline. The thesis outline was also approved by the Graduate School. Approval for the use of human subjects was obtained from the HPER Review Committee at the University of North Dakota; permission was granted following an expedited review of the proposed project.

Instrumentation

All testing was performed on the Cybex II Isokinetic System®, located at the Medical Center Rehabilitation Hospital. Permission to use the equipment and facility was obtained from the Physical Therapy Department and the Office of Clinical Development at the Medical Center Rehabilitation Hospital.

The system components included an electrogoniometer and dynamometer, S-H-D tables, and a duo-channel recorder. The instrumentation was calibrated monthly, according to procedures outlined by the manufacturer (*Cybex II Calibration* . . . 1982).

Subjects

All subjects tested were volunteers from Grand Forks, North Dakota, and the surrounding communities. Presentations to solicit volunteers for the study were made at various civic organizations, churches, and institutions (see Appendix A). Public service announcements were made through public broadcasting companies (see Appendix A). Volunteers were also accepted via "word of mouth" avenues.

All subjects were 36 through 40 years of age, with no recent history of back, hip, knee, or ankle injury; any recurring complication from an old injury, or any surgical procedure to the above areas, excluded the individual from the study. The subjects also had no history of back, hip, knee, or ankle musculoskeletal disease. The subject's general medical status did not contraindicate exercise; specifically, there was no history of cardiopulmonary pathology which previously or presently would limit exercise. No subject was presently participating in a professional sport or involved in isokinetic training. Screening for the above age, medical, and activity criteria was accomplished via verbal questioning. Subjects were expected to answer the questions honestly.

Each subject understood that he could terminate his participation at any point in the procedures. If a subject chose to terminate his participation prior to test completion, none of the data collected from him were used in the study. If a subject participated, but felt unable to give a maximal effort due to pain or instability, his data were also not admissable. Screening and testing of subjects continued until 60 subjects (30 males, 30 females) had completed all testing sequences.

Testing Procedures

Upon arrival for testing, a brief verbal and written explanation of isokinetic exercise and testing procedures was given. The subject signed a consent form (see Appendix B) covering an explanation of isokinetic exercise, the purpose for the study, and a release of liability. Screening for age, medical, and activity criteria was performed. Height and weight were measured. Lower extremity kick dominance was determined by questioning and/or demonstration. Data were recorded on the Data Sheet (see Appendix C). The subject was asked to wear comfortable, loose fitting clothing.

For testing procedures, the subject was seated on the Cybex S-H-D table, with the backrest at the most upright position allowable. Stabilization was accomplished via placement of velcro straps across the chest, pelvis, and distal thigh. The axis of rotation of the dynamometer input shaft and the subject's knee were aligned. The tibial pad was placed on the distal third of the tibia and secured with a velcro strap. During practice and testing procedures, the subject held on to the bench or handgrips for additional stabilization. Subject and equipment positioning is illustrated in Figure 1.

The Cybex II Dual Channel Recorder was adjusted for a Torque Channel damping of "2," and a foot-pound scale of 180. However, if the torque output during the practice sequence exceeded 180 foot-pounds, the 300 foot-pound scale was utilized. On the Position Angle Channel, a degrees scale of 150 was used, and the input direction was adjusted as appropriate. During testing, the ROM was monitored to assure each subject achieved complete extension and at least 90° of knee flexion. The paper speed was set at 25 mm/sec with the 60°/s test velocity; a 5 mm/sec paper speed was utilized at the 180°/s and 300°/s velocities.

Figure 1. The Cybex II Isokinetic System, with positioning for hamstrings and quadriceps testing and training.

Testing sequences of 60°/s, 180°/s, or 300°/s were chosen randomly. Choice of limb on which to begin testing was also chosen randomly. Random selection was made by each subject "drawing from a hat."

After an explanation of the specific test to be performed, namely the velocity to be used, the subject performed five to ten maximal reciprocal contractions as a warm-up and learning tool. A rest period of at least two minutes followed. The subject then performed five maximal reciprocal contractions of the quadriceps and hamstrings; the torque produced during extension and flexion was recorded. Verbal encouragement to "push as hard and as fast as possible" was given preceding and during the test. A rest period of greater than two minutes was given before repeating the sequence with another velocity.

Data Reduction

Peak foot-pounds of torque for each muscle group at all velocities, and the torque developed at 0.2 seconds of contraction, 60°/s velocity, was measured from the recorder strips. Peak torque measurements were obtained using methods outlined by the manufacturer (<u>Isolated Joint</u> . . . 1980); the method used for obtaining and interpreting torque at 0.2 seconds, 60°/s velocity followed procedures utilized in an earlier study (Carter, et al. 1982). Torque values were recorded on the Data Sheet (see Appendix C). All recorder strip torque reduction was performed by a single individual to assure consistency and accuracy of interpretation.

Statistical Analysis

Means and standard deviations were calculated for the heights and weights of the volunteers. The number of right and left kick dominant individuals was determined from the data sheets.

Analysis of variance was utilized to determine if a significant difference existed in any torque value between males and females. A Pearson correlation coefficient determined if a significant relationship existed between height or weight and the quadriceps and hamstrings peak torque at 60°/s, 180°/s, and 300°/s. Multiple classification ANOVA was then utilized to determine if a difference in torque development existed between males and females when height and weight were accounted for statistically.

Peak torque means and standard deviations were determined for the quadriceps and hamstrings at 60°/s, 180°/s, and 300°/s velocities. Data were classified according to kick dominant and nondominant lower extremities. A table was made to array the results. A t-test for matched pairs was utilized to determine if a significant difference existed between kick dominant and nondominant lower extremities.

Peak torque means and standard deviations were determined for the torque dominant and nondominant muscle groups, all velocities. A table was made to array the results. A t-test for matched pairs determined if the absolute difference between the muscle groups was significant. The ratio between nondominant and dominant muscle groups was calculated.

A t-test for matched pairs was utilized to determine if the absolute difference in quadriceps and hamstrings peak torque was significant. The hamstrings:quadriceps ratio was calculated for all velocities.

A t-test for matched pairs was utilized to determine if the difference in quadriceps or hamstrings peak torque between velocities was significant. The percentage change in torque between velocities was calculated for both muscle groups.

Means and standard deviations were calculated for the absolute torque values at 0.2 seconds, 60°/s. These values were also converted to percentages of the mean peak torque at 60°/s.

Significance for all statistical tests was accepted at the $p < 0.05$ level.

Experimental Design

The study was quasi-experimental in nature. A single group of adults, ages 36 through 40, was seen one time only for testing of quadriceps and hamstrings peak torque at selected angular velocities; the rate of tension development was also calculated from the torque curves generated at 60°/s. The group of volunteers was subdivided according to gender.

Independent, dependent, and organizational variables were identified. The sex of the volunteer (male, female), the muscle group tested (quadriceps, hamstrings), and the angular velocity utilized (60°/s, 180°/s, 300°/s) were independent variables. The quadriceps and hamstrings isokinetic peak torque at each velocity and the torque at 0.2 seconds (60°/s velocity) were dependent variables. The results were categorized according to the sex of the individual, the muscle group tested, and the angular velocity utilized. The kick dominant and nondominant limbs, and torque dominant and nondominant muscle groups, were extraneous variables.

Limitations of the study included three factors. If a volunteer misrepresented his medical status, or was not highly motivated, the submaximal performance altered the group mean peak torque and related ratios. The level of fitness of a volunteer also affected the results. A highly fit, or poorly fit, individual would alter the mean and skew the data.

Pilot Study

A pilot study was performed on a similar group of fourteen available subjects who met the same medical and activity criteria. The pilot study confirmed the study procedures, and verified inter-tester reliability of data recording. Raw data from the pilot study are summarized in Appendix D.

CHAPTER III

Data identifying the physical characteristics of the volunteers are given in Table 1. Means and standard deviations for height and weight are identified. Twenty-eight of the 30 males and 25 of the 30 females were right kick dominant.

TABLE 1

PHYSICAL CHARACTERISTICS OF VOLUNTEERS

	Males	Females
Number	30	30
Height	70.6 ± 2.4	63.7 ± 2.0
Weight	181.0 ± 24.0	138.6 ± 23.8
(R) Kick Dominant	28	25
(L) Kick Dominant	2	5

ANOVA determined that significant differences ($p < 0.01$) existed in peak torque development between men and women. These differences existed even when the effects of height and weight were accounted for statistically. Table 2 identifies the ratios between the sexes for both muscle groups, all velocities. Because of these differences, all further data were categorized according to the sex of the individual.

TABLE 2

PEAK TORQUE RATIOS, FEMALES:MALES

	60°/s	180°/s	300°/s
Quadriceps	0.57	0.54	0.50
Hamstrings	0.54	0.53	0.49

The means and standard deviations for peak torque development of both muscle groups, all angular velocities are presented in Table 3. Torque values for kick dominant and nondominant lower extremities are given separately and collectively. The foot-pound difference between kick dominant and nondominant lower extremities was not significant for either sex. Standard scores for quadriceps and hamstrings peak torques are given for males in Appendix E and for females in Appendix F.

TABLE 3

PEAK TORQUE DEVELOPMENT OF THE QUADRICEPS AND HAMSTRINGS

Velocity	Torque, in foot-pounds					
	Quadriceps			Hamstrings		
	Dominant* **	Nondominant* **	$\bar{X}$	Dominant* **	Nondominant* **	$\bar{X}$
			Males			
60°/s	153 ± 22	145 ± 27	149 ± 22	96 ± 17	93 ± 16	94 ± 16
180°/s	94 ± 17	93 ± 20	93 ± 18	60 ± 13	67 ± 23	69 ± 12
300°/s	64 ± 15	61 ± 16	62 ± 15	53 ± 12	51 ± 14	52 ± 13
			Females			
60°/s	84 ± 14	84 ± 14	84 ± 14	52 ± 9	50 ± 8	51 ± 8
180°/s	50 ± 9	49 ± 12	50 ± 10	36 ± 7	36 ± 7	36 ± 6
300°/s	31 ± 7	30 ± 7	31 ± 7	26 ± 6	26 ± 7	26 ± 6

*Dominance determined by lower extremity kick preference.

**No significant difference was found between kick dominant and nondominant lower extremities.

The absolute differences and the ratio between torque dominant and nondominant muscle groups are presented in Table 4 and Table 5. A greater torque value at each velocity determined torque dominance; a given lower extremity was not necessarily torque dominant throughout all tested velocities. A significant difference ($p < 0.01$) was found between between torque dominant and nondominant muscle groups at all velocities. At 60°/s and 180°/s, the difference was 10 percent or less; at 300°/s, a greater percentage of difference was noted. The percentage difference between torque dominant and nondominant muscle groups was similar for males and females.

TABLE 4

PEAK TORQUE DEVELOPMENT OF TORQUE NONDOMINANT AND DOMINANT MUSCLE GROUPS

			Velocity		
			60°/s	180°/s	300°/s
MALES					
QUADRICEPS	TORQUE* in foot-pounds	nondominant	144 ± 26	90 ± 18	59 ± 16
		dominant	155 ± 22	96 ± 18	66 ± 14
		difference	11 ± 19	6 ± 4	7 ± 5
HAMSTRINGS	TORQUE* in foot-pounds	nondominant	90 ± 15	65 ± 12	48 ± 14
		dominant	98 ± 16	71 ± 12	55 ± 12
		difference	8 ± 6	6 ± 5	7 ± 5
FEMALES					
QUADRICEPS	TORQUE* in foot-pounds	nondominant	82 ± 14	48 ± 11	29 ± 7
		dominant	86 ± 14	51 ± 10	32 ± 7
		difference	4 ± 3	4 ± 4	3 ± 3
HAMSTRINGS	TORQUE* in foot-pounds	nondominant	48 ± 8	34 ± 6	24 ± 7
		dominant	54 ± 8	38 ± 7	28 ± 6
		difference	6 ± 4	3 ± 3	4 ± 3

*A significant difference ($p < 0.01$) was found between all torque dominant and nondominant muscle groups.

TABLE 5

THE RATIO OF TORQUE NONDOMINANT
TO DOMINANT MUSCLE GROUPS

Velocity	Muscle	Torque Ratio nondominant:dominant	
		Males	Females
60°/s	Quadriceps	0.93	0.95
	Hamstrings	0.92	0.90
180°/s	Quadriceps	0.93	0.93
	Hamstrings	0.92	0.91
300°/s	Quadriceps	0.89	0.90
	Hamstrings	0.87	0.85

A t-test for matched pairs demonstrated a significant difference in peak torque between the hamstrings and quadriceps muscles ($p < 0.01$). Means of peak torque, absolute differences, and flexor:extensor ratios are given in Table 6. The hamstrings to quadriceps ratio increased with increasing velocities; the ratio for a given velocity was similar between the sexes.

TABLE 6

HAMSTRINGS AND QUADRICEPS PEAK TORQUE DIFFERENCES AND THE HAMSTRINGS TO QUADRICEPS RATIO

Velocity	Muscle Group	Torque in foot-pounds		Torque Ratio Hams:Quads	
		Males	Females	Males	Females
	Hamstrings	94 ± 16	51 ± 8		
60°/s	Quadriceps	149 ± 22	84 ± 14	0.63	0.61
	Difference	55 ± 16	33 ± 9		
	Hamstrings	68 ± 12	36 ± 6		
180°/s	Quadriceps	93 ± 18	50 ± 10	0.73	0.72
	Difference	25 ± 13	14 ± 6		
	Hamstrings	52 ± 13	26 ± 6		
300°/s	Quadriceps	62 ± 15	31 ± 7	0.84	0.84
	Difference	11 ± 11	5 ± 5		

A t-test for matched pairs demonstrated a significant difference ($p < 0.01$) in peak torque between velocities. The amount of change is identified in Table 7. Females demonstrated a greater decrease in peak torque between velocities than did males.

TABLE 7

THE CHANGE IN PEAK TORQUE WITH INCREASING VELOCITY

Velocity	Muscle Groups	Males		Females	
		Foot-Pounds Change	Percentage Change	Foot-Pounds Change	Percentage Change
60°/s to 180°/s	Quadriceps	56 ± 16	0.38	35 ± 6	0.42
	Hamstrings	26 ± 10	0.28	15 ± 4	0.29
60°/s to 300°/s	Quadriceps	87 ± 16	0.58	53 ± 10	0.63
	Hamstrings	42 ± 11	0.45	26 ± 5	0.51
180°/s to 300°/s	Quadriceps	31 ± 7	0.33	19 ± 5	0.38
	Hamstrings	16 ± 5	0.24	10 ± 3	0.28

The rate of tension development values are identified in Table 8. The absolute torque at 0.2 seconds, 60°/s is given, as well as the percentages of peak torque this represents. The rate of tension development, as a percentage of maximum, was greater for males than for females.

TABLE 8

THE RATE OF TENSION DEVELOPMENT

	Males		Females	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Torque at 0.2s/60°/s	107 ± 24	78 ± 17	54 ± 14	38 ± 9
Peak Torque 60°/s	149 ± 22	94 ± 16	84 ± 14	51 ± 8
Ratio	0.72	0.83	0.64	0.75

CHAPTER IV

DISCUSSION

The physical characteristics of this volunteer population compared favorably with those of the general population ages 35 to 44 years (U.S. Bureau of the Census 1982). Females of this group were 63.7 ± 2.0 inches in height and 138.6 ± 23.8 pounds in weight. The U.S. mean female height is 64.1 ± 2.5 inches and weight is 148 ± 35 pounds. The males of this group measured 70.6 ± 2.4 inches and 181 ± 24 pounds; U.S. means are 69.1 ± 2.7 inches and 178 ± 30 pounds. The females of this group were lighter than the general population and the males were approximately 1.5 inches taller.

Height and/or weight have been shown by other researchers to correlate positively with peak torque values (Molnar and Alexander 1973; Gilliam, Sady, Freedson, and Villanacci 1979; Gilliam, Villanacci, Freedson, and Sady 1979; Johnson 1982). Peak torque has been shown to differ significantly between the sexes (Goslin and Charteris 1979). This study supported the earlier findings. Multiple classification ANOVA performed between height-weight-sex and peak torque determined that significant strength differences existed between the sexes even when height and weight were accounted for; differences were significant at $p < 0.01$. Hoffman, Stauffer, and Jackson (1979) felt that lean body weight and height correlated better with strength than did total body weight and height measurements. Under these conditions, differences between male and female cadets were due to upper body, and not lower body, strengths.

When dealing with raw scores, males are acknowledged as having greater strength than females. Harris (1980) stated adult males are 30 to 40 percent stronger than adult females. Petrofsky, Burse, and Lind (1975) found female isometric handgrip strength to be 57 percent of male strength. While not stating a "significant" difference exists between the sexes, Wyatt and Edwards (1981) presented isokinetic data for the two groups separately; investigation of the peak torque data of their study revealed a female to male ratio of 0.58 to 0.60 for both quadriceps and hamstrings at three test velocities. Other researchers (Carter, et al. 1982) found similar ratios. The present data, with smaller female:male ratios at increasing velocities, were not expected. Strength differences between individuals has been attributed to variations in muscle size; i.e., the cross sectional areas (Clark 1975, page 49) and muscle fiber type distribution (Inbar, Kaiser, and Tesch 1981). Research suggests female to male strength differences occur because of variations in muscle mass distribution and/or dissimilarity of use and/or variations in body size (Hoffman, et al. 1979; Harris 1980). Of these, unequal demands for high speed muscle contraction would seem the most plausible explanation for the differing ratios with increasing velocity.

Peak torque values found in this study are compared to those of earlier studies (Wyatt and Edwards 1981; Carter, et al. 1982) in Table 9. Testing and interpretive techniques were similar, but not identical, in the three studies.

TABLE 9

PEAK TORQUE VALUES: A SUMMARY OF THREE STUDIES

		Mabey*	Wyatt Edwards* 1981	Carter Johnson Dowd** 1982
age		36-40	25-34	20-35
N		30	50	60
MALES				
60°/s	Quadriceps	149 ± 22	135 ± 23	144 ± 24
	Hamstrings	94 ± 16	96 ± 17	82 ± 16
180°/s	Quadriceps	93 ± 18	97 ± 14	87 ± 16
	Hamstrings	68 ± 12	75 ± 14	61 ± 10
300°/s	Quadriceps	62 ± 15	66 ± 12	
	Hamstrings	52 ± 13	54 ± 12	
FEMALES				
60°/s	Quadriceps	84 ± 14	79 ± 15	80 ± 12
	Hamstrings	51 ± 8	56 ± 12	48 ± 9
180°/s	Quadriceps	50 ± 10	57 ± 10	48 ± 7
	Hamstrings	36 ± 6	45 ± 9	35 ± 6
300°/s	Quadriceps	31 ± 7	38 ± 8	
	Hamstrings	26 ± 6	32 ± 8	

*values are for $\overline{X}$ of both lower extremities.
**values are for dominant lower extremity.

The population of this study demonstrated greater quadriceps torque at 60°/s than did the other populations. The population of Wyatt and Edwards (1981) demonstrated greater torque development for all remaining muscle groups and velocities. Subject values in this study exceeded all values found by Carter, et al. (1982), even though their population was younger. Further conclusions cannot be drawn, as differences in recorded peak torques occur between populations with procedures (subject positioning and stabilization, cues) and in data reduction (maximum torque values of a single repetition were used in this study, and by Carter, et al. (1982); Wyatt and Edwards (1981) did not state if the peak torque values of one repetition were utilized or if a mean of several repetitions was calculated).

This population showed no significant difference in peak torque development between kick dominant and nondominant lower extremities for either sex. This is in partial disagreement with other studies. Wyatt and Edwards (1981) demonstrated a significant difference ($p < 0.01$) between kick dominant/nondominant lower extremities of males ages 25 through 34; their female population demonstrated no significant differences. Mabey (1984) found a significant difference for males, but not for females, in a population ages 36 through 50, under conditions identical to the current study. Perhaps the isolated male age group of this study, in variance with other studies, participated in occupational and recreational activities placing equal demand on both lower extremities or had a lack of stresses to develop a dominant limb. The activity statements of the volunteers would appear to support this. Of the 30 males tested, 13 exercised three or more times per week; the preferred mode was bicycling or jogging. Of the remaining individuals, ten had no activity separate from their occupation and seven exercised "occasionally." The activity statements of the females were similar; fifteen exercised regularly, four exercised "occasionally," and eleven had no supplemental exercise demands. The exercise modes preferred by the female group were bicycling and walking. Very few individuals, male or female, were employed in jobs demanding physical labor.

Comparisons between the lower extremities have been made by other researchers also, using different comparison criteria. Carter, et al. (1982) found differences in the lower extremities when dominance was determined according to hand dominance. Goslin and Charteris (1979) found no significant differences between right and left lower extremities. Gilliam, Sady, et al. (1979), testing high school football players, found significant differences between right and left for slow quadriceps extension (30°/s) and fast hamstrings flexion (180°/s). Smith, Quinney, Wenger, Steadward, and Sexsmith (1981) found right to left muscle imbalances dependent upon hockey skills required for a given player position.

The differences in strength between torque dominant and nondominant legs in this study was less than 10 percent at 60°/s and 180°/s; the difference was 15 percent or less for 300°/s velocity. Results were similar between quadriceps and hamstrings, males and females. This is a smaller percentage difference than found by Goslin and Charteris (1979). Their ratio (torque nondominant to dominant) was 86.7 percent for males and 81.7 percent for females; quadriceps only were tested at 30°/s. No other isokinetic studies were found dealing with absolute differences in strength between the stronger and weaker extremities.

The hamstrings to quadriceps ratio is related to joint stability and injury prevention. It is derived from peak torque values, and therefore dependent upon positioning of the subject, speed of contraction, data reduction methods, and the population tested. In the studies cited below, subjects were sitting and participating in reciprocal contractions. Raw torque scores were not corrected for gravity (Isolated Joint . . . 1980; Nelson and Duncan 1983). And whereas the flexor to extensor ratio has been shown to vary according to athletic demands (Gilliam, Sady, et al. 1979; Smith, et al. 1981), the subjects of the compared studies were volunteers without professional or varsity sport training.

The results of this study (male hamstrings to quadriceps ratios of 0.63, 0.73, 0.84 at 60, 180, and 300°/s, respectively and female ratios of 0.61, 0.72, and 0.84) were in good agreement with the study by Carter, et al. (1982) whose ratios were 0.60 at 60°/s and 0.75 at 180°/s. The ratios identified by Wyatt and Edwards (1981)--0.72 (0.71), 0.78 (0.79), 0.83 (0.85) for males (females) at 60, 180, and 300°/s, were similar at the fast velocity, but dissimilar at slow and medium velocities.

Comparisons of the hamstrings to quadriceps ratio with any other studies were difficult due to differing procedures or velocities; other findings are summarized as follows: a flexor to extensor ratio of 1:2 at 22.5°/s (Moffroid, et al. 1969); 1:2.25 at 30°/s (Goslin and Charteris 1979); 0.62, with less than 3 percent variation between velocities of 0°/s to 90°/s (Scudder 1980); 0.51 at 0°/s and 30°/s (Knapik and Ramos 1980); 0.67-0.70 at 30°/s and 0.80 at 180°/s (Campbell and Glenn 1982).

This study supported the findings of other researchers in that increased angular velocity resulted in decreased peak torque production (Moffroid, et al. 1969; Thorstensson, et al. 1976; Murray, et al. 1980; Scudder 1980; Knapik and Ramos 1980; Wyatt and Edwards 1981). The ability to produce torque at high velocities has been correlated with fast twitch muscle fibers; the percentage, as well as relative area of the fibers, contribute to the muscle's capabilities (Thorstensson, et al. 1976). The amount of tension developed in a muscle is also determined by the number of cross-bridge formations; as the speed of contraction increases, decreased time for cross-bridge formation occurs; decreased tension is developed (Murray, et al. 1980). Again, comparisons could only be drawn between the study and the ones by Wyatt and Edwards (1981) and Carter, et al. (1982); test procedures or velocities of the other researchers did not coincide with those used in this study. Differences were noted between the populations, in that this study showed a greater decrease in peak torque between 60 and 180°/s and 60 and 300°/s velocities. This was directly related to differences noted earlier in peak torque. Results of this study were most closely identified with changes seen by Carter, et al. (1982); see Table 10.

TABLE 10

PERCENTAGE CHANGE IN PEAK TORQUE WITH INCREASING VELOCITIES; A SUMMARY OF THREE STUDIES

		Mabey		Wyatt Edwards 1981		Carter Johnson Dowd* 1982	
		Males	Females	Males	Females	Males	Females
60°/s to 180°/s	Quadriceps	38	42	28	28	40	40
	Hamstrings	28	29	22	20	26	27
180°/s to 300°/s	Quadriceps	33	38	32	33		
	Hamstrings	24	28	28	29		
60°/s to 300°/s	Quadriceps	58	63	49	52		
	Hamstrings	45	51	44	43		

* values are reported for dominant lower extremity.

The present study demonstrated a greater decrease in peak torque between velocities for females than males; sex differences were not as apparent in the other studies. This again suggested activity influences on peak torque development at high velocities for this group of males and females.

The rate of tension development found in this study can only be compared with the earlier study by Carter, et al. (1982); this study utilized their methods of obtaining and reducing the raw data. Some differences were noted between the results of the two studies.

Their population developed 60 to 63 percent of quadriceps peak torque, and 70 to 73 percent of hamstrings peak torque, in the preset 0.2 seconds; results for males and females were nearly identical. In this study, females developed 64 percent and males 72 percent of peak quadriceps torque in the given time period. The hamstrings percentages were 75 percent for females and 83 percent for males. Female rates between the studies were similar. (It should also be remembered that the values for peak torque between the two studies were more similar for females than males.) This suggested the female populations were similar in abilities, whereas perhaps the activity demands of the males in the present study called for development of strength quickly. Other factors, such as verbal encouragement and motivation, could have affected the data, both in the peak torque values and the production of maximal effort early in the contraction.

Finally, as noted earlier, a need for norms based on an age continuum exists. These data represent the initial efforts to gather data for a population of males and females, 36 through 50, at 60°/s, 180°/s, and 300°/s angular velocities. Age related data will be interpreted when the entire study is completed.

CHAPTER V

CONCLUSION

In summary, selected isokinetic normative data were established for males and females, ages 36 through 40. The following conclusions were made:

Significant differences were present in absolute peak torque values between males and females, even when the effects of height and weight were accounted for statistically. Generally, female torque values were 49-58 percent of male torque values. Data were categorized according to the sex of the individual.

Peak torque normative data for the quadriceps and hamstrings muscles were identified. Values were reported for kick dominant and nondominant extremities separately and collectively. No significant differences were present in torque values between knees, for either males or females, at any test velocity.

Significant differences were demonstrated between torque dominant and torque nondominant quadriceps and hamstrings. The differences were within 10 percent variation at 60°/s and 180°/s velocities, and within 15 percent at 300°/s. Differences were similar between males and females.

The hamstrings to quadriceps ratio, which is peak torque and velocity dependent, was approximately 0.62 at 60°/s, 0.72 at 180°/s, and 0.84 at 300°/s. Again, ratios were similar for males and females.

Peak torque decreased with increasing angular velocity. A decrease of 58 and 63 percent, males and females respectively, was seen in quadriceps peak torque between the 60°/s and 300°/s velocities. Hamstrings peak torque decreased 45 and 51 percent, males and females, for the corresponding velocities. The greater percentage change for females was probably due to differing occupational and recreational demands affecting peak torque production at high speeds of contraction; the differences between lower extremities, and the hamstrings to quadriceps ratios, remained similar between the sexes.

The rate of tension development varied between muscle groups and between sexes. The hamstrings developed a greater percentage of peak torque in 0.2 seconds than did the quadriceps. Males developed a greater percentage of peak torque than did females.

Finally, subjects for this study were volunteers from the general population of the Grand Forks, North Dakota area. It is hoped they are representative of the 36 through 40 year old clinical population seen at the Medical Center Rehabilitation Hospital for restoration of quadriceps and hamstrings function. However, by soliciting "volunteers for strength testing," this particular group of males and females may be more fit than a randomly selected sample or the population at large. It is also recognized that peak torque, and corresponding ratios, will vary according to the occupational and recreational demands placed on the individual. Care must be taken when generalizing the results found here to the parent population or populations elsewhere.

APPENDICES

APPENDIX A

VOLUNTEER SOURCES

VOLUNTEER SOURCES

Organizations

Sertoma's of Grand Forks
Grand Forks Kiwanis
Sunriser Kiwanis, Grand Forks, ND
Lions Club, Grand Forks, ND
Lioness Club, Grand Forks, ND
Grand Forks Rotary
Optimists Club, Grand Forks, ND
Lions Club, East Grand Forks, MN
Lioness Club, East Grand Forks, MN
East Grand Forks Rotary
Optimists Club, East Grand Forks, MN

Churches

Zion United Methodist Church, Grand Forks, ND
St. Michael's Catholic Church, Grand Forks, ND
St. Mary's Catholic Church, Grand Forks, ND
Our Savior's Lutheran Church, East Grand Forks, MN
Family of God Lutheran Church, East Grand Forks, MN
Bible Baptist Church, East Grand Forks, MN
Sacred Heart Catholic Church, East Grand Forks, MN
Mendenhall Presbyterian Church, East Grand Forks, MN

Institutions

Medical Center Rehabilitation Hospital (employees only), Grand Forks, ND
United Hospital (employees only), Grand Forks, ND

Public Broadcasting Companies

Radio

KFJM, Grand Forks, ND
KYTN-Y95, Grand Forks, ND
KNOX, Grand Forks, ND
KKXL AM14-FM93, Grand Forks, ND
KMAV, Mayville, ND
KRRK AM-FM, East Grand Forks, MN
KYCK, Crookston, MN

Television

WDAZ, Grand Forks, ND
KTHI, Grand Forks, ND
KXJB, Grand Forks, ND

APPENDIX B

INFORMED CONSENT MATERIALS

CONSENT FORM

Information About the

Consent to Participate in Research

Title: An Investigation into Isokinetic Normative Data of the Quadriceps and Hamstrings Muscles of Men and Women, Ages 36 Through 40

You are invited to participate in a research study determining the strength of muscles acting on the knee. The strength testing will be done using isokinetic exercise techniques. Even though you will work as "hard and as fast as possible" against the machine, the machine will only allow your leg to move at a pre-set speed. The extra effort you produce becomes increased force, not increased speed. The machine will measure and record the muscle tension (force) you develop.

The information gained from this study will be useful in rehabilitative medicine to set goals and chart progress. The information will apply to persons 36 through 40 years of age that are exercising to increase knee function following disease, injury, or surgery. The information will also help measure the changes that occur in strength due to growing older.

____

You are being invited to participate in this study because you are 36 through 40 years of age. You are within selected height/weight limits. You are healthy, with no history of heart or lung problems. You have not had back, hip, or knee disease, injury, or surgery.

____

You will be here approximately 45 minutes. The actual tests you will be given will take less than 5 minutes.

For the tests, you will be asked to bend and straighten your knee as "hard and as fast as possible" against a machine (the Cybex II). You will be asked to perform five (5) repetitions at three different speeds; the machine will control your speed. The right and left knees will be tested separately. You will be given a practice trial before each of the actual tests. You will be given rest periods between each test.

____

Isokinetic exercise is the most comfortable form of strength testing and training. Muscle soreness usually does not occur.

There is no risk of injury from the machine--if you quit "pushing," the machine quits resisting instantly.

Even though rest periods are given between each test, you may notice slight muscle fatigue.

____

A benefit to you from these tests is an assessment of your knee strength. If you request it, your results can be mailed to you. There is no payment for the service you provide.

____

Any information that is obtained in connection with this study, and that can be identified with you, will remain confidential. It will be disclosed only with your permission.

____

Your decision whether or not to participate will not prejudice your future relations with the University of North Dakota's Medical Center Rehabilitation Hospital. If you decide to particiate, you are free to discontinue participation at any time, without prejudice. No one is required to enter this study.

____

The investigators involved have made themselves available to answer any questions you have concerning this program. In addition, you are encouraged to ask any questions concerning this program that you may have in the future. Questions may be asked by calling: Renee Mabey, R.P.T. at (701) 780-5360.

____

In the unlikely event you are injured as a result of participation in this study, you will be transferred to the United Hospital. Medical treatment will be available to you as it is to members of the general public in similar circumstances. Payment for any such treatment must be provided by you and your third party payer.

____

INFORMED CONSENT STATEMENT

I, ______________________________, have been informed verbally and in writing of the purpose, benefits, and potential hazards of the research project: AN INVESTIGATION INTO ISOKINETIC NORMATIVE DATA OF THE QUADRICEPS AND HAMSTRINGS MUSCLES OF MEN AND WOMEN, AGES 36 THROUGH 40

which is under the direction of: Renee Mabey, R.P.T.

I volunteer of my own free will to participate in this project. I understand that I will be given further explanation of the project and of specific procedures, if I so desire, from the project director. I also understand that I may terminate my participation in the project at any time.

I understand that I will be given access to my records at the end of this study, if I so desire, and that my records will be treated in a confidential manner as a medical record. This agreement does not constitute permission for access by other individuals to records concerning me, other than those covered specifically by this research project.

____

Volunteer's Signature Date

____

Witness Date

____

Witness Date

____

INITIAL

APPENDIX C

DATA SHEET

DATA SHEET

Date __________ Time __________ I.D. Number __________

Name ______________________ Sex ______________________

Address ____________________ Age ______________________

____________________ Height ____________________

Phone--Work ________________ Weight ____________________

Home ________________ Frame ______________________

Occupation _________________ Muscle/Joint Pathology: YES NO

Activity Level _____________ Cardiopulmonary Pathology: YES NO

Kick Dominance: L R Results Requested: YES NO

Test Sequences: L R _____ _____ _____

L R _____ _____ _____

Muscle	Peak Torque, in Foot-Pounds			Torque, 0.2s, 60°/s
	60°/sec	180°/sec	300°/sec	foot-pounds
R quad				
R ham				
L quad				
L ham				

APPENDIX D

PILOT STUDY RAW DATA

TABLE 11

PILOT STUDY RAW DATA

Physical Characteristics						Peak Torque++												Torque at++ 0.2 sec, 60°/s			
						60°/s				180°/s				300°/s							
ID #	Sex	Age	Height (in.)	Weight (lbs.)	L/E Kick Choice	Quad		Ham		Quad		Ham		Quad		Ham		Quad		Ham	
						R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	M	34	70	192		128	145	86	78	82	74	44	42	52	52	42	36	84	140	72	54
2	M	16	74	175	R	160	144	110	95	98	102	73	72	68	65	76	63	114	85	62	72
3	F	54	68	183	R	94	90	65	60	52	52	39	43	32	30	27	20	52	42	38	24
4	F	20	72	136		94	117	67	72	59	76	41	48	50	54	40	38	73	84	42	40
5	M	32	71	196	R	156	158	100	80	114	116	72	72	78	75	60	48	116	120	78	48
6	F	29	69	144	R	92	94	62	65	61	64	44	46	38	40	35	36	52	50	41	37
7	M	21	71	183	R	178	167	95	96	107	104	70	80	74	81	53	63	132	116	83	81
8	F	22	63	128	R	79	65	46	48	50	54	35	34	35	39	26	26	61	40	33	34
9	M	22	74	162	R	146	116	114	94	100	117	72	72	69	84	55	51	104	75	84	72
10	M	20	72	157	R	166	168	105	104	114	97	81	72	80	76	70	60	124	120	88	90
11	F	30	70	155	R	113	108	55	65	68	65	46	47	46	48	38	36	78	72	39	52
12	F	22	64	210	R	98	114	68	65	77	81	52	46	50	49	34	34	68	72	45	51
13	F	30	70	175	R	118	113	58	59	83	75	56	52	56	50	46	36	78	74	40	44
14	M	25	68	139	R	140	125	77	67	90	78	58	50	61	46	48	35	102	74	41	27

++Recorder strips were read repeatedly by same two researchers until interpretation of strips was consistently within three foot-pounds of torque difference.

APPENDIX E

QUADRICEPS AND HAMSTRINGS PEAK TORQUE

AND T-SCORES FOR MALES

TABLE 12

QUADRICEPS PEAK TORQUE AND T-SCORES FOR MALES

T Scale	Torque in Foot-Pounds									T Scale
	60°/s			180°/s			300°/s			
	++ Dominant	Nondominant	$\overline{X}$	++ Dominant	Nondominant	$\overline{X}$	++ Dominant	Nondominant	$\overline{X}$	
100	0	0	0	0	0	0	0	0	0	100
95	0	0	0	0	0	0	0	0	0	95
90	0	0	0	0	0	0	0	0	0	90
85	0	0	0	0	0	0	0	0	0	85
80	0	0	0	145	0	0	0	0	0	80
75	0	212	0	137	0	139	100	102	100	75
70	198	199	194	128	133	130	93	94	92	70
65	186	186	183	120	123	121	86	83	85	65
60	175	172	171	111	113	112	78	77	77	60
55	164	159	160	102	103	102	71	69	70	55
50	153	145	149	94	93	93	64	61	62	50
45	141	132	138	85	83	84	56	53	55	45
40	130	119	127	77	73	75	49	45	48	40
35	119	105	116	68	63	66	42	37	40	35
30	108	92	104	59	52	57	34	0	33	30
25	97	78	0	0	0	0	0	0	0	25
20	0	65	0	0	0	0	0	0	0	20
15	0	52	0	0	0	0	0	0	0	15
10	0	0	0	0	0	0	0	0	0	10
5	0	0	0	0	0	0	0	0	0	5
0	0	0	0	0	0	0	0	0	0	0
N	30	30	30	30	30	30	30	30	30	N
High Score	196	200	191	142	129	135.5	97	98	96.5	High Score
Low Score	106	57	109.5	66	58	62	37	38	39.5	Low Score
Range	90	143	81.5	76	71	73.5	60	60	57	Range
Mean	152.7	145.4	149.1	93.8	92.7	93.3	63.7	61.1	62.4	Mean
S.D.	22.412	26.781	22.399	17.223	20.104	18.310	14.631	16.251	14.877	S.D.
S.C.	2.2412	2.6781	2.2399	1.7223	2.0104	1.831	1.4631	1.6251	1.4877	S.C.

++ dominance determined by lower extremity kick preference

TABLE 13

HAMSTRINGS PEAK TORQUE AND T-SCORES FOR MALES

T Scale	Torque in Foot-Pounds 60°/s ++ Dominant	60°/s Nondominant	60°/s $\overline{X}$	180°/s ++ Dominant	180°/s Nondominant	180°/s $\overline{X}$	300°/s ++ Dominant	300°/s Nondominant	300°/s $\overline{X}$	T Scale
100	0	0	0	0	0	0	0	0	0	100
95	0	0	0	0	0	0	0	0	0	95
90	0	0	0	0	0	0	0	0	0	90
85	0	0	0	0	0	0	0	0	0	85
80	0	0	0	0	0	0	0	0	90	80
75	137	133	133	101	0	97	84	86	83	75
70	127	125	126	94	91	91	78	79	77	70
65	121	117	118	88	85	86	72	72	71	65
60	112	109	110	82	79	80	65	65	64	60
55	104	101	102	75	73	74	59	58	58	55
50	96	93	94	69	67	68	53	51	52	50
45	88	85	86	63	61	62	47	44	45	45
40	79	76	79	56	55	56	40	36	39	40
35	71	68	71	50	49	50	34	29	33	35
30	63	0	63	0	43	45	28	22	26	30
25	0	0	0	0	38	39	22	15	20	25
20	0	0	0	0	0	0	0	8	14	20
15	0	0	0	0	0	0	0	0	0	15
10	0	0	0	0	0	0	0	0	0	10
5	0	0	0	0	0	0	0	0	0	5
0	0	0	0	0	0	0	0	0	0	0
N	30	30	30	30	30	30	30	30	30	N
High Score	132	131	130.5	96	89	92.5	84	85	84.5	High Score
Low Score	64	71	68	44	42	44.5	24	10	17.0	Low Score
Range	68	60	62.5	52	47	48	60	75	67.5	Range
Mean	95.8	92.6	94.2	68.9	67.1	68.0	52.8	50.7	51.7	Mean
S.D.	16.527	16.169	15.697	12.757	11.832	11.748	12.478	14.255	12.684	S.D.
S.C.	1.6527	1.6169	1.5697	1.2757	1.1832	1.1748	1.2478	1.4255	1.2684	S.C.

++ dominance determined by lower extremity kick preference

APPENDIX F

QUADRICEPS AND HAMSTRINGS PEAK TORQUE

AND T-SCORES FOR FEMALES

TABLE 14

QUADRICEPS PEAK TORQUE AND T-SCORES FOR FEMALES

T Scale	Torque in Foot-Pounds 60°/s ++ Dominant	60°/s Nondominant	60°/s $\overline{X}$	180°/s ++ Dominant	180°/s Nondominant	180°/s $\overline{X}$	300°/s ++ Dominant	300°/s Nondominant	300°/s $\overline{X}$	T Scale
100	0	0	0	0	0	0	0	0	0	100
95	0	0	0	0	0	0	0	0	0	95
90	0	0	0	0	0	0	0	0	0	90
85	0	0	0	0	0	0	0	0	0	85
80	0	0	0	0	0	0	0	0	0	80
75	120	0	119	73	0	75	0	49	0	75
70	113	112	112	68	72	70	45	45	45	70
65	106	105	105	64	67	65	42	41	41	65
60	99	98	98	59	61	60	38	38	38	60
55	91	91	91	54	55	55	35	34	34	55
50	84	84	84	50	49	50	31	30	31	50
45	77	77	77	45	44	45	28	27	27	45
40	70	70	70	41	38	40	25	23	18	40
35	63	64	64	36	32	35	21	19	15	35
30	56	57	0	0	26	30	18	16	0	30
25	0	0	0	0	20	0	0	0	0	25
20	0	0	0	0	0	0	0	0	0	20
15	0	0	0	0	0	0	0	0	0	15
10	0	0	0	0	0	0	0	0	0	10
5	0	0	0	0	0	0	0	0	0	5
0	0	0	0	0	0	0	0	0	0	0
N	30	30	30	30	30	30	30	30	30	N
High Score	117	108	112.5	71	71	71	44	46	44	High Score
Low Score	62	63	64	36	23	32.5	19	16	17.5	Low Score
Range	55	45	48.5	35	48	38.5	25	30	26.5	Range
Mean	84.2	84.2	84.2	49.8	49.3	49.6	31.5	30.3	30.9	Mean
S.D.	14.318	13.778	13.783	9.224	11.526	10.050	6.862	7.397	6.856	S.D.
S.C.	1.432	1.378	1.378	.922	1.153	1.005	.6862	.7397	.6856	S.C.

++ dominance determined by lower extremity kick preference

TABLE 15

HAMSTRINGS PEAK TORQUE AND T-SCORES FOR FEMALES

T Scale	Torque in Foot-Pounds									T Scale
	60°/s			180°/s			300°/s			
	Dominant++	Nondominant	$\bar{X}$	Dominant++	Nondominant	$\bar{X}$	Dominant++	Nondominant	$\bar{X}$	
100	0	0	0	0	0	0	0	0	0	100
95	0	0	0	0	0	0	0	0	0	95
90	0	0	0	0	0	0	0	0	0	90
85	0	0	0	0	0	0	0	0	0	85
80	0	0	0	0	0	0	0	0	0	80
75	0	0	0	0	0	0	0	0	0	75
70	70	67	67	49	50	49	37	0	38	70
65	66	63	63	46	47	46	34	36	35	65
60	61	59	59	42	43	42	32	33	32	60
55	57	55	55	39	40	39	29	29	29	55
50	52	50	51	36	36	36	26	26	26	50
45	47	46	47	33	33	33	23	22	23	45
40	43	42	43	29	29	30	20	18	20	40
35	38	38	39	26	25	26	17	15	16	35
30	34	34	35	23	22	24	14	11	13	30
25	29	0	34	0	0	0	11	7	10	25
20	0	0	0	0	0	0	0	0	0	20
15	0	0	0	0	0	0	0	0	0	15
10	0	0	0	0	0	0	0	0	0	10
5	0	0	0	0	0	0	0	0	0	5
0	0	0	0	0	0	0	0	0	0	0
N	30	30	30	30	30	30	30	30	30	N
High Score	68	64	66	47	50	47.5	37	36	36	High Score
Low Score	30	35	33	23	24	24	11	9	12.5	Low Score
Range	38	29	33	24	26	23.5	26	27	23.5	Range
Mean	52.0	50.5	51.3	35.9	36.1	36.0	25.6	25.5	25.6	Mean
S.D.	9.107	8.439	8.084	6.578	7.143	6.473	5.917	7.239	6.100	S.D.
S.C.	.9107	.8439	.8084	.6578	.7143	.6473	.5917	.7239	.6100	S.C.

++ dominance determined by lower extremity kick preference

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