A STUDY OF MUSCULAR DEVELOPMENT AND MUSCULAR STRENGTH IN THE HIGHLY TRAINED FEMALE BODYBUILDER AND THE NON-STRENGTH TRAINED FEMALE

THESIS

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The extent of muscular strength and muscular size in 20 female bodybuilders and 20 non-strength trained females was studied. Body composition and segement volumes and related anthropometric measurements data were obtained along with chest press and knee extension One Repetition Maximum (1RM) and 25 Repetition Maximum (25RM) values. No group differences were present in age, height, weight and segment volumes. The bodybuilders had a lower percent body fat, greater lean body weight (LBW) and larger muscles compared to the non-strength trained females.

The bodybuilders had greater 1RM and 25RM values compared to the non-strength trained females. Body weight and LBW were strongly related to the strength values of the bodybuilders, but were not significantly related to the strength values of the non-strength trained females.

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CHAPTER I

INTRODUCTION

The concept of resistive training to increase muscular strength and endurance has been used for centuries. It is said that the mythical Greek wrestler Milo attained his full strength through resistive training which included lifting a calf each day until it reached its mature growth. Today, resistive training may be conducted using a myriad of resistive machines and free weights. The gains in strength utilizing resistance training are often accompanied by an increase in muscle size. It has been theorized that increases in muscle size are due to muscle hypertrophy (O'Shea, 1966; Goldberg, Etlinger, Goldspink and Jablecki, 1970) and/or hyperplasia (MacDougall, Sale, Elder and Sutton, 1982; Tesch and Larsson, 1982).

The question concerning the relationship between muscle size and muscle strength has been the topic of numerous investigations over the last ninety years. Early strength research evaluated strength through calisthenic type tests, cable tensiometers and isometric dynamometers. Investigations into the area of physiology of strength broadened with the development of the isokinetic device, a more dynamic and sophisticated means of measuring the parameters of strength.

These studies used primarily males as their subject populations (Clarke, 1954; Clarke, 1957; Laubach and McConville, 1969), while research involving females is limited to the work of Carpenter conducted in 1938 (Carpenter, 1938). However, with the development of the isokinetic device, studies including females in the subject population started to appear in the literature.

Recent strength training studies have shown that weight training will produce significant increases in strength in both males and females. However, the effects of strength training on muscle size in males and females appears to be different. In the male subjects, increases in muscle strength are accompanied by increases in muscle size. However, in the female increases in muscle strength may or may not produce increases in muscle size (Wilmore, 1974; Laubach and McConville, 1982; Mayhew and Gross, 1974). The differential response of females to resistance training is not fully understood.

Moritani and DeVries suggest that strength is composed of two factors, a neural component and a hypertrophic component. In the initial stages of strength development the neural component makes the larger contribution. As training progresses, increases in strength are more closely associated with the hypertrophic component as the contribution of the neural component diminishes.

Perhaps the strength increases in females in the absence of significant increases in muscle size can be attributed to an increased input of the neural component. The neural component may be manifested as a greater recruitment of motor units leading to a greater force of contraction. Our understanding of the neural component of strength is not fully understood (Mayhew and Gross, 1974; Moritani and DeVries, 1979).

In an effort to maximize the potential relationship between muscle strength and muscle size, researchers have conducted studies using individuals exhibiting a high degree of muscular strength and muscular development, i.e., male powerlifters, bodybuilders and olympic lifters. The findings from these studies indicate that highly-trained male body-builders exhibit a greatly increased muscle size and lean body mass in comparison with non-strength trained men (Fahey and Larsen, 1975; Katch, Katch, Moffat and Gittleson, 1980). Cross-sectional studies in females indicate that the leg strength of young and old non-strength trained females is related to muscle size. However, no studies evaluating the relationship between muscle size and muscle strength have been conducted in highly trained female bodybuilders.

The magnitude of difference in muscular development and muscular strength between the highly trained female bodybuilder and non-strength trained female has yet to be explored.

Statement of the Problem

In this study we will seek the answers to two questions. First, what is the magnitude of difference in muscular strength and development between highly trained female body-builders and non-strength trained females? Secondly, what is the relationship between muscle strength and muscle size in the highly trained female bodybuilder and the non-strength trained females?

Purpose of the Study

The purpose of this study is twofold. The first purpose is to compare the muscular development and muscular strength of highly trained female bodybuilders with that of non-strength trained females. The second purpose is to compare the relationship between muscular development and muscular strength between these same groups.

Null Hypotheses

1. There will be no significant differences in the physical characteristics and body composition between the highly trained female bodybuilders and the non-strength trained females.
2. There will be no significant differences in the segment volumes and related anthropometric measurements between the highly trained female bodybuilders and the non-strength trained females.

3. There will be no significant differences in the One Repetition Maximum (1RM) values for the chest press and knee extension between the highly trained female bodybuilders and the non-strength trained females.

4. There will be no significant differences in the 25 Repetition Maximum (25RM) values for the chest press and knee extension between the highly trained female bodybuilders and the non-strength trained females.

Limitations and Delimitations

The following limitations are recognized in this study:

(1) A pre-requisite of the bodybuilder population to be tested is that they not be using anabolic steroids presently or have used them in the past. No testing for the presence of anabolic steroids will be conducted.

(2) Although subjects will be given specific instructions pertaining to food intake, sleep and activity habits prior to testing, strict control over these areas will not be exercised.

The delimitations in this study are as follows:

(1) The subject population has been limited to highly trained female bodybuilders and non-strength trained females aged 18 to 35, free of cardiovascular and other chronic diseases.

(2) Work will be performed exclusively on the Hydra-Fitness Omnitron Series III-311.

(3) All studies will be conducted in ambient temperature of 68 to 72°F with a relative humidity of approximately 50%.

Definition of Terms

Muscle Hypertrophy. An increase in the cross-sectional size of a muscle, independent of an increase in muscle cell number.

Muscle Hyperplasia. An increase in muscle cell number.

Force. Mass x acceleration.

Work. Force x distance.

Torque. The interaction between the lever arm of the motion and the muscular forces as they act about a joint.

Peak Torque. The point with the highest torque value.

Isotonic Contraction. Contraction in which the muscle generates force against a constant resistance and movement results, either shortening (concentric) or lengthening (eccentric).

Isokinetic Contraction. Contraction in which the muscle generates force against a variable resistance where the speed of movement is maintained constant.

Isometric Contraction. Contraction in which the muscle generates tension measured as force with no observable movement of the levers of the joint.

Power. Work per unit of time.

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CHAPTER II

REVIEW OF LITERATURE

Arete, or excellence in mind, body and spirit, was a concept that pervaded the ancient Greek way of life. In that society the athletes were the great heroes, and both males and females trained regularly in gymnasiums. The attitudes of society have largely determined the activities deemed appropriate for males and females. Society's attitudes towards females and exercise have come full circle and we are able to see a revival of the concept of Arete. Males and females are actively involved in the quest for physical excellence. Serious strength training is now accepted as an appropriate form of exercise for females.

The scientific study of muscular strength has been dependent upon technological methods and on social attitudes. The methods of assessing strength have progressed from calisthenic batteries to the computerized hydraulic machinery of today. Strength research has become a more sophisticated science with each new technological development.

The topic of females and strength holds many facets. The following review of literature examines the historical perspective of strength research, developments in technology, strength development, muscular development, strength athletes and muscular development in females.

Early Strength Research

The first definitive study of females and strength extends to the work of Carpenter in 1938. Carpenter conducted studies evaluating the factors determining effective strength tests for females (Carpenter, 1938). The data collected on each of her 100 subjects included thirty anthropometric measurements, the sargent jump, standing broad jump, 60-yard dash, six-pound shot put and twenty-eight strength tests. The strength test battery included various calisthenic-type exercises and maximal pushes and pulls on a dynamometer. Carpenter failed to find a significant relationship between strength and size in females, and suggested that calisthenic-type tests were not valid indicators of strength of females. She argued that more reliable methods were needed to accurately define the strength of females.

In 1953 and 1957 Clarke conducted two studies examining the relationship between arm and leg strength to various strength and anthropometric measures in males. Strength was measured through the use of cable tensiometers, dynamometers and calisthenic tests. The anthropometric measures included limb lengths, girths and height measurements. Clarke found a correlation of $r = 0.55$ between upper arm strength and arm girth and a very low correlation between leg strength and leg size (Clarke, 1954; Clarke, 1957).

Similar studies investigating the relationship between strength and muscle size in males were conducted by Laubach and McConville in 1969 and Lamphier and Montoye in 1976. Laubach and McConville evaluated strength statically using cable tensiometers and grip dynamometers. The data collected also included anthropometric measures, body composition and somatotypes. This study found that the computed lean body mass to strength ratio ranged from a correlation of r= 0.27 (knee extension) to r = 0.58 (elbow flexion). Significant correlations with body weight ranged from r = 0.28 (ankle plantar flexion) to r = 0.53 (trunk extension). Laubach and McConville concluded that body size, typology and composition are not true indicators of muscle strength as measured by the cable tensiometer method (Laubach and McConville, 1969).

Lamphier and Montoye evaluated right and left grip strength and the strength of the upper arm via cable tensiometers and grip dynamometers. Body size was assessed through anthropometric measurements and skinfolds. They found five size variables as being important in estimating arm strength and summed grip strength: weight, standing height, biacromial diameter, upper arm girth and triceps skinfold. Lamphier and Montoye found strength to be better predicated from size variables in males than in females (Lamphier and Montoye, 1976).

The Isokinetic Device

The 1970's brought the development of the isokinetic device. Strength research took on a new dimension with the advent of this apparatus. The isokinetic device allowed force to be measured throughout the range of motion with a wide spectrum of multiple repetition batteries. In addition, new parameters could be measured from a variety of angles and speeds, these included torque, peak torque, fatigue curves and the relationship of force and velocity.

Several of the initial isokinetic studies measured the force-velocity relationship of the knee extensors (Perrine and Edgerton, 1978; Scudder, 1980). In 1977 Perrine and Edgerton investigated the force and velocity relationship of the knee extensors at various speeds and found an inverse relationship between force and velocity (Perrine and Edgerton, 1978).

Scudder measured the maximal torque produced by the knee extensors both isometrically and isokinetically, and found that the maximal peak torques occur at the slower velocities, and that peak isometric values were greater than any isokinetic values (Scudder, 1980). Perrine and Edgerton's findings are contrary to Scudder's in that they found peak isokinetic torque occuring at low velocities were often higher than those generated isometrically (Perrine and Edgerton, 1978).

Wickiewicz et al. examined the relationship between muscle architecture and force-velocity. Muscle architecture was determined by the muscle fiber length and cross-sectional area. Each of the twelve subjects generated angle specific force-velocity curves for the knee extensors, knee flexors, ankle plantar flexors and ankle dorsiflexors. The investigators suggested that the predicted maximum torque is proportional to its cross-sectional area (Wickiewicz, Roy, Powell, Perrine and Edgerton, 1984).

Muscular Strength and Development

The findings from several studies support the theory that strength is related to the cross-sectional area of the muscle. In his review of the relationship between muscle strength and muscle cross-sectional area Maughan concluded that the major determinant of muscle strength is its cross-sectional area (Maughan, 1984).

However, many studies have shown a large interindividual variability in the strength per unit cross-sectional area (Maughan, 1984; Young, Stokes, Round and Edwards, 1983; Costill, Coyle, Fink, Lesmes and Witzmann, 1979).

Weight training is a widely accepted means of increasing strength and altering body composition in men. Typically there are significant increases in strength and lean body mass with a slight decrease in body fat.

Hosler and Morrow conducted a study in 1982 examining arm and leg strength compared between young females and males after allowing for differences in body size and composition. They found that lean body weight is the variable most associated with differences in strength once other variables are controlled. Their results suggest that an increase in lean body weight would be a factor in increasing muscle strength (Hosler and Morrow, 1982).

The effects of weight training in females are unclear. It has been proposed that the low levels of androgens in females are responsible for preventing the same degree of muscular hypertrophy as seen in men (Mayhew and Gross, 1975).

Animal studies have shown that work induced hypertrophy occurs independently of growth hormone, insulin, thyroid hormones and testosterone (Goldberg, Etlinger, Goldspink and Jablecki, 1975). This evidence is contrary to the previously mentioned theory of the required presence of large androgen levels in order for muscular hypertrophy to occur. The role of androgen levels in muscular development in females is unknown.

Wilmore conducted a study in 1974 examining the alterations in strength and anthropometric measurements consequent to a ten week training program. Using both male and female subjects, Wilmore completed strength and anthropometric assessments prior to and following the ten week training period. The males and females demonstrated similar increases in muscular strength. However, the males had significant increases in muscle size, while the females had no changes in muscle size (Wilmore, 1974).

Moritani and DeVries conducted a training study exploring the course of muscle strength gain. Moritani and DeVries suggest that strength consists of two factors, a neural component and a hypertrophic component. Utilizing electromyography the investigators separated muscle activation levels from hypertrophic effects in the subjects trained and tested. They found that in the initial stages of strength development the neural component makes the larger contribution. As training progresses, the increases in strength are more closely associated with the hypertrophic component as the contribution of the neural component diminishes (Moritani and DeVries, 1979).

Mayhew and Gross conducted a study examining the effects of a comprehensive high resistance weight training program on the body composition of college women. They found that the increases in muscular strength were accompanied by increases in cross-sectional area as indirectly reflected by the muscle girth measurements. Body weight remained stable while lean body mass increased and fat weight decreased significantly. Muscular hypertrophy was evidenced in the upper body, while the legs did not change in dimension (Mayhew and Gross, 1974).

In the comparison of strength between males and females, the leg strength is much more similar than that of the upper body. The potential for strength and muscular development for women is greater in the upper body than that in the legs. This pattern may be due largely to the manner in which females have been socialized. At an early age females have been discouraged from participation in the strenuous activities of their male counterparts. As a result, many girls do not receive the same physical exercise as boys, especially in regard to the upper body. Thus upper body strength is typically undeveloped in young girls. The neglect of upper body strength in females continues into adulthood. Wilmore suggested that leg strength in males and females is similar due to the similarity in daily activities utilizing the legs (Wilmore, 1974).

If from childhood girls and boys participated in the same physical activities which developed the strength of both the upper and lower body through adulthood, perhaps females would exhibit a greater muscular development in the upper body and more similar levels of strength as compared to men.

Hypertrophy and Hyperplasia as Determinants of Muscle Size

The roles of hypertrophy and hyperplasia as determinants of muscle size are controversial. It had been a long standing belief that muscle hyperplasia did not occur in humans, but that increases in muscle size were due solely to hypertrophy of the muscle fibers (Goldberg, Etlinger, Goldspink and Jablecki, 1975). More recent studies have only served to perpetuate this controversy.

In their 1982 study, Tesch and Larsson examined muscle hypertrophy in bodybuilders. They obtained muscle biopsies from the m. vastus lateralis and the lateral portion of the m.deltoid of three elite male bodybuilders. Tesch and Larsson did not observe any sign of individual fiber enlargement in either the thigh or shoulder musculature of the subjects. Despite the considerabley greater body weight per height and less body fat in bodybuilders compared to habitually trained and age matched man, the mean fiber area did not differ. They suggest that their findings may reflect exercise induced formation of new muscle fibers (hyperplasia) in bodybuilders, either by longitudinal fiber splitting or due to the development of satellite cells (Tesch and Larsson, 1982).

MacDougall et al. conducted a study looking at muscle ultrastructural characteristics of elite powerlifters and bodybuilders. Two needle biopsies were taken from the long head of the triceps of five elite bodybuilders and two international caliber powerlifters for comparison with tissue from weight-trained normals.

MacDougall et al. found that despite large differences in elbow extension strength and arm girth, there was no difference in fiber areas or percentage fiber type between the elite group and the trained normals. They suggested that since mean fiber areas did not differ between the two groups the bodybuilders possessed a greater total number of muscle fibers than did the trained controls. It was concluded that the elite group has either inherited a greater number of muscle fibers in the triceps than the control group did, or that a significant degree of fiber hyperplasia has occurred which may be related to chronic heavy resistance training (MacDougall, Sale, Elder and Sutton, 1982).

The Strength Athletes

In accordance with the concept of specificity, those who train specifically for muscular strength and development will exhibit the most muscular strength and development. The individuals falling into this category are bodybuilders, olympic lifters and powerlifters.

The bodybuilders typically exhibit considerably greater body weight per height, larger muscle girths and less body fat than other athletes and the normal reference man (Fahey, Akka and Rolph, 1975; Pipes, 1979; Katch, Katch, Moffat and Gittleson, 1980).

Katch et al. conducted a study in order to quantify the muscular development and lean body weight in bodybuilders and elite weight lifters. They found that all three groups exhibited extreme muscular development, resulting in excess muscle weight of approxomately 12.5 kg in comparison to the reference man (Katch, Katch, Moffat and Gittleson, 1980).

At the present time no research has been conducted measuring the muscular strength and development of highly trained female bodybuilders. The assessment of muscular strength and development in females has been limited to females who have trained for only brief periods of time, eight to ten weeks. No assessments have been made on females who have been involved in extensive weight training for an extended period of time. The information from such a study would contribute to a greater understanding of females and the parameters of strength.

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CHAPTER III

PROCEDURES

Selection of Subjects

Twenty highly trained female bodybuilders and twenty non-strength trained females aged 18-35 volunteered to participate in this study. For the purpose of this study, the highly trained female bodybuilder was defined as a healthy female who had been actively training for a minimum of 18 months, training each body part a minimum of twice a week, was actively involved in bodybuilding competitions, and had no history of anabolic steroid use.

The non-strength trained female was defined as a healthy female who was not involved in resistance training. Twelve females involved in moderate intensity aerobic activities were included in this group.

The nature and purpose of the study and the risks involved were explained verbally and given on a written form to each subject prior to their formal consent to participate. The protocol and procedures for this study have been approved by the Institutional Review Board for the Protection of Human Subjects of the Texas College of Osteopathic Medicine.

Experimental Design

In this study the experimental design consisted of a direct comparison of two groups; highly trained female body-builders and non-strength trained females. The direct comparisons consisted of the following measures: physical characteristics, including age, height, weight and forced vital capacity; body composition including percent body fat, fat weight, lean body weight and calculated residual volume; chest, arm and thigh volumes and other related anthropometric measurements; One Repetition Maximum (1RM) values for the chest press and knee extension; and 25 Repetition Maximum (25RM) values for the chest press and knee extension.

Specifications of the Hydra-Fitness Omnitron Series III-311

Exercise was performed on the computerized Hydra-Fitness Omnitron Series III-311. This is a resistance device which is similar to an isokinetic device, but is different in that a designated intensity setting may be chosen for both flexion and extension, while the speed of movement is under the control of the individual. This resistance training device has 12 intensity settings which increase in resistance with each ascending setting number. Setting #1 has the lowest resistance and setting #11 is the highest. Setting #0 is the isometric setting at which no movement occurs. The resistance at each setting is determined by the pressure of the hydraulic fluid as it passes through an aperture from one compartment to another within the cylinder. The aperture diameters were arbitrarily assigned by the Hydra-Fitness manufacturer. Each intensity setting has a corresponding aperture diameter. As the resistance is increased, the aperture diameter is decreased creating greater pressure, thus increasing resistance. Table I lists each intensity setting, the drill bit number used to create the aperture, the aperture diameter and the area of the aperture.

TABLE I

SPECIFICATIONS FOR THE HYDRA-FITNESS OMNITRON SERIES III-311 INTENSITY SETTINGS

Intensity Setting #	Drill Bit #	Aperture Diameter (in.)	Aperture Area (sq. in.)
0	..	..	..
1	31	.120	.001131
2	38	.101	.008012
3	43	.089	.006221
4	47	.078	.004778
5	50	.070	.003849
6	52	.063	.003117
7	54	.055	.002376
8	56	.046	.001662
9	61	.039	.001195
10	66	.033	.000855
11	70	.028	.000616

The Hydra-Fitness Omnitron Series III-311 has three movement settings: chest, shoulder and leg. The chest setting allows a movement that closely resembles the movement exhibited in the bench press exercise. For the purposes of this study, the movement executed at the chest setting will be called the chest press. The shoulder setting allows a shoulder or military press type movement and the leg setting allows a knee or leg extension of one leg. For the purposes of this study the movement executed using the leg setting will be called knee extension.

Personal communication from the Hydra-Fitness engineering staff provided in-depth information pertaining to the principles of operation of the Hydra-Fitness Omnitron Series III-311.

The computer system associated with this device possesses a Z80 based microprocessor which allows for the calculation of force or torque, power, and work measurements. These values are displayed on a digital display monitor (DDM).

The lever position against which force is generated is either linear or angular and is measured from the signal obtained from an angular encoder. Output of the angular encoder is fed to a voltage amplifier which drives a monolithic analogue to digital (A/D) converter. The microprocessor system calculates the actual angle or linear position of the lever based upon geometrical information about the mechanical system that is stored in the DDM's memory. During exercise, measurements of the lever position are made 200 times each second.

Force and torque are obtained in a manner similar to that used for lever positional information. An instrument grade pressure transducer senses the pressure in the cylinders used to provide resistance. The output of the sensor is directed to an A/D converter via an intermediate instrumentation amplifier. The Z80 system calculates forces or torques based upon the machine geometry, reading on the pressure transducer and reading on the angular encoder. During exercise force or torque measurements are made 200 times a second.

An accurate crystal time base is provided in the DDM. From the time base and positional information, the velocity can be accurately calculated. Work and power measurements are obtained from the position, force or torque and time measurements.

The pressure and angular encoders are automatically calibrated with the Z80 to compensate for any systematic offsets associated with either the encoders or the system. The Omnitron Exercise machines are put in their nominal positions and no external force is applied to the loading members for this calibration. When the CAL switch is pulsed, the offsets associated with all transducers are measured from all readings of the transducers. The linearity specifications of the encoders themselves are sufficiently tight to circumvent the need for any linearity calibration.

Development of Strength Testing Protocol

The objective of the strength testing protocol was to measure maximum strength of each subject, and also to measure the strength of each subject over a series of high intensity repetitions. Three separate strength testing protocols were developed to find the best test protocol for the measurement of absolute strength. This protocol would allow each subject to work at a high intensity, and complete a series of high intensity repetitions.

The first strength test protocol consisted of two parts. The first part was a maximal isometric contraction at both the chest press and knee extension exercises. The subject had three trials, with the best of the three recorded as the isometric One Repetition Maximum (1RM). The second part consisted of 15 maximum repetitions (15RM) test at the intensity setting of #8, for both the chest press and knee extension. Four subjects participated in this protocol: three strength trained (subjects T, R and RX) and one non-strength trained (subject K). The first strength test protocol was designated as Chest 1 and Leg 1. Upon examination of the results from these tests (Appendices A-B), it was observed that trained individuals had higher force, power and work values compared to the non-strength trained subject. The graphic representation of the data showed little decline in performance over the 15 repetitions for either the strength trained or non-strength trained individuals.

The second strength test protocol was designated as Chest 2 and Leg 2. In this protocol, the isometric test was retained, while the intensity setting for the 15RM test was increased to setting #9. Compared to Chest 1 and Leg 1, the results from these tests (Appendices C-D) showed greater absolute chest press and knee extension force, power and work values. Moreover, the values of the trained individuals were higher than those of the non-strength trained. The scores from the 15RM test indicated that there was a slightly greater decline in performance towards the end of the test, with a definite decrease in value at 15th repetition.

The 15RM protocol was first decided upon because it was a number of repetitions that could be completed by all individuals, and it fell within the range of the number of repetitions normally utilized in weight lifting training. However, the 15RM protocol did not allow the subjects to exhibit a continuous decline in performance, which might be representative of the onset of muscular fatigue.

At this point two questions arose. If the number of repetitions was increased would a greater amount of muscular fatigue be observed? Secondly, would an individual show a greater rate of decline in her strength values? Based upon these considerations a third strength test protocol was developed. In this protocol, absolute strength was assessed by taking the best of three trials at the intensity setting of #11, for both the chest press and knee extension, and from a 25RM test performed at the intensity setting of #9. Three subjects, one trained (RX) and two non-strength trained (ML and K) participated to determine the utility of this protocol. The results from this protocol indicated that the trained subjects had greater absolute 1RM values compared to those of the non-strength trained subjects. The strength trained subject also had greater values over the 25RM test (Appendices E-J). In addition, there was a greater decline in performance over the 25RM test compared to that observed in either of the 15RM tests.

Thus, it was decided to utilize this protocol as the strength testing vehicle in this study.

Tests and Measurements

Each subject performed a one repetition maximum (1RM-a single maximal concentric contraction) using both the chest press and knee extension exercises at the intensity setting of #11. Work or exercise consisted of 25 continuous maximal concentric contractions (25RM) using both the chest press and knee extension exercises at the #9 intensity setting.

Force generated from each contraction was stored in the Omnitron's computer from which measurements of peak torque, total work and power were calculated. These measures were retrieved from the DDM and tabulated. Tabulated records were transferred into a computer data file for subsequent analysis.

Body density was determined utilizing the hydrostatic weighing procedure as described by Katch et al. (Katch, Michael and Horvath, 1967). This procedure entails underwater weighing of the individual while seated in a specialized chair. The individual exhales as much air as possible from the lungs and completely submerges the body and head under the water's surface. This procedure is repeated several times with the mean chair and subject weight used as the final measurement. Residual volume was calculated from body density values according to the formulas of Brozek et al. and Siri (Brozek, Grande, Anderson and Keys, 1963; Siri, 1961).

Muscle size was measured indirectly using the anthropometric model of assessing body volume developed by Sady et al. (Sady, Freedson, Keys and Reynolds, 1979). This model uses a series of limb lengths and circumferences to divide the body into distinct segments. The data pertaining to each segment is put into a formula and the volume for each segment is calculated. The segments used include the chest, upper arm, lower arm and the thigh. The following gives each segment volume, its' related anthropometric measurements and the formulas used to obtain the segment volumes.

<u>Chest</u>

b= biacromial breadth

l= chest depth

h= chest length

volume= b * h *l

<u>Upper Arm</u>

h= shoulder to elbow length

R= bicep circumference relaxed / 2 pi

r= wrist circumference / 2 pi

$$\text{volume} = pi * h/3 * (R^2 + r^2 + Rr)$$

<u>Lower Arm</u>

h= elbow to wrist length

R= elbow circumference relaxed / 2 pi

r= wrist circumference / 2 pi

$$\text{volume} = pi * h/3 * (R^2 + r^2 + Rr)$$

<u>Thigh</u>

h= crotch height minus popliteal height

R= upper thigh circumference / 2 pi

r= knee circumference / 2 pi

$$\text{volume} = pi * h/3 * (R^2 + r^2 + Rr)$$

Reliability Study

A reliability study was conducted in order to assess the test-retest reliability of the strength and body composition measurements.

Ten subjects participated in the reliability study. anthropometric measurements along with body composition and strength data were obtained from each subject on two separate occasions

Correlation coefficients were calculated for percent body fat and several of the strength measures. The correlation coefficients calculated on the strength measures include the 1RM values for force, power and work for both the chest press and knee extension along with the force correlations for the means of the first five and last five repetitions of the 25RM. The test-retest correlation coefficients were r= 0.9845 for percent body fat, r= 0.9413 for chest press 1RM force, r= 0.84849 for chest press 1RM power, r= 0.8444 for chest press 1RM work, r= 0.85295 for knee extension 1RM force, r= 0.84468 for knee extension 1RM power, r= 0.77950 for knee extension 1RM work, r= 0.85647 for chest press repetition 1-5 force $\bar{x}$, r= 0.95337 for chest press repetition 21-25 force $\bar{x}$, r= 0.84969 for knee extension repetition 1-5 force $\bar{x}$, and r= 0.71860 for knee extension repetition 21-25 force $\bar{x}$. The test-retest correlation coefficients are presented in Table II.

TABLE II

RELIABILITY STUDY CORRELATIONS

Variable	Test-Retest Correlation
% Body Fat	r= 0.9845
Chest	
1RM Force	r= 0.94123
1RM Power	r= 0.84849
1RM Work	r= 0.8444
Repetition 1-5 Force $\bar{x}$	r= 0.85467
Repetition 21-25 Force $\bar{x}$	r= 0.95337
Leg	
1RM Force	r= 0.85295
1RM Power	r= 0.84468
1RM Work	r= 0.77950
Repetition 1-5 Force $\bar{x}$	r= 0.84969
Repetition 21-25 Force $\bar{x}$	r= 0.71860

Analysis of Data

The Student's T-Test was used to compare the two groups: highly trained female bodybuilders and the non-strength trained females for all variables except the 25 Repetition Maximum values. T-Test analysis was conducted on the following measures: age, height, weight, forced vital capacity, residual volume, percent body fat (PBF), fat weight (FW), lean body weight (LBW), chest width, chest depth, chest length, pectoral skinfold, chest volume, upper arm length, relaxed biceps circumference, flexed biceps circumference, relaxed elbow circumference, triceps skinfold, upper arm volume, lower arm length, wrist circumference, forearm skinfold, lower arm volume, thigh length, thigh circumference, knee circumference, femoral skinfold, thigh volume and One Repetition Maximum (1RM) force, power, and work values, for both the chest press and the knee extension. A 25x2 repeated measures ANOVA was used to analyze the effects of group, repetitions and interaction of group and repetitions on chest press force, power and work values and knee extension force, power and work values. This analysis was performed for absolute force, power and work values and for the values expressed relative to lean body weight.

Correlation coefficients were used to examine chest, upper arm, lower arm and thigh volumes in relation to PBF, LBW and FW. Correlational analysis was also used to examine age, body weight, height, LBW, PBF, chest, upper arm, lower arm and thigh volumes in relation to all the chest press and knee extension values.

CHAPTER REFERENCES

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CHAPTER IV

RESULTS

Comparison of the subjects utilizing the Students T-Test indicated that age, height, weight and forced vital capacity values were similar ($p > 0.05$) between the two groups. However, statistically significant differences were found for the body composition variables; percent body fat ($p = 0.0001$), fat weight ($p = 0.0002$), and lean body weight ($p = 0.05$). Means ($\bar{x}$) and standard deviations (S.D.) for each group are presented in Table III.

TABLE III

PHYSICAL CHARACTERISTICS AND BODY COMPOSITION FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED WOMEN

Variable	Strength Trained (n=20)		Non-Strength Trained (n=20)		P-Value
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
Age,(yr)	26.9	4.7	25.9	5.2	0.5232
Weight,(kg)	56.6	6.4	59.0	6.0	.2278
Height,(cm)	162.8	5.9	165.0	6.1	.2278
Forced Vital Capacity,(L)	4.2	0.2	4.2	0.6	.8797
Residual Volume,(L)	1.5	0.2	1.0	0.2	.3131
Body Fat,(%)	13.8	3.9	21.8	6.4	.0001
Fat Weight,(kg)	7.9	2.6	13.1	4.9	.0002
Lean Body Weight,(kg)	48.7	5.4	45.9	3.3	.0500

Analysis of the related anthropometric measurements indicated statistically significant differences for flexed bicep ($p = 0.0008$), pectoral skinfold ($p = 0.0001$), triceps skinfold ($p = 0.0001$), forearm skinfold ($p = 0.0001$), and thigh skinfold ($p = 0.0001$). There was a significant difference between the groups for biacromial breadth ($p = 0.014$), and knee circumference ($p = 0.014$). However, there were no significant differences for the segment volumes or for the circumferences and other measurements associated with the segment volume calculations. Means and standard deviations for the segment volumes and related anthropometric measurements for the two groups are presented in Table IV.

The One Repetition Maximum (1RM) values for the chest press and knee extension indicated statistically significant differences between the two groups for chest press force, power and work, and for knee extension force and power. The knee extension 1RM work value was not significantly different between the two groups. The 1RM values expressed relative to LBW show the same pattern of significant differences as the absolute 1RM values. Means and standard deviations for the absolute 1RM values and the 1RM values expressed relative to LBW for chest press and knee extension force,power and work for the two groups are presented in Table V.

TABLE IV

SEGMENT VOLUMES AND RELATED ANTHROPOMETRIC MEASUREMENTS FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES

Variable	Strength Trained (n=20)		Non-Strength Trained (n=20)		P-Value
	$\bar{x}$	S.D	$\bar{x}$	S.D.	
Chest					
Chest Width,(cm)	34.4	1.2	33.2	1.6	0.0138
Chest Depth,(cm)	17.1	1.5	16.4	1.2	.0862
Chest Length,(cm)	25.2	2.1	25.1	2.6	.984
Pectoral Skinfold,(mm)	5	2	9	3	.0001
Chest Volume,(L)	14.8	1.9	13.7	1.8	.0002
Upper Arm					
Upper Arm Length,(cm)	32.5	1.8	32.6	1.7	.8564
Relaxed Bicep Circ.,(cm)	26.4	1.4	25.4	1.7	.0694
Flexed Bicep Circ.,(cm)	30.6	2.6	27.9	2.0	.0008
Relaxed Elbow Circ.,(cm)	23.1	1.2	24.1	2.8	.1597
Tricep Skinfold,(mm)	13	6	20	5	.0001
Upper Arm Volume,(L)	1.6	0.2	1.6	0.3	.9246
Lower Arm					
Lower Arm Length,(mm	24.1	0.9	23.9	1.2	.5650
Relaxed Elbow Circ.,(cm)	23.1	1.2	24.1	2.8	.1597
Wrist Circ.,(cm)	14.8	0.5	15.0	0.6	.2633
Forearm Skinfold,(mm)	5	2	9	3	.0001
Lower Arm Volume,(L)	0.7	0.1	0.8	0.2	.2473
Thigh					
Thigh Length,(cm)	32.8	1.8	32.7	2.3	.8040
Thigh Circ.,(cm)	55.2	4.4	55.9	5.0	.6444
Knee Circ.,(cm)	33.4	1.6	35.1	2.3	.0140
Femoral Skinfold,(mm)	19	8	33	8	.0001
Thigh Volume,(L)	5.3	0.7	5.5	0.9	.2976

TABLE V

ONE REPETITION MAXIMUM CHEST PRESS AND KNEE EXTENSION ABSOLUTE AND EXPRESSED RELATIVE TO LBW VALUES FOR HIGHLY TRAINED FEMALE BODY BUILDERS AND NON-STRENGTH TRAINED FEMALES

Variable	Strength Trained (n=20)		Non-Strength Trained (n=20)		P-Value
	$\overline{X}$	S.D	$\overline{X}$	S.D.	
Chest					
Force, (Nm)	19.90	3.35	16.34	2.37	0.0004
Force/LBW, (Nm)	0.41	0.04	0.36	0.05	.0009
Power, (Nm)	12.61	4.98	9.18	2.67	.0110
Power/LBW, (Nm)	.25	.04	.20	.06	.0162
Work, (Nm)	20.08	4.86	15.91	3.25	.0031
Work/LBW, (Nm)	.37	.07	.35	.07	.0059
Leg					
Force, (Nm)	12.28	1.42	10.01	1.83	.0001
Force/LBW, (Nm)	.25	.02	.22	.04	.0014
Power, (Nm)	10.67	2.24	8.33	2.97	.0078
Power/LBW, (Nm)	.22	.03	.18	.06	.0243
Work, (Nm)	11.68	2.16	10.22	2.41	.0509
Work/LBW, (Nm)	.24	.04	.22	.05	.2737

A 2 x 25 analysis of variance (ANOVA) utilizing group and repetition as independent variables indicated statistically significant group and repetition effects and a statistically non-significant interaction effect for chest press and knee extension force, power and work throughout the 25RM test. Means and standard deviations for the 25RM chest press and knee extension force, power and work for the groups are presented in Tables VI through XI. Graphical representation of the 25RM chest press force, power and work values and for knee extension force, power and work values are presented in Figures 1 through 6.

TABLE VI

25 REPETITION MAXIMUM FORCE VALUES FOR CHEST PRESS FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition #	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	15.4	2.8	12.5	3.2
2	16.0	3.0	13.0	2.0
3	16.0	2.8	12.6	2.0
4	15.9	2.7	12.2	2.0
5	15.6	2.6	12.0	1.5
6	15.2	2.5	11.9	1.8
7	15.0	2.4	11.5	1.5
8	14.7	2.3	11.2	1.7
9	14.4	2.1	11.0	1.7
10	14.3	2.0	10.6	1.7
11	14.2	2.0	10.3	1.8
12	13.9	1.9	10.2	1.8
13	13.6	2.0	9.7	1.9
14	13.4	2.1	9.7	1.8
15	13.1	2.0	9.4	1.7
16	12.9	1.9	9.3	1.6
17	12.6	2.4	8.8	1.7
18	12.4	2.1	8.8	1.6
19	11.9	2.4	8.5	1.6
20	11.8	2.0	8.3	1.7
21	11.8	2.7	8.0	1.3
22	11.4	2.4	8.1	1.6
23	10.9	2.1	7.9	1.8
24	10.7	2.2	7.9	2.2
25	10.4	2.2	7.1	1.6

*Values obtained at setting #9.

TABLE VII

25 REPETITION MAXIMUM POWER VALUES FOR CHEST PRESS FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition #	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	17.1	5.8	12.3	4.9
2	19.9	6.6	14.3	3.9
3	19.9	6.6	13.7	3.7
4	20.0	6.3	13.2	3.5
5	19.6	6.2	12.9	3.7
6	19.9	5.8	12.3	3.0
7	18.2	5.5	11.7	2.8
8	17.5	6.0	11.4	2.8
9	17.0	5.7	11.0	2.6
10	17.2	5.1	10.4	2.7
11	17.0	4.9	9.8	2.8
12	16.6	4.9	9.6	2.5
13	16.0	4.9	9.0	2.6
14	15.3	4.9	8.8	2.6
15	14.8	4.7	8.6	2.2
16	14.3	5.5	8.2	2.2
17	13.9	4.9	7.9	2.1
18	13.5	4.6	7.5	2.2
19	12.9	4.6	7.2	2.2
20	12.4	4.2	7.0	2.0
21	12.1	4.5	6.6	1.8
22	11.8	4.5	6.5	2.1
23	11.2	4.3	6.2	2.0
24	10.6	4.1	5.8	1.9
25	10.1	4.0	5.2	2.0

*Values obtained at setting #9.

TABLE VIII

25 REPETITION MAXIMUM WORK VALUES FOR CHEST PRESS FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition #	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	13.4	3.4	10.6	3.4
2	15.3	3.2	12.4	2.7
3	15.9	3.2	11.8	2.7
4	15.9	3.0	11.5	2.2
5	15.7	3.0	11.5	2.0
6	15.4	2.9	11.2	1.7
7	14.9	3.2	10.8	2.1
8	14.7	2.9	10.6	1.7
9	14.6	2.9	10.4	1.9
10	14.5	2.7	10.2	2.1
11	14.3	2.6	10.0	2.0
12	14.2	2.6	9.7	1.9
13	13.9	2.8	9.3	1.8
14	13.7	2.8	9.3	1.9
15	14.0	3.7	9.1	1.7
16	13.1	2.7	9.0	1.7
17	12.8	2.8	8.6	1.7
18	12.4	2.7	8.4	1.6
19	12.1	2.8	8.3	1.4
20	11.8	2.7	8.0	1.3
21	11.6	2.6	7.7	1.3
22	11.5	2.7	7.6	1.5
23	11.2	2.7	7.5	1.3
24	10.9	2.5	7.3	1.4
25	11.0	2.4	7.2	1.6

*Values obtained at setting #9.

TABLE IX

25 REPETITION MAXIMUM FORCE VALUES FOR KNEE EXTENSION FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition #	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	7.5	1.8	6.6	2.1
2	9.1	2.3	7.2	1.7
3	9.4	2.7	7.6	2.0
4	9.8	3.1	7.8	2.5
5	10.1	3.0	7.6	2.2
6	9.6	2.8	7.3	2.1
7	9.3	3.1	7.1	1.9
8	9.2	2.9	7.1	2.1
9	9.1	3.1	6.7	2.1
10	8.7	2.8	6.7	1.9
11	8.5	2.6	6.3	1.7
12	8.2	2.3	6.0	1.5
13	7.8	1.8	5.8	1.2
14	7.5	1.9	5.6	1.2
15	7.2	1.9	5.6	1.2
16	6.9	1.8	5.2	1.3
17	6.8	2.0	5.0	1.0
18	6.5	1.9	5.0	1.1
19	6.2	1.7	4.7	0.9
20	6.2	2.0	4.7	1.2
21	6.1	1.8	4.6	1.1
22	6.0	1.7	4.3	1.0
23	5.6	1.8	4.2	0.8
24	5.6	2.1	4.1	0.8
25	5.5	2.0	4.0	1.0

*Values obtained at setting #9.

TABLE X

25 REPETITION MAXIMUM POWER VALUES FOR KNEE EXTENSION FOR HIGHLY TRAINED FEMALE BODY BUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition #	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	9.5	4.0	8.2	4.1
2	14.0	4.0	10.1	4.2
3	14.6	4.1	11.5	3.6
4	14.5	3.9	11.3	3.3
5	14.7	3.7	10.9	3.3
6	14.2	3.7	10.7	2.4
7	13.5	3.4	10.5	2.4
8	12.8	3.2	10.0	2.4
9	12.6	2.7	9.6	2.4
10	11.7	2.5	9.3	2.1
11	11.5	2.2	8.5	2.2
12	10.9	2.1	8.1	2.0
13	10.4	2.0	8.0	1.9
14	9.8	2.1	7.5	1.0
15	9.6	2.2	7.0	1.7
16	9.3	2.3	6.8	1.7
17	9.0	2.3	6.4	1.8
18	8.5	2.4	6.3	1.6
19	8.0	2.8	6.0	1.5
20	7.9	2.3	5.9	1.7
21	7.4	2.1	5.6	1.6
22	7.3	2.2	5.2	1.4
23	7.1	2.4	5.1	1.3
24	6.4	2.3	4.8	1.2
25	6.1	2.3	4.1	1.2

*Values obtained at setting #9.

TABLE XI

25 REPETITION MAXIMUM WORK VALUES FOR KNEE EXTENSION FOR HIGHLY TRAINED FEMALE BODY BUILDERS AND NON-STRENGTH TRAINED FEMALES*

Repetition	Strength Trained (n=20)		Non-Strength Trained (n=20)	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	6.9	2.3	5.7	2.4
2	8.6	1.6	7.0	2.2
3	8.9	1.6	7.3	1.9
4	8.9	1.5	7.2	1.7
5	9.0	1.4	7.1	1.7
6	8.7	1.3	6.9	1.4
7	8.4	1.3	6.8	1.6
8	8.1	1.3	6.5	1.6
9	7.9	1.1	6.3	1.5
10	7.6	1.1	6.0	1.5
11	7.4	1.1	5.8	1.4
12	7.1	1.2	5.6	1.4
13	6.9	1.2	5.5	1.4
14	6.6	1.2	5.3	1.3
15	6.5	1.4	4.9	1.3
16	6.4	1.4	4.8	1.3
17	6.6	2.2	4.7	1.2
18	5.9	1.5	4.5	1.2
19	5.8	1.3	4.4	1.2
20	5.6	1.4	4.4	1.3
21	5.4	1.3	4.1	1.1
22	5.4	1.3	4.0	1.1
23	5.3	1.4	3.9	1.0
24	5.0	1.4	3.7	1.0
25	5.1	1.4	3.7	0.9

*Values obtained at setting #9.

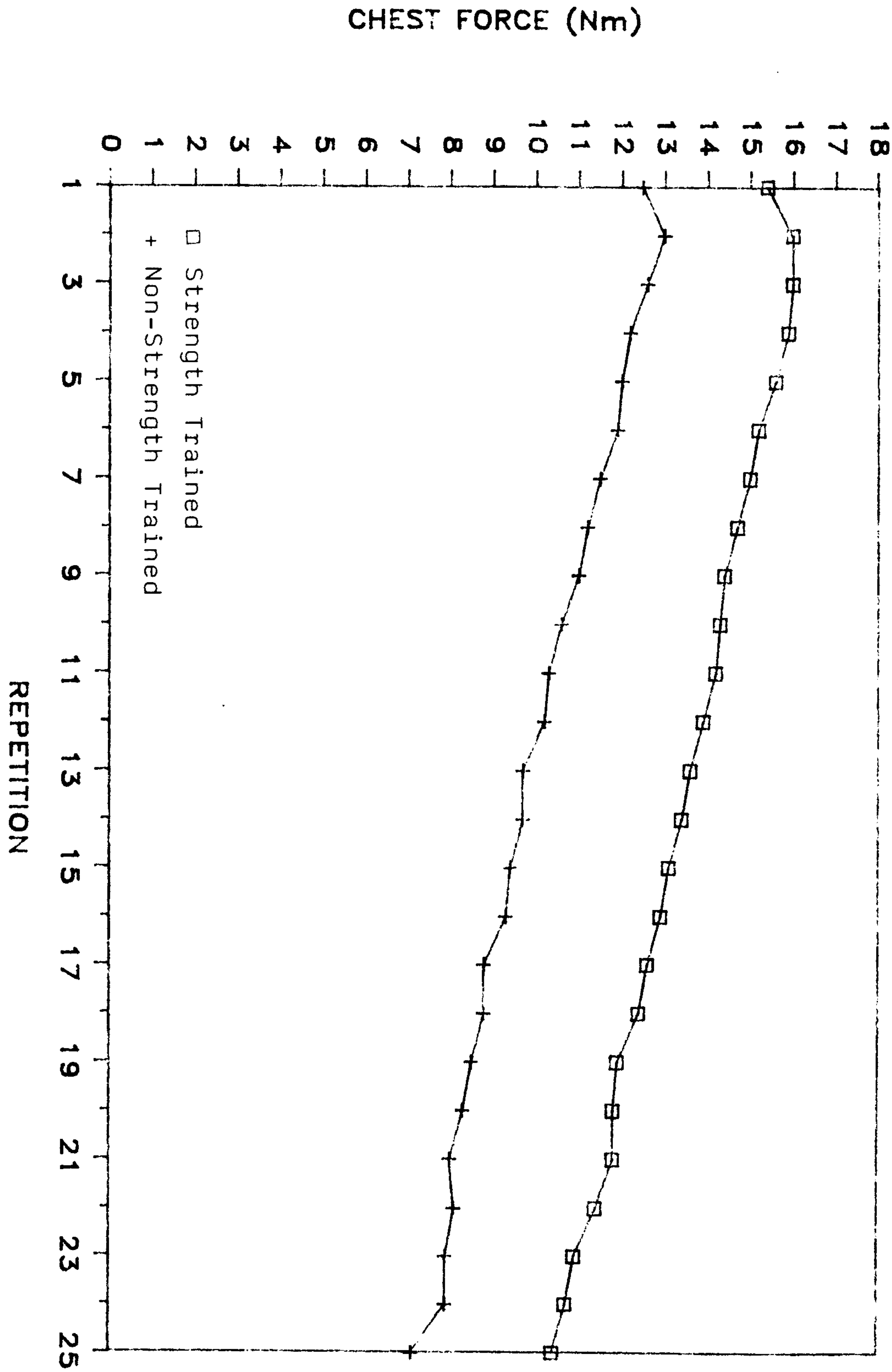

Fig. 1--25RM chest press force

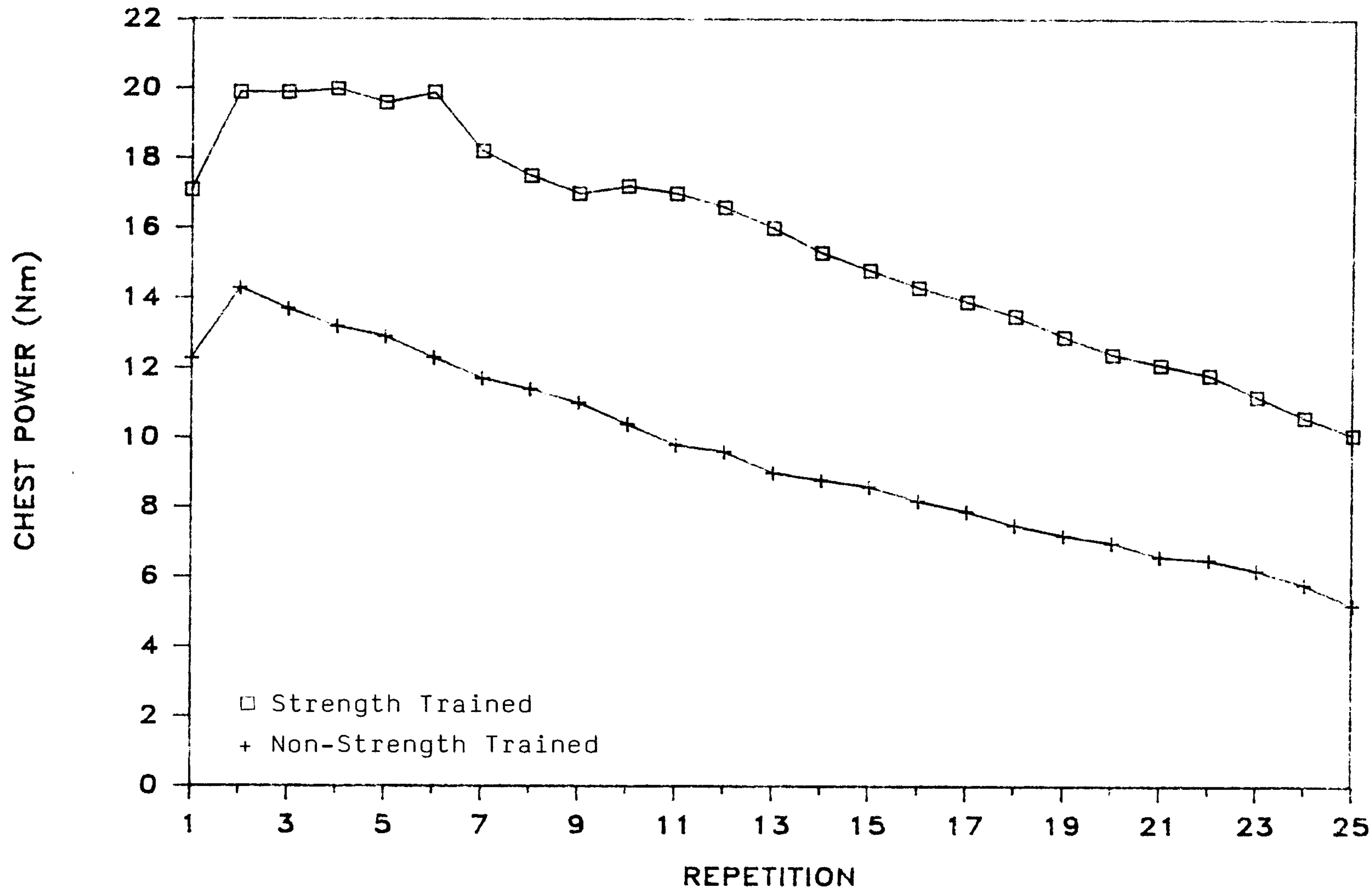

Fig. 2--25RM chest press power

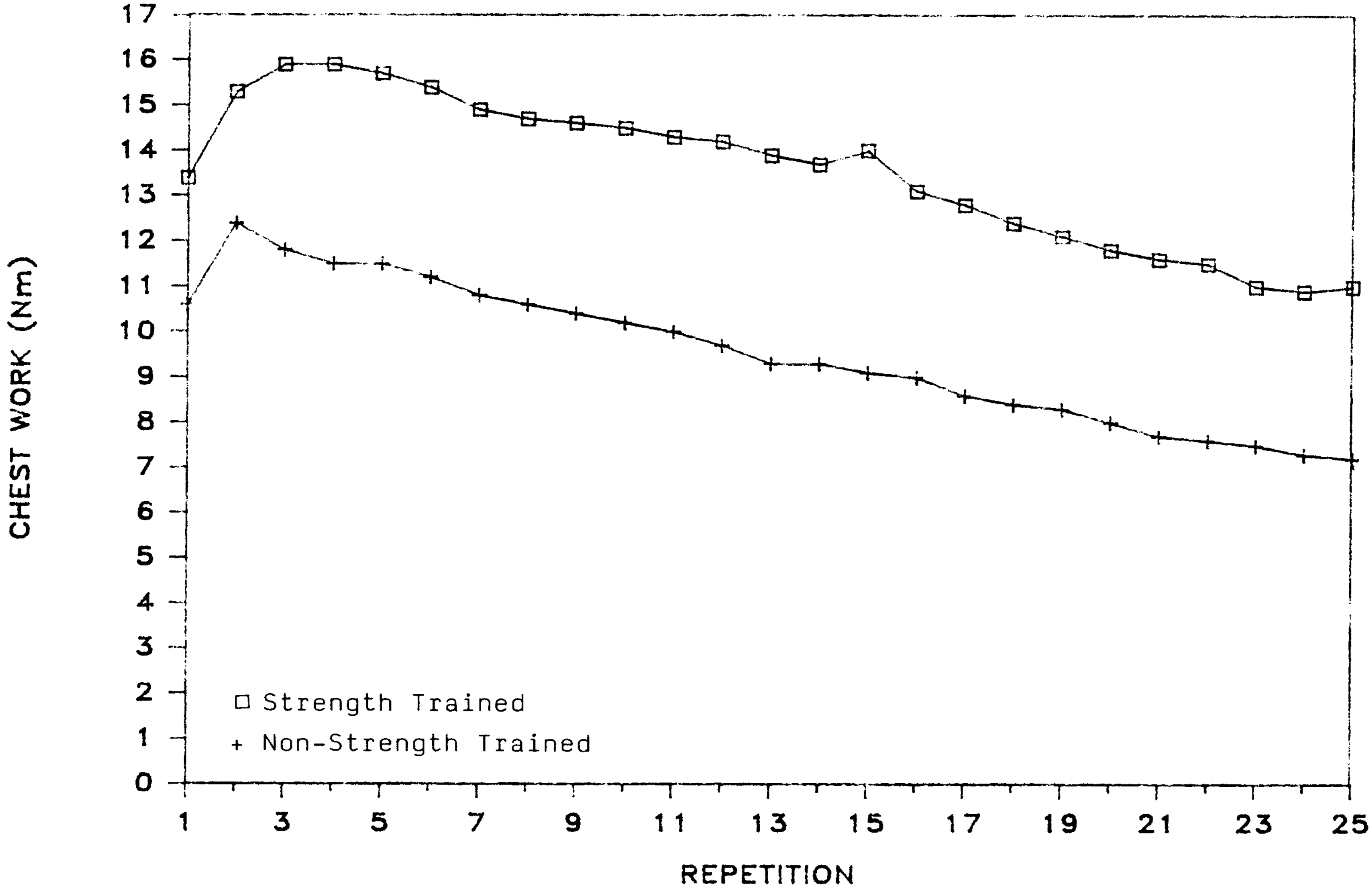

Fig. 3--25RM chest press work

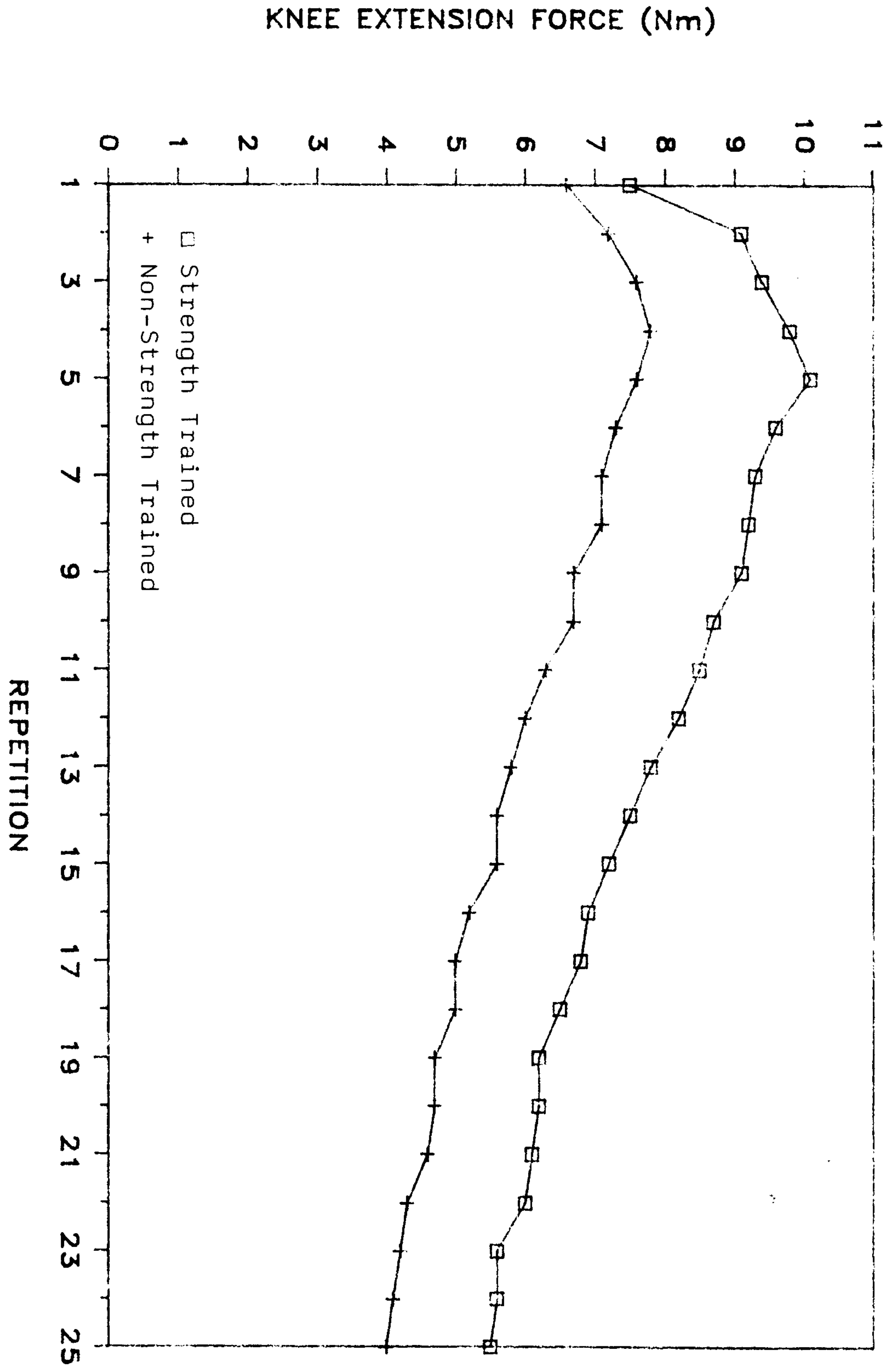

Fig. 4--25RM knee extension force

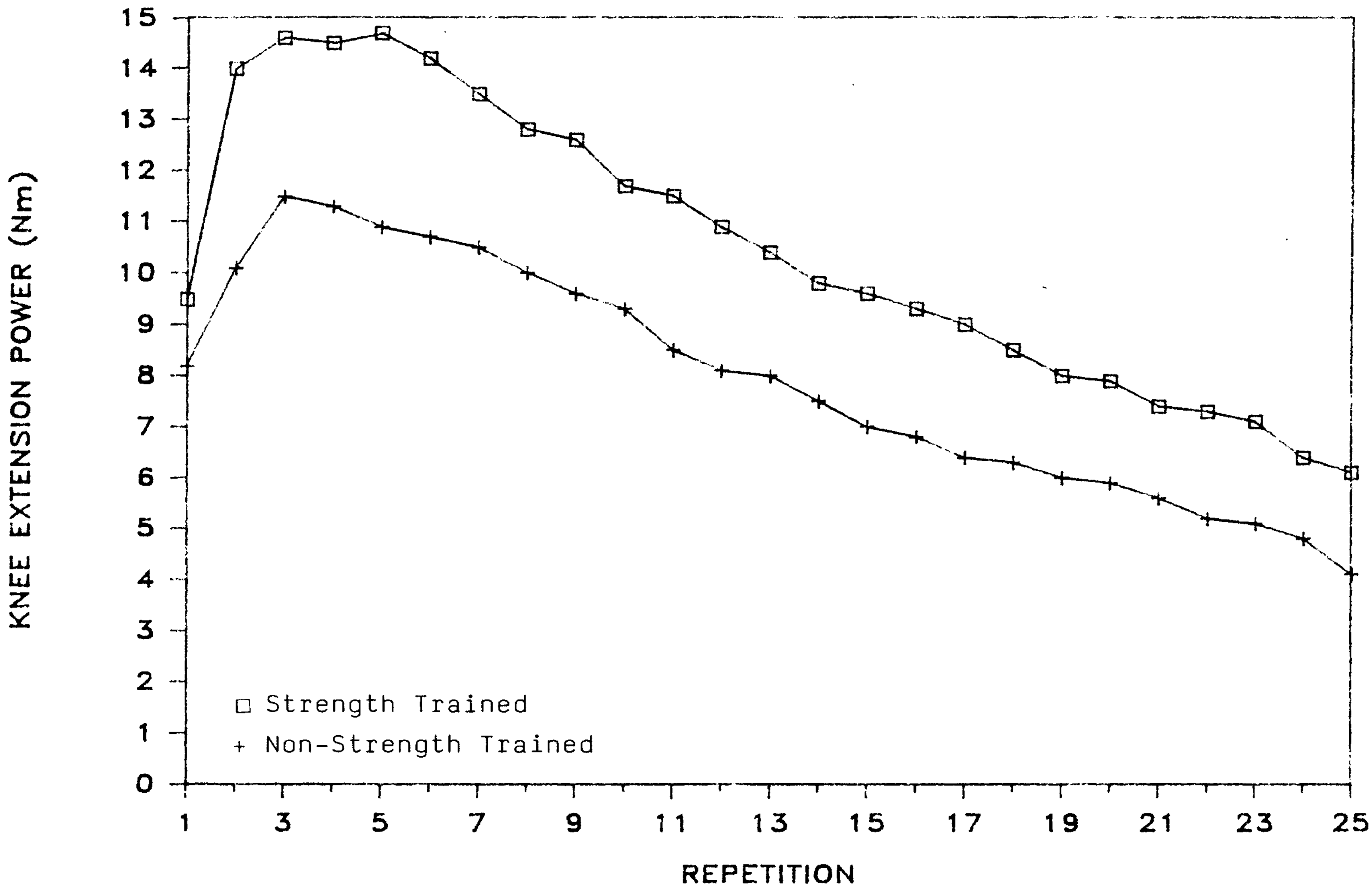

Fig. 5--25RM knee extension power

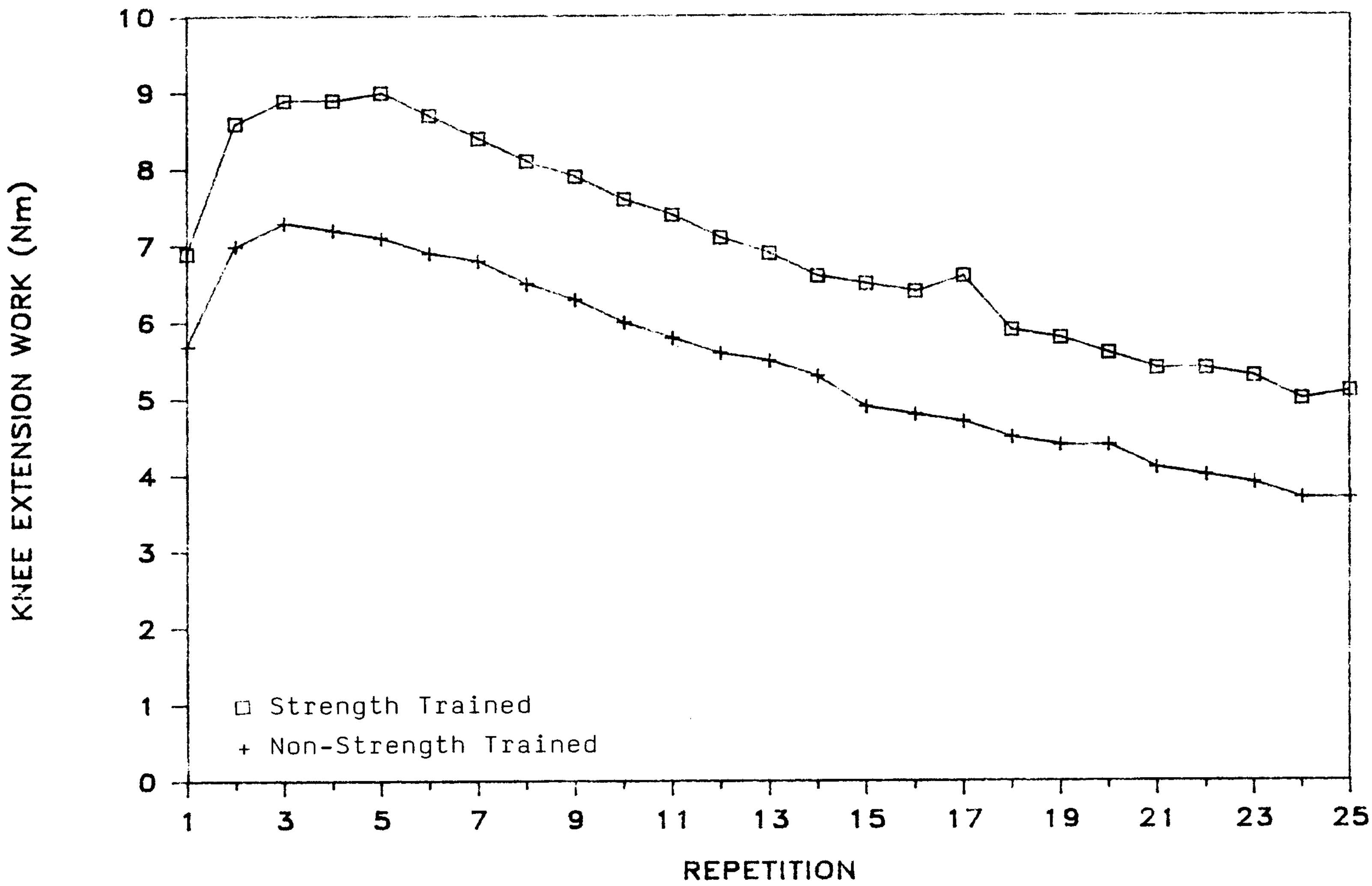

Fig. 6--25RM knee extension work

ANOVA and Tukey post-hoc analysis for 25RM chest press force, power and work values are found in Tables XII through XVII.

Analysis of variance indicated statistically significant group and repetition effects and a statistically non-significant interaction effect for chest press and knee extension force, power and work expressed relative to LBW throughout the 25 repetitions. Analysis of variance and Tukey post-hoc analysis for 25RM chest press force, power and work values and for knee extension force, power and work values expressed relative to lean body weight are found in Tables XVIII through XXIII, respectively. The final section of each ANOVA table is a comparison of each repetition in relation to all of the other repetitions. Repetitions with the same letters are similar to each other. Repetitions which are separated by a space and differ in letter designation are significantly different.

TABLE XII

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS FORCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	315921.316	6447.373	28.72	0.0001	0.597
ERROR	950	213290.200	224.516			
CORRECTED TOTAL	999	529211.516				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	157602.916	701.97	0.0001
NUM	24	157303.116	29.19	0.0001
CATG*NUM	24	1015.284	0.19	1.0000

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS FORCE

ALPHA = 0.05 DF = 950 MSE = 224.516
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 1.8597

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	97.5320	500	1
B	72.4240	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS FORCE

ALPHA = 0.05 DF = 950 MSE = 224.516
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 12.293

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY	GROUPING	MEAN	N	NUM
	A	104.750	40	2
	A			
B	A	103.650	40	3
B	A			

TABLE XII--Continued

TUKEY GROUPING							MEAN	N	NUM
	B		A		C		101.775	40	4
	B		A		C				
	B		A		C		100.950	40	1
	B		A		C				
	B	D	A		C		99.875	40	5
	B	D	A		C				
E	B	D	A		C		98.025	40	6
E	B	D	A		C				
E	B	D	A		C	F	95.750	40	7
E	B	D	A		C	F			
E	B	D	A	G	C	F	93.825	40	8
E	B	D		G	C	F			
E	B	D	H	G	C	F	91.950	40	9
E		D	H	G	C	F			
E		D	H	G	C	F	90.200	40	10
E		D	H	G		F			
E	I	D	H	G		F	88.525	40	11
E	I		H	G		F			
E	I		H	G	J	F	87.200	40	12
	I		H	G	J	F			
	I	K	H	G	J	F	84.1	40	13
	I	K	H	G	J				
L	I	K	H	G	J		83.375	40	14
L	I	K	H		J				
L	I	K	H		J	M	81.200	40	15
L	I	K	H		J	M			
L	I	K	H		J	M	80.650	40	16
L	I	K			J	M			
L	I	K	N		J	M	77.425	40	17
L		K	N		J	M			
L		K	N		J	M	75.800	40	18
L		K	N			M			
L	O	K	N			M	73.625	40	19
L	O	K	N			M			
L	O	K	N			M	72.650	40	20
L	O		N			M			
L	O		N			M	71.525	40	21
	O		N			M			
	O		N			M	70.675	40	22
	O		N						
	O		N				67.875	40	23
	O		N						
	O		N				65.900	40	24
	O								
	O						63.175	40	25

TABLE XIII

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS POWER

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	900644.896	18380.508	20.31	0.0001	0.511
ERROR	950	859925.900	905.185			
CORRECTED TOTAL	999	1760570.796				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	474629.796	524.35	0.0001
NUM	24	419862.346	19.33	0.0001
CATG*NUM	24	6152.754	0.28	0.9998

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS POWER

ALPHA = 0.05 DF = 950 MSE = 905.185
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 3.7342

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	112.088	500	1
B	68.516	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS POWER

ALPHA = 0.05 DF = 950 MSE = 905.185
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 24.684

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY	GROUPING	MEAN	N	CATG
	A	123.775	40	2
	A			
B	A	121.500	40	3
B	A			

TABLE XIII--Continued

TUKEY GROUPING								MEAN	N	NUM
	B			A				120.050	40	4
	B			A						
	B			A		C		117.275	40	5
	B			A		C				
	B	D		A		C		112.800	40	6
	B	D		A		C				
E	B	D		A		C		107.600	40	7
E	B	D		A		C				
E	B	D		A		C		106.150	40	1
E	B	D		A		C				
E	B	D		A		C	F	104.825	40	8
E	B	D		A		C	F			
E	B	D		A	G	C	F	101.125	40	9
E	B	D		A	G	C	F			
E	B	D	H	A	G	C	F	99.650	40	10
E	B	D	H		G	C	F			
E	B	D	H		G	C	F	96.875	40	11
E		D	H		G	C	F			
E		D	H	I	G	C	F	94.650	40	12
E		D	H	I	G		F			
E	J	D	H	I	G		F	90.475	40	13
E	J		H	I	G		F			
E	J		H	I	G	K	F	87.100	40	14
E	J		H	I	G	K	F			
E	J		H	I	G	K	F	84.650	40	15
	J		H	I	G	K	F			
	J	L	H	I	G	K	F	81.175	40	16
	J	L	H	I	G	K				
M	J	L	H	I	G	K		78.950	40	17
M	J	L	H	I		K				
M	J	L	H	I		K		75.950	40	18
M	J	L		I		K				
M	J	L		I		K		71.975	40	19
M	J	L		I		K				
M	J	L		I		K		70.075	40	20
M	J	L				K				
M	J	L				K		67.450	40	21
M	J	L				K				
M	J	L				K		66.050	40	22
M		L				K				
M		L				K		62.850	40	23
M		L								
M		L						59.150	40	24
M										
M								55.425	40	25

TABLE XIV

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS WORK

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	338228.184	6902.616	22.25	0.0001	0.536556
ERROR	950	292140.100	307.515			
CORRECTED TOTAL	999	630368.284				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	212576.400	691.27	0.0001
NUM	24	123385.084	16.72	0.0001
CATG*NUM	24	2266.700	0.31	0.9995

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS WORK

ALPHA = 0.05 DF = 950 MSE = 307.516
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 2.1765

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	97.734	500	1
B	68.574	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR 25RM CHEST PRESS WORK

ALPHA = 0.05 DF = 950 MSE = 307.516
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 14.387

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	100.300	40	3
A			
A	99.600	40	2
A			

TABLE XIV--Continued

TUKEY GROUPING	MEAN	N	NUM
A	98.750	40	4
A			
A	98.400	40	5
A			
B A	95.850	40	6
B A			
B A C	92.950	40	7
B A C			
B D A C	90.725	40	8
B D A C			
B D A C	90.375	40	9
B D A C			
E B D A C	89.150	40	10
E B D A C			
E B D A C F	87.600	40	11
E B D A C F			
E B D A C F	86.750	40	1
E B D A C F			
E B D A C F	86.725	40	12
E B D C F			
E B D G C F	83.650	40	13
E B D G C F			
E B D G H C F	83.050	40	14
E D G H C F			
E I D G H C F	80.750	40	15
E I D G H C F			
E I D J G H C F	79.500	40	16
E I D J G H F			
E I D J G H F	77.300	40	17
E I J G H F			
E I J G H F	75.175	40	18
I J G H F			
I J G H F	73.625	40	19
I J G H			
I J G H	71.750	40	20
I J G H			
I J G H	69.400	40	21
I J H			
I J H	69.225	40	22
I J			
I J	66.850	40	23
J			
J	65.775	40	25
J			
J	65.625	40	24

TABLE XV

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION FORCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	120515.549	2459.500	13.33	0.0001	0.407437
ERROR	950	175273.687	184.498			
CORRECTED TOTAL	999	295789.236				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	32599.532	176.69	0.0001
NUM	24	86390.757	19.51	0.0001
CATG*NUM	24	1525.259	0.34	0.9987

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM KNEE EXTENSION FORCE

ALPHA = 0.05 DF = 950 MSE = 184.499
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 1.6859

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	54.607	500	1
B	43.1886	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION FORCE

ALPHA = 0.05 DF = 950 MSE = 184.499
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 11.144

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	62.675	40	4
A			
A	62.325	40	5
A			

TABLE XV--Continued

TUKEY GROUPING	MEAN	N	NUM
B A	60.462	40	3
B A			
B A C	59.982	40	6
B A C			
B A C	59.162	40	8
B A C			
B A C	59.060	40	7
B A C			
B D A C	57.952	40	2
B D A C			
B D A C	57.727	40	9
B D A C			
E B D A C	56.195	40	10
E B D A C			
E D D A C F	53.545	40	11
E B D C F			
E B D C F	51.110	40	12
E B D C F			
E B D G C F	49.777	40	1
E D G C F			
E H D G C F	48.912	40	13
E H D G F			
E H D G F	47.022	40	14
E H G F			
E H G I F	45.922	40	15
H G I F			
H J G I F	43.930	40	16
H J G I F			
H J G I F	42.967	40	17
H J G I F			
H J G I F	42.495	40	18
H J G I			
H J G I	39.797	40	19
H J G I			
H J G I	39.667	40	20
H J G I			
H J G I	39.010	40	21
H J I			
H J I	37.825	40	22
J I			
J I	35.757	40	23
J			
J	34.737	40	24
J			
J	34.435	40	25

TABLE XVI

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION POWER

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	392364.317	8007.435	21.52	0.0001	0.526059
ERROR	950	353491.667	372.096			
CORRECTED TOTAL	999	745855.985				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	72379.257	194.52	0.0001
NUM	24	314362.730	35.20	0.0001
CATG*NUM	24	5622.329	0.63	0.9159

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION POWER

ALPHA = 0.05 DF = 950 MSE = 372.096
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 2.3942

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	75.561	500	1
B	58.546	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION POWER

ALPHA = 0.05 DF = 950 MSE = 372.096
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 15.826

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	94.982	40	3
A			
A	94.255	40	4
A			

TABLE XVI--Continued

TUKEY GROUPING						MEAN	N	NUM
			A			93.920	40	5
			A					
	B		A			90.047	40	6
	B		A					
	B		A	C		88.090	40	7
	B		A	C				
	B		A	C		86.282	40	2
	B		A	C				
	B	D	A	C		83.442	40	8
	B	D	A	C				
E	B	D	A	C		80.402	40	9
E	B	D		C				
E	B	D	F	C		76.925	40	10
E		D	F	C				
E	G	D	F	C		73.230	40	11
E	G	D	F					
E	G	D	F	H		69.312	40	12
E	G		F	H				
E	G	I	F	H		67.225	40	13
	G	I	F	H				
J	G	I	F	H		63.515	40	14
J	G	I	F	H				
J	G	I	F	H	K	61.777	40	1
J	G	I		H	K			
J	G	I		H	K	61.045	40	15
J	G	I		H	K			
J	G	I	L	H	K	58.892	40	16
J		I	L	H	K			
J		I	L	H	K	57.095	40	17
J		I	L	H	K			
J	M	I	L	H	K	54.842	40	18
J	M	I	L		K			
J	M	I	L	N	K	51.490	40	19
J	M		L	N	K			
J	M		L	N	K	50.652	40	20
J	M		L	N	K			
J	M		L	N	K	48.555	40	21
	M		L	N	K			
	M		L	N	K	46.620	40	22
	M		L	N				
	M		L	N		45.065	40	23
	M			N				
	M			N		40.945	40	24
				N				
				N		37.705	40	25

TABLE XVII

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION WORK

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	107249.833	2188.772	20.04	0.0001	0.508272
ERROR	950	103758.991	109.219			
CORRECTED TOTAL	999	211008.824				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	26221.568	240.08	0.0001
NUM	24	80507.813	30.71	0.0001
CATG*NUM	24	520.451	0.20	1.0000

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION WORK

ALPHA = 0.05 DF = 950 MSE = 109.22
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 1.2971

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	50.199	500	1
B	39.958	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION WORK

ALPHA = 0.05 DF = 950 MSE = 109.22
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = 8.5743

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	59.310	40	3
A			
A	58.785	40	4
A			

TABLE XVII--Continued

TUKEY GROUPING	MEAN	N	NUM
A	58.785	40	5
A			
B A	56.585	40	6
B A			
B A C	55.575	40	2
B A C			
B A C	55.542	40	7
B A C			
B D A C	53.167	40	8
B D A C			
E B D A C	51.755	40	9
E B D C			
E B D F C	49.582	40	10
E D F C			
E G D F C	47.990	40	11
E G D F			
E G D F H	45.680	40	12
E G D F H			
E G D F H	45.275	40	13
E G F H			
E F I F H	44.300	40	1
E G I F H			
E G I F H J	43.405	40	14
G I F H J			
K G I F H J	41.952	40	15
K G I H J			
K G I H J	40.602	40	16
K G I H J			
K G I L H J	40.040	40	17
K I L H J			
K I L H J	38.482	40	18
K I L H J			
K I L H J	37.357	40	19
K I L J			
K I L J	36.470	40	20
K L J			
K L J	35.195	40	21
K L			
K L	34.147	40	22
K L			
K L	33.627	40	23
L			
L	31.777	40	24
L			
L	31.582	40	25

TABLE XVIII

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	113.831	2.323	36.10	0.0001	0.650591
ERROR	950	61.134	0.064			
CORECTED TOTAL	999	174.966				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	42.281	657.03	0.0001
NUM	24	70.993	45.97	0.0001
CATG*NUM	24	0.556	0.36	0.9982

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM CHEST PRESS FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .06435
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = .03149

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	1.996	500	1
B	1.585	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM CHEST PRESS FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .06435
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = .20813

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY	GROUPING	MEAN	N	NUM
	A	2.208	40	2
	A			
B	A	2.186	40	3
B	A			

TABLE XVIII--Continued

TUKEY GROUPING	MEAN	N	NUM
B A	2.148	40	4
B A			
B A C	2.128	40	1
B A C			
B D A C	2.106	40	5
B D A C			
E B D A C	2.068	40	6
E B D A C			
E B D A C F	2.020	40	7
E B D C F			
E B D G C F	1.979	40	8
E D G C F			
E H D G C F	1.940	40	9
E H D G F			
E H D G I F	1.903	40	10
E H G I F			
E H G I F	1.866	40	11
H G I G			
H G I F	1.839	40	12
H G I			
H J G I	1.771	40	13
H J I			
H J K I	1.756	40	14
J K I			
L J K I	1.711	40	15
L J K I			
L J K I	1.701	40	16
L J K			
L J K M	1.629	40	17
L J K M			
L J K M	1.594	40	18
L K M			
L N K M	1.548	40	19
L N M			
L N O M	1.530	40	20
L N O M			
L N O M	1.504	40	21
N O M			
N O M	1.485	40	22
N O M			
N O M	1.427	40	23
N O			
N O	1.385	40	24
O			
O	1.326	40	25

TABLE XIX

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS POWER
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	333.851	6.813	28.61	0.0001	0.596063
ERROR	950	226.242	0.238			
CORECTED TOTAL	999	560.094				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	145.735	611.95	0.0001
NUM	24	185.920	32.53	0.0001
CATG*NUM	24	2.195	0.38	0.9969

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM CHEST PRESS POWER
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = 0.23815
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = .06057

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	2.264	500	1
B	1.501	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM CHEST PRESS POWER
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = 0.23815
CTITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = .40038

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	2.583	40	2
A			
A	2.538	40	3
A			

TABLE XIX--Continued

TUKEY GROUPING							MEAN	N	NUM
	B		A				2.510	40	4
	B		A						
	B		A		C		2.449	40	5
	B		A		C				
	B	D	A		C		2.356	40	6
	B	D	A		C				
E	B	D	A		C		2.246	40	7
E	B	D	A		C				
E	B	D	A		C		2.216	40	1
E	B	D	A		C				
E	B	D	A		C	F	2.187	40	8
E	B	D			C	F			
E	B	D	G		C	F	2.111	40	9
E		D	G		C	F			
E	H	D	G		C	F	2.081	40	10
E	H	D	G			F			
E	H	D	G		I	F	2.021	40	11
E	H	D	G		I	F			
E	H	D	G	J	I	F	1.975	40	12
E	H		G	J	I	F			
E	H	K	G	J	I	F	1.885	40	13
	H	K	G	J	I	F			
L	H	K	G	J	I	F	1.814	40	14
L	H	K	G	J	I				
L	H	K	G	J	I	M	1.764	40	15
L	H	K		J	I	M			
L	H	K	N	J	I	M	1.693	40	16
L		K	N	J	I	M			
L		K	N	J	I	M	1.641	40	17
L		K	N	J		M			
L	O	K	N	J		M	1.579	40	18
L	O	K	N			M			
L	O	K	N		P	M	1.495	40	19
L	O		N		P	M			
L	O		N		P	M	1.458	40	20
	O		N		P	M			
	O		N		P	M	1.401	40	21
	O		N		P	M			
	O		N		P	M	1.371	40	22
	O		N		P				
	O		N		P		1.304	40	23
	O				P				
	O				P		1.227	40	24
					P				
					P		1.147	40	25

TABLE XX

ANALYSIS OF VARIANCE FOR 25RM CHEST PRESS WORK
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	118.144	2.411	30.15	0.0001	.608598
ERROR	950	75.982	0.079			
CORRECTED TOTAL	999	194.125				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	62.228	778.05	0.0001
NUM	24	54.896	28.60	0.0001
CATG*NUM	24	1.019	0.53	0.9692

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM CHEST PRESS WORK
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .079980
CTITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 0.0351

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	1.994	500	1
B	1.495	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD) TEST FOR 25RM CHEST PRESS WORK
EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .079980
CTITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = .23203

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	2.104	40	3
A			
A	2.089	40	2
A			

TABLE XX--<u>Continued</u>

TUKEY GROUPING						MEAN	N	NUM
			A			2.075	40	4
			A					
	B		A			2.066	40	5
	B		A					
	B		A	C		2.013	40	6
	B		A	C				
	B	D	A	C		1.950	40	7
	B	D	A	C				
E	B	D	A	C		1.906	40	8
E	B	D	A	C				
E	B	D	A	C	F	1.897	40	9
E	B	D	A	C	F			
E	B	D	A	C	F	1.873	40	10
E	B	D		C	F			
E	B	D	G	C	F	1.840	40	11
E		D	G	C	F			
E		D	G	C	F	1.821	40	12
E		D	G	C	F			
E		D	G	C	F	1.820	40	1
E		D	G		F			
E	H	D	G		F	1.754	40	13
E	H	D	G		F			
E	H	D	G		F	1.743	40	14
E	H		G		F			
E	H		G	I	F	1.695	40	15
	H		G	I	F			
	H	J	G	I	F	1.667	40	16
	H	J	G	I				
K	H	J	G	I		1.620	40	17
K	H	J		I				
K	H	J	L	I		1.576	40	18
K	H	J	L	I				
K	H	J	L	I		1.543	40	19
K		J	L	I				
K		J	L	I		1.504	40	20
K		J	L					
K		J	L			1.455	40	21
K		J	L					
K		J	L			1.449	40	22
K			L					
K			L			1.400	40	23
			L					
			L			1.379	40	24
			L					
			L			1.375	40	25

TABLE XXI

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > R	R-SQUARE
MODEL	49	45.674	0.932	18.30	0.0001	0.485533
ERROR	950	48.396	0.050			
CORRECTED TOTAL	999	94.071				

SOURCE	DF	ANOVA SS	F VALUE	PR > R
CATG	1	7.541	148.04	0.0001
NUM	24	37.689	30.83	0.0001
CATG*NUM	24	0.443	0.36	0.9980

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .050944
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = .02801

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	1.112	500	1
B	0.938	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION FORCE EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 0.05 MSE = .050944
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = .18518

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	1.315	40	4
A			
A	1.307	40	5
A			

TABLE XXI--Continued

TUKEY GROUPING	MEAN	N	NUM
B A	1.269	40	3
B A			
B A C	1.256	40	6
B A C			
B D A C	1.235	40	8
B D A C			
B D A C	1.234	40	7
B D A C			
B D A C	1.220	40	2
B D A C			
E B D A C	1.203	40	9
E B D A C			
E B D A C F	1.173	40	10
E B D C F			
E B D G C F	1.120	40	11
E D G C F			
E H D G C F	1.072	40	12
E H D G F			
E H D G F	1.051	40	1
E H G F			
E H G F	1.026	40	13
H G F			
H G I F	.989	40	14
H G I			
H J G I	.965	40	15
H J I			
H J K I	.922	40	16
H J K I			
L H J K I	.900	40	17
L H J K I			
L H J K I	.889	40	18
L J K I			
L J K I	.837	40	19
L J K I			
L J K I	.831	40	20
L J K I			
L J K I	.819	40	21
L J K			
L J K	.794	40	22
L K			
L K	.751	40	23
L			
L	.729	40	24
L			
L	.720	40	25

TABLE XXII

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION POWER EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	157.696	3.218	26.57	0.0001	0.578135
ERROR	950	115.071	0.121			
CORRECTED TOTAL	999	272.767				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	17.745	146.50	0.0001
NUM	24	138.409	47.61	0.0001
CATG*NUM	24	1.540	0.53	0.9696

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION POWER EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = 0.12112
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 0.0432

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	1.541	500	1
B	1.275	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION POWER EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = 0.12112
CRITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENCE = .28554

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING		MEAN	N	NUM
	A	1.990	40	3
	A			
B	A	1.976	40	4
B	A			

TABLE XXII--Continued

TUKEY GROUPING						MEAN	N	NUM
	B		A			1.971	40	5
	B		A					
	B		A	C		1.889	40	6
	B		A	C				
	B		A	C		1.848	40	7
	B		A	C				
	B	D	A	C		1.809	40	2
	B	D	A	C				
	B	D	A	C		1.752	40	8
	B	D		C				
	B	D	E	C		1.692	40	9
		D	E	C				
	F	D	E	C		1.618	40	10
	F	D	E					
	F	D	E	G		1.541	40	11
	F		E	G				
	F	H	E	G		1.460	40	12
	F	H	E	G				
I	F	H	E	G		1.416	40	13
I	F	H		G				
I	F	H	J	G		1.338	40	14
I		H	J	G				
I	K	H	J	G		1.300	40	1
I	K	H	J	G				
I	K	H	J	G		1.282	40	15
I	K	H	J					
I	K	H	J	L		1.237	40	16
I	K	H	J	L				
I	K	H	J	L	M	1.198	40	17
I	K		J	L	M			
I	K		J	L	M	1.151	40	18
	K		J	L	M			
	K	N	J	L	M	1.083	40	19
	K	N	J	L	M			
O	K	N	J	L	M	1.062	40	20
O	K	N		L	M			
O	K	N		L	M	1.019	40	21
O		N		L	M			
O		N		L	M	.978	40	22
O		N			M			
O		N			M	.946	40	23
O		N						
O		N				.858	40	24
O								
O						.789	40	25

TABLE XXIII

ANALYSIS OF VARIANCE FOR 25RM KNEE EXTENSION WORK EXPRESSED RELATIVE TO LEAN BODY WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE
MODEL	49	42.621	0.869	22.33	0.0001	0.535210
ERROR	950	37.013	0.038			
CORRECTED TOTAL	999	79.634				

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CATG	1	6.649	170.66	0.0001
NUM	24	35.845	38.33	0.0001
CATG*NUM	24	0.126	0.14	1.0000

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION WORK EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .038961
CRITICAL VALUE OF STUDENTIZED RANGE = 2.775
MINIMUM SIGNIFICANT DIFFERENCE = 0.0245

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	CATG
A	1.031	500	1
B	.868	500	2

POST-HOC TUKEY'S STUDENTIZED RANGE(HSD)TEST FOR 25RM KNEE EXTENSION WORK EXPRESSED RELATIVE TO LEAN BODY WEIGHT

ALPHA = 0.05 DF = 950 MSE = .038961
CTITICAL VALUE OF STUDENTIZED RANGE = 5.189
MINIMUM SIGNIFICANT DIFFERENC = 0.16194

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	NUM
A	1.249	40	3
A			
A	1.237	40	5
A			

TABLE XXIII--Continued

TUKEY GROUPING	MEAN	N	NUM
A	1.237	40	4
A			
B A	1.191	40	6
B A			
B A C	1.172	40	2
B A C			
B A C	1.170	40	7
B A C			
B D A C	1.119	40	8
B D A C			
E B D A C	1.091	40	9
E B D C			
E B D F C	1.045	40	10
E D F C			
E G D F C	1.012	40	11
E G D F			
E G D F H	.963	40	12
E G F H			
E G F H	.954	40	13
E G F H			
E G I F H	.933	40	1
G I F H			
J G I F H	.916	40	14
J G I H			
J G I K H	.882	40	15
J G I K H			
J G I K H L	.854	40	16
J I K H L			
J I K H L	.842	40	17
J I K H L			
J M I K H L	.809	40	18
J M I K L			
J M I K L	.787	40	19
J M K L			
J M K L	.766	40	20
M K L			
M K L	.740	40	21
M L			
M L	.718	40	22
M L			
M L	.708	40	23
M			
M	.668	40	24
M			
M	.664	40	25

Correlational analysis indicated that body weight was highly correlated to chest, upper arm, lower arm and thigh segment volumes in both groups of subjects Lean body weight was moderately correlated to segment volumes in the female bodybuilders, but was not significantly related (p > 0.05) to the segment volumes in the non-strength trained female. Correlation coefficients for body weight and LBW in relation to the segment volumes for both groups are presented in Table XXIV.

TABLE XXIV

CORRELATION COEFFICIENTS FOR BODY WEIGHT AND LEAN BODY WEIGHT IN RELATION TO SEGMENT VOLUMES FOR THE HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES*

Segment Volumes	Female Bodybuilders		Non-Strength Trained Female	
	Body Weight	LBW	Body Weight	LBW
Chest	0.71	0.59	0.55	0.20*
Upper Arm	.90	.87	.77	.31*
Lower Arm	.87	.79	.58	.22*
Thigh	.77	.55	.82	.40*

*Values are non-significant (p > 0.05

Body weight and LBW were strongly correlated to the 1RM chest press force, power and work values in the highly trained female bodybuilders. The r values for body weight and lean body weight in relation to 1RM chest press force, power and work were 0.78, 0.80, and 0.63, and 0.80, 0.78 and 0.71, respectively. However, there was no significant ($p > 0.05$) relationship between weight and LBW to the 1RM chest press values in the non-strength trained females. Correlation coefficients for weight and LBW to 1RM chest press force, power and work values for both groups are presented in Table XXV.

TABLE XXV

CORRELATION COEFFICIENTS FOR BODY WEIGHT AND LEAN BODY WEIGHT IN RELATION TO 1RM CHEST PRESS FORCE, POWER AND WORK FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES

Chest Press 1RM	Female Bodybuilders		Non-Strength Trained Female	
	Body Weight	LBW	Body Weight	LBW
Force	0.78	0.80	0.30*	0.16*
Power	.80	.78	.24*	.04*
Work	.63	.71	.05*	.32*

*Values are non-significant ($p > 0.05$)

Lean body weight was moderately related to the 1RM knee extension force, power and work values, while body weight was less markedly related to 1RM knee extension force and power in the female bodybuilder. Correlation coefficients for body weight to 1RM knee extension force, power and work were 0.59, 0.65 and 0.49, respectively. Correlation coefficients for LBW to 1RM knee extension force and power were 0.51 and 0.65. Body weight and LBW were not significantly related to 1RM knee extension force, power and work values in the non-strength trained females. Correlation coefficients for body weight and LBW in relation to knee extension 1RM values are presented in Table XXVI.

TABLE XXVI

CORRELATION COEFFICIENTS FOR BODY WEIGHT AND LEAN BODY WEIGHT IN RELATION TO 1RM KNEE EXTENSION FORCE, POWER AND WORK FOR HIGHLY TRAINED FEMALE BODYBUILDERS AND NON-STRENGTH TRAINED FEMALES

Knee Extension 1RM	Female Bodybuilders		Non-Strength Trained Females	
	Body Weight	LBW	Body Weight	LBW
Force	0.51	0.59	0.45	0.37*
Power	.65	.65	.15*	.32*
Work	.39	.49	.21*	.08*

*Values are non-significant ($p > 0.05$)

For the female bodybuilders, body weight, LBW and chest volumes were moderately, highly, and poorly related, respectively, to all the chest press 25RM values. Correlation coefficients for LBW to chest force, power and work averaged 0.79, 0.80 and 0.72 respectively.

Correlation coefficients for body weight to chest press force, power and work values averaged 0.67, 0.75 and 0.69. Body weight and LBW were not significantly related to the 25RM chest press force, power and work values in the non-strength trained females.

Weight and LBW were significantly related to the 25RM knee extension force, power and work values in the highly trained female bodybuilders. Correlation coefficients for weight to knee extension force, power and work, averaged 0.68, 0.56 and 0.49, respectively. Correlation coefficients for LBW to knee extension force, power and work averaged 0.71, 0.61 and 0.46, respectively. Weight and LBW were not significantly related to the 25RM knee extension force, power and work values in the non-strength trained females.

CHAPTER V

DISCUSSION

In his review of the factors contributing to muscle strength, Maughan concluded that the major determinant of muscle strength was its cross-sectional area (Maughan, 1984).

Schantz et al. reported no differences in strength per unit cross-sectional area between elite male bodybuilders and untrained physical education students (Schantz, Randall-Fox, Hutchison, Tyden and Astrand, 1983).

Clarke investigated the relationship between arm and leg strength and various anthropometric measurements in men and found a correlation coefficient of 0.55 between upper arm strength and arm girth and a correlation of 0.52 between leg strength and thigh girth (Clarke, 1954; Clarke, 1957).

Lamphier and Montoye examined the relationship between muscle strength and muscle size and found that the computed lean body mass to strength ratio produced a correlation coefficient of 0.27 for knee extension and 0.58 for elbow flexion. They concluded that strength was better predicted from size variables in men than in women (Lamphier and Montoye, 1967).

Hosler and Morrow (Hosler and Morrow, 1982) examined the arm and leg strength of young women and men and found that lean body weight accounted for most of the differences in strength. Their findings suggest that lean body weight is a factor contributing to the greater strength of men.

In this study, the mean age, height and weight of the female bodybuilders and the non-strength trained females were similar. However, PBF and LBW were significantly different between the two groups. The female bodybuilders had a PBF of 13.8% and a LBW of 48.7 kg, while the non-strength trained females had values of 21.8% and 45.9 kg, respectively.

Prior research investigating the body composition of female athletes has served to document the physical characteristics and body composition of several different types of female athletes (McArdle, Katch and Katch, 1981). Interestingly, the age (21 years), height (165 cm), weight (58.6 kg), PBF (13.7%) and LBW (49 kg), of olympic sprinters are the most similar to those of female bodybuilders.

In a previous study investigating muscular development and lean body weight of male bodybuilders and weight lifters, Katch et al., found that the bodybuilders had a LBW which was approximately 14.5 kg greater than the lean body weight of 'reference man' (Katch, Katch, Moffatt and Gittleson, 1980). Compared to the present study, this difference is larger than the 3 kg difference in LBW observed between the female bodybuilders and non-strength trained females.

The differences in LBW observed in the female compared to the male bodybuilders studied by Katch et al. may be attributed to the fact that Katch's bodybuilders were world class, elite bodybuilders and thus of a higher caliber than the bodybuilders who participated in this current study. Another contributing factor to the greater LBW of the male bodybuilders could be due to the use of anabolic steroids. The bodybuilders who participated in this study were steroid free, with no past history of the use of anabolic steroids.

Another consideration is the undefined criteria for the proper competitive physique in women's bodybuilding. In men's bodybuilding the proper competitive physique is clearly defined, i.e., the bodybuilder must have a large amount of muscle mass which is distributed proportionally to each body part. In addition, the bodybuilder must have a very low body fat at the time of competition. In the early years, female competitive bodybuilders adopted this definition as the criteria for the female competitive physique. However, in recent years a new concept of what the competitive physique should be in women's bodybuilding has arisen and an alternative competitive physique has emerged. This alternative physique is characterized by a less massive female bodybuilder with a more sleek, streamlined and lean appearance. Thus, the great majority of the female bodybuilders in this study could be defined as members of this latter category of female bodybuilders.

The difference in the desired competitive physique between the female and male bodybuilders may account for part of the difference seen in their relative lean body weight. This different training concept may also contribute to the similarity in body weight and segment volumes between the female body builders and the non-strength trained females.

There were no significant differences in the segment volumes and related anthropometric measurements between the female bodybuilders and the non-strength trained females. However, further analysis indicates that there are differences in the size of the muscles.

The two groups showed significant differences for the flexed-bicep, and the pectoral, tricep, forearm and thigh skinfolds as well as significant differences for biacromial breadth and knee circumference.

Thus, the greater lean body weight and lower skinfold thicknesses and PBF of the female bodybuilders indicate that the female bodybuilders have a greater muscle mass.

The greater lean body weight and larger muscle mass of the female bodybuilders may be a result of their strength training. Whether the greater lean body weight of the female bodybuilders is a result of muscular hypertrophy or hyperplasia is unknown.

Tesch and Larsson examined hypertrophy and hyperplasia as determinants of muscle size in male bodybuilders via muscle biopsies of the m. vastus lateralis and m. deltoid. They found no significant differences in the cross-sectional area of individual muscle fibers between the bodybuilders and the controls. Tesch and Larsson suggested that the greater muscle size of the bodybuilders may reflect exercise induced formation of new muscle fibers (hyperplasia) in bodybuilders, either by longitudinal fiber splitting or due to the development of satellite cells (Tesch and Larsson, 1982).

MacDougall et al. conducted a study investigating the muscle ultrastructural characteristics of elite powerlifters and bodybuilders (MacDougall, Sale, Elder and Sutton, 1982). The cross-sectional area of the individual muscle fibers between the bodybuilders and the controls was not significantly different, however, the bodybuilders had a greater total number of muscle fibers than the untrained controls. Their findings suggest the presence of hyperplasia as opposed to muscular hypertrophy.

There were statistically singificant differences between the two groups for the absolute 1RM chest press and knee extension force, power and work values.

The 1RM chest press and knee extension force, power and work values expressed relative to LBW were significantly different between the two groups.

The magnitude of differences in between the two groups' absolute 1RM values is unequal for the chest press and knee extension. The magnitude of difference between the two groups' 1RM chest press values is greater than that for the 1RM knee extension values. The differences in chest press force, power and work between the two groups were 22%, 37% and 26%, respectively. The differences in knee extension force, power and work between the two groups were 23%, 28% and 14% respectively.

In the comparison of strength between men and women, men typically have greater upper body strength, while leg strength is more similar (Wilmore, 1974). This pattern is similar to that seen in the comparison of the differences in upper and lower body strength between the female body-builders and the non-strength trained females. This finding suggests that there is a great potential for the improvement of the upper body strength of women, and through strength training the magnitude of difference between the upper body strength of men and women could be reduced.

Analysis of the 25RM chest press and knee extension force, power and work values indicated significant group and repetition effects and a non-significant interaction effect.

The female bodybuilders had consistently higher values for force, power and work throughout the 25RM tests for both the chest press and knee extension. When the 25RM values are expressed relative to LBW, the female bodybuilders continue to show higher force, power and work values for the chest press and knee extension. However both groups showed a steady decline in performance over the 25 repetitions, which was equivalent for both groups.

The similarity in the rate of decline in performance between the two groups over the 25 repetitions would suggest that although the female bodybuilders are stronger than the non-strength trained females, they do not demonstrate higher muscular endurance.

Thus, the higher force, power and work values for the female bodybuilders may be explained in part by their greater LBW. However, when performance was expressed relative to LBW, the female bodybuilders continued to show higher values for force, power and work for both the chest press and knee extension. This indicates that there may be other factors besides LBW contributing to the higher strength values of the female bodybuilders.

Neural factors may contribute to the greater strength of the female bodybuilders. Though not well defined, the neural factors may be explained by disinhibition or neural facilitation leading to a greater recruitment of muscle fibers (Moritani and DeVries, 1978).

Correlational analysis indicated that body weight, LBW and chest volume were significantly related to the chest press 1RM and 25RM values for the female bodybuilders. Body weight and chest volume were moderately related to the chest press values while LBW was highly related to chest press force, power and work values.

Body weight, LBW and thigh volume were significantly correlated to the knee extension 1RM and 25RM values. Body weight was moderately related to the knee extension values, while LBW was highly related to the knee extension values. Thigh volume was less markedly related to the knee extension values. However, neither the chest press nor the knee extension values were significantly related to body weight, LBW or segment volumes for the non-strength trained females.

Body weight is moderately related and LBW is highly related to the strength measures of the female bodybuilders. The correlation coefficients for strength in relation to size in the female bodybuilders are higher than those cited for men in previous studies. However, the correlation coefficients for strength values in relation to size and body composition for the female bodybuilders are more similar to those cited for men, than these same correlations for the non-strength trained females. Thus, the results of this study suggest that body size and LBW are better predictors of strength for female bodybuilders than for non-strength trained females.

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In conclusion the findings from this study indicate that:

1. The highly trained female bodybuilders have a higher LBW and a lower PBF than non-strength trained women.

2. Highly trained female bodybuilders have a larger muscle mass than non-strength trained females.

3. Highly trained female bodybuilders have higher absolute strength values than the non-strngth trained females.

4. Highly trained female bodybuilders have higher strength values than the non-strength trained females, when expressed relative to lean body weight.

5. Highly trained female bodybuilders and non-strength trained females have similar rates of muscular fatigue.

6. Body weight and lean body weight are highly correlated to strength in the highly trained female bodybuilder.

7. Body weight and lean body weight are not significantly related to strength in non-strength trained females.

8. The correlational values obtained for highly trained female bodybuilders in relation to strength and muscle size are higher than the values obtained for males

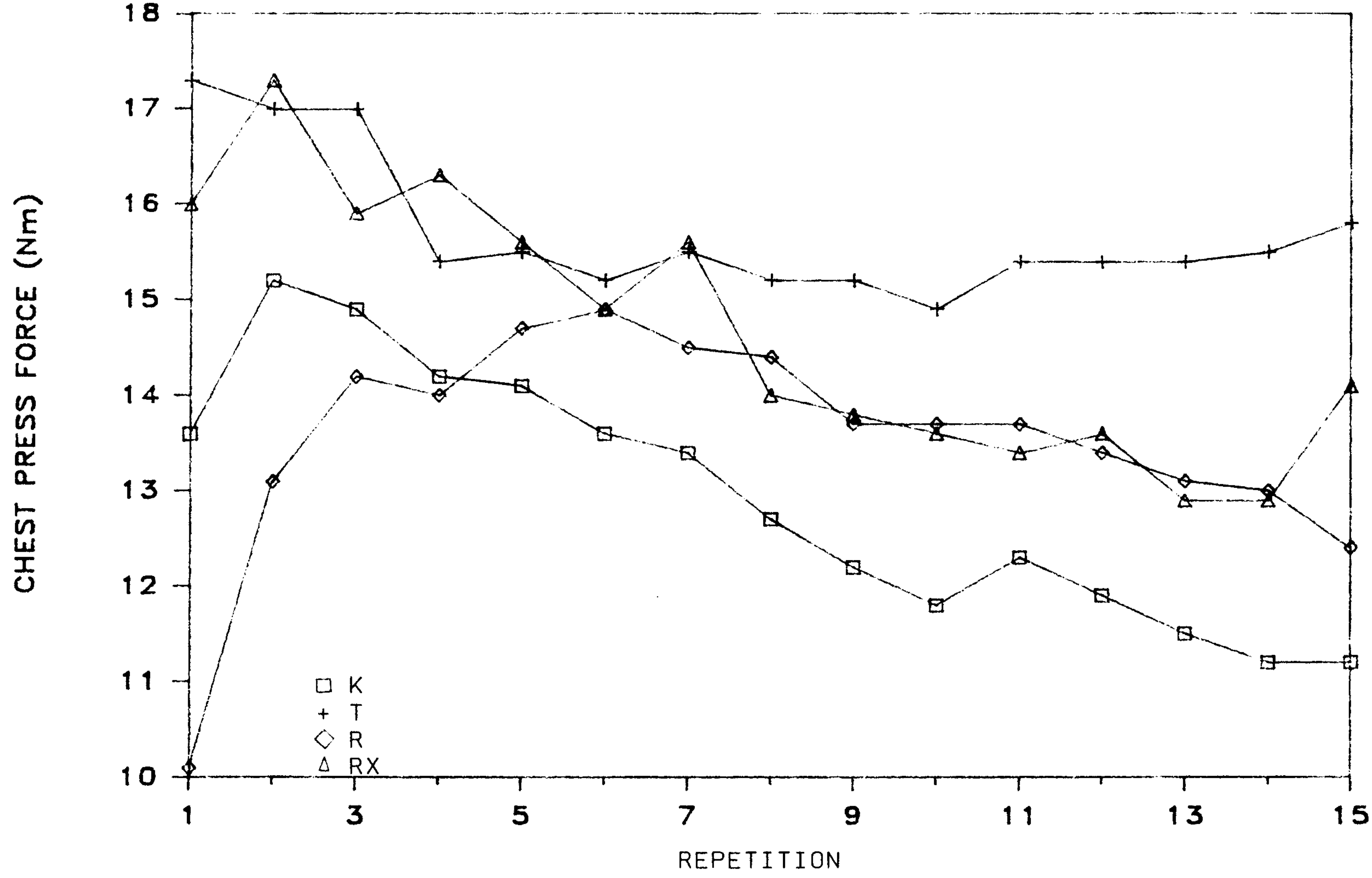
by previous investigators.

9. The correlational values obtained for non-strength trained females in relation to strength and muscle size are dissimilar to the values obtained for males by previous investigators.

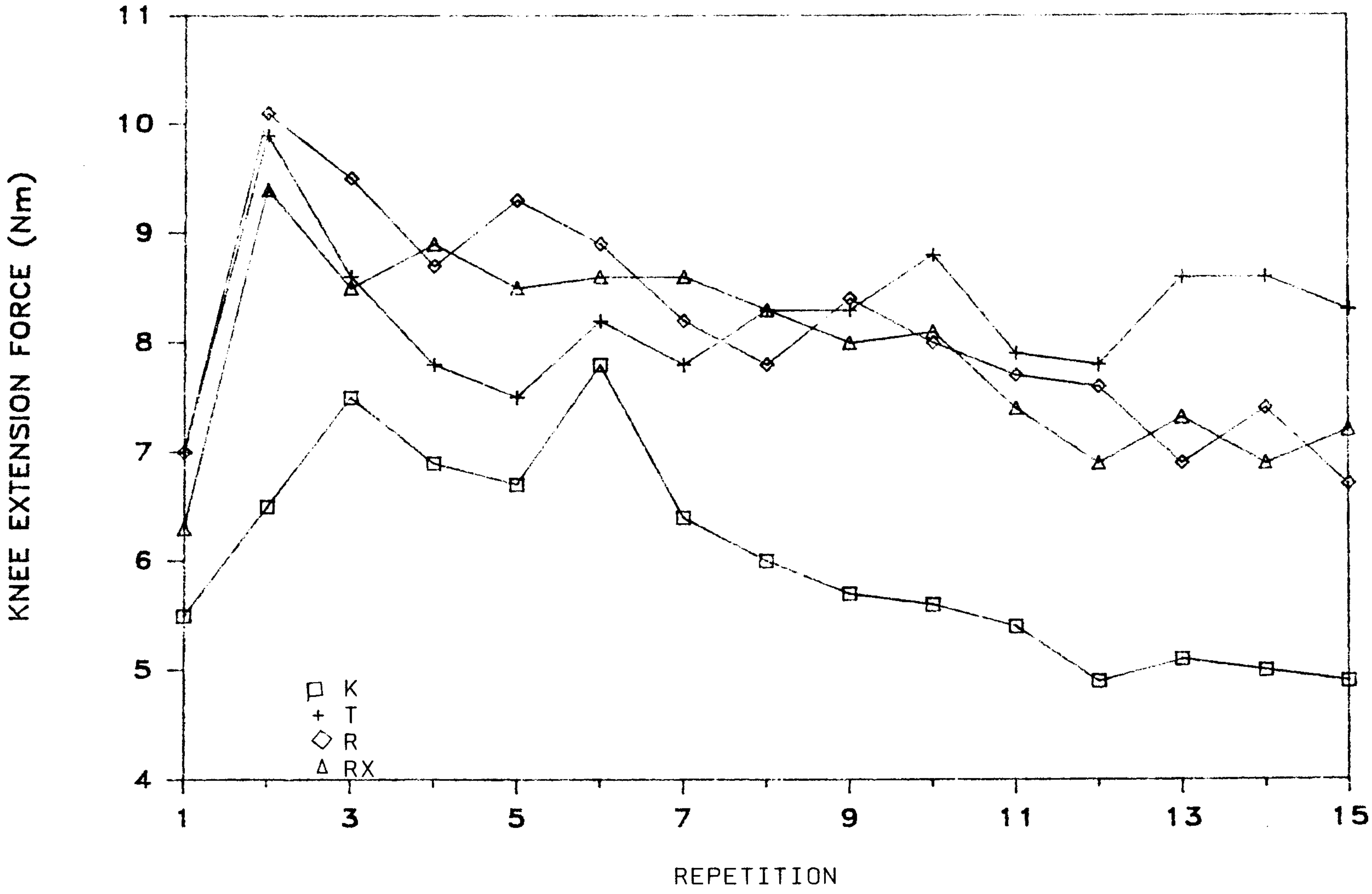
Recommendations

The following recommendations are made based on the results of the data:

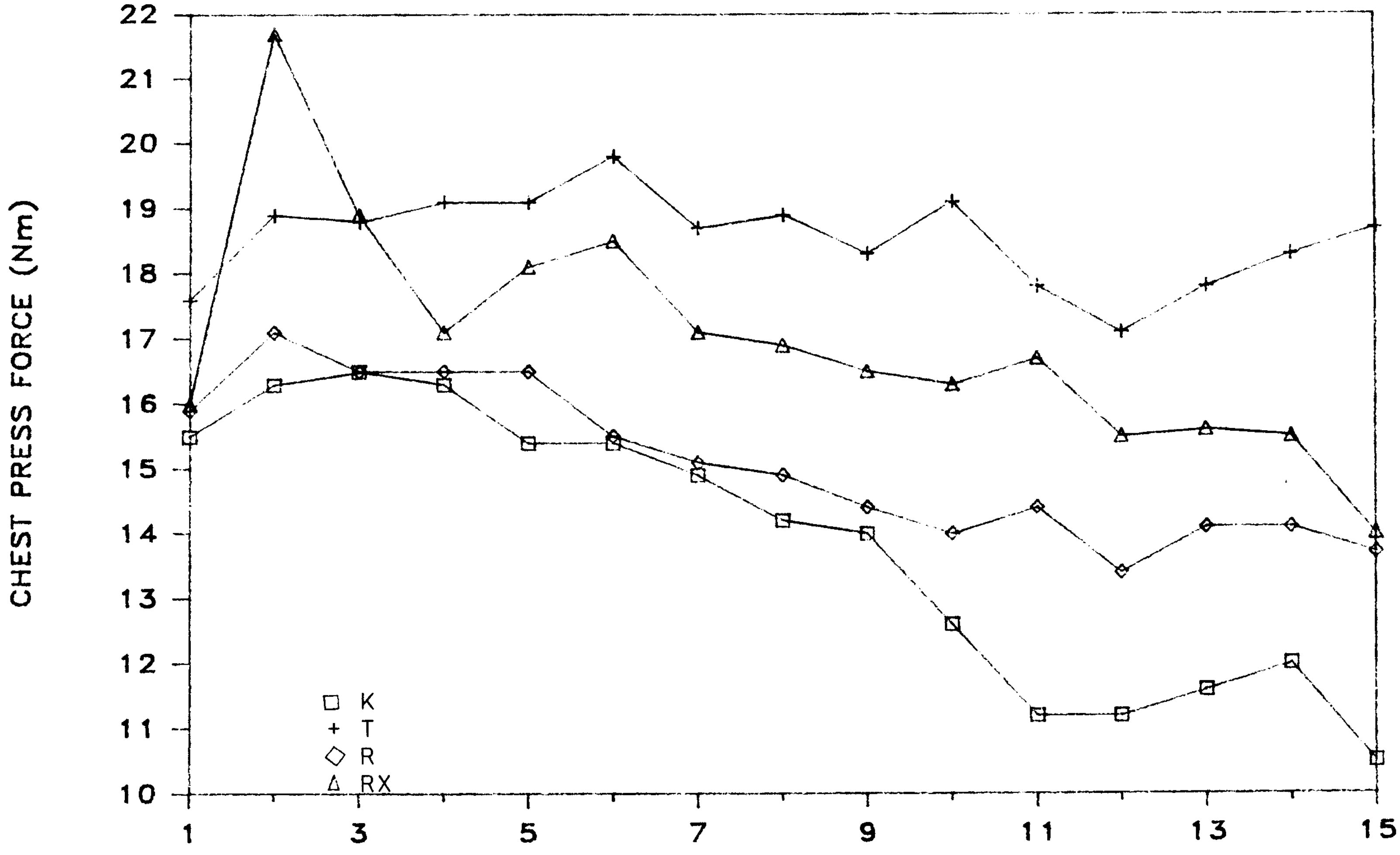
1. The recruitment of world class elite female body-builders is recommended in order to further document muscle hypertrophy/hyperplasia in females as a result of strength training.
2. The recruitment of sedentary controls is recommended in order to better assess the magnitude of difference in the body composition, muscle size and muscle strength between trained and untrained subjects.
3. A valid method must be found for determining the size of individual muscles. Perhaps computer tomagraphy would be a method that could safely and reliability perform this measurement.



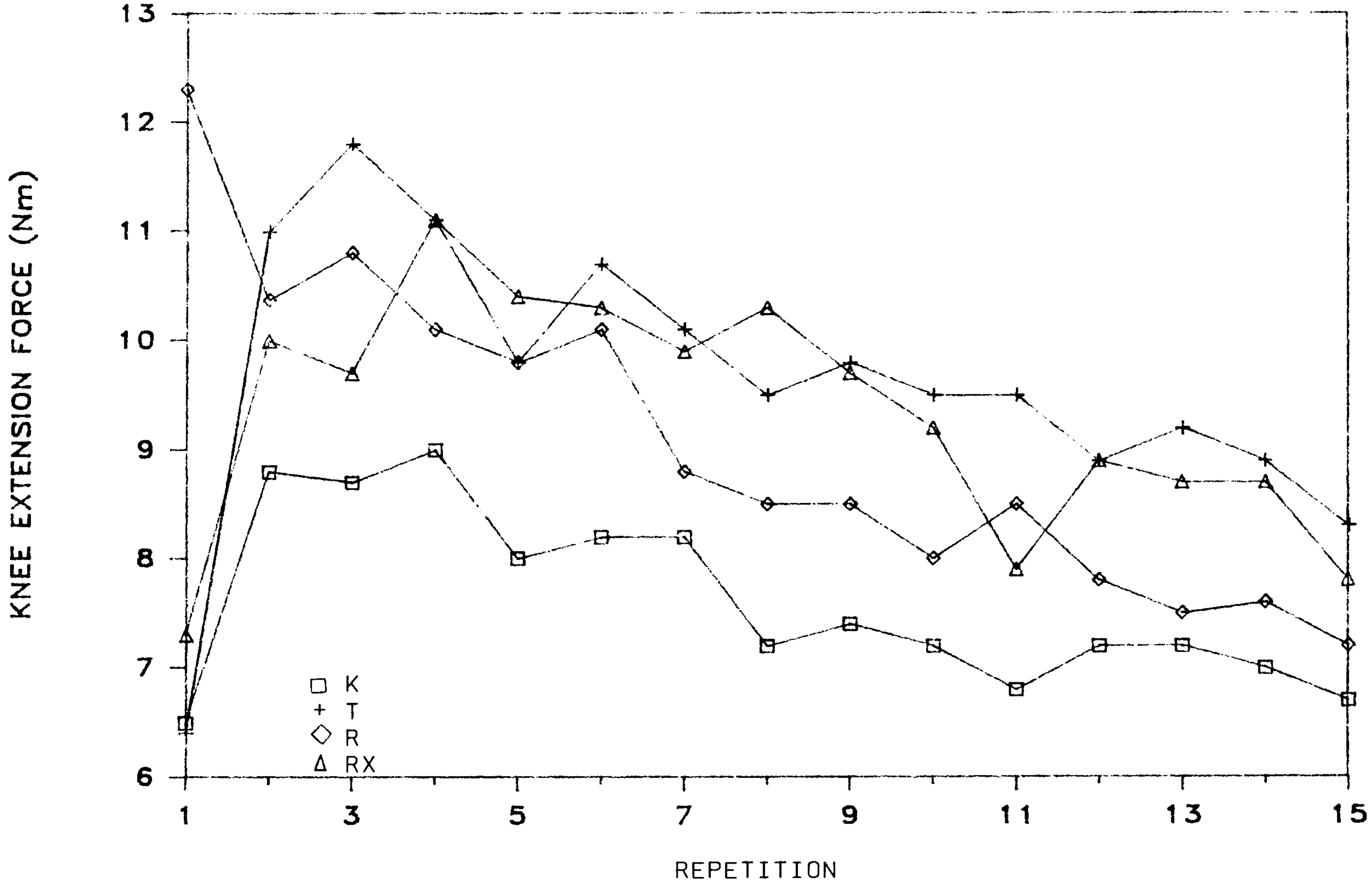
APPENDIX A--CHEST 1



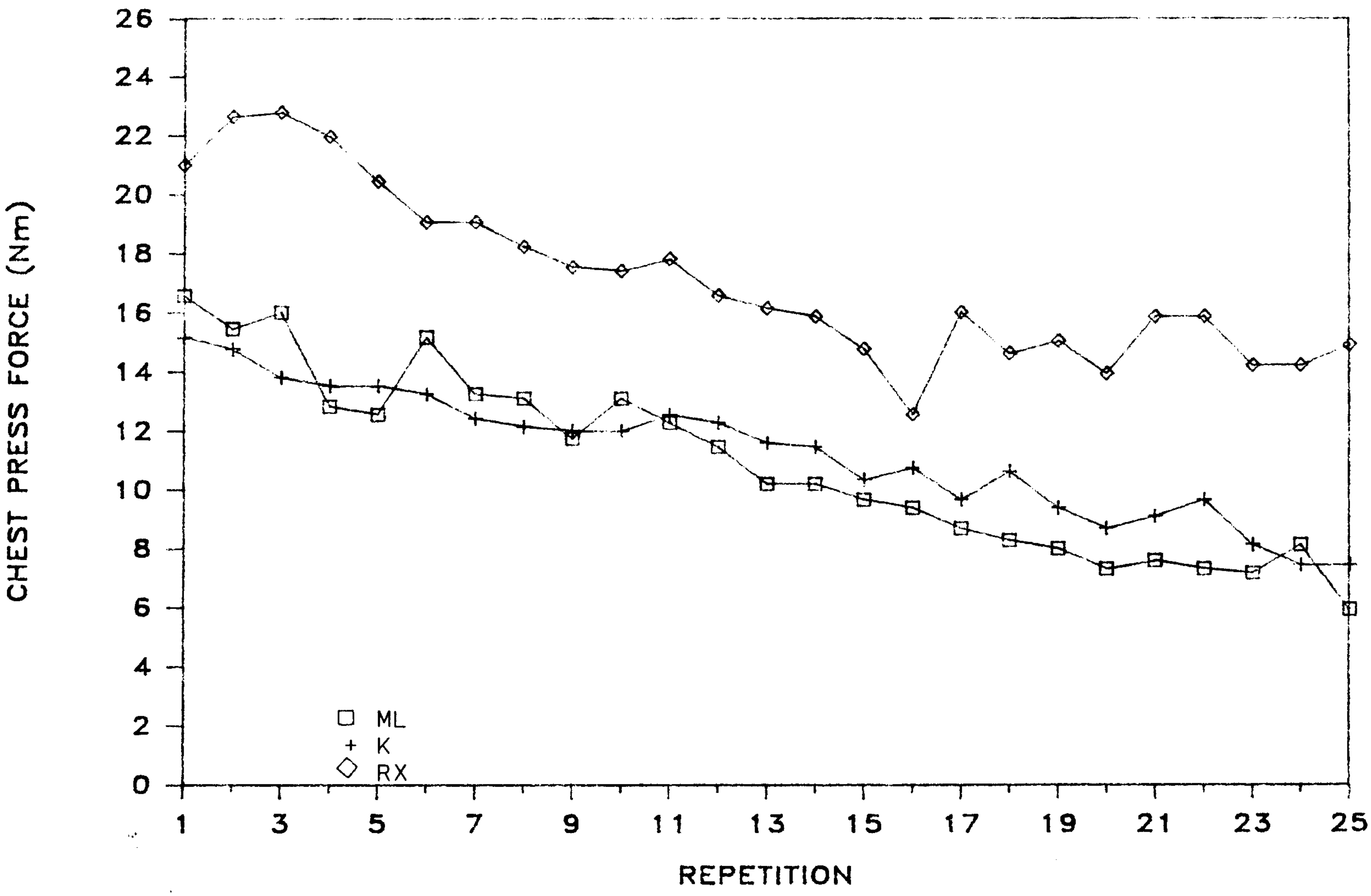
APPENDIX B--LEG 1



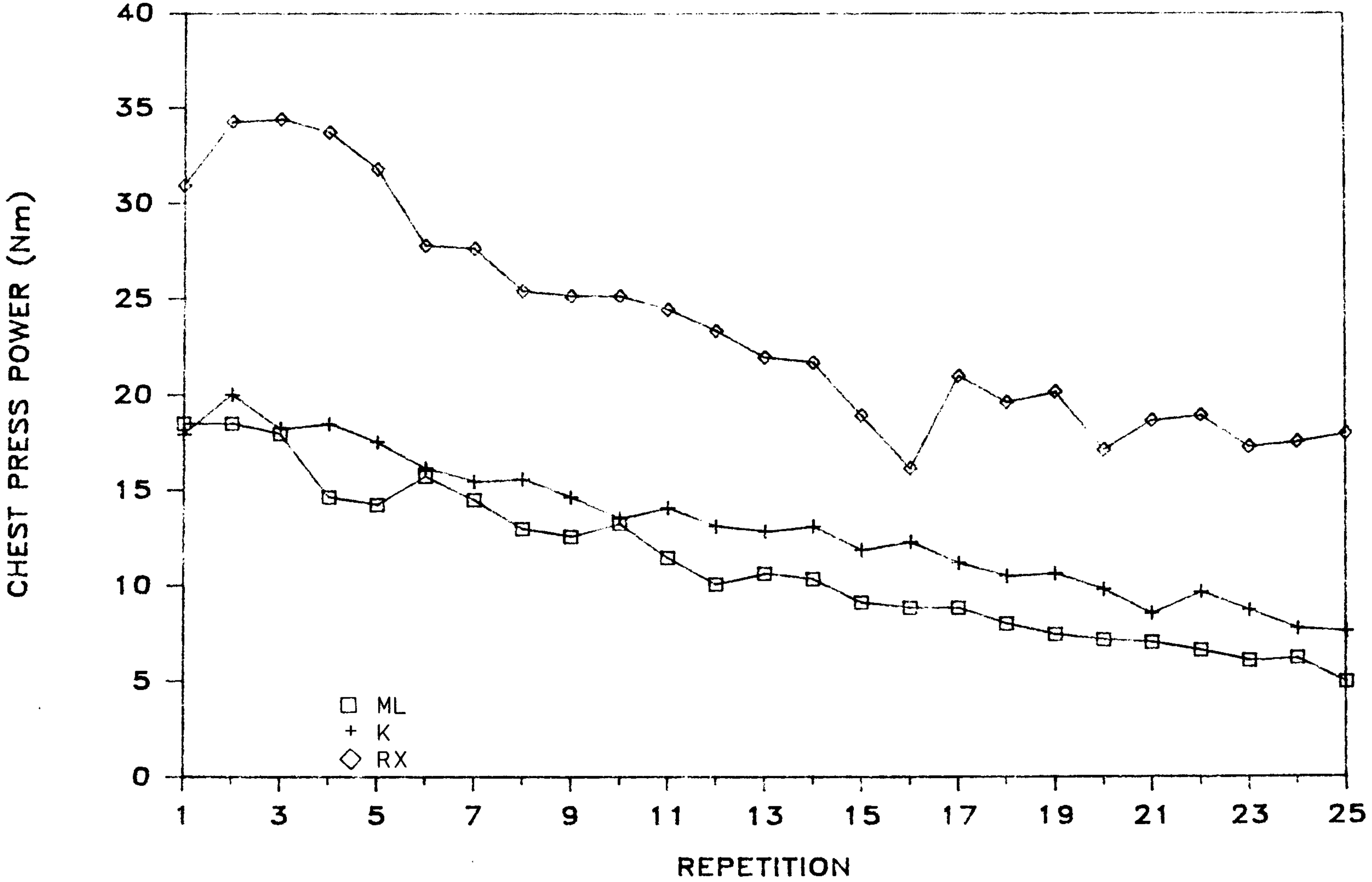
APPENDIX C--CHEST 2



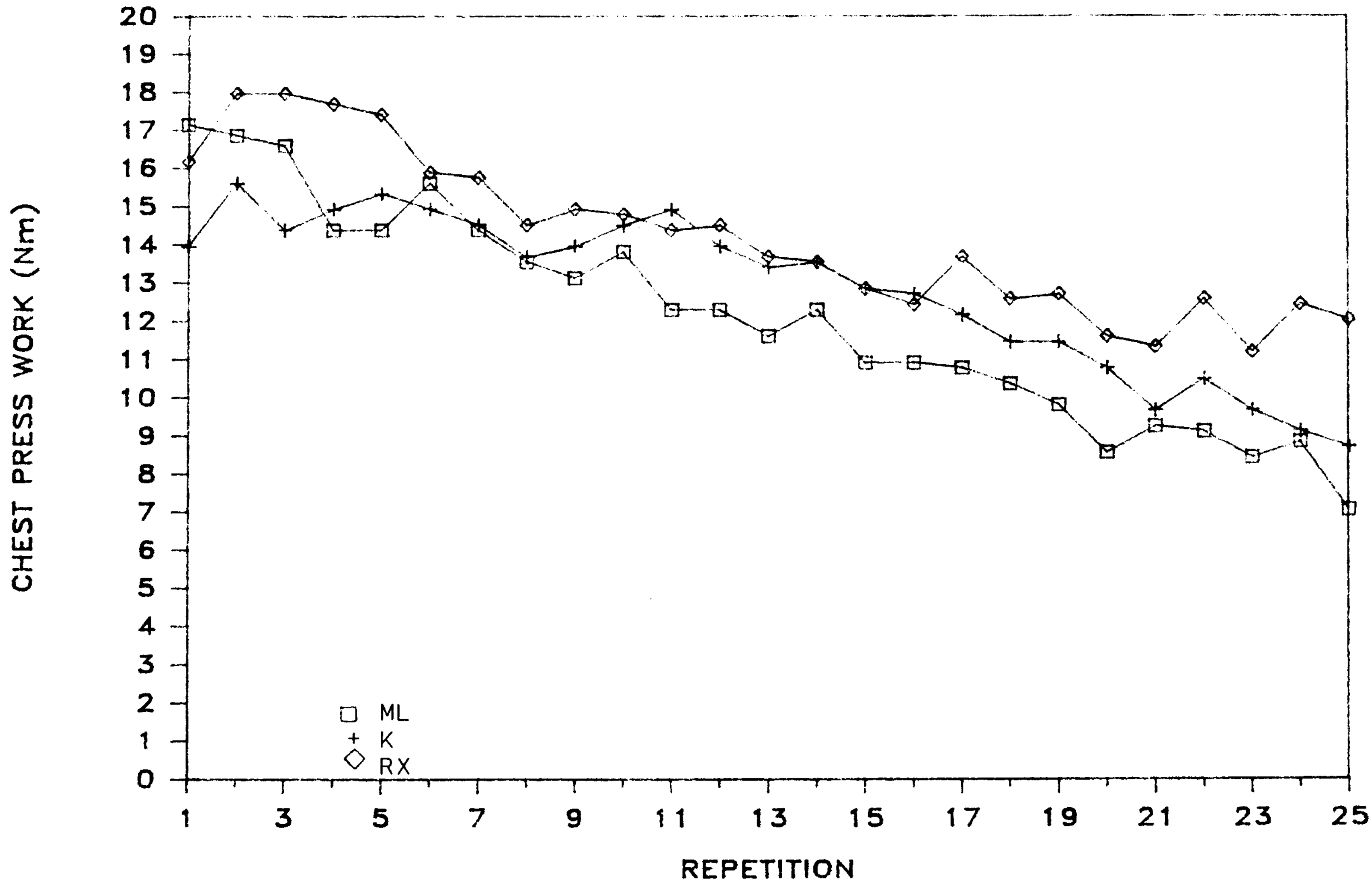
APPENDIX D--LEG 2



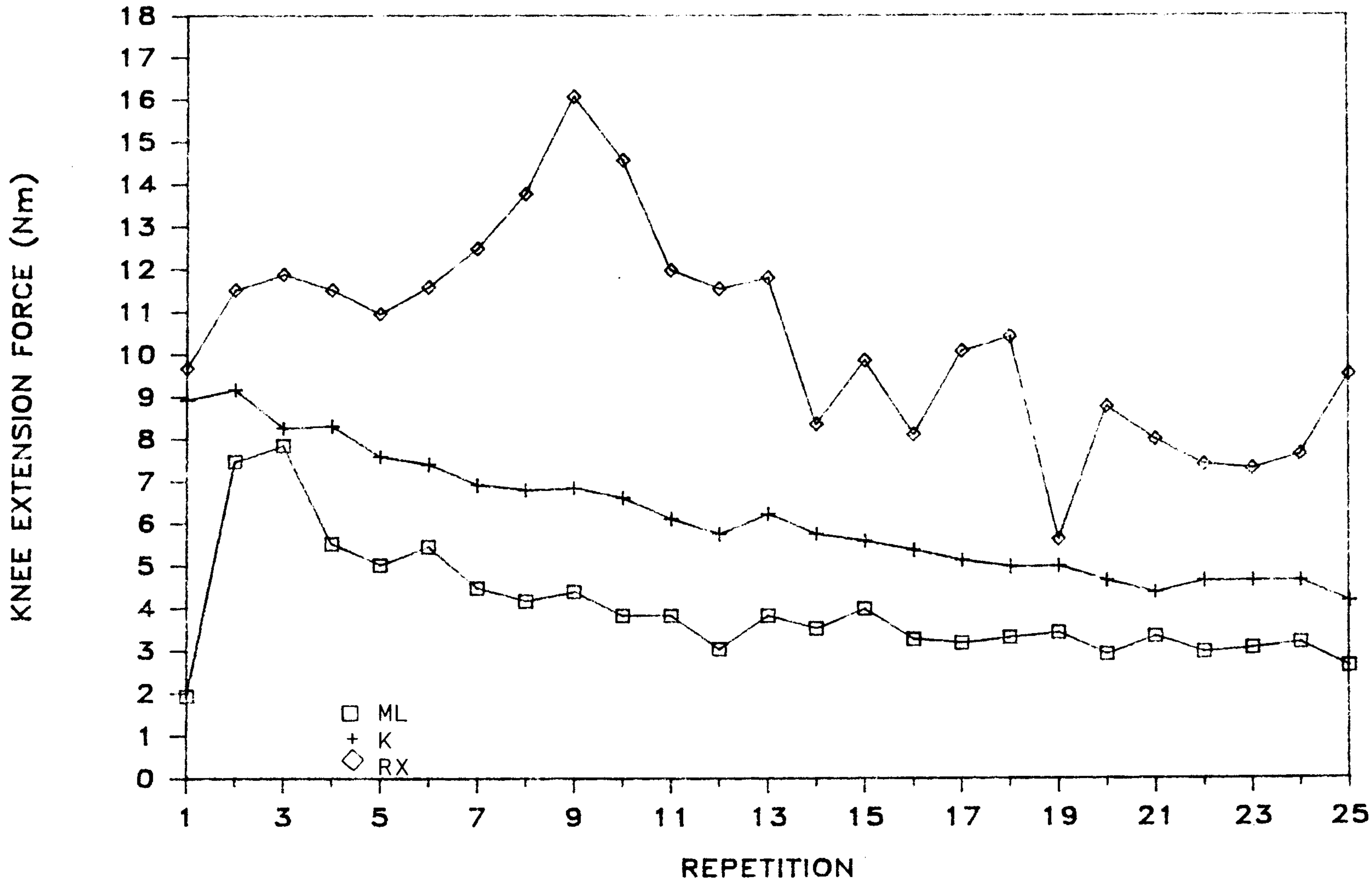
APPENDIX E--CHEST 3 FORCE



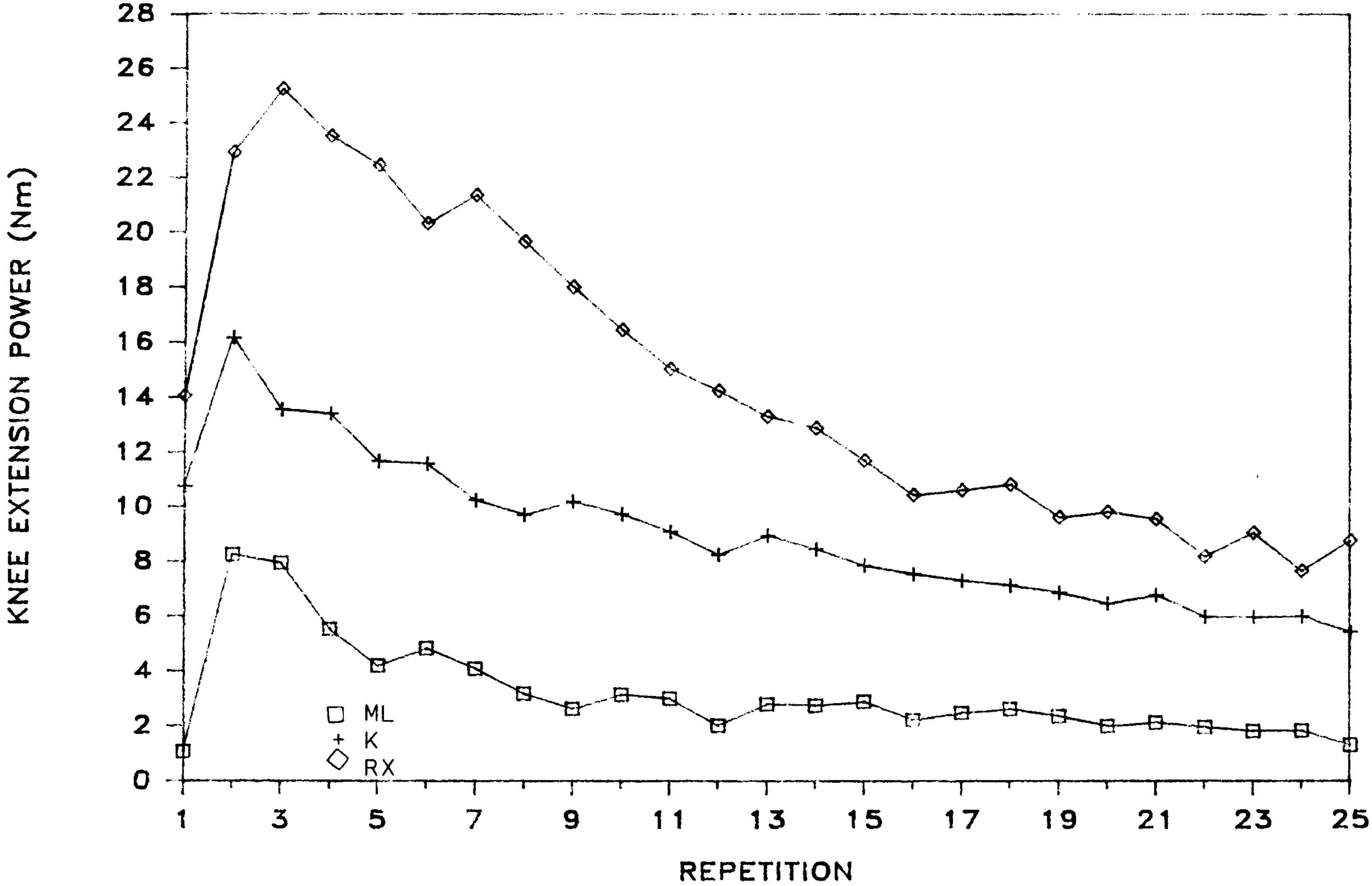
APPENDIX F--CHEST 3 POWER



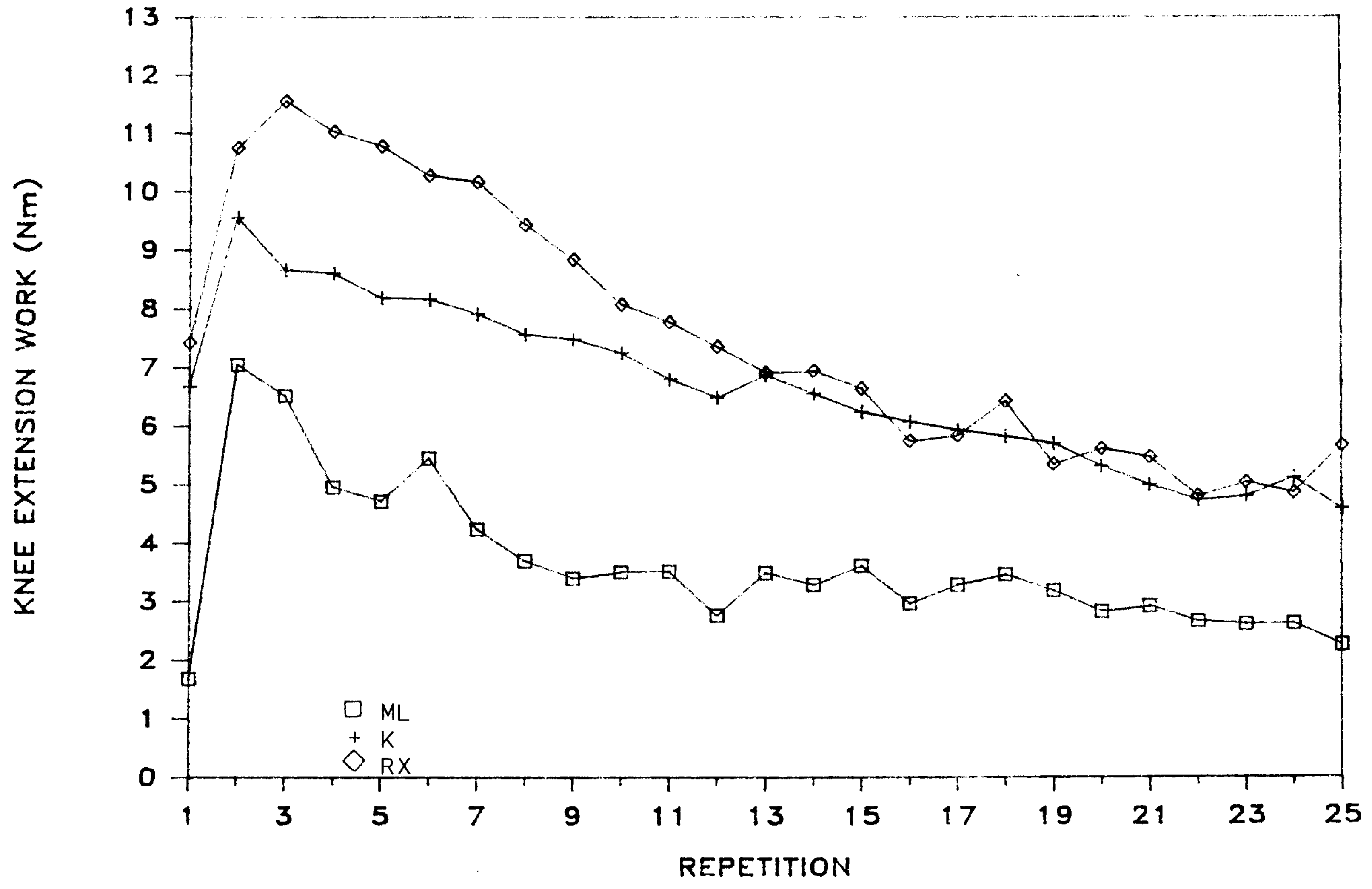
APPENDIX G--CHEST 3 WORK



APPENDIX H--LEG 3 FORCE



APPENDIX I--LEG 3 POWER



APPENDIX J--LEG 3 WORK

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