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THE UNIVERSITY OF ALBERTA

ISOKINETIC EVALUATION OF KNEE FLEXOR AND KNEE EXTENSOR MUSCLE ENDURANCE IN RUNNERS AND UNTRAINED MALES

by

© Svandis Sigurdardottir

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ISOKINETIC EVALUATION OF KNEE FLEXOR AND KNEE EXTENSOR MUSCLE ENDURANCE IN RUNNERS AND UNTRAINED MALES submitted by Svandis Sigurdardottir in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date....MAY 20, 1988........

DEDICATION

This thesis is dedicated to my mother,

Gudrun Audunsdottir,

and my late father,

Sigurdur Betuelsson.

Ritgerdin er tileinkud foreldrum minum,

Gudrunu Audunsdottur

og

Sigurdi Betuelssyni

ABSTRACT

The purpose of this study was to analyse the isokinetic muscle endurance of the knee flexors and knee extensors in three groups of male subjects: sprinters, middle-distance runners and untrained men.

The CYBEX II+ isokinetic dynamometer was used to measure the muscle endurance. The endurance test consisted of a 45 second trial of high speed reciprocal extension and flexion of the knee at the velocity settings of 180 degrees per second and 240 degrees per second. A fatigue index (per cent decline in peak torque) was calculated for the endurance test.

The data showed that there was no difference in thigh muscle endurance between left and right lower limbs of the subjects. Only middle-distance runners showed a significant difference in endurance patterns between the knee flexors and knee extensors. The test showed no difference in muscle endurance of the thigh muscles between sprinters, middle-distance runners and untrained subjects. There was a significant difference in thigh muscle endurance between the two velocity settings among middle-distance runners and untrained subjects. There was no difference in the hamstrings to quadriceps (H/Q) endurance ratio between sprinters and middle-distance runners at the faster

velocity, nor was there a significant difference in this ratio between the three groups of subjects. Thigh muscle fatigue was highly correlated with initial strength level but not strongly correlated with body weight.

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I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

Clinicians dealing with the care and treatment of athletes often encounter problems concerned with muscle strength and endurance, both in rehabilitation and injury prevention programs (1,2). In fact, rehabilitation of muscle function is considered a major problem in sports medicine (2).

Muscle endurance is of great importance in many sports. For example, knee stability depends, to a large degree, on the strength and endurance of the quadriceps and hamstring muscles. Traditionally, however, rehabilitative training has been limited to strength development of the muscles supporting the knee, with little emphasis on endurance (3,4,5). Consequently, athletes who have regained their muscle strength after knee injury may not necessarily be able to exercise for prolonged periods and may even reinjure the knee when, the muscles fatigue and fail to provide the adequate support (3,6). In the last ten years the endurance component has achieved more emphasis (7,8,9,10,11,12).

With the development of objective measurement instruments, such as the CYBEX II isokinetic dynamometer (Cybex, Division of Lumex, Inc., 2100 Smithtown Ave., Ronkonkoma, NY 11779), sports medicine professionals have been giving more attention to the assessment of specific characteristics of skeletal muscle performance in athletes. In the healthy athlete, muscular performance in terms of strength, speed, or endurance is indirectly known by the athlete's level of achievement in his or her sport. In the case of the injured or deconditioned athlete, however, more specific information about affected muscle groups may be needed (8).

The importance of musculoskeletal profiling in orthopedic sportsmedicine has been emphasized (13,14,15,16). When testing athletes, the results must be compared to normal values to be properly interpreted. If healthy baseline data on an individual athlete are not available, the next most specific set of data would be a profile derived from athletes of the same sport, competitive level, playing position and anthropometric characteristics. Therefore, normal values for sport-specific parameters, such as muscle strength, endurance and power, must be determined for well-defined groups of athletes. When such norms are available, they can be used for both screening and rehabilitation purposes and as return to play criteria after injury. Computed parameters, such as the ratio of strength, endurance or power between agonist-antagonist muscle groups about a joint, or between right and left extremities for a given muscle group, have been found to be more sensitive indicators of musculoskeletal abnormalities than the raw data parameters (13,17).

Although many studies are now available concerning muscle performance in athletes, this research has largely been confined to studies of muscular strength and strength ratios (1,18,19,20,21). The few studies examining muscle endurance or fatigue of the thigh muscles have normally only reported the endurance of the knee extensors (9,10,11,22,23,24,25). It was considered to be of particular interest, however, to investigate the endurance of both the extensors and flexors by analysing the fatigability of these muscle groups separately under isokinetic conditions.

B. OBJECTIVES OF THE STUDY

The purpose of the study was to analyse the muscle endurance of the knee flexors and extensors. More specifically, the isokinetic endurance of the knee flexors and extensors was studied separately, and left and right limbs were compared with regards to muscle endurance.

C. RESEARCH HYPOTHESES

It was hypothesized that for each of the two speeds examined:

1. there would be no significant difference in muscle endurance between right and left lower limbs of the subjects in each group for the knee flexors and extensors.
2. there would be a significant difference in endurance patterns between the knee flexors and knee extensors in all three groups of subjects.
3. the middle-distance runners would show greater endurance of both knee flexors and knee extensors than the other two groups studied.

In order to compare the two different speeds (180 degrees/second and 240 degrees/second), it was hypothesized that:

4. there would be a significant difference in muscle endurance of the quadriceps and hamstring muscles at the faster velocity as compared to the slower velocity in all three groups of subjects.
5. there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio of middle-distance runners as compared to sprinters at the faster velocity.

6. there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio at the faster velocity as compared to the slower velocity in all three groups.

D. SIGNIFICANCE OF THE STUDY

With expanded profile data about the muscle performance characteristics of various categories of athletes, training and rehabilitation programs may be adapted to meet the strength, speed, and endurance requirements of a given sport. These improved programs may, in turn, enhance the quality of participation and prevent the occurrence of injury or reinjury (8,13,15).

The only parameter analysed in this study was muscle endurance, in order to shed some light on the endurance patterns of the three groups studied. The results are offered as examples of normal values for these particular groups.

E. OPERATIONAL DEFINITIONS

<u>Isokinetic exercise</u>: Dynamic muscular activity performed at a constant angular velocity controlled by an external dynamometer (26,27,28).

<u>Angular velocity:</u> The rate of change with respect to time of angular displacement, given in units of radians per second or degrees per second (29).

<u>Torque:</u> A measure of a force that rotates an object about an axis of rotation. Torque is equal to the length of the lever arm, measured from the axis of rotation to the point of application of the force, multiplied by the component of force that is perpendicular to the lever arm (29).

<u>Peak torque:</u> The highest torque value of each contraction.

<u>Work:</u> A force moving a resistance through a distance. The amount of work done by a force is the product of the amount of force in the direction of the displacement times the distance the resistance is moved (29,30). Work can be determined by the formula:

$$\text{WORK} = T \times 2\pi \times d$$

where T is the torque in foot pounds, d is the portion of the arc travelled and π (pi) is a mathematical constant, 3.14.

<u>Power:</u> The rate that work is done with respect to time. In isokinetic terms, it is torque times angular velocity (29,30). It is determined by the formula:

$$\text{POWER} = \frac{\text{torque} \times 2\pi \times \text{revol. per min.}}{\text{time (min.)}}$$

<u>Endurance:</u> Average power output of a muscle group during 45 seconds of activity (8,31,32,33).

<u>Fatique Index:</u> Per cent decline in peak torque, calculated on the basis of the mean peak torque of the three highest peaks out of the first five repetitions and the last three repetitions of a 45 second trial of isokinetic exercise (8).

<u>Hamstrings/Quadriceps Endurance Ratio:</u> Per cent decline of peak torque in hamstrings divided by per cent decline of peak torque in quadriceps on a 45 second endurance test.

<u>Initial strength:</u> The single highest torque value obtained during the first five repetitions at each of the two speed settings.

F. DELIMITATIONS

The study was delimited to the following:

1. Two speed settings, 180 and 240 degrees per second, on the Cybex II+ isokinetic exercise unit manufactured by the Lumex Corporation of New York (18,20,31,34).

2. Examination of ten male sprinters (100 m, 200 m or 400 m), ten male middle-distance runners (800 m up to 5000 m) and ten normal, healthy men who were not engaged in a formal athletic program. All subjects were between eighteen and thirty two years of age and without a history of knee or thigh pathology (13,35,36,37).

G. LIMITATIONS

1. The precision of torque records was limited to the recording accuracy of the Cybex II+ isokinetic apparatus.

2. The ability of each subject to exert a maximum effort during eacn test session and the individual subject's perception of maximum effort were beyond the control of the investigator.

II. REVIEW OF THE LITERATURE

The review of literature is organized into three main areas: muscle fatigue, general principles of isokinetic exercise, and isokinetic muscle endurance.

A. MUSCLE FATIGUE

Muscle generates force, and failure to maintain force (or work output) during sustained or repeated contractions is termed 'fatigue'. The mechanisms underlying fatigue of human skeletal muscle have been extensively investigated (38,39,40).

The first to objectively study muscle fatigue in humans was Mosso(41). He made it possible to study the fatigue phenomena by constructing a simple apparatus which he called an ergograph. Mosso's experiments demonstrated that under 'physiological conditions', that is, with the muscles in situ stimulated voluntarily through the intact nervous system, there may be two basic mechanisms of fatigue, namely, central and peripheral (42). 'Central' means proximal to the motor neurons, mainly in the brain. 'Peripheral' means within the motor units, that is the motor neurons, the peripheral nerves, the motor end plates, and the muscle fibers themselves.

In peripheral muscle fatigue, there are at least two different sites where repeated contractions may cause impairment: the 'transmission mechanism' (neuromuscular junction, muscle membrane, and endoplasmic reticulum), and the 'contractile mechanism' (myofilaments). Their separate levels of susceptibility to fatigue are well known (42,43). Peripheral muscle fatigue, whether it is located in the transmission or in the contractile mechanism, seems to be due to local changes in the internal environment of the muscles. These changes may be biochemical, consisting of the depletion of such substrates as glycogen, high energy phosphate compounds in the muscle fibers, and acetylcholine in the terminal motor nerve branches; or, they may be due to accumulation of metabolites, such as hydrogen ions as a result of lactate production, or of other substances (e.g. electrolytes) liberated from the muscles during activity(38,42).

Central fatigue was demonstrated by Mosso in his fatigue tests (41). The theoretical mechanism for central fatigue involves afferent impulses arising from receptors within the fatigued muscle, which inhibit the motor pathway at sites anywhere from the voluntary motor centers in the brain to the spinal motoneurons (42,44). It has been demonstrated that better motivation to endure can appreciably prolong time to exhaustion (42), and in well motivated, normal subjects, there is little evidence of central fatigue (43).

'Peripheral and 'central' fatigue may appear separately or combined, depending on the specific situation (42,43,44). Any one link in the long chain from the voluntary motor centers in the brain to the contractile filaments in the single muscle fibers, may be the weaker and thus the most direct cause of muscle fatigue. Thus, it appears that there are probably many different types of fatigue, and that each may occur with a particular form of muscular activity (43,45).

In order to elucidate the fatigue phenomenon, Tesch (12) designed a study by combining established histochemical, biochemical and electrophysiological methods when examining high intensity exercise of short duration, more specifically, isokinetic knee extensions. He suggested lactate accumulation and associated metabolic changes interfering with the contractile mechanism to be responsible for muscle fatigue in this situation. A more recent study by Horita and Ishiko (46) found that electromyographic changes and changes in the contractile property of the vastus lateralis muscle during isokinetic knee extensions also correlated with lactate accumulation in the same muscle. They concluded that the decrease in efficiency of the electrical activity in the muscle suggested peripheral fatigue.

B. GENERAL PRINCIPLES OF ISOKINETIC EXERCISE

The speed of muscle shortening is known to be inversely related to the load against which it shortens. This basic finding in muscle mechanics was first made by Fenn and Marsh (47) in 1935 and formulated in mathematical terms by Hill (48) in 1938. This force-velocity relationship applies both to smooth and striated muscle. In studies that established this relationship, either resistance or velocity was kept constant (49,50,51,52). In 1967, a new method based on the force-velocity principle was designed by Perrine and associates (26,27,28) , in which different constant velocity levels (i.e. isokinetic) could be achieved. The force output of different muscle groups during maximal contractions could then be studied at different muscle shortening velocities. Thus, isokinetic contraction, or exercise, is defined as dynamic muscular activity performed at a constant angular velocity (28).

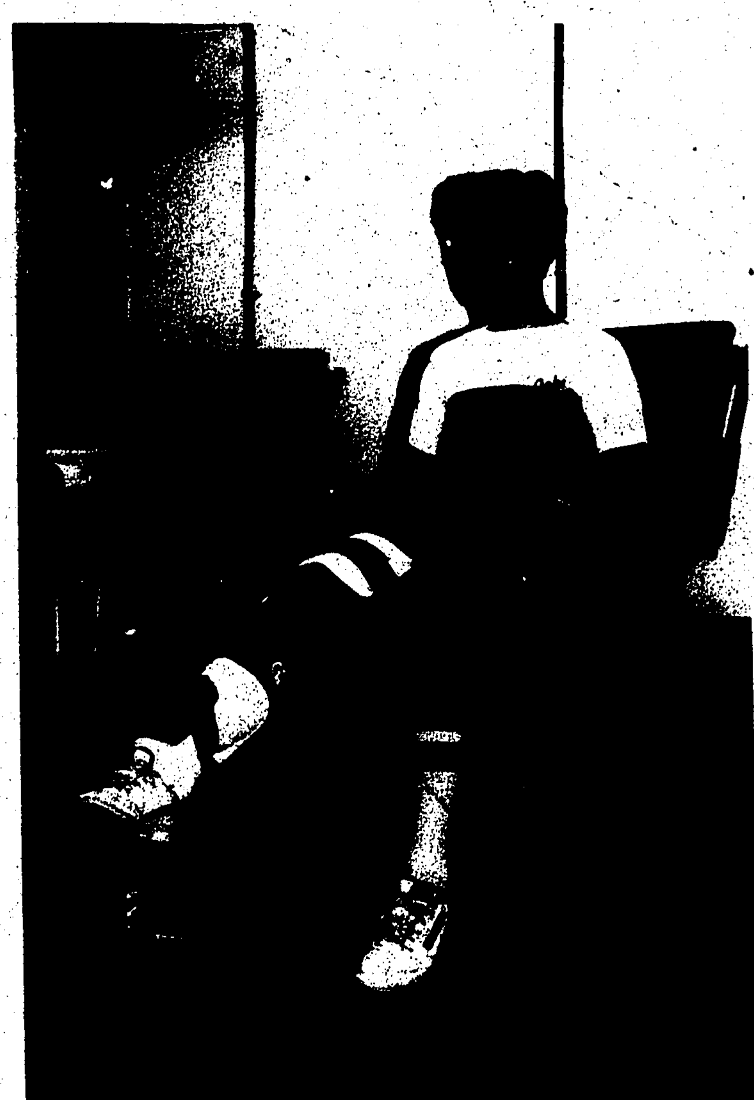
The Cybex II+ isokinetic apparatus consists of a lever arm which can be attached to a part of the body and carried through a range of motion (Figure 1). This isokinetic dynamometer is designed to create resistance in the internal mechanism when the exercising limb attempts to exceed the pre-selected speed setting (28,30,53). With the isokinetic system, a muscle or muscle group can work maximally throughout the full arc of motion, as speed control, rather than a fixed external weight, is applied (28).

The muscular force exerted by a subject against the lever arm of the device is transmitted by a recording device as a torque curve (Figure 2). Work is force times distance or the area under the torque curve (53). Thus, the work of one repetition or the work of many repetitions can be measured from the torque tracings. The rate of doing work is power. It is traditionally the measure of work per unit of time. Average power output during a stated duration constitutes an operational definition of endurance in isokinetic terms (31,32,33).

C. ISOKINETIC MUSCLE ENDURANCE

Measures of fatigability or indicators of endurance using the Cybex instrumentation have been defined in several ways(8). All definitions, however, are based on the decline in torque occurring over some prolonged series of repeated contractions, commonly performed at a relatively high speed (180 degrees per second)(8,9,12,22,34). Only a limited number of studies have investigated fatigue effects produced by repeated isokinetic contractions. The few studies examining muscle endurance or fatigue of the thigh muscles have normally reported the endurance of the knee extensors

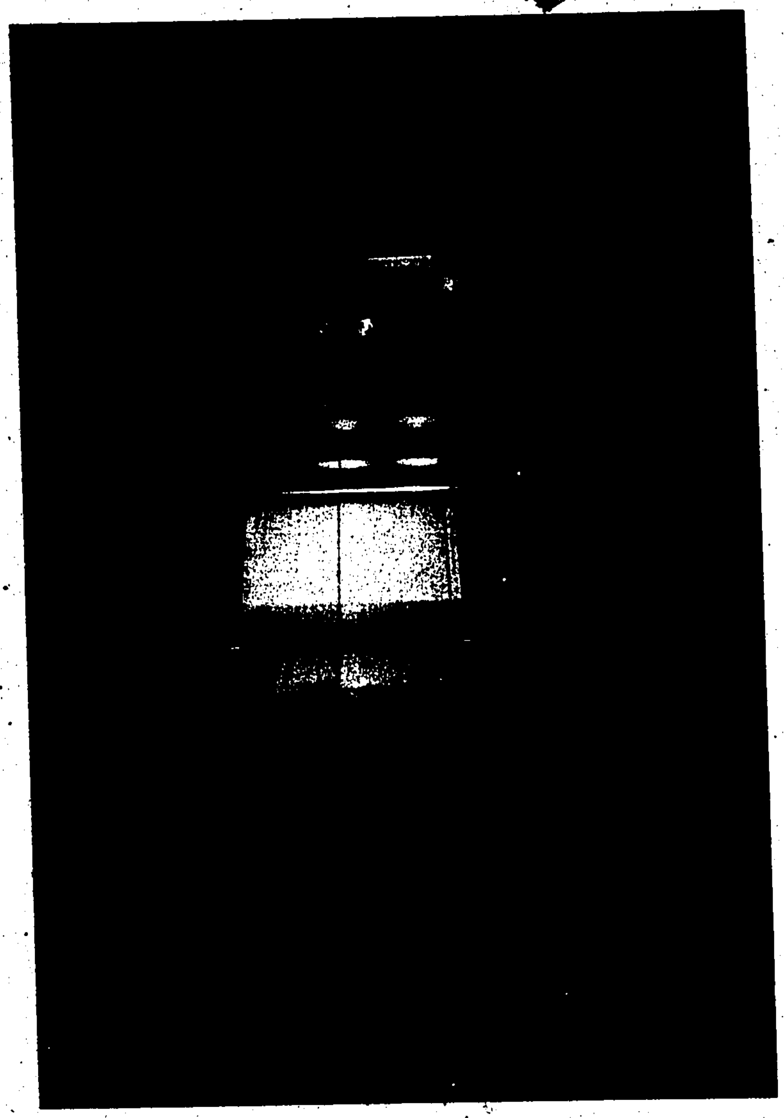
Figure 1. Cybex II+ Isokinetic Dynamometer.



alone (e.g. 9, 10, 11,22,23,24,25) or a common fatigue index for knee extensors and flexors (54). Some of these studies have considered the relationship between muscle fibre type and local muscle fatigue. For example, Tesch et al. (23,24) and Thorstensson and Karlsson (22) found that an increasing proportion of slow twitch (ST) fibres in the quadriceps muscles corresponded to better sustained muscle force during repeated isokinetic knee extensions. Clarkson et al. (10), on the other hand, did not find a significant relationship between muscle fibre type and knee extensor isokinetic endurance. In their study, the endurance had a significant negative correlation with initial strength; the stronger subjects fatigued faster. Similarly, Ivy et al. (11) showed that the respiratory capacity of the knee extensors appears to be more influential than fibre type in determining the rate of fatigue development during a 45 second test of repeated maximum isokinetic leg extension-flexion contractions.

If a reciprocal alternating contraction test mode is used, whereby antagonistic pairs of muscles are studied simultaneously, the fatigue rates of the two muscles may be different because of differences in metabolic demands, histologic make-up, or training effects (8,22,49,55). A method of testing fatigability, which avoids undue stress on the more easily fatigued muscle, is to measure the per cent

Figure 2. Cybex II+ Dual-Channel Recorder



decline in torque within a time limit (fatigue index)(8). In a preliminary pilot study on thirteen normal male subjects , nine non-competitive long-distance runners and seventeen professional hockey players, Watkins and Harris calculated a fatigue index for both 15 and 30 seconds (8). In this study, the differences in endurance between the hamstrings and quadriceps muscles were clearer at the end of the 30-second run. In general, the hamstring muscles seemed to show more endurance than the quadriceps muscles in all three groups. The group of runners showed a relatively low per cent decline in torque values of the hamstring muscles, and the authors suggested this finding may indicate specificity of training. In another study, Harris (56) showed that an intense long distance running program alters isokinetic hamstring performance in females. Hamstrings peak torque (at angular velocity of 180 degrees per second), the hamstrings to quadriceps ratio, and the total amount of work generated over 15 seconds for the hamstring muscles increased after training. No significant differences were noted in the runners' quadriceps performance.

In a study of professional ballerinas, muscle endurance was estimated by calculating the time between onset of testing and the point at which peak torque was reduced to 50 per cent of the initial value with an angular velocity of 180 degrees per second (57). The hamstring muscles showed significantly more endurance than the quadriceps muscles, and this difference was consistent in each dancer. The authors explained this difference as reflecting the demands placed upon the hamstring muscles to decelerate the rapid movements of the lower extremity in dance.

A more recent study on non-athletic males and females also showed the relative endurance of the hamstring muscle group to be greater than the endurance of the quadriceps muscle group (58). The authors suggest this difference may be due, in part, to the interaction between gravity and the test position. In the sitting position, the quadriceps muscle group performs work against gravity and therefore, appears to be more fatigable than the hamstring muscle group which is assisted by gravity.

None of the authors of these studies (8,57,58) reported that a gravitational correction had been included in the calculations.

As muscle endurance of the knee flexors and knee extensors remains largely uninvestigated, it was hoped that the findings of this study would shed some light on the endurance patterns of these muscles.

III. METHODS AND PROCEDURES

A. SUBJECTS

Ten male sprinters, ten male middle-distance runners and a group of ten normal, untrained male subjects were studied. It was expected that the two groups of runners would show differences in thigh muscle endurance due to their differences in histologic make-up of their muscles and training effects (59,60). Subjects were recruited on a volunteer basis from various track clubs in Edmonton and from students at the University of Alberta. The subjects were between 18 and 32 years of age with no history of any major knee or thigh pathology. Individuals who had sustained an injury to the thigh or knee that kept them from sports participation for more than one week, were excluded from the study (13). The subjects were asked to give their informed consent (Appendix A) prior to participating in the study.

B. APPARATUS

The Cybex II+ apparatus used in the study is shown in Figure 3.

The apparatus consists of three components:

1. A dynamometer (Figure 1) which measures torque inputs up to 360 foot-pounds. When force is applied by a subject

Figure 3. Cybex II+ Dynamometer, Speed Selector, and Dual-Channel Recorder

to the lever arm, a series of reducing gears absorbs the force and thus gives a resistance which accommodates the subject's input force (53). The muscular force exerted against the lever arm is transmitted by a recorder as a torque curve (in foot-pound units).

2. A speed selector with remote digital control (Figure 4) which pre-sets the speed of rotation of the dynamometer from 0 to 300 degrees per second. The set speed is non-acceleratable, no matter how much force is applied to the lever arm of the dynamometer. As more force is applied, more resistance is encountered by the subject's limb.
3. A dual-channel recorder (Figure 2) with two heated styli which records and displays a permanent record of the applied torque and its position angle. The speed of the graph paper can be set at 5 millimeters per second or 25 millimeters per second. In this study, the graph paper speed was set at 5 mm per second, except for the weighing of the limb, where the paper speed was 25 mm per second.

A damping knob on the torque channel controls the speed of response of the torque stylus. When testing the knee, a damping factor of 2 is used (34).

Figure 4. Cybex II+ Speed Selector with Remote Digital Control

The Cybex II+ isokinetic dynamometer was calibrated daily throughout the study according to the procedures suggested by the Cybex manufacturer (34,61,62) (see Appendix B). The reliability and validity of the dynamometer has been reported to be high (30,49,63). The torque calculations are reported with and without a gravitational correction factor (19,34,64,65,66,67,68).

C. INITIAL FAMILIARIZATION

All subjects that volunteered for the study came to the Cybex laboratory in the Faculty of Rehabilitation Medicine for a practice session. At the beginning of this session, the subjects were asked to read the information in the Informed Consent Form (Appendix A). They were then placed in the isokinetic apparatus as shown in Figure 1, and the investigator explained the general principles of isokinetic exercise to the subjects. The experimental procedure was then fully explained to the subjects and they were given the opportunity to practise using the dynamometer with both legs at the two different speeds selected for the study. Finally, the subjects were asked to sign the Informed Consent Form.

D. TESTING PROCEDURE

There were two separate testing sessions for each subject, one for each speed setting selected for the study (180 and 240 degrees per second). Testing took place during the outdoor track season (June and July). Subjects were asked to refrain from any strenuous physical activity for at least forty eight hours prior to each testing session (69). The second testing session took place at the same time of the day as the first session, as certain physiological processes (such as body temperature, blood pressure and oxygen consumption) have circadian rhythms (70,71,72). At the beginning of the first session, some basic anthropometric measurements were made (see Appendix C). At the beginning of the second session, the torque resulting from the weight of the leg and the input accessories (including lever arm) was determined by the method of Nelson and Duncan (64) for the purpose of calculating the gravitational correction factor. Subjects wore similar clothing and identical footwear during the two test sessions.

The subjects were seated on a padded hinged table with a firm padded board under the thigh to be tested (Figure 1). Stabilizing straps were secured around that thigh and across the pelvis and chest, and subjects were instructed to hold on to the sides of the table or the handgrips with both hands (8,34,73). The input shaft of the dynamometer was aligned with the knee joint axis and the shin pad on the distal end of the lever arm was secured with a velcro strap to the subject's lower leg, so that the bottom edge of the pad was level with the superior border of the medial malleolus (34). The starting position was with the knee positioned at 90 degrees and the hip at 110 degrees, measured by a standard goniometer (34,74,75,76,77). Extra back support was used when necessary to reach this test position (34). No flexion stop was used to limit range of motion, thus flexion was only limited by the performing leg of the subject meeting the seating apparatus.

As a warm-up procedure, the subjects performed five to ten consecutive submaximal repetitions of reciprocal knee extension and flexion at the preset speed for that session, followed by 3-5 identical maximal repetitions (34,78). A three minute rest period was given before the actual testing started. The endurance test consisted of a 45 second trial of high speed reciprocal extension and flexion of the knee with the speed selector set at 180 degrees per second for one session and at 240 degrees for the other session (randomly assigned). Both lower limbs were tested each time, and the subjects randomly chose by draw which limb was tested first in each session. (For time sequence flow chart, see Figure 5). The subjects were instructed to push and pull

Figure 5. Time Sequence Flow Chart for the Testing Procedure

MEASUREMENTS	- height, weight, thigh circumference
PREPARATION	- randomly choose test speed and limb to be tested first - positioning, stabilization
WARM-UP AND FAMILIARIZATION	- 5-10 consecutive, submaximal repetitions of reciprocal knee extension and flexion at the pre-set speed - followed by 3-5 identical maximal repetitions
3 - MINUTE REST	- sitting relaxed in the chair
45 - SECOND ENDURANCE TEST	- 45 second trial of reciprocal extension and flexion of the knee at the pre-set test speed
5 - MINUTE REST	- change chairs, positioning, stabilization
REPEAT WARM-UP AND TESTING SEQUENCE FOR THE OTHER LIMB	

against the lever arm through the full available range of motion as fast and as hard as possible until notified to stop. They were verbally encouraged by the investigator and periodically given the time remaining of the test (at twenty, ten and five seconds remaining).

A fatigue index (per cent decline in peak torque) was calculated on the basis of the mean peak torque of the three highest peaks out of the first five repetitions and the last three repetitions of the 45 second trial (8). The single highest torque value obtained during the first five repetitions was defined as initial strength at each of the two speed settings examined in the study.

E. EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The design of this study was four factorial (79,80) in which:

Factor A was the three groups of subjects, namely, sprinters, middle-distance runners and untrained males,

Factor B was the two muscle groups, namely, the hamstrings and quadriceps,

Factor C was the velocity at which the limbs were tested, namely, 180 degrees per second and 240 degrees per second, and

Factor D was the limbs tested, namely, the right and left limbs.

The data for the per cent decline in peak torque were analysed using a four-way analysis of variance with repeated measures on Factors B,C and D above (79,80). For the endurance ratios of the muscle groups, a three-way analysis of variance with repeated measures on velocity and limbs was used. A Tukey test was used (a priori) to compare selected pairs of means. Selected correlational calculations were performed as well (79). Values were considered to be significant at the .05 level of confidence.

IV. RESULTS

The purpose of the study was to analyse the isokinetic muscle endurance of knee flexors and knee extensors in runners and untrained men. Ten male sprinters, ten male middle-distance runners and a group of ten normal, untrained male subjects, at the age of 18 - 32 years, were studied. The Cybex II+ isokinetic apparatus was used in the study, and two different velocity settings were compared (180 and 240 degrees per second). The endurance test consisted of a 45 second trial of reciprocal knee flexion and extension for each limb.

Anthropometric data of the subjects are shown in Appendix C. The mean, standard deviation, and range of the subjects' age, height, weight, thigh girth and initial strength are shown in Table I. The raw data, corrected for gravity and uncorrected, are shown in Appendix D.

The results of the study are presented in terms of the six hypotheses previously stated, followed by a section on various correlations between variables. The summary of the analysis of variance for the per cent decline in peak torque is provided in Appendix E. The results indicated no significant four way interaction, which suggested that there were no significant differences between the three groups of subjects for the per cent decline in peak torque of the right and left limbs.

It was expected that there would be no significant difference in muscle endurance between left and right lower limbs of the subjects in each group for the knee flexors and extensors. The results of the Tukey test showed this hypothesis to be true (p>.05) (Table II).

As no significant difference was observed between the left and right sides, the data for both limbs were combined in the analysis of the remaining hypotheses.

It was hypothesized that there would be a significant difference in endurance patterns between the knee flexors and knee extensors in all three groups of subjects. As seen in Table III and Figure 6, this hypothesis was true only for middle-distance runners at the velocity setting of 180 degrees per second. The knee flexors showed significantly greater endurance than the knee extensors in this case.

It was hypothesized that the middle-distance runners would show greater endurance of both knee flexors and knee extensors than the other two groups studied. None of these comparisons were significantly different, however, as seen in Table IV (Figure 7).

Table I

Mean, Range and Standard Deviation of Age and Some Physical Characteristics of Subject Groups

Group	Age	Height (cm)	Weight (kg)	Thigh Girth (cm)		Initial Strength (ft. lbs.)							
				L	R	Hams 180 R	Quads 180 R	Hams 180 L	Quads 180 L	Hams 240 R	Quads 240 R	Hams 240 L	Quads 240 L
Sprinters													
Mean	21	179.2	68.9	51.6	51.4	87.9	108.2	88.1	111.5	79.4	93	82.8	96.9
Range	19-24	169-191.5	61-81.1	46.5-55.5	46.5-55	73-108	80-132	75-102	85-142	59-96	68-124	56-102	72-121
SD	1.6	7.3	7.5	2.5	2.4	11.9	17.3	10.3	18.3	10.9	18.1	15.0	17.4
MDR													
Mean	20	177.1	66.8	49.7	49.7	80.4	99.5	76.5	100	73.6	84.3	74.8	86.4
Range	18-32	162.5-186	53.5-80	45.4-56.5	45.5-55.5	64-89	73-114	61-91	67-115	54-88	64-96	52-88	61-107
SD	4.0	6.8	7.6	3.5	3.5	6.7	10.9	10.4	12.9	8.3	9.3	9.8	11.9
Untrained													
Mean	25	181.8	69.9	49.1	49.5	80.2	102.7	80.5	103.2	75	86.9	78.3	89
Range	20-31	170-192	63.8-85	47-52	46.5-53	61-102	87-144	60-104	80-158	54-105	68-132	58-115	72-140
SD	3.0	6.5	5.9	1.4	1.9	11.6	17.4	13.7	21.9	13.7	17.3	15.1	18.7

MDR = Middle-Distance Runners
SD = Standard Deviation
L = Left
R = Right

Hams = Hamstrings
Quads = Quadriceps
180 = 180 degrees/second
240 = 240 degrees/second
ft. lbs. = foot pounds

Table II

Comparison Between the Per Cent Decline of Peak Torque of the Left and Right Lower Limbs on a 45 Second Endurance Test

(Values are means with S.D.'s in parenthesis)

Group	Speed	Muscle	Limb Right		Limb Left	
Sprinters	180 deg/sec	Hamstrings	40.6%	(7.6)	41.3%	(9.5)
		Quadriceps	44.9%	(10.4)	42.9%	(8.9)
	240 deg/sec	Hamstrings	44.6%	(8.6)	41.2%	(9.8)
		Quadriceps	49.0%	(11.6)	44.7%	(11.6)
Middle-Distance Runners	180 deg/sec	Hamstrings	33.4%	(7.1)	38.8%	(8.5)
		Quadriceps	43.6%	(7.8)	41.5%	(6.5)
	240 deg/sec	Hamstrings	41.9%	(9.5)	41.3%	(9.0)
		Quadriceps	43.8%	(6.8)	42.1%	(7.3)
Untrained	180 deg/sec	Hamstrings	43.3%	(9.8)	37.8%	(9.6)
		Quadriceps	42.1%	(7.1)	42.5%	(6.3)
	240 deg/sec	Hamstrings	46.3%	(10.0)	45.2%	(9.7)
		Quadriceps	45.9%	(7.0)	45.2%	(5.2)

($p = 0.05$)

Table III

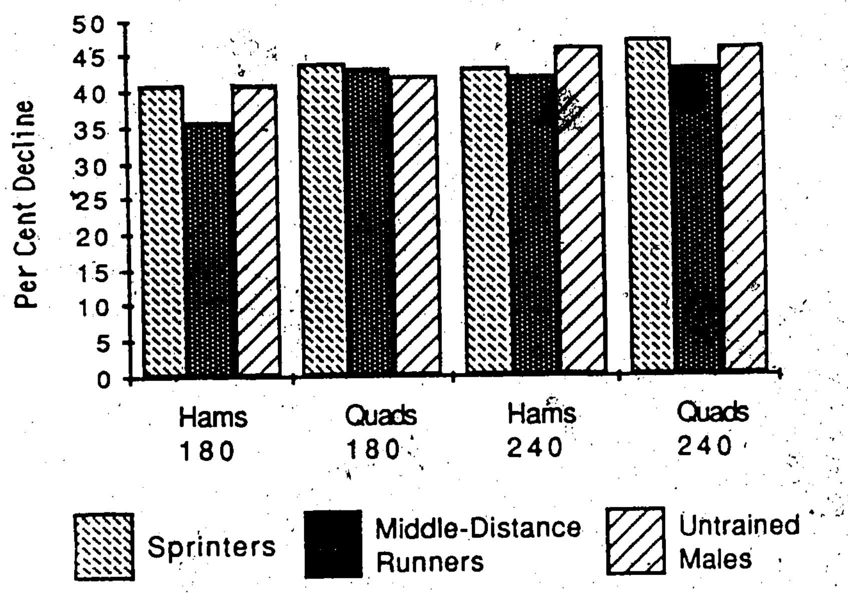
Comparison Between the Per Cent Decline of Peak Torque in the Hamstring and Quadriceps Muscle Groups on a 45 Second Endurance Test

(Values are means with S.D.'s in parenthesis)

Group	Speed	Muscle: Hamstrings	Muscle: Quadriceps
Sprinters	180 deg/sec	41% (8.4)	44% (9.5)
	240 deg sec	43% (9.2)	47% (11.5)
Middle-Distance Runners	180 deg/sec	36% (8.1)	43% (7.0)*
	240 deg sec	42% (9.0)	43% (6.9)
Untrained	180 deg/sec	41% (9.9)	42% (6.5)
	240 deg sec	46% (9.6)	46% (6.0)

* statistically significant (p = 0.05)

Figure 6. Comparison Between the Per Cent Decline of Peak Torque in the Hamstring and Quadriceps Muscle Groups on a 45 Second Endurance Test.



Hams = Hamstrings
Quads = Quadriceps
180 = 180 degrees/second
240 = 240 degrees/second

Table IV

Comparison Between the Per Cent Decline of Peak Torque in Sprinters, Middle-Distance Runners and Untrained Males on a 45 Second Endurance Test

(Values are means with S.D.'s in parenthesis)

Muscle	Speed	Group					
		Spr		MDR		Unt	
Hamstrings	180 deg/sec	41%	(8.4)	36%	(8.1)	41%	(9.9)
	240 deg sec	43%	(9.2)	42%	(9.0)	46%	(9.6)
Quadriceps	180 deg/sec	44%	(9.5)	43%	(7.0)	42%	(6.5)
	240 deg sec	47%	(11.5)	43%	(6.9)	46%	(6.0)

(p = 0.05)

Spr = Sprinters
MDR = Middle-Distance Runners
Unt = Untrained Males

Figure 7. Comparison Between the Per Cent Decline of Peak Torque in Sprinters, Middle-Distance Runners and Untrained Males on a 45 Second Endurance Test.

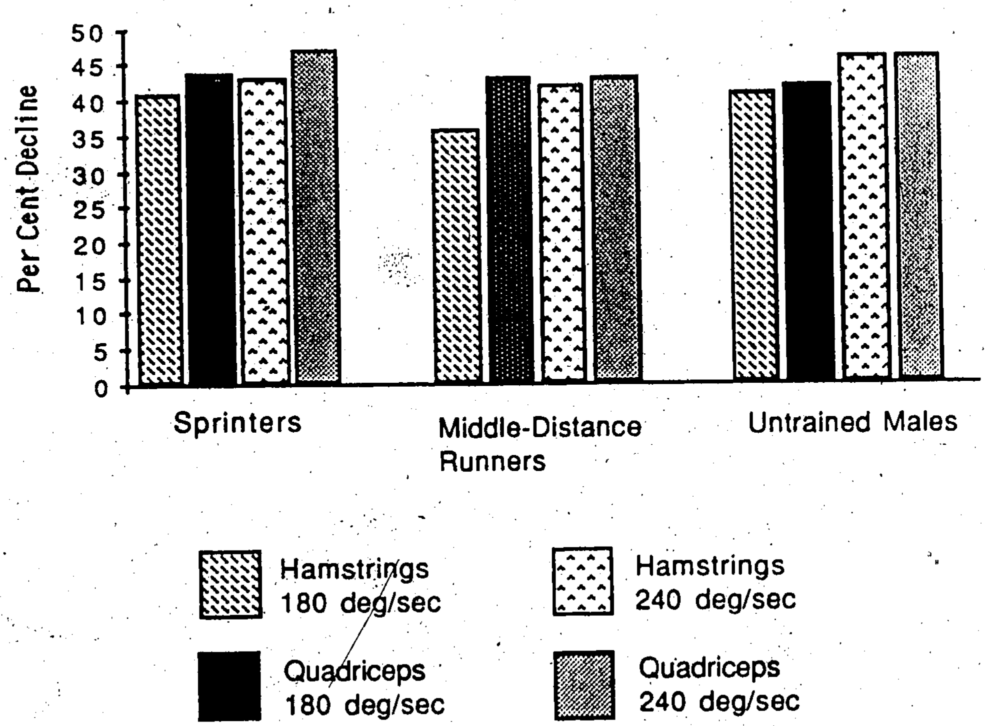


Table V

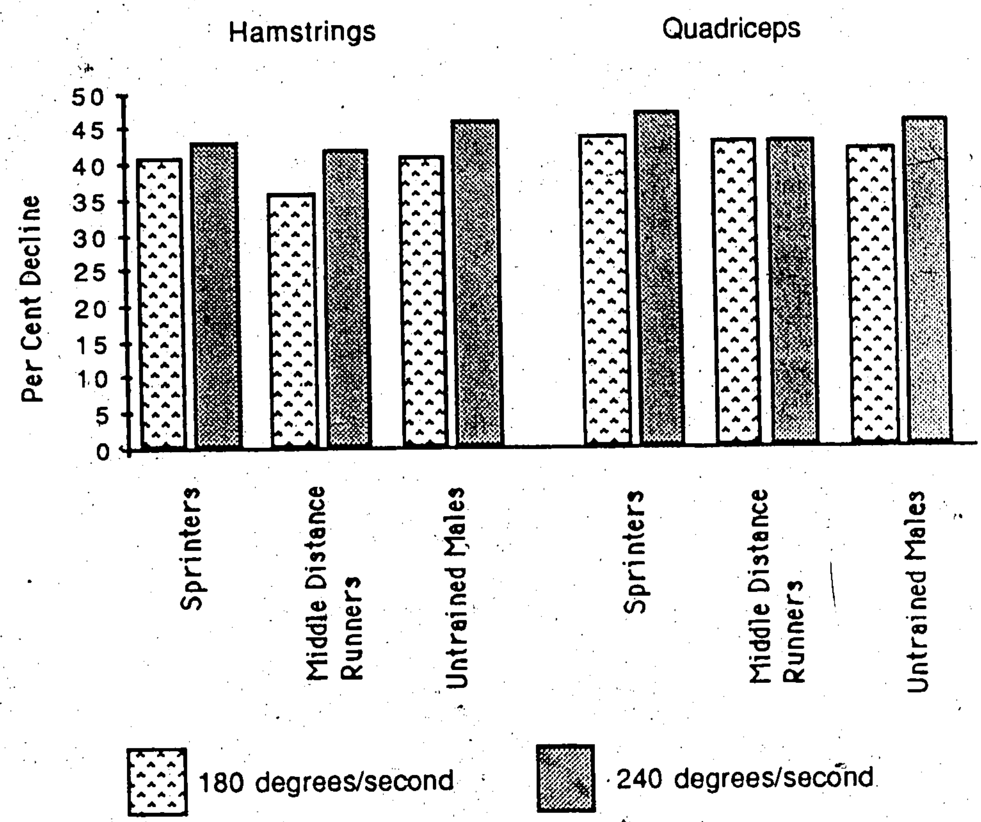
Comparison Between the Per Cent Decline of Peak Torque at 180 Degrees/Second and 240 Degrees/Second

(Values are means with S.D.'s in parenthesis)

Group	Muscle	Speed 180 deg/sec	240 deg/sec
Sprinters	Hamstrings	41% (8.4)	43% (9.2)
	Quadriceps	44% (9.5)	47% (11.5)
Middle-Distance Runners	Hamstrings	36% (8.1)	42% (9.0)*
	Quadriceps	43% (7.0)	43% (6.9)
Untrained	Hamstrings	41% (9.9)	46% (9.6)*
	Quadriceps	42% (6.5)	46% (6.0)*

* statistically significant (p = 0.05)

Figure 8. Comparison Between the Per Cent Decline of Peak Torque at 180 Degrees/Second and 240 Degrees/Second on a 45 Second Endurance Test.



It was hypothesized that there would be a significant difference in muscle endurance of the quadriceps and hamstring muscles at the faster velocity as compared to the slower velocity in all three groups of subjects. Table V shows this hypothesis to be true for the hamstring muscles of middle-distance runners and for both hamstring and quadriceps muscles of the untrained group (p=0.05) (Figure 8). The per cent decline was greater at the faster velocity.

The summary of the three-way analysis of variance for the endurance ratios is given in Appendix E. The results indicated that the three way interaction was not significant.

It was expected that there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio of middle-distance runners as compared to sprinters at the faster velocity. This difference, on analysis, was found to be non-significant (p>.05) (Table VI).

Finally, it was expected that there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio at the faster velocity as compared to the slower velocity in all three groups. Again, the results showed that the difference was non-significant (p>.05) (Table VII).

The correlation between thigh muscle fatigue and body weight is shown in Table VIII. These variables were not strongly correlated and the hamstring fatigue had a considerably lower correlation with body weight than the quadriceps fatigue did.

Table IX shows the correlation between thigh muscle fatigue and initial strength. The quadriceps fatigue was highly correlated with initial strength, whereas hamstring fatigue had a somewhat lower correlation with initial strength.

Table VI

Comparison Between the Hamstrings/Quadriceps (H/Q) Endurance Ratio# in Sprinters and Middle-Distance Runners

(Values are means with S.D.'s in parenthesis)

Speed	Group Spr		MDR	
180 deg/sec	0.95	(.20)	0.86	(.19)
240 deg/sec	0.95	(.24)	0.97	(.16)

($p = 0.12$)

#H/Q Endurance Ratio = Per cent decline of peak torque in hamstrings divided by per cent decline of peak torque in quadriceps on a 45 second endurance test

Spr = Sprinters
MDR = Middle-Distance Runners

Table VII

Comparison Between the Hamstrings/Quadriceps (H/Q) Endurance Ratio# in Sprinters, Middle-Distance Runners and Untrained Males at 180 Degrees/Second and 240 Degrees/Second

(Values are means with S.D.'s in parenthesis)

Group	Speed 180 deg/sec	240 deg/sec
Sprinters	0.95 (.20)	0.95 (.24)
Middle-Distance Runners	0.86 (.19)	0.97 (.16)
Untrained	0.98 (.27)	1.03 (.28)

($p = 0.12$)

#H/Q Endurance Ratio = Per cent decline of peak torque in hamstrings divided by per cent decline of peak torque in quadriceps on a 45 second endurance test

Table VIII

Pearson Correlation Coefficients (r) for Per Cent Decline in Peak Torque (Fatigue Index) and Body Weight

	r
Quads 180 L	.35 *
Quads 180 R	.33 *
Quads 240 L	.33 *
Quads 240 R	.19
Hams 180 L	.20
Hams 180 R	.06
Hams 240 L	.12
Hams 240 R	.09

* Statistically significant (p = 0.05)

Quads = Quadriceps
Hams = Hamstrings
180 = 180 degrees/second
240 = 240 degrees/second
L = left
R = right

Table IX

Pearson Correlation Coefficients (r) for Per Cent Decline in Peak Torque (Fatigue Index) and Initial Strength

	r
Quads 180 L	.80 *
Quads 180 R	.69 *
Quads 240 L	.76 *
Quads 240 R	.62 *
Hams 180 L	.46 *
Hams 180 R	.52 *
Hams 240 L	.40 *
Hams 240 R	.25

* Statistically significant (p = 0.05)

Quads = Quadriceps
Hams = Hamstrings
180 = 180 degrees/second
240 = 240 degrees/second
L = left
R = right

V. DISCUSSION

The purpose of this study was to analyse the isokinetic muscle endurance of knee flexors and knee extensors in runners and untrained men. Left and right lower limbs were compared as well as performance at two different velocity settings on the Cybex II+ isokinetic apparatus.

The discussion is organized into sections based on the six hypotheses stated in the Introduction, followed by sections on various correlations between variables, and clinical implications.

Hypothesis 1 - Comparison of Muscle Endurance Between Left and Right Lower Limbs

It was hypothesized that there would be no significant difference in muscle endurance between left and right lower limbs of the subjects in each group for the knee flexors and extensors (for each of the two speeds examined).

As expected, there was no difference in endurance between the left and right lower limbs (Table II). Running is basically a symmetrical sport, so the training effects should be the same for both sides. Of the thirty-subjects, twenty eight had a right dominant lower limb, as determined by kicking a ball (20,58,65). Thus, limb dominance had no effect on isokinetic muscle endurance of the subjects in this study. This finding is consistent with results from studies on fencers (54), high school football players (81) and female basketball players (82) where no significant differences in muscle endurance between dominant and nondominant lower limbs were found.

These results suggest that when rehabilitating sprinters, middle-distance runners or untrained men, both lower limbs should be equally endurant by the end of the training program.

Hypothesis 2 - Difference in Muscle Endurance Between the Hamstrings and Quadriceps Muscles

It was hypothesized that there would be a significant difference in endurance patterns between the knee flexors and knee extensors in all three groups of subjects (for each of the two speeds examined).

In the present study, a significant difference between the endurance of the hamstring muscles and the quadriceps muscles was found only in the group of middle-distance runners at the velocity setting of 180 degrees per second and not in the group of sprinters or the untrained subjects (Table III). Except for the finding for the group of middle-distance runners, these results are in contrast with other recent studies on the endurance of the thigh muscles, all of which have shown the hamstring muscles to have more endurance than the quadriceps muscles (8,57,58). The authors of these studies do not report that a gravitational correction had been included in the calculations. It has been pointed out, however, by many authors (19,64,65,66,67,68,83) that correcting for gravity is necessary in this test position (sitting), especially at high velocities with many repetitions. In the sitting position, the quadriceps muscle group performs work against gravity and therefore, appears to be more fatigable than the hamstring muscle group which is assisted by gravity. During both endurance and high velocity testing, the relative contribution of gravity to recorded torque values becomes increasingly large as active torque generation decreases (34,64,66). Therefore, a gravitational correction factor was used in this study. The torque due to gravity was added to the torque produced during extension movements and subtracted from torque produced during flexion movements (64). The apparent neglect of other studies to account for the influence of gravity on the recorded torques could be, in part, the source of the discrepancies found between the results of those studies and the present one.

Training effects are the most likely explanation for the difference in endurance between the hamstring and quadriceps muscles in the middle-distance runners in this study. Watkins and Harris (8) found that in a group of long-distance runners, there was a relatively low per cent decline in torque values of the hamstring muscles as compared to professional hockey players. Harris (56) has also shown that an intense long distance running program increased the endurance of the hamstring muscles in females. Similarly, specificity of training has been suggested as a reason for greater endurance in the hamstrings than the quadriceps in professional ballerinas (57). Sprinters, on the other hand, showed no difference in muscle endurance between these muscle groups in the present study. No comparative data on sprinters are available but training effects of sprinting may possibly result in this kind of endurance pattern. Thus, the results of the present study as well as studies of other sport groups (8,57) indicate that performance demands specific to each sport may require different patterns of muscular endurance. These differences need further investigation.

Initial strength level of the hamstring muscles and the quadriceps muscles may be another reason for a difference in their endurance among middle-distance runners. As seen in Table I, the quadriceps muscles are stronger than the hamstring muscles, and thus they perform more work at the beginning of the endurance test, since work is the area under the torque curve and higher torque values give larger area (31,53). However, this is true also for the other two groups studied, the sprinters and the untrained, but neither group showed a significant difference in endurance between the hamstring and quadriceps muscles. In both groups, the hamstring muscles show slightly more endurance than the quadriceps muscles but not enough to be statistically significant.

Despite the contradictary findings resulting from the analysis of hypothesis 2, the data of Table III should be useful to physical therapists in a clinical setting. They could use the data as examples of normal values for comparison when evaluating, rehabilitating and defining treatment goals for the injured runner, for example.

Hypothesis 3 - <u>Difference in Muscle Endurance Between Sprinters, Middle-Distance Runners and Untrained Subjects</u>

It was hypothesized that the middle-distance runners would show greater endurance of both knee flexors and knee extensors than the other two groups studied (for each of the two speeds examined). This hypothesis was rejected in the present study.

The main reasons the middle-distance runners were expected to have greater endurance of both the hamstring and quadriceps muscles than the other two groups, are the histologic make-up of their muscles and training effects (59,60,84,85,86,87). Two basic types of fibres in human skeletal muscle have been identified: slow twitch fibres (ST; Type I) and fast twitch fibres (FT; Type II). The ST fibres have relatively slow contractile properties as indicated by the time to peak tension and are well-endowed with enzymes in the metabolic pathways for the terminal oxidation of fuels to carbon dioxide and water (aerobic). Consequently, they fatigue slowly (60). Conversely, FT fibres have fast-twitch properties and low biochemical potentials for terminal oxidative metabolism, but have highly effective systems for adenosine triphosphate (ATP) production from the Embden-Meyerhof pathway (anaerobic). Such fibres produce tension for short periods of time and fatigue easily (60).

In general, distance runners tend to have more ST fibres than sprinters, although considerable variation exists in the fibre composition of the skeletal muscle within athletic groups (59,60). Interindividual differences in fibre type distribution and maximal anaerobic power, have been claimed to be almost entirely determined by heredity (88,89,90). Endurance performance responses to training have also been found to be hereditary (91). As ST fibres are well suited for endurance work, and in their training programs, middle-distance runners emphasize aerobic work, this group was expected to show less decline in torque in the 45 second endurance test than the other two groups studied. However, this 45 second high intensity endurance test may have been too intense (maximal effort) and too short to elicit a difference in endurance between the three groups. A person's capacity for high-intensity, short-term exercise, where the force generated by repeated muscular contractions approaches that of a maximal voluntary contraction, is primarily dependent upon anaerobic processes for energy release (92,93).

Several other factors could contribute to the similarity in thigh muscle endurance of all three groups. Some of the middle-distance runners were young athletes (18 - 19 years) and thus had a shorter training background than the sprinters. Novice middle-distance runners have been shown to have a thirty to fifty percent lower oxidative enzyme activity than experienced sportsmen (87). Some of the sprinters were borderline middle-distance runners, as they would occasionally compete in 800 m races in addition to their 200 m and 400 m events. Furthermore, training programs of sprinters and middle-distance runners are somewhat similar as middle-distance runners emphasize anaerobic work as well as aerobic work (94). The so-called "Untrained" subjects were a group of physically active students who had done recreational sports for a long time, and therefore would have developed some training effects.

Hypothesis 4 - Difference in Muscle Endurance Between the Two Velocity Settings (180 and 240 Degrees Per Second)

It was hypothesized that there would be a significant difference in muscle endurance of the quadriceps and hamstring muscles at the faster velocity as compared to the slower velocity in all three groups of subjects.

This difference was expected because of different fibre type recruitment at each velocity. The FT fibres were expected to be more involved at the faster velocity and therefore more fatigue would be evident. Such may be the case in the group of untrained subjects for both the quadriceps and hamstring muscles and for the hamstrings in middle-distance runners who showed significantly more fatigue at the faster velocity (Table V). In the group of sprinters, who generally have a predominance of FT fibres (59,60,84), there was no difference in muscle endurance between the two velocity settings.

These findings indicate that results from isokinetic endurance tests at different velocities are not necessarily comparable. Therefore, clinicians dealing with runners as well as untrained subjects should only compare their results with available norms at the same velocity setting.

Hypothesis 5 - <u>Difference in the Hamstrings/Quadriceps Endurance Ratio Between Sprinters and Middle-Distance Runners</u>

It was hypothesized that there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio of middle-distance runners as compared to sprinters at the faster velocity.

In this study, this hypothesis was rejected as there was no significant difference (Table VI). Sapega et al. (13,17) have stated that computed parameters, such as the ratio of strength, endurance or power between agonist-antagonist muscle groups about a joint, are more sensitive indicators of musculoskeletal abnormalities than the raw data parameters. Several investigators (18,19,21,67,81) have studied the strength ratio between the hamstring and the quadriceps muscles. On the other hand, no comparative data have been reported on the endurance ratio between these muscle groups. Thus, only further prospective studies will tell if this parameter is of any actual value in evaluating athletes. Through further research, it needs to be determined if there is a critical hamstrings to quadriceps (H/Q) endurance ratio that might be indicative of injury or predictive of injury or pathology.

Hypothesis 6 <u>Difference in the Hamstrings/Quadriceps</u>

Endurance Ratio Between the Two Velocity Settings (180 and 240 Degrees Per Second)

It was hypothesized that there would be a significant difference in the hamstrings to quadriceps (H/Q) endurance ratio at the faster velocity as compared to the slower velocity in all three groups.

This hypothesis was rejected as this study showed no such significant difference (Table VII).

As there are no comparative data available, additional research is needed to replicate the findings of this study and to investigate the potential predictive use of endurance ratios of the hamstring and quadriceps muscles.

Correlations

The correlation tables (VIII and IX) showed that thigh muscle fatigue was strongly correlated with initial strength, whereas the correlation with body weight was low.

The former relationship is in agreement with previous observations. Clarkson et al. (10) found a significant correlation between muscle fatigue and initial strength level of the quadriceps muscles at the velocity setting of 180 degrees per second. Similarly, Tesch et al. (95) reported that muscle fatigue elicited in the quadriceps at the velocity setting of 180 degrees per second correlated significantly with maximum strength at the velocity setting of 300 degrees per second. No comparative data are available on the relationship of thigh muscle fatigue and body weight.

These findings suggest that physical therapists should consider the relationship between thigh muscle endurance and initial strength when using normal values in the clinical setting.

Clinical Implications

The accurate assessment of muscular strength, endurance, power, and flexibility through quantitative testing methods has become increasingly important in the evaluation and rehabilitation of athletes with orthopedic problems. To be properly interpreted, the test results should be compared to the normal range of values for these parameters.

The only parameter examined in this study was muscular endurance. There are minimal data available on muscle endurance of the knee musculature in runners. The 45 second isokinetic endurance test used in the study should be a convenient test in the clinical setting. Therefore, the isokinetic data resulting from the study are offered as examples of normal values for thigh muscle endurance in sprinters, middle-distance runners and untrained men.

These data could be of particular value to physical therapists and other sports medicine professionals who are able to obtain isokinetic measures on their runners for injury prevention and rehabilitation purposes and to use as return to play criteria after injury. For example, when rehabilitating a runner following a thigh or knee injury, these data may be used to establish treatment goals where endurance training is included in the rehabilitation program.

VI. CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. There was no difference in thigh muscle endurance between left and right lower limbs of sprinters, middle-distance runners and untrained subjects.

2. There was no difference in endurance patterns between the knee flexors and knee extensors except in middle-distance runners at the velocity setting of 180 degrees per second, where the knee flexors showed greater endurance than the knee extensors.

3. There was no difference in muscle endurance of knee flexors and knee extensors between sprinters, middle-distance runners and untrained subjects.

4. There was a difference in muscle endurance of the quadriceps and hamstring muscles between the two velocity settings (180 and 240 degrees per second) in the group of untrained subjects. This difference was also seen only in the hamstring muscles of middle-distance runners. The per cent decline was greater at the faster velocity. No such difference was

seen in the group of sprinters.

5. There was no difference in the hamstrings to quadriceps (H/Q) endurance ratio between sprinters and middle-distance runners at the faster velocity (240 degrees per second).

6. There was no difference in the hamstrings to quadriceps (H/Q) endurance ratio between the two velocity settings in any of the three groups studied (sprinters, middle-distance runners and untrained subjects).

7. Thigh muscle fatigue and body weight were not strongly correlated.

8. Thigh muscle fatigue and initial strength were highly correlated.

Recommendations

It is recommended that the isokinetic muscle endurance of knee flexors and knee extensors be studied more extensively. For example:

1. Larger samples of various sport groups should be

investigated.

2. Normal values for these groups should be established for clinical use.
3. The potential predictive use of the muscle endurance parameter should be investigated through prospective studies for injury prevention purposes.
4. The findings of the present study should be replicated through research on larger samples of subjects.

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APPENDIX A

INFORMED CONSENT FORMS

Faculty of Rehabilitation Medicine
Department of Physical Therapy
University of Alberta
Edmonton, Alberta

Informed Consent Form for Research Study:

"Isokinetic Evaluation of Knee Flexor and Knee Extensor Muscle Endurance"

Although many studies are now available concerning muscle performance in athletes, this research has largely been confined to studies of muscular strength and strength ratios. The few studies examining muscle endurance or fatigue of the thigh muscles have normally only reported the endurance of the knee extensors.

The purpose of this study is to analyse the muscle endurance of both the knee flexors and extensors. More specifically, the isokinetic endurance of the knee flexors and extensors will be analysed separately, and left and right limbs will be compared with regards to muscle endurance.

The study will involve one practice session (20-30 min.) and two testing sessions (approximately 30-40 minutes each) performed on separate days and will be arranged at your convenience. If you agree to participate in the study you will be asked not to perform any strenuous physical activity for at least 48 hours prior to each testing session. During each of the two testing sessions you will be asked to carry out a 45 second endurance test for each lower limb on the Cybex II isokinetic apparatus.

When you arrive in the laboratory, your height, weight and thigh circumference will be measured. Then you will be asked to sit in the Cybex chair and you will have a strap placed around your ankle to connect you to the testing machine. You will be firmly secured in the chair by means of straps around your thigh and across the pelvis and chest.

As a warm-up and familiarization procedure you will perform five to ten submaximal repetitions of reciprocal knee flexion and extension at the preset speed for that session, followed by three to five identical maximal repetitions. A three minute rest period will be given before the actual test starts.

The endurance test itself consists of a 45 second trial of high speed reciprocal flexion and extension of the knee with the speed selector set at 180 degrees per second for one session and at 240 degrees for the other session. Both lower limbs will be tested each time.

You will be asked to ensure that you are making a maximal effort with each contraction throughout the test and to work as fast and as hard as you can. You will be verbally encouraged by the investigator and periodically given the time remaining of the test.

The major risk associated with participation is that related to muscular soreness following the contraction efforts. This discomfort is expected to be minor and similar to that which you may have experienced previously after exercise to which you were unaccustomed. A secondary risk relates to the possible development of knee discomfort as a result of the high intensity contraction efforts. Such discomfort is uncommon and usually temporary when it occurs. If you develop knee joint pain at any time during the study your participation in the study will be immediately stopped.

The results of this study will be offered as examples of normal values of muscle endurance for sprinters and middle-distance runners as well as for untrained males. With expanded profile data about the muscle performance characteristics of various categories of athletes, training and rehabilitation programs may be adapted to meet the strength, speed and endurance requirements of a given sport.

Any questions you may have before, during or after the sessions will be gladly answered.

You have the right to withdraw from participation at any time for any reason.

All information and data collected during the study will be property of the investigators. Access to these will be restricted to those conducting the study, except where written approval is given by the subject to provide specific individuals with their data.

Please retain this explanation for your own records.

Thank you.

In the event that questions concerning the study arise, please feel free to contact Svandis Sigurdardottir, at 432-2068 (work) or 439-7505 (home).

Department of Physical Therapy
Faculty of Rehabilitation Medicine

University of Alberta
1987

INFORMED CONSENT FORM FOR RESEARCH STUDY

Isokinetic Evaluation of Knee Flexor and Knee Extensor Muscle Endurance

Subject Consent (retained by investigators)

I ________________________________ do hereby agree to
(PLEASE PRINT NAME)
participate as a subject in the research study entitled "Isokinetic Evaluation of Knee Flexor and Knee Extensor Muscle Endurance" to be conducted by Svandis Sigurdardottir, B.A., B.P.T. under the supervision of Dr. D.J. Magee.

The nature of the study has been explained to me and I understand that I may withdraw from participation in this study at any time.

________________________________ ________________
SUBJECT'S SIGNATURE DATE

________________________________ ________________
ADDRESS PHONE NUMBER

I hereby certify that I have given to the above individual an explanation of the contemplated study and any possible side effects.

________________________________ ________________
INVESTIGATOR'S SIGNATURE DATE

Department of Physical Therapy
Faculty of Rehabilitation Medicine

University of Alberta
1987

INFORMED CONSENT FORM FOR RESEARCH STUDY

Isokinetic Evaluation of Knee Flexor and Knee Extensor Muscle Endurance

Subject Consent (retained by investigators)

I ______________________________ do hereby agree to
(PLEASE PRINT NAME)

allow the investigators of the above named study to provide my data arising from this study to

______________________________ ______________________________
NAME ASSOCIATION

______________________________ ______________________________
SUBJECT'S SIGNATURE DATE

______________________________ ______________________________
ADDRESS PHONE NUMBER

I was witness to the signature of the subject.

______________________________ ______________________________
WITNESS' SIGNATURE DATE

Torque Channel Calibration

Turn the RDSC (Remote Digital Speed Control) speed selector ON. Press 60, then ENTER on the RDSC. Control. Move the input adapter back and forth being sure to meet resistance in both directions. Press 30, then ENTER on the RDSC.

A. Zero or null out recorder to resting signal of dynamometer, as follows:

1. Set DAMPING control at zero, CHART SPEED at 5 MM/SEC with speed selector at 30 deg/sec. Make sure there is no load on the dynamometer. Do this by removing any adapters from the dynamometer.

2. Set FT.LBS.SCALE on 180 and zero recorder stylus on baseline usihg ZERO ADJ. knob for Torque Channel.

3. Switch FT.LBS.SCALE to 30.

4. If stylus deflects from baseline, adjust ZERO NULL potentiometer on side of recorder with calibration screwdriver to zero stylus on chart baseline.

5. Repeat steps 2 through 4 until stylus deflects less than 1/2 minor division when switching back and forth between 180 and 30 ft-lbs scales.

6. Set CHART SPEED at STANDBY.

B. Calibrate each Torque Range Scale, as follows:

1. Set Torque Channel to ft-lbs scale to be calibrated (the 180 ft-lbs scale in this study). Set DAMPING control at 3.

2. Press 30, then ENTER on the RDSC. Make sure there is no load on the dynamometer. Adjust stylus to zero baseline

using Torque Channel ZERO ADJ. knob.

3. Insert T-bar calibration arm into long input adapter and set effective input arm length for ft-lbs scale being calibrated (arm length B is used for the 180 ft-lbs scale).

4. Add appropriate amount of disc weights for ft-lbs scale being calibrated (32.5 lbs for the 180 ft-lbs scale). Cybex certified calibration weights, used in this study, are accurate to 0.01%.

5. Set CHART SPEED at 5 MM/SEC.

6. Lift weighted T-bar calibration arm to vertical position above dynamometer. Pull or push weighted arm forward gently to engage isokinetic resistance before letting go so that arm falls smoothly until it contacts the floor.

7. Check the torque reading on the chart recording. The peak value for the 180 ft-lbs scale setting should be five major divisions above baseline.

8. If the chart recording does not agree with the above value, adjust the potentiometer for the 180 ft-lbs scale with the calibration screwdriver. Turning the potentiometer clockwise increases the torque reading, counterclockwise decreases it. The weight swing must be repeated each time an adjustment is made.

9. Once the torque value is correct, re-check twice to make sure reading is consistent.

10. Remove T-bar calibration arm from long input adapter.

Position Angle Channel Calibration

To calibrate CYBEX II+ Position Angle Channel, use the following procedure:

1. With recorder power ON set DEG. SCALE to 150.

2. Set CHART SPEED at 5 MM/SEC.

3. Set INPUT DIRECTION to CW (clockwise).

4. While depressing ZERO TEST button, use Position Angle ZERO ADJ. knob to adjust stylus to zero baseline. Release ZERO TEST button. Note that Position Angle ZERO ADJ. knob is for calibration only. It must be set so that the stylus returns to zero baseline whenever ZERO TEST button is depressed. Position Angle ZERO ADJ. knob is not to be used for zeroing stylus during testing.

5. Adjust Position Angle Channel stylus to zero baseline by turning goniometer dial on dynamometer clockwise. Note that stylus may jump off scale at one point in goniometer range - this is normal.

6. Recheck steps 4 and 5 until the stylus does not deviate from zero baseline when zero test button is pressed or released.

7. Using the white line under the goniometer dial as an index mark, rotate the dial clockwise precisely 150 degrees. If the stylus traces a line exactly on the top line of the Position Angle chart, no adjustment is necessary. If the stylus lies above or below the top line, repeat steps 4 through 7 to veryfy the reading. If adjustment is necessary, proceed with step 8.

8. Locate the DEG. CAL. screw on the recorder panel. Using a 7/16 inch wrench, slightly loosen the locking nut that secures the screw. With a standard screwdriver, turn the screw to move the stylus line precisely to the top line on the Position Angle chart. Using the screwdriver to hold the screw in the adjusted position, snug down the

locking nut. Recheck calibration by repeating steps 4-7.

APPENDIX C

SUBJECTS' ANTHROPOMETRIC DATA

DATA SHEET

NAME DATE

AGE

SPORT GROUP

HEIGHT

WEIGHT

THIGH CIRCUMFERENCE - mid-thigh (i.e., midway between gr. trochanter and knee joint line)

- with muscles relaxed

- R __________ cm L __________ cm

INITIAL STRENGTH LEVEL - 180°/sec R $\frac{H}{Q}$ ____ ft.lbs. L $\frac{H}{Q}$ ____ ft.lbs.

- 240°/sec R $\frac{H}{Q}$ ____ ft.lbs. L $\frac{H}{Q}$ ____ ft.lbs.

DOMINANT LIMB - used to kick a ball

Anthropometric Measurement Techniques

Measurement of Height

The subject, dressed in shorts and tee shirt, stood comfortably with feet about 5 cm apart on a physician's scale. The axis of the subject's vision was horizontal, eyes looking straight ahead. A rule was applied directly to the top of the skull with minimal pressure. Results were read and entered to the nearest 0.1 cm.

Measurement of Weight

Dressed in shorts and tee shirt, the subject stood on the platform of the physician's scale with weight evenly distributed over both feet. The weight measurement was read to the nearest 0.1 kg.

Measurement of Thigh Girth

The subject, dressed in shorts and tee shirt, stood on the floor while measurement was made between the tip of the greater trochanter and knee joint line with an ordinary tape measure. Midway between these anatomical landmarks a penmark was made. With the subject lying supine with a pillow under his knees, a thigh circumference measurement was made below the penmark bilaterally. Results were read and entered to the nearest 0.1 cm.

ID	GROUP	AGE	HEIGHT	WEIGHT	THIGHL	THIGHR	HAM180R	QUAD180R	HAM180L	QUAD180L	HAM240R	QUAD240R	HAM240L	QUAD240L
1	1	23	191.5	80.6	53.5	52.0	108	132	102	142	96	109	95	118
2	1	22	187.5	63.6	51.5	51.5	85	119	83	124	86	114	89	104
3	1	24	177.5	77.7	54.0	54.7	103	117	102	95	86	87	100	87
4	1	20	175.5	64.1	50.0	49.5	75	84	77	88	76	81	73	84
5	1	22	175.0	61.0	46.5	46.5	73	80	77	85	76	81	60	72
6	1	21	173.5	67.1	50.5	50.5	77	90	86	102	70	69	78	81
7	1	22	175.5	61.6	49.5	49.5	78	102	75	109	59	68	56	78
8	1	20	190.0	81.1	55.5	55.0	97	128	102	133	94	124	102	121
9	1	19	177.0	69.8	52.0	52.3	97	115	84	112	70	94	88	110
10	1	19	169.0	63.2	53.0	52.5	86	115	93	125	81	103	87	114
11	2	19	181.0	65.4	47.0	47.0	81	95	84	99	77	86	78	84
12	2	18	179.0	68.5	51.0	51.0	81	114	78	96	73	88	79	85
13	2	18	179.0	68.1	47.2	47.2	82	90	76	91	77	74	80	80
14	2	20	175.0	59.2	45.5	45.5	88	106	88	112	75	91	84	99
15	2	22	162.5	53.5	46.0	46.0	64	73	61	67	54	64	52	61
16	2	21	185.0	72.5	52.5	52.0	78	108	74	107	79	96	79	97
17	2	22	186.0	73.7	51.0	51.0	82	102	86	105	72	93	70	84
18	2	18	175.0	57.9	47.5	47.2	84	105	64	102	67	78	72	81
19	2	18	179.5	80.0	56.5	55.5	89	99	91	115	88	83	88	107
20	2	32	169.0	69.5	53.5	55.0	75	103	63	106	74	90	66	86
21	3	20	192.0	84.9	51.0	52.0	92	144	104	158	105	132	115	140
22	3	23	170.0	63.8	49.0	48.5	71	87	67	80	62	68	75	79
23	3	23	177.0	69.0	50.0	51.0	61	108	60	115	54	86	58	94
24	3	23	184.0	68.8	49.0	50.0	90	99	94	108	85	92	89	96
25	3	26	175.0	64.3	49.0	49.0	78	88	75	86	68	71	71	76
26	3	29	185.5	70.0	47.0	46.5	79	98	84	92	74	88	80	78
27	3	26	177.0	71.8	52.0	53.0	74	90	73	87	70	81	71	72
28	3	27	188.5	66.1	47.5	47.5	85	102	83	97	86	90	78	87
29	3	31	185.5	74.9	48.5	49.0	102	123	97	118	79	90	84	91
30	3	25	184.0	66.0	48.3	48.5	70	88	68	91	67	71	62	77

Group 1 = sprinters
Group 2 = middle-distance runners
Group 3 = untrained males
Height in cm
Weight in kg
L = left
R = right
Thigh = thigh circumference
Ham = Hamstrings
Quad = Quadriceps

180 = 180 degrees per second
240 = 240 degrees per second

The last 8 columns show initial strength in ft.lbs. (defined as the single highest torque value obtained during the first five repetitions of the endurance test).

APPENDIX D

RAW DATA

ID	BEG1	BEG2	BEG3	BEG4	BEG5	BEG6	BEG7	BEG8
1	148.1900	129.9100	128.2600	114.3800	88.0400	99.2000	82.6500	84.8600
2	128.2600	127.4800	105.4500	116.2200	71.5000	73.5200	78.7400	73.4300
3	98.1300	120.9800	92.0600	91.5300	89.8300	90.0400	89.0700	75.8900
4	92.9400	87.3200	89.9400	86.8600	64.7400	64.2800	61.7100	66.0000
5	91.5000	86.9200	76.7100	87.7500	62.0600	57.9800	45.7800	64.6400
6	106.8500	93.2600	89.4200	73.4700	71.0700	65.2700	66.5500	61.4900
7	114.7100	106.3700	88.5900	77.7800	67.6300	68.9900	43.6300	44.2200
8	139.9500	133.2100	129.6200	125.3200	85.7100	83.2500	88.7300	76.5500
9	119.2700	120.7700	119.2800	95.4000	73.2100	87.5700	74.1600	59.6900
10	130.5600	119.5400	122.4700	110.0600	81.6700	73.6700	74.6700	66.9400
11	107.6300	102.6700	91.4100	93.3000	71.7800	65.1100	65.6200	59.5800
12	102.0400	116.3400	89.8400	94.5600	63.1100	67.2000	66.5700	55.6000
13	97.5000	95.1600	86.5200	83.0200	66.1400	71.0200	66.3900	62.6500
14	116.8400	108.1500	102.6000	96.5600	75.7100	75.9800	70.3300	61.8500
15	70.7300	77.7400	65.3900	68.3900	52.6500	56.8400	44.5600	45.9900
16	110.0300	109.9200	100.5400	100.9200	67.5500	69.1000	72.1800	67.3300
17	115.4700	109.7[illegible]00	91.1200	101.9000	64.8000	64.4500	52.2000	58.6800
18	110.9000	108.[illegible]00	91.6500	84.0700	51.8400	74.5600	56.8100	59.3100
19	123.0200	107.5800	113.4200	89.1300	78.0600	76.2100	75.5600	75.5500
20	110.2000	105.7100	92.4900	96.0100	53.6700	65.5100	55.6300	64.6600
21	169.4600	154.6000	151.1800	138.2500	84.1500	74.2300	94.9000	86.9700
22	89.2800	92.8100	84.9200	74.8500	53.5500	60.5800	62.4200	54.2600
23	119.6600	115.1100	98.2900	92.4400	50.2000	51.2200	48.8700	46.2200
24	118.4200	107.9600	105.4200	101.6100	78.4300	73.0100	71.3900	70.5100
25	91.3700	94.2600	81.3700	80.0900	67.6300	67.0700	62.9600	57.9800
26	102.5700	105.4200	88.5700	94.3600	65.8900	60.3300	63.6600	57.0100
27	95.7500	99.5400	80.6100	89.5700	60.5300	60.6200	57.9500	56.2800
28	108.3400	112.3100	98.0200	97.3100	66.2500	68.7200	61.5800	68.8800
29	127.7800	128.7800	101.5100	100.1900	83.8300	89.2100	67.5400	65.2200
30	102.6400	95.3600	85.5300	79.8400	54.5800	57.4700	48.5800	57.1400

Mean peak torque (corrected for gravity) at the beginning of the endurance test

Fatigue index (per cent decline in peak torque)may be calculated for each subject on the basis of these torque values and the matching torque values at the end of the endurance test presented on the following page.

ID 1-10 = Sprinters
ID 11-20 = Middle-distance Runners
ID 21-30 = Untrained Males

BEG1 = Quadriceps 180 deg/sec left
BEG2 = Quadriceps 180 deg/sec right
BEG3 = Quadriceps 240 deg/sec left
BEG4 = Quadriceps 240 deg/sec right
BEG5 = Hamstrings 180 deg/sec left
BEG6 = Hamstrings 180 deg/sec right
BEG7 = Hamstrings 240 deg/sec left
BEG8 = Hamstrings 240 deg/sec right

ID	END1	END2	END3	END4	END5	END6	END7	END8
1	67.6400	61.5500	47.8100	59.4000	49.7100	49.5500	42.1200	45.6300
2	58.9000	50.5500	47.9200	39.6800	46.1400	38.3700	48.0800	36.0400
3	69.6300	76.0200	58.8800	59.3600	54.1900	45.0800	44.4600	43.1100
[illegible]	61.3300	56.3600	55.1600	50.5800	44.3000	42.8200	41.5500	39.0500
5	63.7000	61.3600	47.3700	50.0900	43.0700	45.7800	30.4800	34.8900
6	54.8600	53.9900	43.7900	45.0200	31.2100	33.6900	29.5300	31.1400
7	64.6200	65.6200	59.8600	57.1900	37.7500	37.9600	27.6300	28.3800
8	73.0200	73.6500	60.1600	62.7800	55.1600	55.1100	48.9300	53.2600
9	60.9800	70.6000	48.2400	58.5500	40.5100	53.9000	32.8900	47.6600
10	54.8700	62.7300	45.4600	44.8300	45.3300	40.6700	38.3300	34.0000
11	68.1600	68.6700	59.4000	65.8300	46.5400	44.9400	47.0600	40.6100
12	60.1800	69.6700	55.2100	60.9100	41.5300	41.5300	36.4300	34.0700
13	50.1400	53.2600	50.4000	49.4600	40.3100	42.6400	43.2300	40.9900
14	57.8400	56.3800	48.2900	45.6700	47.3800	39.9800	29.5100	30.2500
15	53.0600	55.6100	41.3500	45.0300	39.4700	42.9400	29.9900	31.2300
16	55.6900	58.2500	46.2000	55.2100	53.4700	39.9900	44.1800	41.3800
17	64.5200	61.6500	54.9600	55.6000	37.9400	37.6200	29.6000	23.8800
18	58.6500	60.8000	51.3400	48.7400	34.5500	38.3000	24.9900	37.2600
19	67.5200	65.7100	55.5000	48.0900	46.2500	40.3000	43.6500	38.8300
20	57.1000	55.1000	51.9100	47.7800	39.5100	47.4300	33.4100	37.8900
21	72.7600	71.8900	67.2900	63.6400	47.2400	56.3000	52.8700	49.0600
22	59.0800	52.8300	48.2600	44.0400	33.2200	40.3400	28.9700	35.5600
23	70.7000	65.7000	47.2500	53.6900	39.5400	40.2200	38.7000	33.8900
24	66.7600	68.4200	57.7000	58.4200	42.4700	43.0100	35.9300	37.5100
25	52.3700	49.1700	40.1200	38.6000	35.9900	36.3000	32.7100	30.5100
26	57.1700	63.6200	44.6400	47.2000	34.7000	38.6500	35.8300	30.8900
27	62.5600	64.4600	53.6400	52.1800	37.2900	39.8800	30.4500	30.8800
28	66.7700	67.6100	53.3700	53.9800	38.6600	36.8000	32.9100	37.4600
29	65.0200	64.2700	52.7100	54.0900	39.7900	45.4700	27.9000	30.1800
30	65.5600	61.1700	54.9500	49.5700	23.1100	30.8900	24.3000	21.3300

Mean peak torque (corrected for gravity) at the end of the endurance test.

These torque values may be used to calculate the fatigue index for each subject as explained on the preceding page.

ID 1-10 = Sprinters
ID 11-20 = Middle-distance runners
ID 21-30 = Untrained Males

END1 = Quadriceps 180 deg/sec left
END2 = Quadriceps 180 deg/sec right
END3 = Quadriceps 240 deg/sec left
END4 = Quadriceps 240 deg/sec right
END5 = Hamstrings 180 deg/sec left
END6 = Hamstrings 180 deg/sec right
END7 = Hamstrings 240 deg/sec left
END8 = Hamstrings 240 deg/sec right

ID	BEG1	BEG2	BEG3	BEG4	BEG5	BEG6	BEG7	BEG8
1	138.0000	121.3300	117.3300	104.6700	99.3300	106.0000	94.0000	92.6700
2	119.6700	116.3300	100.0000	107.3300	81.6700	84.6700	87.0000	85.0000
3	92.0000	114.6700	83.6700	83.3300	98.6700	100.6700	99.0000	85.0000
4	86.6700	82.3300	83.0000	79.6700	75.0000	73.6700	72.0000	73.6700
5	83.6700	78.0000	69.6700	80.6700	76.0000	71.6700	58.0000	74.6700
6	98.3300	87.0000	78.6700	65.0000	85.0000	76.6700	76.0000	68.0000
7	107.6700	99.3300	76.6700	66.3300	74.6700	77.0000	54.0000	55.6700
8	130.3300	124.6700	120.0000	120.0000	100.3300	95.6700	101.0000	92.3300
9	110.6700	112.6700	108.0000	90.6700	83.0000	95.6700	86.0000	69.0000
10	120.6700	112.0000	112.0000	101.6700	92.3300	84.3300	85.0000	80.0000
11	97.6700	93.0000	83.3300	85.3300	84.0000	79.3300	77.0000	76.0000
12	93.0000	109.3300	81.6700	86.0000	74.6700	79.3300	78.0000	68.6700
13	90.0000	89.0000	79.6700	73.3300	75.0000	79.6700	78.0000	75.6700
14	109.3300	102.0000	94.0000	89.0000	86.3300	86.6700	83.0000	73.3300
15	65.0000	72.3300	59.6700	62.6700	59.6700	62.6700	51.0000	53.0000
16	105.0000	104.3300	96.0000	95.3300	73.3300	77.0000	78.0000	77.0000
17	101.6700	100.6700	81.0000	92.0000	82.3300	77.3300	68.0000	71.3300
18	100.0000	101.6700	80.3300	77.0000	64.0000	82.3300	70.0000	65.0000
19	112.6700	96.3300	106.3300	82.3300	90.3300	87.6700	86.0000	87.0000
20	104.6700	101.0000	84.6700	88.6700	62.3300	71.6700	65.0000	72.0000
21	152.3300	140.0000	136.3300	129.6700	103.3300	90.6700	113.0000	104.0000
22	79.0000	82.3300	75.3300	67.0000	65.0000	71.6700	73.0000	61.3300
23	112.6700	107.3300	90.6700	84.6700	58.6700	59.0000	56.0000	54.0000
24	107.0000	96.6700	94.0000	91.0000	92.6700	87.3300	87.0000	84.0000
25	84.3300	86.6700	74.3300	71.0000	74.6700	74.6700	70.0000	67.6700
26	91.0000	94.3300	77.0000	85.6700	81.3300	77.0000	78.0000	72.3300
27	86.3300	90.0000	71.0000	79.6700	72.0000	72.0000	69.0000	67.6700
28	96.3300	101.0000	86.0000	86.0000	82.6700	84.0000	78.0000	84.3300
29	116.6700	117.6700	90.0000	87.3300	95.3300	100.0000	81.0000	78.3300
30	90.6700	85.3300	75.3300	70.0000	67.0000	67.6700	61.0000	66.6700

Mean peak torque (uncorrected for gravity) at the beginning of the endurance test

Fatigue index (per cent decline in peak torque) may be calculated for each subject on the basis of these torque values and the matching torque values at the end of the endurance test presented on the following page.

ID 1-10 = Sprinters
ID 11-20 = Middle-distance runners
ID 21-30 = Untrained Males

BEG1 = Quadriceps 180 deg/sec left
BEG2 = Quadriceps 180 deg/sec right
BEG3 = Quadriceps 240 deg/sec left
BEG4 = Quadriceps 240 deg/sec right
BEG5 = Hamstrings 180 deg/sec left
BEG6 = Hamstrings 180 deg/sec right
BEG7 = Hamstrings 240 deg/sec left
BEG8 = Hamstrings 240 deg/sec right

ID	END1	END2	END3	END4	END5	END6	END7	END8
1	57.0000	52.3300	37.3300	49.6700	62.0000	61.0000	55.0000	55.3300
2	49.6700	41.6700	39.3300	33.0000	56.6700	51.6700	56.0000	46.3300
3	62.3300	69.0000	49.6700	51.0000	63.6700	54.3300	53.0000	53.0000
4	54.0000	49.6700	48.0000	44.6700	56.0000	53.6700	51.0000	48.0000
5	52.6700	51.3300	40.3300	43.0000	56.6700	59.0000	42.0000	45.6700
6	45.0000	45.0000	33.6700	35.3300	44.6700	38.6700	41.0000	40.6700
7	54.6700	55.6700	47.6700	45.0000	45.0000	45.0000	38.0000	38.3300
8	62.6700	65.6700	53.0000	53.6700	68.0000	68.0000	64.0000	67.3300
9	50.0000	63.0000	37.6700	49.3300	52.0000	62.0000	42.0000	56.0000
10	47.3300	53.6700	39.3300	38.0000	56.0000	51.3300	49.0000	44.6700
11	58.0000	59.0000	53.6700	57.3300	58.3300	59.6700	60.0000	55.3300
12	50.6700	62.6700	46.0000	52.3300	53.6700	53.6700	49.0000	46.6700
13	45.3300	49.3300	42.3300	42.3300	50.3300	52.3300	54.0000	53.3300
14	50.3300	50.0000	37.6700	37.6700	58.0000	50.6700	41.0000	40.3300
15	47.3300	51.3300	35.0000	38.3300	46.6700	48.6700	37.0000	38.0000
16	50.6700	52.6700	41.6700	49.0000	58.6700	49.6700	50.0000	50.0000
17	53.0000	54.0000	44.0000	47.3300	53.3300	48.3300	44.0000	39.6700
18	47.3300	52.6700	38.3300	41.6700	45.0000	46.6700	38.0000	44.3300
19	56.0000	54.6700	48.0000	45.0000	59.0000	54.3300	54.0000	50.6700
20	50.3300	51.6700	42.3300	40.6700	47.3300	53.3300	42.0000	46.0000
21	58.0000	62.6700	55.6700	55.3300	66.0000	73.3300	68.0000	64.3300
22	46.6700	42.6700	38.6700	36.0000	44.6700	52.0000	39.0000	45.3300
23	64.3300	57.6700	41.0000	45.3300	47.3300	48.0000	47.0000	41.6700
24	55.3300	58.0000	47.3300	45.6700	57.0000	56.6700	51.0000	52.0000
25	45.3300	41.0000	32.6700	34.6700	44.0000	44.3300	42.0000	43.6700
26	43.0000	51.3300	35.3300	38.0000	49.6700	54.6700	50.0000	46.0000
27	52.0000	52.3300	43.6700	42.3300	48.6700	52.0000	42.0000	43.0000
28	54.0000	54.6700	44.6700	42.6700	54.3300	52.0000	49.0000	53.0000
29	53.3300	53.6700	39.0000	40.3300	52.0000	57.6700	43.0000	44.6700
30								

Mean peak torque (uncorrected for gravity) at the end of the endurance test

These torque values may be used to calculate the fatigue index for each subject as explained on the preceding page.

ID 1-10 = Sprinters
ID 11-20 = Middle-distance runners
ID 21-3o = Untrained Males

END1 = Quadriceps 180 deg/sec left
END2 = Quadriceps 180 deg/sec right
END3 = Quadriceps 240 deg/sec left
END4 = Quadriceps 240 deg/sec right
END5 = Hamstrings 180 deg/sec left
END6 = Hamstrings 180 deg/sec right
END7 = Hamstrings 240 deg/sec left
END8 = Hamstrings 240 deg/sec right

APPENDIX E

SUMMARIES OF ANALYSES OF VARIANCE

Summary of four-way analysis of variance for per cent decline in peak torque

HIERARCHICAL SUMMARY TABLE OF F-RATIOS FOR: PERC1

TYPE	PART OF MODEL	SSH	SSE	MSH	MSE	F-RATIO	DFH	DFE	PROB
UNIV	GRAND MEAN	43.67	0.75	43.67	.27824D-1	1569.44	1.0	27.0	0.0
UNIV	GROUP	.41098D-1	0.75	.20549D-1	.27824D-1	0.74	2.0	27.0	0.4872
UNIV	CASES(GROUP)	* 0.75	.44544D-1	.27824D-1	.16497D-2	16.87	27.0	27.0	0.0
ERROR	TERM: CASES(GROUP)								
UNIV	MUSCLE	.43760D-1	0.43	.43760D-1	.15892D-1	2.75	1.0	27.0	0.1086
UNIV	GROUP*MUSCLE	.11607D-1	0.43	.58039D-2	.15892D-1	0.37	2.0	27.0	0.6974
UNIV	MUSCLE*CASES(GROUP)	* 0.43	.44544D-1	.15892D-1	.16497D-2	9.63	27.0	27.0	0.0
ERROR	TERM: MUSCLE*CASES(GROUP)								
UNIV	SPEED	.62079D-1	.95876D-1	.62079D-1	.35509D-2	17.48	1.0	27.0	0.0003
UNIV	GROUP*SPEED	.32937D-2	.95876D-1	.16468D-2	.35509D-2	0.46	2.0	27.0	0.6338
UNIV	SPEED*CASES(GROUP)	*.95876D-1	.44544D-1	.35509D-2	.16497D-2	2.15	27.0	27.0	0.0256
ERROR	TERM: SPEED*CASES(GROUP)								
UNIV	LIMB	.90149D-2	0.13	.90149D-2	.47359D-2	1.90	1.0	27.0	0.1790
UNIV	GROUP*LIMB	.71370D-2	0.13	.35685D-2	.47359D-2	0.75	2.0	27.0	0.4804
UNIV	LIMB*CASES(GROUP)	* 0.13	.44544D-1	.47359D-2	.16497D-2	2.87	27.0	27.0	0.0040
ERROR	TERM: LIMB*CASES(GROUP)								
UNIV	MUSCLE*SPEED	.61689D-2	.37404D-1	.61689D-2	.13853D-2	4.45	1.0	27.0	0.0442
UNIV	GROUP*MUSCLE*SPEED	.94216D-2	.37404D-1	.47108D-2	.13853D-2	3.40	2.0	27.0	0.0482
UNIV	MUSCLE*SPEED*CASES(GROUP)	*.37404D-1	.44544D-1	.13853D-2	.16497D-2	0.84	27.0	27.0	0.6734
ERROR	TERM: MUSCLE*SPEED*CASES(GROUP)								
UNIV	MUSCLE*LIMB	.13835D-2	.44475D-1	.13835D-2	.16472D-2	0.84	1.0	27.0	0.3675
UNIV	GROUP*MUSCLE*LIMB	.14148D-1	.44475D-1	.70740D-2	.16472D-2	4.29	2.0	27.0	0.0240
UNIV	MUSCLE*LIMB*CASES(GROUP)	*.44475D-1	.44544D-1	.16472D-2	.16497D-2	1.0	27.0	27.0	0.5016
ERROR	TERM: MUSCLE*LIMB*CASES(GROUP)								
UNIV	SPEED*LIMB	.31158D-2	0.11	.31158D-2	.39699D-2	0.78	1.0	27.0	0.3835
UNIV	GROUP*SPEED*LIMB	.72033D-2	0.11	.36016D-2	.39699D-2	0.91	2.0	27.0	0.4156
UNIV	SPEED*LIMB*CASES(GROUP)	* 0.11	.44544D-1	.39699D-2	.16497D-2	2.41	27.0	27.0	0.0130
ERROR	TERM: SPEED*LIMB*CASES(GROUP)								
UNIV	CASES(GROUP)	* 0.75	.44544D-1	.27824D-1	.16497D-2	16.87	27.0	27.0	0.0
UNIV	MUSCLE*CASES(GROUP)	* 0.43	.44544D-1	.15892D-1	.16497D-2	9.63	27.0	27.0	0.0
UNIV	SPEED*CASES(GROUP)	*.95876D-1	.44544D-1	.35509D-2	.16497D-2	2.15	27.0	27.0	0.0256
UNIV	LIMB*CASES(GROUP)	* 0.13	.44544D-1	.47359D-2	.16497D-2	2.87	27.0	27.0	0.0040
UNIV	MUSCLE*SPEED*LIMB	.28249D-3	.44544D-1	.28249D-3	.16497D-2	0.17	1.0	27.0	0.6823
UNIV	GROUP*MUSCLE*SPEED*LIMB	.92014D-2	.44544D-1	.46007D-2	.16497D-2	2.79	2.0	27.0	0.0793
UNIV	MUSCLE*SPEED*CASES(GROUP)	*.37404D-1	.44544D-1	.13853D-2	.16497D-2	0.84	27.0	27.0	0.6734

AN ASTERICK (*) INDICATES IF APPROPRIATE ERROR TERM CANNOT BE FOUND. IF SO, RESIDUAL IS USED.

Summary of three-way analysis of variance for endurance ratios

HIERARCHICAL SUMMARY TABLE OF F-RATIOS FOR: RATIO1

TYPE	PART OF MODEL	SSH	SSE	MSH	MSE	F-RATIO	DFH	DFE	PROB
UNIV	GRAND MEAN	110.01	4.43	110.01	0.16	669.75	1.0	27.0	.135E-19
UNIV	GROUP	0.15	4.43	0.08	0.16	0.46	2.0	27.0	0.63379
ERROR	TERM: CASES(GROUP)								
UNIV	SPEED	0.08	0.39	0.08	0.01	5.68	1.0	27.0	0.02445
UNIV	GROUP*SPEED	0.07	0.39	0.03	0.01	2.34	2.0	27.0	0.11529
ERROR	TERM: SPEED*CASES(GROUP)								
UNIV	LIMB	0.3746E-2	0.47	0,3746E-2	0.02	0.22	1.0	27.0	0.64484
UNIV	GROUP*LIMB	0.15	0.47	0.07	0.02	4.32	2.0	27.0	0.02351
ERROR	TERM: LIMB*CASES(GROUP)								
UNIV	SPEED*LIMB	0.8873E-3	0.50	0.8873E-3	0.02	0.05	1.0	27.0	0.82787
UNIV	GROUP*SPEED*LIMB	0.07	0.50	0.04	0.02	1.90	2.0	27.0	0.16864
UNIV	CASES(GROUP)	* 4.43	0.50	0.16	0.02	8.92	27.0	27.0	0.105E-6
UNIV	SPEED*CASES(GROUP)	* 0.39	0.50	0.01	0.02	0.78	27.0	27.0	0.74124
UNIV	LIMB*CASES(GROUP)	* 0.47	0.50	0.02	0.02	0.94	27.0	27.0	0.56694
UNIV	SPEED*LIMB*CASES(GROUP)	* 0.50	****	0.02	****	****	27.0	****	****
ERROR	TERM: SPEED*LIMB*CASES(GROUP)								

AN ASTERICK (*) INDICATES IF APPROPRIATE ERROR TERM CANNOT BE FOUND. IF SO, RESIDUAL IS USED.

APPENDIX F

CORRELATION OF RELIABILITY

CORRELATION OF RELIABILITY

Both intra-rater and inter-rater reliability of graph readings was calculated. Intraclass correlation coefficient (ICC) was used (from Bartko and Carpenter, 1976).[1]

Intra-Rater Relability

Graph Reading of:	ICC
PT Hams 180 deg/sec	.97
PT Quads 180 deg/sec	.99
PT Hams 240 deg/sec	.99
PT Quads 240 deg/sec	.99
PT Angle Hams 180 deg/sec	.83
PT Angle Quads 180 deg/sec	.93
PT Angle Hams 240 deg/sec	.94
PT Angle Quads 240 deg/sec	.82

Inter-Rater Relability

Graph Reading of:	ICC
PT Quads 180 deg/sec	.99
PT Quads 240 deg/sec	.99
PT Angle Quads 180 deg/sec	.85
PT Angle Quads 240 deg/sec	.83

PT = Peak torque
Hams = Hamstrings
Quads = Quadriceps

1 Bartko, J.J. and Carpenter, W.T.: On the methods and theory of reliability. J. Nerv. and Ment. Dis. 163: 307-317, 1976.