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THE UNIVERSITY OF ALBERTA

PATTERNS OF MUSCULAR FATIGUE DURING REPEATED MAXIMAL CONCENTRIC AND ECCENTRIC CONTRACTIONS.

by

© PETER NORMAN WIEBE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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FACULTY OF PHYSICAL EDUCATION

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Patterns of Muscular Fatigue During Repeated Maximal Concentric and Eccentric Contractions", submitted by Peter Norman Wiebe in partial fulfilment of the requirements for the degree of Master of Science in Physical Education.

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Supervisor

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Date..August 3rd 1976..

ABSTRACT

The purpose of this study was to investigate the patterns of muscular fatigue of the forearm flexors during concentric and eccentric repeated maximal contractions in males and females.

Twelve male and twelve female subjects participated in the study. Each subject performed repeated maximal concentric and eccentric forearm contractions through a range of 90^{o} at a constant velocity of 18^{o} per second. Contraction time was five seconds and rest interval seven seconds.

Results indicated that mean eccentric maximum force output was significantly greater than mean concentric maximum force output, by 42.19% for males and 15.06% for females. Male mean maximum muscular force was significantly greater than the female by 119.80% and 108.28% in concentric and eccentric contraction respectively.

The mean total eccentric force output was greater than the mean total concentric force output by 14.61% and 18.15% for males and females respectively. The male mean total muscular force output was significantly grater than the female by 85.00% and 79.47% in concentric and eccentric contraction respectively.

There was a large individual variation in electrical activity generated between subjects in both types of contraction. There was no significant difference between the con-

centric and eccentric electrical activity produced by males or females.

The pattern observed in both male and female concentric and eccentric fatigue was of a curvilinear nature with an initial rapid decline in force output over the first 20 contractions. During the last 100 contractions the force output tended to level out.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

It is generally agreed that walking up several flights of stairs is physiologically more exhausting than walking down the same several flights at an equivalent rate of speed. Although the actions are not identical in the physical sense (the almost identical but opposite movement to walking upstairs would be walking backwards downstairs) according to Abbott et al (2:388), the same amount of mechanical work is performed. The identical, but opposite, actions of raising oneself by pulling the body up a rope and lowering oneself by the same means at the same speed serve to illustrate the physiological difference between positive work (pulling upward - where concentric contraction is used to overcome the gravitational force) and negative work (lowering - where eccentric contraction is used to resist the gravitational force). In these instances it feels much more fatiguing to perform positive work than it does to perform negative work.

The Problem

If the physiological cost of positive work is much greater, in relative terms, than the physiological cost of negative work, it would seem logical to assume that muscular fatigue experienced subjectively and observed from recorded data would become evident much sooner by performing positive work, thus leading to a cessation of activity, than would be experienced by performing an equivalent amount of negative work. Furthermore, it is possible that more mechanical work can be accomplished eccentrically than concentrically.

Sub-problems

A number of sub-problems arising from the main problem were investigated:

1. The difference between the maximum concentric force and maximum eccentric force produced by each subject.
2. The difference in the rate of decline in force output between concentric and eccentric contraction.
3. The difference between the total concentric force output and the total eccentric force output.
4. The difference between the total concentric integrated electrical activity (IEMG) and the total eccentric IEMG.
5. Male and female differences for the above measurements.

Definition of Terms

For the purpose of the study the following definitions apply:

CONTRACTION: The active process within a muscle for generating force.

CONCENTRIC CONTRACTION: A contraction in which the muscle shortens.

ECCENTRIC CONTRACTION: A contraction in which the muscle lengthens due to an external force.

POSITIVE WORK: The work performed when a muscle contracts concentrically.

NEGATIVE WORK: The work performed when a muscle contracts eccentrically.

FATIGUE: The decrease in the physical capacity of a muscle to perform work.

ELECTROMYOGRAPHY: Recording of the changes in electrical potential of a muscle by means of surface electrodes.

SURFACE ELECTRODES: Silver discs, connected to an amplifier, that are placed on the surface of the skin for the purpose of recording muscle action potentials.

INTEGRATED ELECTRICAL ACTIVITY: A quantification of the area under the curves of electrical activity recorded by the surface electrodes.

FORCE OUTPUT: The torque produced by the forearm flexors measured in kilogram-metres.

TOTAL FORCE: The addition of the maximum torque exerted throughout the range of motion for each contraction.

Limitations of the Study

1. The study was limited to the analysis of muscular tension and IEMG within the muscle.
2. The daily activities of the subjects were not controlled.
3. The range of movement was limited to 90° between angles of 56° and 146°.
4. The angular velocity was limited to 18° per second.
5. Only the right arm of each subject was used.
6. The motivation was limited to asking for a maximum effort in performing each contraction, once only at the beginning of the testing session.

Delimitations of the Study

1. Surface electrodes were used to record electrical activity.

CHAPTER II

REVIEW OF THE LITERATURE

Muscle Contraction and Human Movement

In everyday human movement some skeletal muscles shorten (concentric contraction) and others lengthen in eccentric contraction. In lowering a heavy weight, the lengthening is forceful although in many other movements this is not so. When a muscle shortens with force, it is regarded as having produced work. When a muscle lengthens with force, it is regarded as having absorbed work (4, 12, 30, 46).

Comparisons between the two types of contraction have been made a number of ways.

Thermodynamic Comparison

In order to perform mechanical work against a load, a muscle shortens obtaining energy from chemical reactions. According to Hill (30), the energy liberated by a muscle can be measured as work and heat. In changing its state from one of rest to one of activity, the muscle produces 'heat of activation' which Hill (30:898) designates 'A'. Maintaining the activity requires the heat of activation to continue as heat of 'maintenance'.

Regardless of the work performed, for a simple, specific amount of shortening, there is a proportional amount of extra heat liberated. So if 'a' is a constant related to the maximum strength of the muscle, 'x' the amount of shortening that occurs and 'W' the amount of mechanical work produced, Hill's equation for total energy released by the muscle appears as:

$$\text{Total energy released} = A + ax + W \quad (30{:}898)$$

He goes on to say that the greatest mechanical output would be when $\frac{A+ax}{W}$ was as small as possible. In other words, when the heat energy expended divided by the mechanical work accomplished was as small as possible.

If, on the other hand, the muscle in attempting to contract and shorten, is lengthened (eccentric contraction), it resists the stretch very strongly. When measuring the heat remaining in the muscle at the end of the contraction, Hill (30:899) discovered that it was no greater than the work put into it.

> The muscle itself apparently had produced no heat at all of its own, although it had resisted the stretch very strongly (30:899).

It thus appears obvious that with the much restricted liberation of heat in eccentric contraction, the mechanical output so produced would be much greater than that for concentric contraction.

Apparent Absorption of Heat in Eccentric Contraction

If a relaxed muscle is stretched, all the work is turned into heat. If we suppose that the same thing happens when an actively contracting muscle is stretched then, when measuring the energy of the muscle performing eccentric contraction, the muscle appears to have produced much less heat than it would have done if it had not been stretched at all. The muscle appears to have absorbed much of the work done in the stretch (4, 3, 46).

In an attempt to explain this phenomenon in terms of heat of shortening, Abbott et al (2) coined the term 'negative heat of lengthening', when investigating the apparent disappearance of work and reversal of heat of shortening in slow muscle stretches.

In 1960, Hill (30) showed that muscle has a coefficient of thermal expansion similar to that of ebonite. Although incorrectly stated by Rasch (49:78), it seems as though a physical parallel can be drawn between the stretching of a muscle with absorption of heat and the fact that when a wire is stretched, the temperature falls during the stretch and rises when it is released (30, 46).

The observation that the muscle when stretched appears to produce no heat of its own has lead to the supposition that the chemical reactions which produce heat in the muscle when shortening under load are reversed when resisting lengthening (2, 7, 30, 49).

Muscle Tension and Motor Unit Recruitment

The force of voluntary muscular contraction can be increased in two ways: (a) an increase in the number of active motor units (or recruitment) or (b) an increase in the rate of discharge of the motor units already firing (or frequency of discharge) (5). According to Vander et al (56:209), total tension development in a muscle depends on the number of muscle fibres contracting at a given time and the amount of tension that can be developed by each contracting fibre. Thus, the total number of activated motor units (recruitment) will determine the total tension that the muscle develops.

From their investigations with human subjects, Henneman et al (28) were unable to show variety in the recruitment pattern of voluntarily activated motor units: the first easily recruited motor unit could not be made to stop firing while those recruited later than the first continued to discharge. However, Grimby & Hannerz (24) did observe changes in the recruitment order depending on the speed of movement.

The results reported by Milner-Brown et al (45) indicated an orderly recruitment of motor units during increasing voluntary muscular contraction which is related to the size of the contraction they produce (28, 48). The first motor units recruited in tonic activity appeared to be resistant to fatigue (24).

When increasing the force of voluntary contraction at low levels of force, recruitment is the major mechanism. Only at intermediate force levels does the increase in frequency become the more important mechanism. Throughout the whole physiological range though, frequency of firing is the major contributer to increased force (45). Furthermore, the rapid decline in recruitment of motor units with larger twitch tensions or higher thresholds as the force was increased was noted. It was concluded that recruitment accounted for less and less of the increase in force at high force levels. However, Granit (23) and Grillner & Udo (25) emphasized recruitment as a major mechanism of muscular force increase. Grillner & Udo (25) did go on to point out that if during maximal voluntary effort all the motor units in a muscle could be activated, then the only way the force could be further increased would be by increasing the firing rate of the active motor units.

In 1965, Henneman et al (29) working with decerebate cats found that by the time the tension generated in stretching the soleus muscle had reached 50% of its final value, already 90% of the available motor units had been recruited. As well, it appeared that no more motor units were recruited beyond 75% of the final tension indicating that any further increases in tension must have been produced by increased frequency of discharge. The extra force encountered was attributed to stiffness resulting from the stretching of contracting muscle.

<u>Comparison of Fibre Utilization and Muscular Tension</u>

Since the force exerted by a muscle when it is stretched appears to be much greater than the force exerted by the same muscle when shortening at the same speed (2, 20, 53), a smaller number of fibres, it would seem, would be needed for the lesser force output (concentric contraction). However, a smaller number of fibres can be used eccentrically to produce a given concentric force. If the tension exerted by a muscle to produce an isometric contraction is thought of as the product of the number of fibres activated and the frequency of stimulation of those fibres, then to perform a concentric contraction in which the number of fibres and their frequency of stimulation will be less than in the isometric position, concentric contraction of muscle will require a greater tension (2) hence more muscle fibres and the corresponding recruitment of more motor units. Looking at it another way, it could be stated that the muscle resists stretch with a greater tension than that required for an isometric contraction under the same conditions (49:78).

Comparing concentric, isometric and eccentric strength, using isometric strength as a criterion:

(a) Asmussen et al (6) found that maximal concentric force was only 75 - 80% that of isometric force whereas eccentric strength at the same velocity was 125 - 130% that of isometric.

(b) Doss & Karpovich (20), investigating the elbow flexors, found that maximum concentric force was only 77% that of isometric force whereas eccentric strength was 113.5% that of isometric.

(c) Olsen et al (48) investigating the hip abductor muscles found examples where concentric force was only 70% that of isometric force whereas eccentric strength was 130% that of isometric.

In 1966, Singh & Karpovich (53) reported greater eccentric force when compared to concentric force of the elbow flexors (32.65%) and similarly for the elbow extensors (14.22%).

Elastic Component of Muscle

Within the muscle there appears to be a contractile component and a non-contractile component. Guyton (27:87) suggested that the non-contractile component included the tendons, the sarcolemmal ends of the muscle fibres where the tendonous attachments occur and possibly the membranes of the myofibrils themselves. Close (15:138) divided the non-contractile component into: (a) a lightly damped series elastic component and (b) a parallel elastic component. Hill (30:898) thought that part of the series elastic component may reside in the contractile component itself. Close (15) went on to explain that when a muscle is allowed to shorten freely after an isometric contraction against a load that is less than the isometric tension, there was an initial rapid movement which was completed within a few milliseconds. After this rapid release of energy stored in the elastic component of the muscle, a slower second phase of movement is attributable to the shortening of the contractile component. Hill (31 and 32) and Wilkie (59) showed the same kind of results from the experiments they did using the frog sartorius muscle. To make up for the stretch in the elastic elements, the muscle was estimated to have to shorten an extra 3 - 5% (27:87).

In comparing the isometric and isotonic twitch characteristics in the same muscle cell, Vander et al

(56:204) noted that the latent period (following excitation) is considerably longer in the isotonic twitch. Furthermore, as the load increases so does the latent period. But, the velocity of shortening, duration of the isotonic twitch and the distance shortened all decrease. The point was made that only when tetanus occurs is the active state (tension produced internally by the muscle proteins) held long enough to completely stretch the series elastic component so that the tension produced is equal to that of the active state.

> The heavier the load the longer it takes to develop the amount of stretching of the series elastic element required to lift the load and thus the longer the latent period (56:208).

If a muscle is stretched during contraction a large part of the work done on it does not appear as heat or as elastic mechanical energy. However, the muscle strongly resists the stretch, the tension rising to a high value.

Oxygen Consumption Comparison

From a purely mechanical point of view, most authorities agree that whether moving the body upward or downward, the force required to overcome, in one instance, or resist, in the other, the gravitational pull, is also equal. Apart from the empirical evidence that it is much more fatiguing to perform positive work than it is to perform negative work, when Abbott et al (2) required one subject to resist the forward pedalling motion of another on coupled ergocycles, they found that 3.7 times more oxygen was consumed by the subject pedalling forward at 35 revolutions per minute (concentrically) than was consumed by the subject resisting (eccentrically). In other experiments involving walking on a motor-driven treadmill (16) and bicycle riding on a motor-driven treadmill (7) it appears evident that eccentric muscular contraction is by far the cheapest way of doing work. If the velocity of shortening of a muscle producing a constant force is increased, the consumption of oxygen increases rapidly. If, on the other hand, the velocity of lengthening of a muscle producing the same constant force is increased the consumption of oxygen remains approximately the same (1, 2).

Electromyographical Comparison

Since it may be reasoned that the number of muscle fibres recruited and their frequency of discharge determine the tension in a muscle, an indication of the tension so produced may be obtained by integrating the electrical potentials set up by the motor units. The integration gives a relative expression of the number of muscle fibres active in a given situation and can be used as an optional measure of muscle activity (49:78, 57). In voluntary, human, isometric muscular contractions, the results of different experiments are not wholly in agreement even though the investigations were performed under similar conditions. The linear relationship between IEMG and force (9, 19, 21, 33, 50, 54) has been found to be more than linear (curvilinear) by other investigators (11, 36, 38, 40, 43, 61). From their investigations, using surface EMG with the electrodes located over the biceps brachii, Vredenbregt & Rau (57), obtained a more than linear (curvilinear) increase with increasing force at the wrist. It should be noted that this EMG/force relationship involves the brachialis and brachioradialis as well as the biceps brachii and what is recorded is really a group of active muscles referred to as a 'muscle equivalent' by Bouisset (10). Surface electrode information from a triceps location also indicated a non-linear relationship which varied at different angles (57:612).

<u>Fatigue</u>

Fatigue is a very complex phenomenon which may be investigated from many different aspects. Muscular fatigue is evidenced by the decreasing force output from the muscle both in concentric and eccentric contraction over an extended period of time. If the force a muscle exerts is held for a long period of time, muscular fatigue occurs.

There is an increase in electrical activity when constant force is maintained which is apparently due to the recruitment of additional motor units in order to keep the force output at the desired value (9, 19, 21, 40, 50).

The internal torque generated within a muscle in response to the torque of an external force in dynamic movement is produced by the motor unit activity within the muscle. It depends on (a) the length of the active muscle fibres and (b) on the lever length of the muscle force (47). The point is made that in isometric contractions it is easy to control important variables like external force and joint angle but in dynamic movements these variables cannot be controlled. The maximum torque produced by a particular muscle group tends to vary at different joint angles (14, 20, 53, 60).

When comparing concentric and eccentric contractions the EMG activity is greater when the muscle is shortening than when it is lengthening under the same load at the same velocity (8, 9). On the other hand, when Komi (37) investigated the relationship between tension, EMG and velocity of contraction under concentric and eccentric conditions, he could not obtain clear differences in the relationship between IEMG and tension at any type or velocity of contraction when the muscle tension was expressed in percent of maximum voluntary contraction (MVC).

The Use of Muscle Elasticity in Exercise

Thys (55) measured vertical acceleration of extension from the flexed position in deep knee bends under two conditions: (a) where the extension followed immediately after bending and (b) where the extension followed after allowing time for the extensors to relax. He found that under condition (a), extension speed, mean power and mechanical efficiency were greater and consequently the time required for the positive work was less. He interpreted this as evidence that when a muscle is stretched (eccentric phase of an exercise) potential energy is stored in the elastic component which is used to assist in the performance of the positive phase of the work. Investigating the isolated frog gastrocnemius muscle, Cavagna (12) came to a similar conclusion.

Concentric and Eccentric Strength Training

When using bench press (concentric) and bench repress (eccentric) movement as well as knee flexion-extension movement as a training procedure with ten repetitions each training session three times a week for eight weeks, Johnson (34) found significant increases in strength from both concentric and eccentric training but no significant difference between the two contraction types. Even the week to week strength changes between the two types were not essentially different. Each Friday a one repetition maximum established the training resistance for the following week. Strength measures, using this method, at the beginning and end of the training period showed a significant mean increase for both eccentric and concentric strength but neither procedure was found to be superior to the other. Similar findings were reported by other investigators. Logan (42) using a leg press machine with thirty repetitions every other day for a period of seven weeks, Seliger (51) with squat and bench press exercise in sessions of two hours twice a week for thirteen weeks and Mannheimer (44) concerned with the triceps and using two sets of five repetitions five days per week for six weeks are notable examples.

Komi & Buskirk (38) using an electric dynamometer to train the forearm flexors with six maximal contractions four times a week for seven weeks reported that eccentric training increased muscular strength more than did concentric training. When investigating the effect of eccentric training of agonists on antagonistic muscles, Singh & Karpovich reported percentwise, practically twice as much effect on concentric as on eccentric strength. Their training procedure involved twenty maximal eccentric contractions four times a week for eight weeks.

CHAPTER III

METHODS AND PROCEDURE

Subjects

Subjects for the study volunteered from the Faculty of Physical Education. Each subject was required to report three times. The first visit was for familiarization purposes and included recording name, age, sex, height, weight, relaxed upper arm girth (with the arm hanging at the side), hand dominance and forearm length. The forearm length was recorded as the distance measured from the lateral epicondyle of the humerus to the end of the radius. Two later appointments were arranged at this time. During these appointments the subjects were required to perform repeated concentric (and eccentric) maximum voluntary contractions (MVCs).

Three criteria were used to terminate the experiment:

(a) The subject reached 25% of his initial maximum force output. (The initial maximum force output was taken as the greatest output of the first three contractions). This was controlled by the investigator.

(b) The subject reached 200 contractions. This was controlled by the investigator.

(c) Excessive distress of any kind suffered during the testing period that caused the subject to request termination of the experiment.

There was random assignment of the type of contraction to be performed on the first visit. Thus, half of the male subjects and half of the female subjects would perform concentric contraction on the first visit and the remaining subjects (male and female) would perform eccentric contraction on the first visit.

Not less than one seven-day week was required to elapse between visits to allow for restoration to the pre-test physiological state.

Experimental Equipment

Electric Dynamometer : The testing instrument was an electrically operated dynamometer which consisted of an isokinetic lever arm with the angular velocity set at 18° per second. The isokinetic property of the lever arm was maintained by means of a gear reduction box which absorbed the force applied sufficiently to prevent acceleration of the arm. The force applied by a subject to the arm was sensed by a strain gauge installed in the lever arm. The strain gauge changed the capacitance of an electric circuit which was then amplified to drive a mirror galvanometer.

Visicorder : Mirror galvanometers, incorporated in the Honeywell visicorder, produced deflections on light sensitive paper. Thus EMG waves, force output curves and integrated electrical potential were able to be recorded.

Integrator : The EMG potentials were fed into an electrically operated integrator with full wave rectification. From the variables of amplitude, frequency and spike shape, the integrator was able to produce an arbitrary, quantitative figure (denoted as IEMG in the study).

Electrodes : Electrical potentials in the muscle were sensed by means of silver disc surface electrodes with adhesive collars. Saline 'electrode jelly' was used to improve electrical contact.

Experimental Procedure

Each subject was required to perform on each occasion either repeated voluntary maximum concentric muscular contractions or repeated voluntary maximum eccentric muscular contractions striving for the maximum isokinetic force of the forearm flexors through a 90° range of motion from 56° to 146°. The angular velocity was set at 18° per second. For both types of contraction the muscles were allowed to relax while the lever arm was returning to the starting position. Placement of the electrodes on the biceps was standardized.

Testing Procedure

Upon entering the lab each subject was re-familiarized with the requirements and techniques of the recording procedure.

To standardize the placement of the surface electrodes on the belly of the biceps brachii the ground electrode was located one third of the way along a line extending from where the tendon of the biceps brachii enters the cubital fossa to the palpated greater tubercle of the humerus. The two remaining electrodes were placed along the same axis with a distance of four centimeters between the centres of the electrode discs. Before the electrodes were attached the skin above the muscle belly was cleansed and abraided to allow for facilitated electrical conductance of the myoelectrical impulse to the amplifier. The subject was secured to the seat by a belt around the waist and, in addition, a strap was placed around the left shoulder to restrict synergistic compensation as fatigue progressed. Stabilizing pads were adjusted over the shoulders to provide kinesthetic feedback to further restrict synergistic compensation. The subject was requested to sit tall and look straight ahead where a mark had been constructed from thumb tacks pressed into a board. Background music from a radio supplied pleasant sounds in an attempt to relieve any repetition boredom.

PLATE I: ELECTRODE PLACEMENT ON MALE SUBJECT

PLATE II: ELECTRODE PLACEMENT ON FEMALE SUBJECT

Placement of the elbow on the elbow pad was done in such a way that the olecranon process of the ulna was not supported on the elbow pad in an attempt to eliminate any tendency to use the pad as a lever. The shoulders of the subject were horizontally set by raising or lowering the seat. The lateral epicondyle of the right humerus was aligned directly opposite the axis of rotation of the lever arm. A wrist pad, with which the subject would exert force on the lever arm, was adjusted to the proximal end of the wrist. These adjustments were made for each subject. The wrist was taped to the pad to avoid inadvertant movement either toward or away from the axis of rotation of the lever arm as fatigue progressed. The feet were placed comfortably on a flat board to minimise any attempt to use leverage from the muscles of the legs.

The subject was requested to begin contraction immediately after the twelve second automatic reset signal on the integrator.

Any subject indicating muscle soreness between 24 and 48 hours after testing was advised of DeVries' static stretching method of relief (17:306). After the eccentric exercise some subjects had ice placed on the biceps brachii for a period of fifteen minutes.

PLATE III: A MALE SUBJECT PERFORMING CONTRACTION

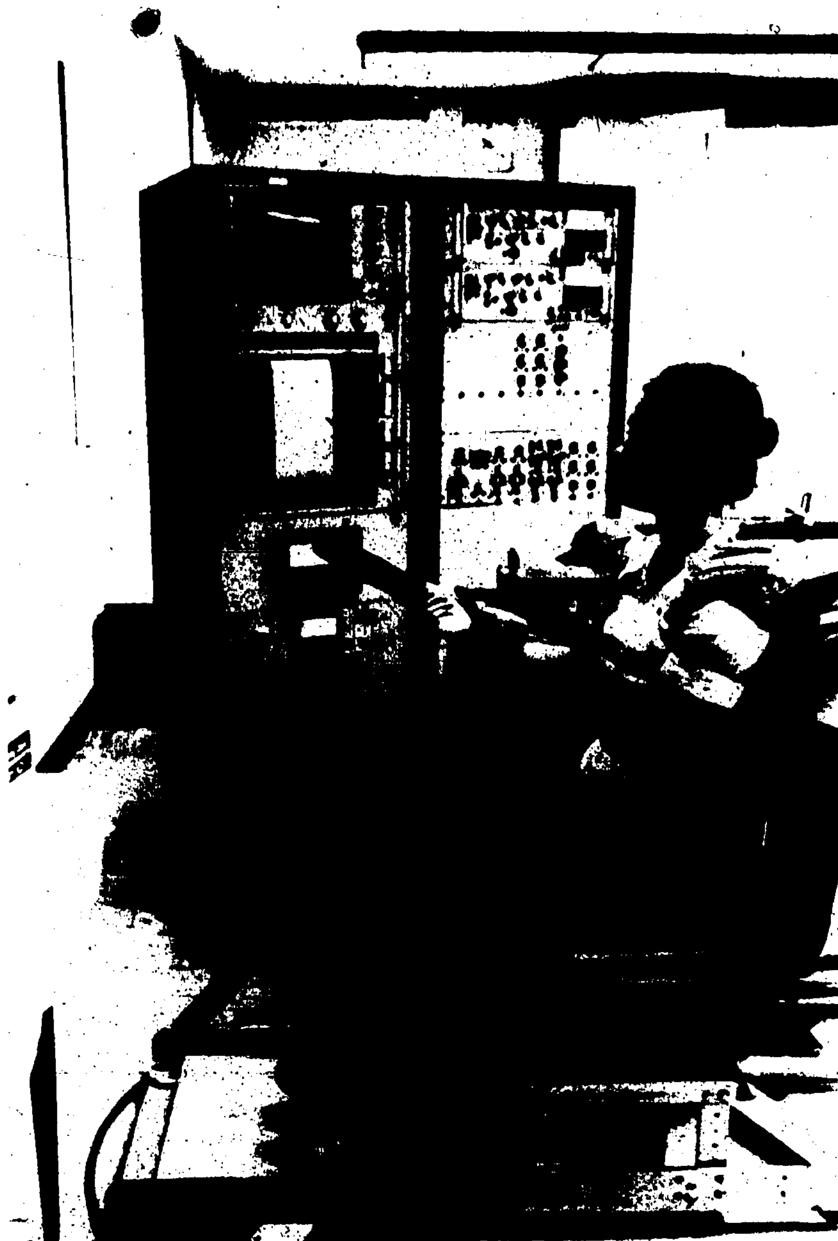

PLATE IV: A FEMALE SUBJECT PERFORMING CONTRACTION

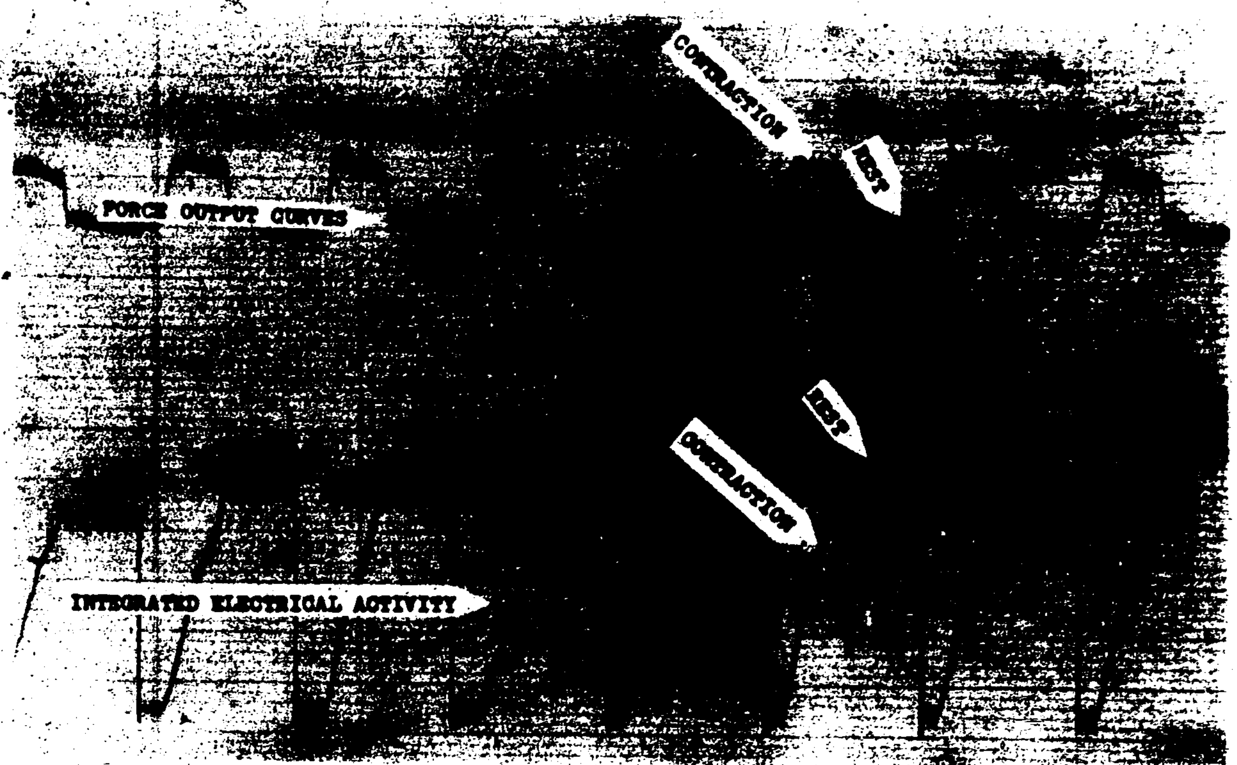

PLATE V: EXAMPLE OF RECORDED DATA

Motivation

The dramatic effect of motivation is recognized and in an attempt to standardize motivation for all subjects a request for maximal effort in performing each contraction was made during the familiarization visit and called for once only before the testing began. No other motivational procedure was used. Only the investigator and the subject were present during the experiment. Any significant comments were recorded as the experiment progressed.

Calibration of the Apparatus

The output from the force transducers on the lever arm was calibrated using known weights (in pounds) placed twelve inches from the axis of rotation of the lever arm. Conversion to the metric system was later made. Output from the integrator was calibrated by setting the automatic reset control each ten units from ten to one hundred microamperes and recording electrical potential to each of these limits. In both cases galvanometer deflections were noted and a relationship calculated using the grid lines on the light sensitive recording paper. One subject performed ten MVCs, waited for thirty minutes and performed another ten MVCs. A correlation coefficient of 0.85 was obtained between the recordings. Thus it appeared safe to assume that any significant changes in the data records of subjects under experimental conditions were due to physiological phenomena and not the apparatus.

Statistical Treatment

The following is a list of variables that were involved in the experimentation:

(a) type of contraction

(b) time (or number of the contraction performed)

(c) force output

(d) IEMG

(e) Sex of subjects

(f) range of motion

(g) angular velocity.

From the above list, (f) range of motion and (g) angular velocity were held constant throughout the experiment.

Repeated measures for each contraction type were recorded. The quantification of the maximum force produced throughout the range of motion for each contraction by each subject was recorded. The IEMG was also quantified and recorded for each contraction by each subject. Significant differences were investigated in the following manner:

(a) Maximum concentric force output versus maximum eccentric force output for males and females.

(b) Mean total concentric force output versus mean total eccentric force output for males and females.

(c) Mean for each concentric contraction versus mean for each eccentric contraction for males and females to determine at what time significant difference between the two contraction types ended.

(d) Mean percentage decline in force output at specified intervals in concentric versus eccentric contraction for males and females. The greatest force output of the first three contractions was taken as 100% and each contraction thereafter was measured as a percentage of the greatest force output.

(e) Concentric IEMG versus eccentric IEMG for males and females.

(f) Mean male concentric maximum force output versus mean female concentric maximum force output.

(g) Mean male eccentric maximum force output versus mean female eccentric maximum force output.

(h) Mean total male concentric force output versus mean total female concentric force output.

(i) Mean total male eccentric force output versus mean total female eccentric force output.

(j) Mean total male concentric IEMG versus mean total female concentric IEMG.

(k) Mean total male eccentric IEMG versus mean total female eccentric IEMG.

CHAPTER IV

RESULTS AND DISCUSSION

Subject Data

Statistics for the variables of age, height, weight, relaxed upper arm girth and forearm length (see Appendix A for raw data) as presented in Tables I and II were analysed for significant differences between males and females. With the exception of age, all variables were significantly different at the .01 level between the sexes (see Table III). Twenty-six male and female subjects began the study. Due to muscle soreness from the eccentric type one male and one female subject failed to complete the concentric phase of the experiment and the final analysis was conducted on twelve male and twelve female subjects.

Maximum Concentric and Eccentric Force Output

The maximum force (torque) exerted was taken as the greatest force output of the first three MVCs for each subject both concentrically and eccentrically. These values (see Appendix B) were submitted for a t test analysis. The maximum eccentric force output for males was significantly greater at the .01 level than the maximum concentric force output in a one-tailed test (see Table IV). A similar result showed the female maximum eccentric

TABLE I

MEAN, STANDARD DEVIATION AND RANGE OF AGE, HEIGHT WEIGHT, RELAXED UPPER ARM GIRTH AND FOREARM LENGTH FOR 12 FEMALE SUBJECTS

VARIABLE		$\bar{X}$	S.D.	RANGE	
Age	(yrs)	25.33	3.58	18.0-32.0	(14.0)
Height	(cms)	165.25	5.82	156.0-180.0	(24.0)
Weight	(kgs)	57.23	5.92	48.4-69.9	(21.5)
Relaxed Upper Arm Girth	(cms)	25.53	1.42	23.5-27.5	(4.0)
Forearm Length	(cms)	23.96	1.03	23.0-26.5	(3.5)

TABLE II

MEAN, STANDARD DEVIATION AND RANGE OF AGE, HEIGHT WEIGHT, RELAXED UPPER ARM GIRTH AND FOREARM LENGTH FOR 12 MALE SUBJECTS.

VARIABLE		$\overline{X}$	S.D.	RANGE	
Age	(yrs)	26.83	2.55	23.0-33.0	(10.0)
Height	(cms)	173.25	3.49	166.0-178.0	(12.0)
Weight	(kgs)	72.20	11.84	52.5-102.3	(49.8)
Relaxed Upper Arm Girth	(cms)	31.00	2.16	28.5-35.0	(6.5)
Forearm Length	(cms)	25.96	0.92	24.0-27.5	(3.5)

TABLE III

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE ANTHROPOMETRICAL DATA

VARIABLE		$\overline{X}$	S.D.	t	P
AGE	Male	26.83	2.55	1.18	0.250
	Female	25.33	3.58		
HEIGHT	Male	173.25	3.50	4.08	0.000*
	Female	165.25	5.82		
WEIGHT	Male	72.20	11.84	3.92	0.001*
	Female	57.22	5.92		
ARM GIRTH	Male	31.00	2.16	7.33	0.000*
	Female	25.53	1.42		
FOREARM LENGTH	Male	25.96	0.92	5.02	0.000*
	Female	23.96	1.03		

Note: * denotes significance at the .01 level.

TABLE IV

t-TEST FOR SIGNIFICANCE BETWEEN THE MAXIMUM CONCENTRIC FORCE AND THE MAXIMUM ECCENTRIC FORCE OF THE MALE SUBJECTS

VARIABLE	$\overline{X}$	S.D.	t	df	P
Maximum Concentric Force (kgs)	17.87	4.69			
			-3.89	11	0.003*
Maximum Eccentric Force (kgs)	25.41	10.64			

Note: * denotes significance at .01 level.

force output to be significantly higher than the maximum female concentric force output (see Table V) at the .01 level in a one-tailed test.

Total Concentric and Eccentric Force Output

The total force exerted by each subject (see Appendix C) was found by adding the maximum torque recorded throughout the range of motion for every contraction. The concentric and eccentric values were submitted for variance analysis. The total eccentric force exerted by the male subjects, although approaching significance (P=.068) was not significantly different from the total concentric force exerted (see Table VI). The total eccentric force exerted by the females was significantly higher (at the .05 level) than the total concentric force exerted (see Table VII).

Total Concentric and Eccentric IEMG

The total concentric integrated electrical activity originating from the forearm flexors (see Appendix D) throughout the range of movement was not significantly different from the electrical activity generated by eccentric contraction for males (see Table VIII) or females (see Table IX). The large standard deviation existing in the data from both males and females indicates the large individual variation between subjects.

TABLE V

t-TEST FOR SIGNIFICANCE BETWEEN MAXIMUM CONCENTRIC FORCE AND MAXIMUM ECCENTRIC FORCE EXERTED BY FEMALE SUBJECTS

VARIABLE	$\bar{X}$	S.D.	t	df	P
Maximum Concentric Force (kgs)	8.13	2.13	-4.16	11	0.002*
Maximum Eccentric Force (kgs)	12.20	4.12			

Note: * denotes significance at .01 level.

TABLE VI

t-TEST FOR SIGNIFICANCE BETWEEN THE TOTAL CONCENTRIC FORCE AND THE TOTAL ECCENTRIC FORCE OF THE MALE SUBJECTS

VARIABLE	$\overline{X}$	S.D.	t	df	P
Mean Concentric Force (kgs)	9.99	4.11	-2.02	11	0.068
Mean Eccentric Force (kgs)	11.45	4.01			

TABLE VII

t-TEST FOR SIGNIFICANCE BETWEEN TOTAL CONCENTRIC FORCE AND TOTAL ECCENTRIC FORCE EXERTED BY FEMALE SUBJECTS

VARIABLE	$\overline{X}$	S.D.	t	df	P
Mean Concentric Force (kgs)	5.40	1.13			
			-2.32	11	0.041*
Mean Eccentric Force (kgs)	6.38	1.85			

Note: * denotes significance at .05 level.

TABLE VIII

t-TEST FOR SIGNIFICANCE BETWEEN TOTAL CONCENTRIC AND TOTAL ECCENTRIC INTEGRATED ELECTRICAL ACTIVITY OF THE MALE SUBJECTS

VARIABLE	$\bar{X}$	S.D.	t	df	P
Mean Concentric IEMG (Microamperes)	48.93	21.02	0.74	11	0.477
Mean Eccentric IEMG (Microamperes)	44.94	20.59			

TABLE IX

t-TEST FOR SIGNIFICANCE BETWEEN TOTAL CONCENTRIC AND TOTAL ECCENTRIC INTEGRATED ELECTRICAL ACTIVITY OF THE FEMALE SUBJECTS

VARIABLE	$\overline{X}$	S.D.	t	df	P
Mean Concentric IEMG (Microamperes)	31.63	17.36			
Mean Eccentric IEMG (Microamperes)	37.92	23.33	-1.27	11	0.229

Graphical Representation of the Fatigue Pattern Associated With Concentric and Eccentric Contraction

The mean concentric force output when graphed with the mean eccentric force output for each contraction performed by males (see Figure 1) and females (see Figure 2), show a similar pattern which appears more pronounced for the males. There is an initial rapid decline in force output during both concentric and eccentric contraction. A correlated t-test for significance between the concentric and eccentric mean force output for each contraction was undertaken to determine at what stage the difference between concentric and eccentric force output became continually non-significant. For males, eccentric force output was consistently significantly higher than concentric force output up to the 58th contraction. After this there was no further consistent significant difference in force output for the two types of contraction. For females, eccentric force output was consistently significantly higher than concentric force output up to the 71st contraction. After this there was no further consistent significant difference in force output for the two types of contraction. An obvious curvilinear fatigue pattern appears for both

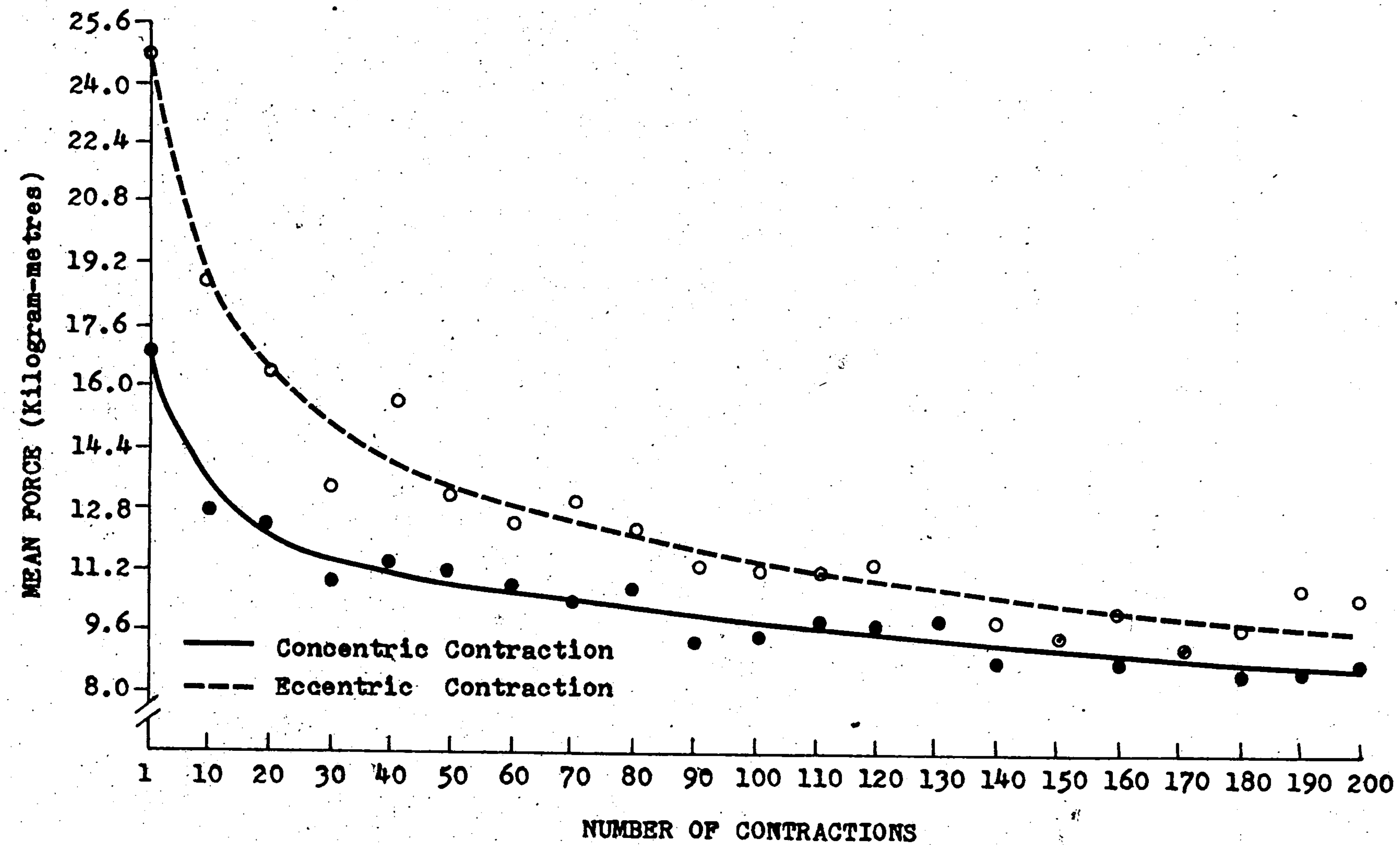

FIGURE 1: MALE CONCENTRIC AND ECCENTRIC MEANS

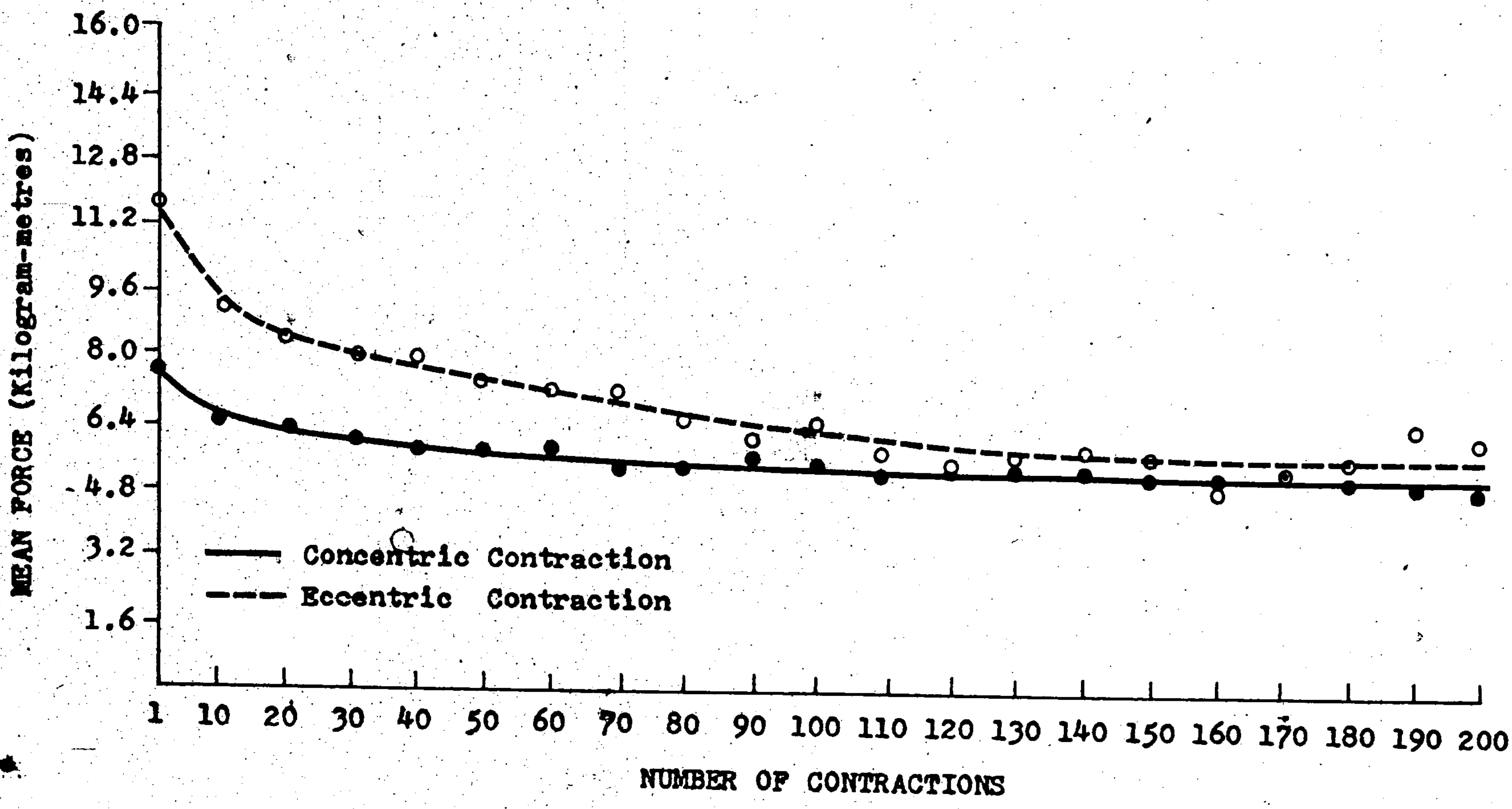

FIGURE 2: FEMALE CONCENTRIC AND ECCENTRIC MEANS

sexes in both contraction types. The initial rapid decline in force output begins at a higher level and falls at a faster rate for eccentric contraction when compared to concentric contraction for both males and females.

Graphical Representation of Concentric and Eccentric Fatigue Patterns as Percentages of the Initial Maximum Force Output

When the force output of each contraction performed by each subject both concentrically and eccentrically is presented as a percentage of the initial maximum force output for that subject (taken as the greatest single force output generated in the first three contractions) the following observations may be made (see Tables X and XI with Figures 3,4 and 5:

(a) The initial rapid decline in force output was evident in both sexes for both contraction types.

(b) For males the concentric pattern tended to decline initially at a greater rate, however, after the 20th contraction, eccentric decline was at a greater rate than concentric decline.

(c) For females the eccentric decline was at a greater rate than concentric decline throughout the experimental time period.

TABLE X

MEAN PERCENTAGE DECLINE IN INITIAL MAXIMUM FORCE OUTPUT FOR CONCENTRIC AND ECCENTRIC CONTRACTION OF MALE SUBJECTS

Contraction Type	Number of Contractions 1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
CONCENTRIC	97	72	69	61	64	61	60	57	58	51	52	54	55	52	47	51	48	48	44	46	49
ECCENTRIC	97	75	69	56	64	55	53	54	51	47	48	46	47	42	42	40	42	38	40	42	42

TABLE XI

MEAN PERCENTAGE DECLINE IN INITIAL MAXIMUM FORCE OUTPUT FOR CONCENTRIC AND ECCENTRIC CONTRACTION OF FEMALE SUBJECTS

Contraction Type	Number of Contractions 1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
CONCENTRIC	94	80	79	77	73	73	74	69	66	70	69	66	68	68	67	65	65	68	64	63	61
ECCENTRIC	95	73	69	67	66	63	60	62	55	53	56	55	50	50	52	51	45	49	50	57	48

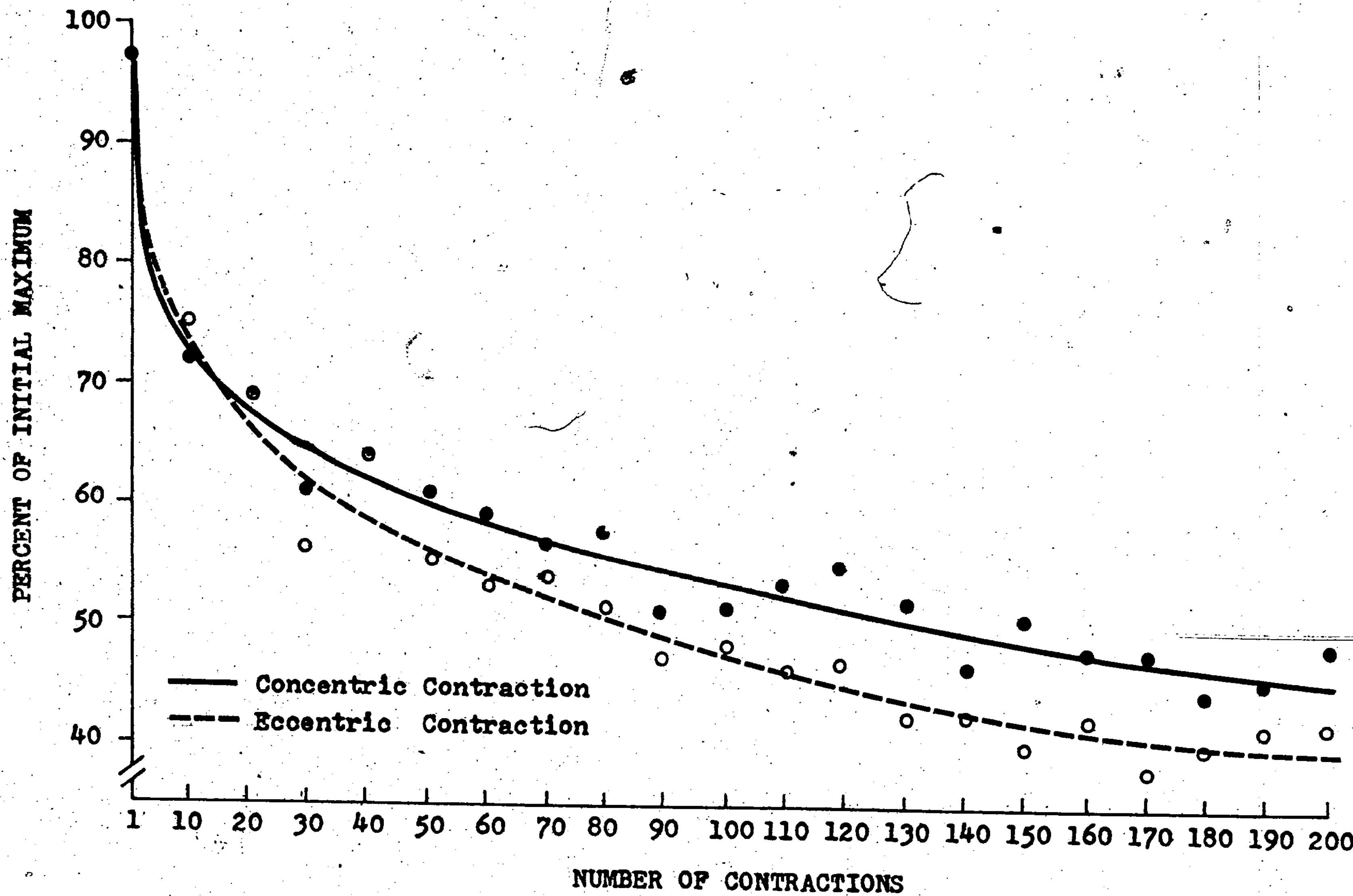

FIGURE 3: PERCENTAGE DECLINE OF INITIAL MAXIMUM FORCE OUTPUT FOR MALES

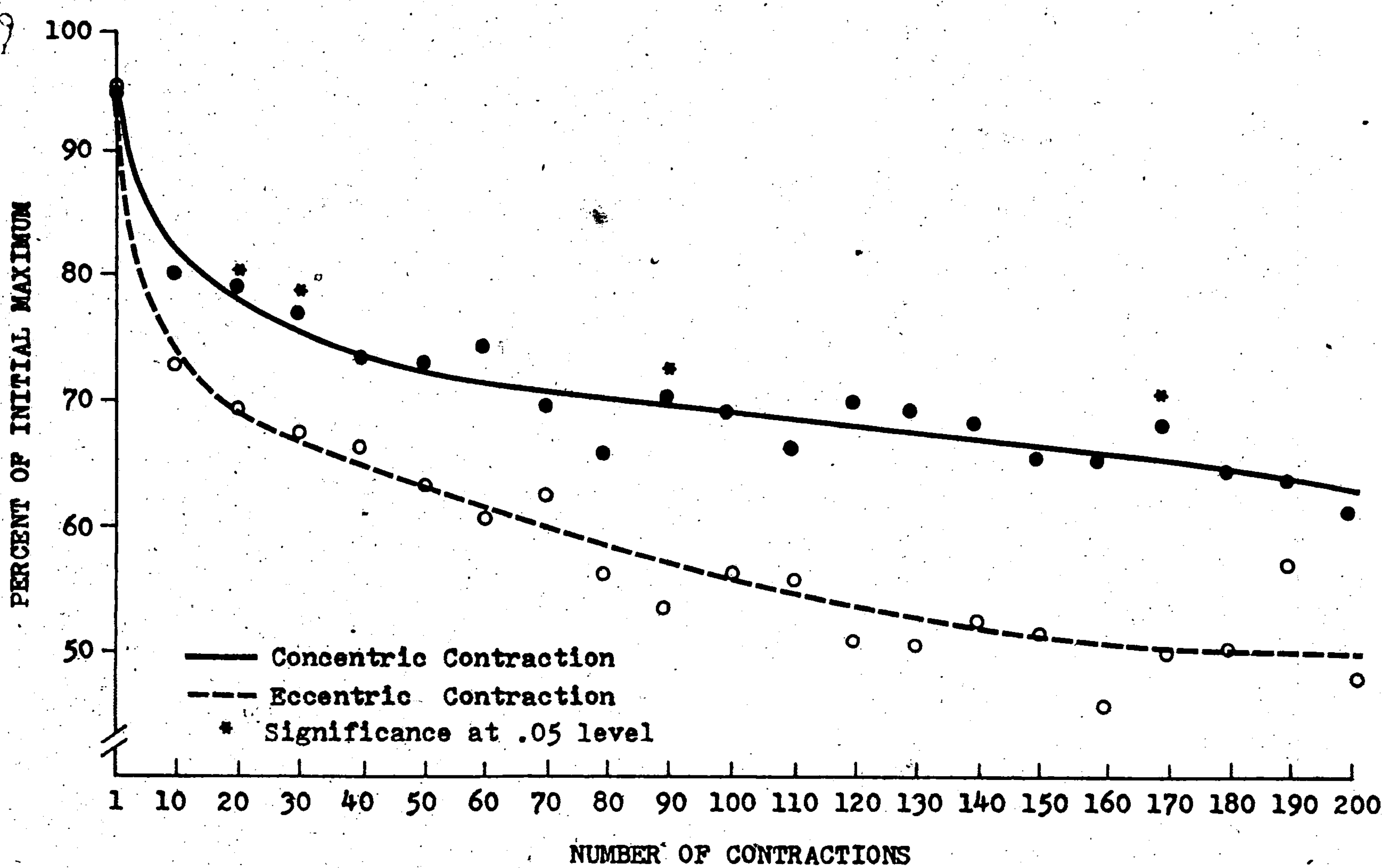

FIGURE 4: PERCENTAGE DECLINE OF INITIAL MAXIMUM FORCE OUTPUT FOR FEMALES

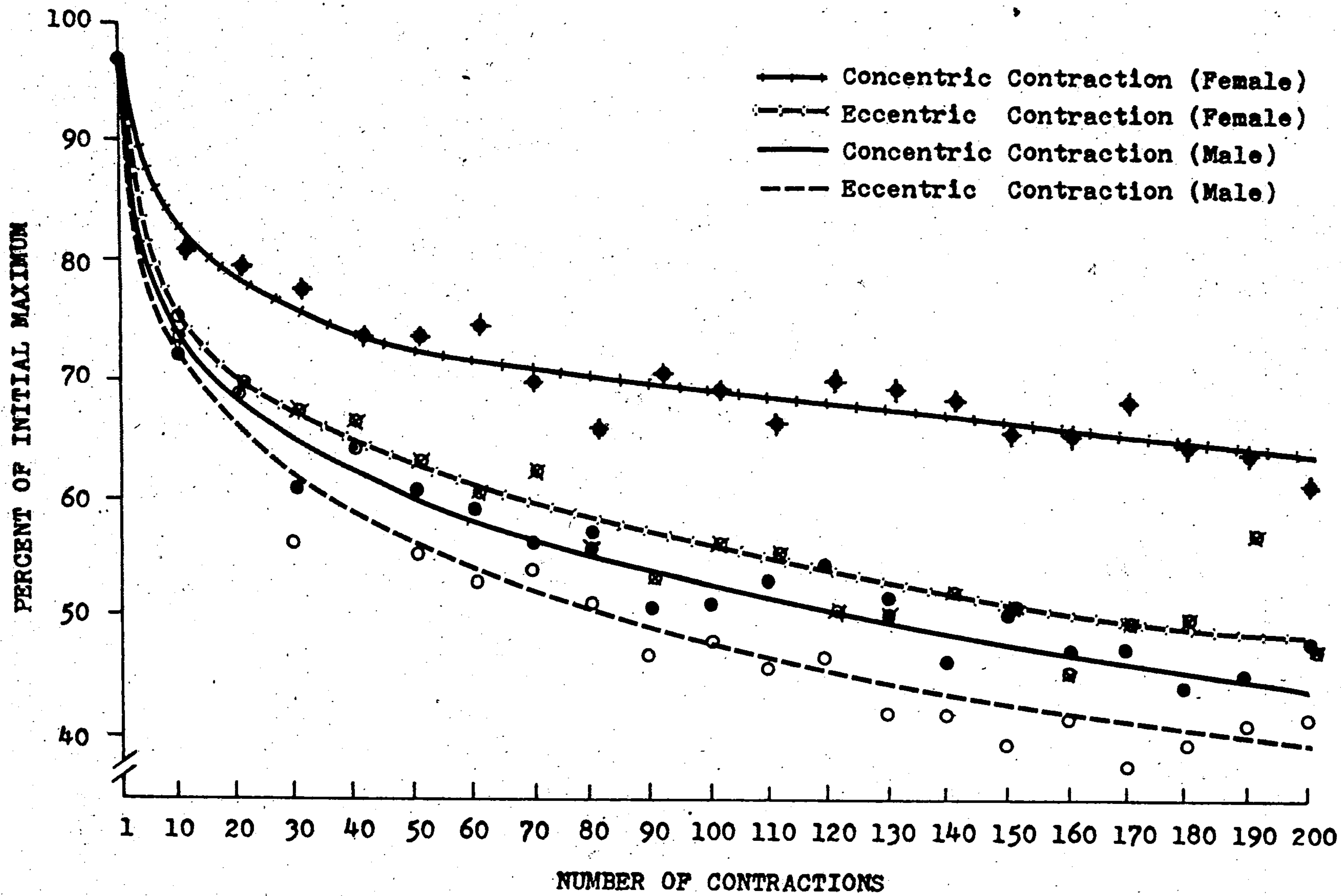

FIGURE 5: PERCENTAGE DECLINE OF INITIAL MAXIMUM FORCE OUTPUT FOR MALES AND FEMALES

(d) The concentric pattern tended to level off at a higher percentage of initial maximum for males, than the eccentric pattern (54% and 47% respectively). A similar result was found for females (72% and 56% concentric and eccentric respectively).

Graphical Representation of the IEMG Pattern Associated With Concentr[illegible]entric Fatigue

When [illegible]n microamperes, the concentric IEMG for males (see [illegible]re 6) wa[illegible] greater than the eccentric IEMG. However, after approximately 110 - 120 contractions, the eccentric IEMG became greater. The greater eccentric IEMG at this stage appeared due to a continuing gradual decline in concentric IEMG rather than a rise in eccentric IEMG. Blood occlusion (and hence much more rapid fatigue) is not considered of major importance here since the seven second rest period between each contraction was sufficient for blood to flush the working muscles. The decline in concentric IEMG, however, could be due to the synergistic compensation for declining biceps brachii force output from the brachialis and brachioradialis muscles. The extent of change in the electrical activity of these muscles was not monitored. Less synergistic compensation is anticipated in the eccentric resistance movement and hence a greater

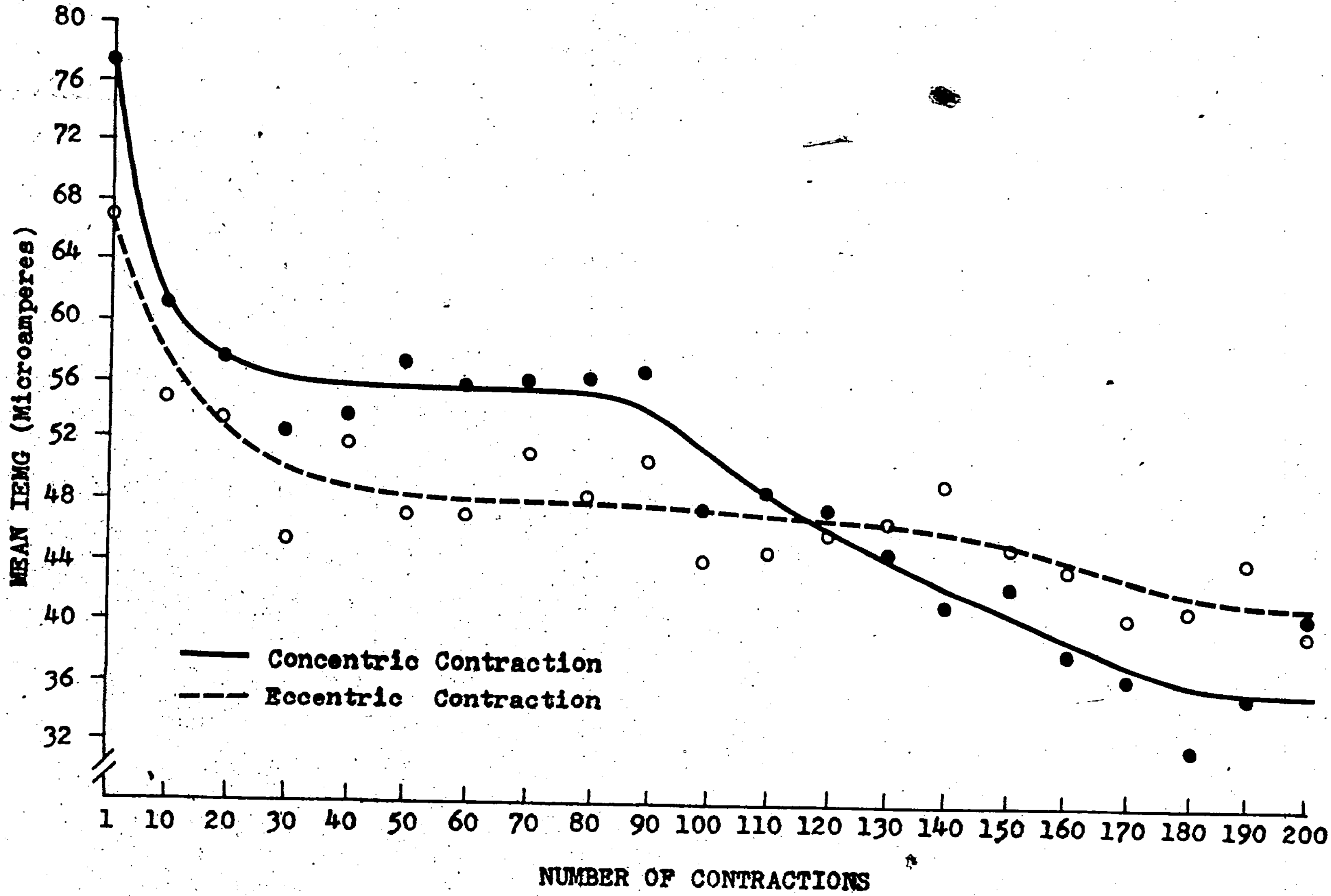

FIGURE 6: CONCENTRIC AND ECCENTRIC IEMG (MALES)

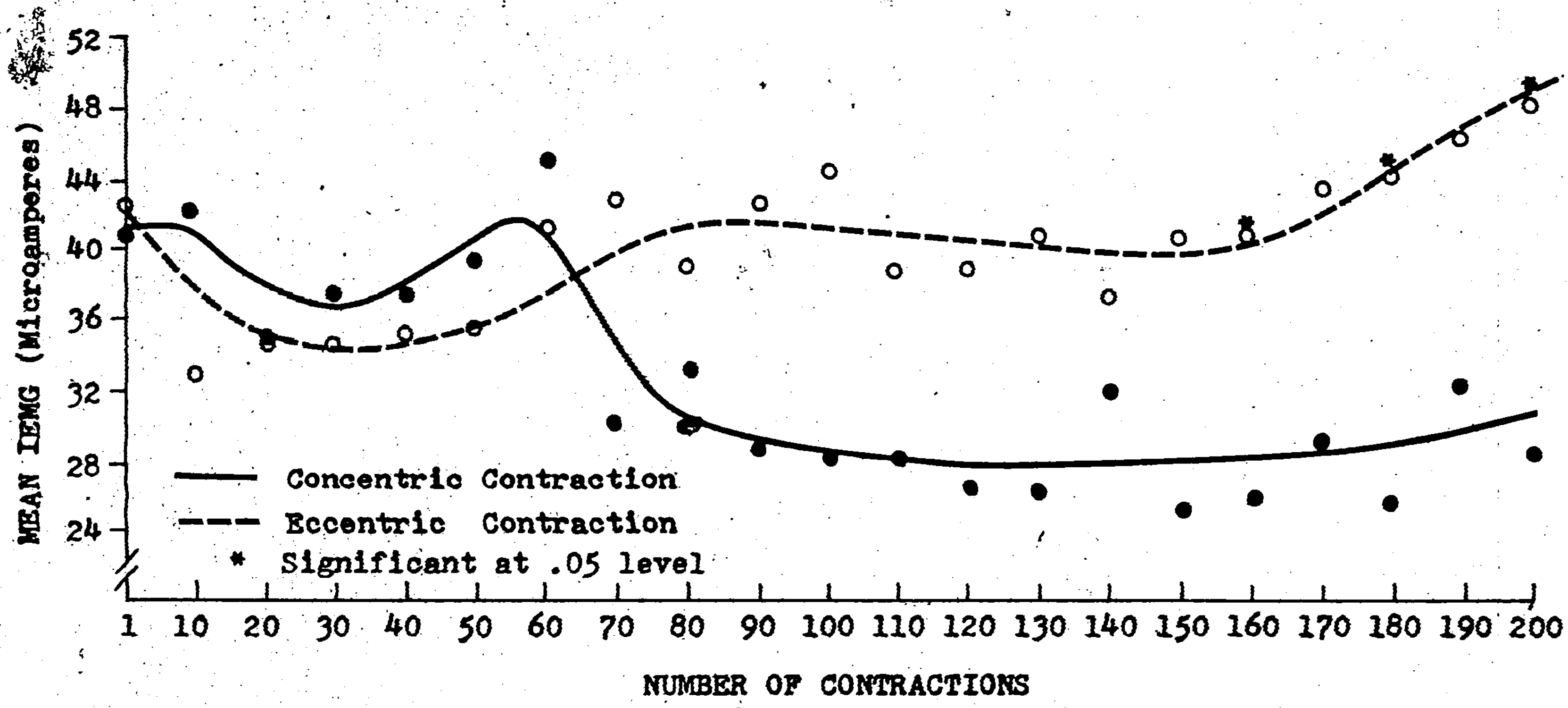

FIGURE 7: CONCENTRIC AND ECCENTRIC IEMG (FEMALES)

recorded electrical activity in the biceps brachii. Between the 30th and 80th contraction the concentric IEMG displayed a plateau phase in the declining pattern. A similar pattern was observed in the eccentric decline which appeared to last twice as long. This 'second-wind'phenomena proved interesting since in both contraction types it occurred at roughly 70% of maximum IEMG.

For females a plateau phase was observed for both contraction types between the 80th and 160 th contractions. In the concentric pattern the 'second-wind' phenomena occurred at roughly 70% of maximum IEMG (similar to the males) however, the eccentric pattern exhibited the 'second-wind' at roughly 100% of maximum IEMG in a rising trend. Thus it appears that there is a greater synchronization of motor units presenting a plateau pattern in both male and female concentric and eccentric contraction. It occurs between the 30th and 80th contractions for males and the 80th and 160th contractions for females. Initially, the female concentric IEMG tended to be greater than the eccentric IEMG. After roughly 60 - 70 contractions, however, The concentric IEMG declined sharply (see Figure 7).

Concentric and eccentric IEMG appeared to be equal between 110 and 120 contractions for males and between 60 and 70 contractions for females.

Male and Female Differences

Maximum Force Output : The maximum concentric force output for males was highly significantly larger (at the .001 level) than the maximum concentric force output for females (see Table XII).

The maximum eccentric force output for males was also highly significantly larger (at the .001 level) than the maximum eccentric force output for females (see Table XIII).

Mean Total Force Output : The mean total concentric force output for males was highly significantly larger (at the .001 level) than the mean total concentric force output for females (see Table XIV).

The mean total eccentric force output for males was also highly significantly larger (at the .001 level) than the mean total eccentric force output for females (see Table XV).

Mean Total IEMG : The mean total concentric IEMG for males was significantly larger (at the .05 level) than the mean total concentric IEMG for females (see Table XVI).

However, the mean total eccentric IEMG for males was not significantly different from the mean total eccentric IEMG for females (see Table XVII). This could be due

TABLE XII

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MAXIMUM CONCENTRIC FORCE OUTPUT

VARIABLE	$\overline{X}$	S.D.	t	df	P
Male Maximum Concentric Force Output (kgs)	17.87	4.69			
Female Maximum Concentric Force Output (kgs)	8.13	2.13	6.54	22	0.000*

Note: * denotes significance at .001 level.

TABLE XIII

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MAXIMUM ECCENTRIC FORCE OUTPUT

VARIABLE	$\bar{X}$	S.D.	t	df	P
Male Maximum Eccentric Force Output (kgs)	25.40	10.64			
Female Maximum Eccentric Force Output (kgs)	12.20	4.12	4.01	22	0.001*

Note: * denotes significance at .001 level

TABLE XIV

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MEAN TOTAL CONCENTRIC FORCE OUTPUT

VARIABLE	$\bar{X}$	S.D.	t	df	P
Male Mean Total Force Output (kgs)	9.99	4.11			
Female Mean Total Force Output (kgs)	5.40	1.13	3.73	22	0.001*

Note: * denotes significance at .01 level.

TABLE XV

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MEAN TOTAL ECCENTRIC FORCE OUTPUT

VARIABLE	$\overline{X}$	S.D.	t	df	P
Male Mean Total Force Output (kgs)	11.45	4.01			
Female Mean Total Force Output (kgs)	6.38	1.85	3.98	22	0.001*

Note: * denotes significance at .01 level.

TABLE XVI

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MEAN TOTAL CONCENTRIC IEMG

VARIABLE	$\bar{X}$	S.D.	t	df	P
Male Mean Total IEMG (Microamperes)	48.93	21.02			
Female Mean Total IEMG (Microamperes)	31.63	17.36	2.20	22	0.039*

Note: * denotes significance at .05 level.

TABLE XVII

t-TEST FOR SIGNIFICANCE BETWEEN MALE AND FEMALE MEAN TOTAL ECCENTRIC IEMG

VARIABLE	$\overline{X}$	S.D.	t	df	P
Male Mean Total IEMG (Microamperes)	44.94	20.59			
			0.78	22	0.443
Female Mean Total IEMG (Microamperes)	37.92	23.33			

to the fact that there was a significantly greater (at the .05 level) eccentric mean total force output when compared to concentric mean total force output for females while the eccentric mean total force output for males was not significantly different from the concentric mean total force output. Thus, more force was generated between the two types of contraction (on a relative basis) by females than by males. This may explain why the greater eccentric mean total IEMG needed to produce this force output approached the male value.

Discussion

The male and female subjects differed significantly in all anthropometrical measurements with the exception of age. On the average, the male subjects were 4.84% taller, 26.18% heavier, had a 21.43% greater arm girth and an 8.35% longer forearm than the female subjects.

The average maximum eccentric force output for male subjects was significantly (42.19%) greater than the maximum concentric force output. As well, the average maximum eccentric force output for female subjects was significantly (15.06%) greater than the maximum concentric force output. These results agree with those of other investigators (6, 20, 30, 48, 53). The average maximum concentric force output for males was significantly (119.80%) greater than that for females. Undoubtedly, the 21.43% difference in relaxed upper arm girth, the 8.35% difference in forearm length, cultural stereotype and motivational phenomena had considerable effect here.

The mean total eccentric force for males was 14.61% greater than the mean total concentric force for females. Although this was not a significant difference, it approached significance with a probability of .068. For females, the mean total eccentric force output was significantly (18.15%) greater than the mean total concentric force output.

A large individual variation was observed between subjects when recording both concentric and eccentric IEMG. For male subjects, there was a difference of just 3.37% between concentric and eccentric IEMG with the eccentric total being the greater of the two. A correlation coefficient of 0.593 was significant at the .05 level. For females, however, the concentric IEMG was greater than the eccentric IEMG by 28.70%. Here a correlation coefficient of 0.682 was also significant at the .05 level. Nevertheless, for males and females, as fatigue progressed, more electrical activity was observed in eccentric contraction than in concentric contraction. This result is not in agreement with two other investigations (8, 9). However, in these investigations the total testing time was much less. If Komi's testing time had been of a longer duration a similar result may have been found (37). It is possible that the result may have been due to the greater total force output during eccentric contraction. In other words, the muscles performing more work fatigue sooner and thus recruit more motor units in an attempt to keep the desired force output as great as possible (9. 19, 21, 40, 50).

As fatigue progressed, there was an initial rapid decline in force output in both types of contraction for both males and females. The decline levelled out as more contractions were performed presenting a curvilinear overall pattern in both types of contraction for both males and females.

There was no significant difference in the rate of decline in force output during concentric or eccentric contraction for males when compared by percentage of initial maximum force output. For females, significant differences occurred in a somewhat random fashion (see Figure 4) not exhibiting any consistent trend. It must be remembered that comparison by initial maximum percentage eliminates any sex effect.

After completing the experiment, each subject was given a questionnaire (see Appendix F) in an attempt to subjectively analyse the effects of muscle soreness experienced after both types of contraction.

Results indicated that muscle soreness was much greater after having performed eccentric contraction. Minimal discomfort was reported following concentric contraction which took, on the average, less than a day to restore to the pre-exercised condition. It was interesting to note that one subject who had been training eccentrically for a month before the experiment did not suffer any muscle soreness after performing either contraction type. Muscle soreness was experienced though, when he began his eccentric training regimen initially.

CHAPTER V

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to compare the patterns of muscular fatigue of the forearm flexors during repeated maximal concentric and eccentric contractions. Sub-problems investigated were : (a) the difference between maximum concentric and eccentric force output, (b) the difference between total concentric and total eccentric force output, (c) the difference in the rate of decline in force output between concentric and eccentric contractions measured as a percentage of the initial maximum force output, (d) the difference between the total concentric and total eccentric electrical activity generated by the muscles of the forearm and, (e) the difference between males and females on the above measures.

Each subject performed repeated maximum voluntary concentric and eccentric muscular contractions on two different occasions striving for maximum isokinetic force of forearm flexors through a 90° range of motion from 56° to 146°. Whether concentric or eccentric contraction was performed on the first visit or on the second was randomized. The angular velocity of the lever arm was set at 18°

per second. After each five second contraction a seven second rest period was given to permit the lever arm to return to its original position. No subject was allowed to proceed past 200 contractions. Almost all subjects reached 200 contractions in both concentric and eccentric contraction although the experiment was terminated if (a) 25% of the initial maximum force output was reached before the 200 th contraction, (b) the subject felt that the experiment must be stopped due to excessive fatigue, pain or distress.

The following results emerged:

1. (a) For males, the mean maximum eccentric force was significantly greater (42.19%) than the mean maximum concentric force.
   (b) For females, the mean maximum eccentric force was significantly greater (15.06%) than the mean maximum concentric force.
   (c) The mean maximum concentric force for males was 119.80% greater than the concentric for females.
   (d) The mean maximum eccentric force for males was 108.28% greater than the eccentric for females.
2. (a) The mean total eccentric force was greater (14.61%) than the mean total concentric force for males performing 200 contractions. This value approached significance (P=.068).

(b) The mean total eccentric force was significantly greater (18.15%) than the mean total concentric force for females.

(c) The mean total concentric force for males was 85.00% greater than the concentric force for females.

(d) The mean total eccentric force for males was 79.47% greater than the eccentric force for females.

3. (a) A large individual variation in electrical activity was observed among the subjects for both types of contraction. Correlation coefficients between concentric and eccentric IEMG were 0.593 and 0.682 for males and females respectively. Both coefficients were significant at the .05 level.

(b) There was no significant difference for male total IEMG between concentric and eccentric contraction as fatigue progressed.

(c) There was no significant difference for female total IEMG between concentric and eccentric contraction as fatigue progressed.

4. (a) The forearm flexors in concentric fatigue for both males and females present a curvilinear pattern with an initial rapid decline in force output which levels out at approximately 54% for males and 72% for females of the initial maximum force output for up to 200 contractions of five seconds duration with a seven second rest period between each contraction.

(b) The forearm flexors in eccentric fatigue for both males and females present a curvilinear pattern with an initial rapid decline in force output which levels out at approximately 47% for males and 56% for females of the initial maximum force output for up to 200 contractions.

5. For both males and females the forearm flexors appeared to fatigue at a greater rate during eccentric contractions than during concentric contractions when compared by percentage of initial maximum force output.

6. A greater amount of exercise, in terms of maximum force output and total force output over a given time period can be accomplished by eccentric muscular contraction as compared to concentric muscular contraction.

7. Very little discomfort from muscle soreness or fatigue feeling was experienced after performing concentric contraction compared to that experienced after performing eccentric contraction. The discomfort lasted, on the average, less than one day for concentric contraction while an average of four days was needed to recover from the discomfort after performing eccentric contraction.

Conclusions

In conclusion, when performing eccentric contraction with the forearm flexors through a range of 90° from 56° to 146° at a constant velocity of 18° per second and exerting maximal voluntary force for five seconds with a seven second rest period between each contraction, whether male or female, it appears possible to :

(a) be able to exert a greater maximal force,

(b) be able to perform a greater total amount of work,

(c) decline from the initial maximum force output at a faster rate,

(d) be able to continually maintain after levelling out (to 200 contractions) a lesser percentage of initial maximum force output,

(e) generate an equal amount of electrical activity and

(f) develop greater discomfort for a longer period of time

than when performing concentric contraction under the same conditions.

Recommendations

In this study an attempt was made to investigate dynamic fatigue under controlled conditions. Dynamic muscular fatigue, as well as static muscular fatigue, is an inevitable outcome of the continuously active human being.

In further studies of this nature it would be interesting to:

(a) increase the velocity throughout the range of motion and decrease the rest period under the same conditions,

(b) reduce the rest period to one second using an automatic lever arm return,

(c) integrate the force output in addition to the electrical activity so that a valid area comparison could be made between the two measurements.

BIBLIOGRAPHY

1. Abbott, B.C., and B. Bigland, "The Effects of Force and Speed Changes on the Rate of Oxygen Consumption During Negative Work," Journal of Physiology, 120 (1953), pp. 319-325.

2. Abbott, B.C., B. Bigland, and J.M. Ritchie, "The Physiological Cost of Negative Work," Journal of Physiology, 117 (1952), pp. 380-390.

3. Abbott, B.C., and X.M. Aubert, "Changes of Energy in a Muscle During Very Slow Stretches," Royal Society of London Proceedings, Ser.B., 139 (1952), pp. 104-117.

4. Abbott, B.C., X.M. Aubert, and A.V. Hill, "The Absorption of Work by a Muscle Stretched During a Single Twitch of a Short Tetanus," Royal Society of London Proceedings, Ser. B., 139 (1951), pp. 84-104.

5. Adrian, E.O., and D.W. Bronk, "The Discharge of Impulses in Motor Nerve Fibres, Part II The Frequency of Discharge in Reflex and Voluntary Contractions," Journal of Physiology, 67 (1929), pp. 119-151.

6. Asmussen, E., O. Hansen, and O. Lammer, "The Relation Between Isometric and Dynamic Muscle Strength in Man," Comm. Danish National Association for Infant Paralysis, 20 (1965).

7. Asmussen, E., "Positive and Negative Work," Acta Physiologica Scandinavica, 28 (1953), pp. 364-382.

8. Basmajian, J.V., "Muscles Alive: Their Functions Revealed by Electromyography," 2nd Edition (Williams & Wilkins Company: Baltimore), 1967

9. Bigland, B., and O.C.J. Lippold, "The Relation Between Force, Velocity and Integrated Electrical Activity in Human Muscles," Journal of Physiology, 123 (1954), pp. 214-224.

10. Bouisset, S., "EMG and Muscle Force in Normal Motor Activities," New Developments in Electromyography and Clinical Neurophysiology, Vol 1, Editor J. Desmedt (Karger: Basel) 1 (1973), pp. 547-583.

11. Bouisset, S., and B. Maton, "Comparison Between Surface and Intramuscular EMG During Voluntary Movement," New Developments in Electromyography and Clinical Neurophysiology, Vol 1, Editor J. Desmedt (Karger: Basel) 1 (1973), pp. 533-539.

12. Cavagna, G.A., B Dusman, and R. Margaria, "Positive Work Done by a Previously Stretched Muscle," Journal of Applied Physiology, 24 (1968) pp. 21-32.

13. Cavagna, G.A., F.P. Saivene, and R. Margaria, "Effect of Negative Work on the Amount of Positive Work Performed by Isolated Muscle," Journal of Applied Physiology, 20 (1965), pp. 157-158.

14. [illegible]arke, H., E. Elkins, G. Martin, and K. Wakim, "Relationship Between Body Position and the Application of Muscle Power to the Movement of Joints," Archives of Physical Medicine, 31 (1950), pp. 81-89.

15. Close, R.I., "Dynamic Properties of Mammalian Skeletal Muscles," Physiological Reviews, Vol 52, No 1.

16. Davies, C.T.M. and C. Barnes, "Negative (Eccentric) Work IV Physiological Responses to Walking Uphill and Downhill on a Motor-Driven Treadmill," Ergonomics, 15 (1972) pp. 121-131.

17. DeVries, H.A., "Physiology of Exercise," 2nd Edition (Wm C. Brown Company: Iowa), 1974.

18. DeVries, H.A., "Efficiency of Electrical Activity as a Physiological Measure of the Functional State of Muscle Tissue," American Journal of Physical Medicine, 4[illegible] (1968), pp. 10-22.

19. DeVries, H.A., "Method for Evaluation of Muscle Fatigue and Endurance From Electromyographic Fatigue Curves," American Journal of Physical Medicine, 47 (1968) pp. 125-135

20. Doss, W.S., and P.V. Karpovich, "A Comparison of Concentric, Eccentric and Isometric Strength of Elbow Flexors," Journal of Applied Physiology, 20(1965), pp. 351-355.

21. Edwards, R.G., and O.C.J. Lippold, "The Relation Between Force and Integrated Electrical Activity in Fatigued Muscle," Journal of Physiology, 132 (1956), pp. 677-681.

22. Ferguson, G.A., "Statistical Analysis in Psychology and Education," (McGraw-Hill Book Company : New York), 1971.

23. Granit, R., "Receptors and Sensory Perception," (Yale University Press: New Haven), 1955.

24. Grimby, L., and J. Hannerz, "Tonic and Phasic Recruitment Order of Motor Units in Man Under Normal and Pathological Conditions," New Developments in Electromyography and Clinical Neurophysiology, Vol 3, Editor J. Desmedt (Karger: Basel) 3 (1973), pp. 226-332.

25. Grillner, S., and M. Udo, "Recruitment in the Tonic Stretch Reflex," Acta Physiologica Scandinavica 81 (1971), pp. 571-573.

26. Grossman, W.I., and H. Weiner, "Some Factors Affecting the Reliability of Surface Electromyography," Psychosomatic Medicine, 28 (1966), pp. 78-83.

27. Guyton, A.C., "Textbook of Medical Physiology," 4th Edition (W.B. Saunders Company: Toronto), 1971.

28. Henneman, E., "Peripheral Mechanisms Involved in the Control of Muscle," Medical Physiology 12th Edition Editor V.B. Mountcastle (C.V. Mosby Company: St Louis), 1968.

29. Henneman, E., G. Sonyen, and D.O. Carpenter, "Functional Significance of Cell Size in Spinal Motorneurons," Journal of Neurophysiology, 28 (1965), pp. 560-580.

30. Hill, A.V., "Production and Absorption of Work by Muscle," Science, 131 (1960) pp. 897-903.

31. Hill, A.V., "The Series Elastic Component of Muscle," Royal Society of London Proceedings, 137 (1950), pp. 273-280.

32. Hill, A.V., "The Heat of Shortening and Dynamic Constants of Muscle," Royal Society of London Proceedings, Ser. B, 126 (1938) pp. 136-195.

33. Inman, V.T., H.J. Ralston, J.B. Saunders, B. Feinstein, and E.W. Wright Jr, "Relation of Human Electromyogram to Muscle Tension," Electroencephalogrophy and Clinical Neurophysiology, 4 (1952) pp. 187-194.

34. Johnson, B.L., J.W. Adamczyk, K.O. Tennoe, and S.B. Stromme, "A Comparison of Concentric and Eccentric Muscle Training," Medicine and Science in Sports, Vol 8, 1 (1976) pp. 35-38.

35. Johnson, B.L., "Eccentric Versus Concentric Muscle Training for Strength Development," Medicine and Science in Sports, 4 (1972), pp. 111-115.

36. Knowlton, G.E., T.P. Hines, K.W. Keever, and R.L. Bennett, "Relation Between Electromyographic Voltage and Load," Journal of Applied Physiology 9 (1956), pp. 473-476.

37. Komi, P.V., "Relationship Between Muscle Tension, EMG and Velocity of Contraction Under Concentric and Eccentric Work," New Developments in Electromyography and Clinical Neurophysiology, Vol 1, Editor J. Desmedt (Karger: Basel) 1 (1973), pp. 596-606.

Komi, P. V., and E. Buskirk, "Reproducibility of Electromyographic Measurements With Inserted Wire Electrodes and Surface Electrodes," Electromyography, 10 (1970), pp. 357-367.

39. Komi, P.V., and E. Buskirk, "Effect of Eccentric and Concentric Muscle Conditioning on Tension and Electrical Activity of Human Muscle," Ergonomics, 15 (1972), pp. 417-434.

40. Kuroda, E., V. Klissouras, and H.J. Milsum, "Electrical and Metabolic Activity and Fatigue in Human Isometric Contraction," Journal of Applied Physiology 29 (1970), pp. 358-367.

41. Lippold, O.C.J., "The Relation Between Integrated Action Potentials in a Human Muscle and Its Isometric Tension," Journal of Physiology, 117 (1952), pp. 492-499.

42. Logan, G.A., "Comparative Gains in Strength Resulting From Eccentric and Concentric Muscular Contraction," (Unpublished Master's Thesis, University of Illinois), 1952.

43. Malmo, R.B., C. Shagass, and J.F. Davies, "Electromyographic Studies of Muscular Tension in Psychiatric Patients Under Stress," Journal of Clinical and Experimental Psychopathology, 12 (1951) pp. 45-66.

44. Mannheimer, J.S., "A Comparison of Strength Gain Between Concentric and Eccentric Contractions," Physical Therapy 49 (1969), pp. 1201-1207.

45. Milner-Brown, H.S., R.B. Stein, and R. Yemm, " Changes in Firing Rate of Human Motor Units During Linearly Changing Voluntary Contractions," Journal of Physiology, 230 (1973), pp. [illegible]1-390.

46. Mommaerts, W.F., "Energetics of Muscular Contraction," Physiological Reviews, 49 (1969), pp. 427-508.

47. Moritz, U., G Svantesson, and D. Haffajee, "A Biomechanical Study of Muscle Torque as Affected by Motor Unit Activity, Length-Tension Relationship and Muscle Force Lever," New Developments in Electromyography and Clinical Neurophysiology, Vol 1, Editor J. Desmedt (karger: Basel) 1 (1973) pp. 675-682.

48. Olsen, C., et al, "Orderly Recruitment of Muscle Action Potentials," Archives of Neurological Psychiatry (London), 19 (1968), pp. 591-597.

49. Rasch, P.J., "The Present Status of Negative (Eccentric) Exercise: [illegible]ew," American Corrective Therapy Journal, V[illegible], 3 (1974), pp. 77-94.

50. Scherrer, J., and A. Bourguignon, "Changes in the Electromyogram Produced by Fatigue in Man," American Journal of Physical Medicine, 4 (1959), pp. 148-158.

51. Seliger, V., L. Dolejas, V. Karas, and I. Pachlopnikova, "Adaptation of Trained Athletes' Energy Expenditure to Repeated Concentric and Eccentric Muscle Contraction," Internationale Zeitschrift für Angewandte Physiologie einschlafen Arbeitsphysiologie, 26 (1968), pp. 227-234.

52. Singh, M., and P.V. Karpovich, "Effect of Eccentric Training of Agonists on Antagonistic Muscles," Journal of Applied Physiology, 23 (1967), pp. 742-[illegible]

53. Singh, M., and P.V. Karpovich, "Isotonic and Isometric Forces of Forearm Flexors and Extensors," Journal of Applied Physiology, 21 (1966), pp. 1435-1437.

54. Stephens, J.A., and A. Taylor, "The Relationship Between Integrated Electrical Activity and Force in Normal and Fatiguing Human Voluntary Muscle Contractions," New Developments in Electromyography and Clinical Neurophysiology, Vol 1, Editor J. Desmedt (Karger: Basel) 1 (1973), pp. 623-627.

55. Thys, H., T. Faraggiana, and R. Margaria, "Utilization of Muscle Elasticity in Exercise," Journal of Applied Physiology, 32 (1972), pp. 491-494.

56. Vander, A.J., J.H. Sherman, and D.S. Luciano, "Human Physiology-The Mechanisms of Body Function," 2nd Edition (McGraw-Hill Book Company: New York), 1975.

57. Vredenbregt, J., and G. Rau, "Surface Electromyography in Relation to Force, Muscle Length and Endurance," New Developments in Electromyography and Clinical Neurophysiology, Vol 1 Editor J. Desmedt (Karger: Basel) 1 (1973), pp. 607-622.

58. Weiner, B.J., "Statistical Principles in Experimental Design," (McGraw-Hill Book Company: New York), 1971.

59. Wilkie, D.R., "The Mechanical Properties of Muscle," British Medical Bulletin, 12 (1956), pp. 177-182.

60. Williams, H., and L. Stutzman, "Strength Variation Through the Range of Joint Motion," Physical Therapy Review, 39 (1959), pp. 145-152.

61. Zuniga, E.N., and D.G. Simons, "Nonlinear Relationship Between Averaged Electromyograms, Potential and Muscle Tension in Normal Subjects," Archives of Physical Medicine and Rehabilitation, 50 (1969), pp. 613-619.

APPENDIX A

ANTHROPOMETRICAL DATA

AGE, HEIGHT, WEIGHT, HAND DOMINANCE, RELAXED UPPER ARM GIRTH AND FOREARM LENGTH FOR 12 MALE SUBJECTS

SUBJECT	Age (yrs)	Height (cms)	Weight (kgs)	Hand Dominance	Relaxed Arm Girth (cms)	Forearm Length(cms)
01	26	176	52.5	R	28.5	26.0
02	27	170	71.6	R	29.0	26.0
03	23	176	67.3	R	33.0	26.0
04	33	175	74.1	R	33.0	26.0
05	25	171	69.8	R	29.5	24.0
06	26	171	102.3	R	37.0	25.5
07	26	174	71.8	R	30.0	27.5
08	29	178	71.4	R	29.5	26.5
09	26	177	78.2	R	32.0	27.0
10	[illegible]	174	78.9	[illegible]	33.5	26.5
11	27	166	[illegible]	[illegible]	29.5	25.0
12	29	171	[illegible]	R	29.5	25.5

AGE, HEIGHT, WEIGHT, HAND DOMINANCE, RELAXED UPPER ARM GIRTH AND FOREARM LENGTH FOR 12 FEMALE SUBJECTS

SUBJECT	Age (yrs)	Height (cms)	Weight (kgs)	Hand Dominance	Relaxed Arm Girth (cms)	Forearm Length
13	29	163	61.8	R	26.5	24.0
14	22	163	60.5	R	27.5	24.0
15	24	161	54.5	R	24.0	23.0
16	26	166	53.9	R	23.5	24.0
17	22	165	55.9	L	24.5	23.0
18	26	169	56.8	R	25.5	24.0
19	26	180	69.9	R	26.8	26.5
20	26	166	57.5	R	26.5	23.0
21	27	165	53.8	R	24.0	24.5
22	26	161	50.5	R	25.5	23.0
23	18	156	48.4	R	24.5	23.5
24	32	168	63.4	R	25.5	21.0

APPENDIX B

MAXIMUM CONCENTRIC AND ECCENTRIC FORCE

MAXIMUM CONCENTRIC AND ECCENTRIC FORCE
GENERATED BY 12 MALE SUBJECTS

SUBJECT	Concentric Maximum (kgs)	Eccentric Maximum (kgs)
01	19.2	27.2
02	17.6	21.6
03	17.6	25.6
04	12.0	21.6
05	13.6	13.6
06	28.8	54.4
07	16.8	20.8
08	12.0	16.8
09	16.0	24.0
10	22.4	35.2
11	17.6	19.2
12	20.8	24.8

MAXIMUM CONCENTRIC AND ECCENTRIC FORCE
GENERATED BY 12 FEMALE SUBJECTS

SUBJECT	Concentric Maximum (kgs)	Eccentric Maximum (kgs)
01	11.2	18.4
02	11.2	9.6
03	7.2	8.0
04	4.8	8.8
05	5.6	6.4
06	8.0	16.8
07	11.2	17.6
08	4.8	12.8
09	8.8	12.8
10	8.0	9.6
11	7.2	9.6
12	8.0	16.0

APPENDIX C

TOTAL FORCE AND MEAN FORCE

TOTAL FORCE AND MEAN FORCE GENERATED IN CONCENTRIC AND ECCENTRIC CONTRACTION BY MALE SUBJECTS

Subject	Concentric Total(kgs)	Concentric Mean (kgs)	Eccentric Total(kgs)	Eccentric Mean(kgs)
01	1579.2	8.0	2431.7*	10.2*
02	1780.8	9.6	2517.6	12.8
03	2258.4	11.2	3284.0	16.0
04	1115.2	4.8	1911.2	9.6
05	1420.0	6.4	2108.0	11.2
06	4261.6	20.8	3991.2	19.2
07	2595.2	12.8	2741.6	14.4
08	1494.4	8.0	1687.2	8.0
09	1860.0	9.5	2593.6	12.8
10	2207.2	12.8	2029.6	11.2
11	1592.8	8.0	1337.6	6.4
12	1780.0	9.5	2144.8	11.2

Note: * indicates substitution of group mean for missing data.

TOTAL FORCE AND MEAN FORCE GENERATED IN CONCENTRIC AND ECCENTRIC CONTRACTION BY FEMALE SUBJECTS

Subject	Concnetric Total(kgs)	Concentric Mean (kgs)	Eccentric Total(kgs)	Eccéntric Mean(kgs)
13	1114.4	5.6	1805.6	9.0
14	1246.4	6.2	1732.8	8.7
15	675.2	4.2	571.2	3.6
16	968.8	4.8	812.8	4.1
17	771.2	3.9	1090.4	5.5
18	1090.4	5.5	1498.4	7.5
19	1200.0	6.0	1025.6	7.8
20	966.4	4.8	1374.4	6.9
21	1267.2	6.3	1327.2	6.6
22	1276.8	6.4	1146.4	5.7
23	932.8	4.7	1302.4	6.5
24	1455.2	7.3	1627.2	8.1

APPENDIX D

TOTAL IEMG AND MEAN IEMG

TOTAL IEMG AND MEAN IEMG GENERATED IN CONCENTRIC
AND ECCENTRIC CONTRACTION
BY MALE SUBJECTS

Subject	Conc. Total (Microamps)	Conc. Mean (Microamps)	Ecc. Total (Microamps)	Ecc. Mean (Microamps)
01	8770	42.86	9137*	45.74*
02	18068	90.34	10343	52.70
03	9916	49.58	12630	63.16
04	15238	76.20	10632	53.16
05	3078	15.40	4882	24.42
06	5846	29.24	5954	29.78
07	7476	37.38	10814	54.08
08	8804	44.02	6436	32.18
09	5616	28.08	2790	13.96
10	12244	68.02	11000	61.12
11	10498	52.50	9054	45.28
12	11874	53.38	17744	88.72

Note: * indicates substitution of group mean for missing data.

TOTAL IEMG AND MEAN IEMG GENERATED IN CONCENTRIC AND ECCENTRIC CONTRACTION BY FEMALE SUBJECTS

Subject	Conc. Total (Microamps)	Conc. Mean	Ecc. Total (Microamps)	Ecc. Mean
13	3568	17.84	7614	38.08
14	7478	37.40	3142	15.72
15	4346	27.16	2802	17.52
16	3500	17.50	1936	9.68
17	2310	11.56	4808	24.04
18	7970	39.86	14018	70.10
19	6746	33.74	4088	30.98
20	10116	50.58	10156	50.78
21	5218	26.10	9630	48.16
22	14818	74.10	16746	83.74
23	4192	20.96	10082	50.42
24	5638	29.90	5976	29.88

APPENDIX E

PERCENTAGE DECLINE IN INITIAL MAXIMUM FORCE

DECLINE IN ECCENTRIC FORCE OUTPUT AS A PERCENT OF INITIAL MAXIMUM FOR MALE SUBJECTS

Subject	Number of Contractions																				
	1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
01	100	82	74	59	56	44	41	54*	51*	48*	47*	46*	47*	42*	42*	37*	42*	38*	40*	37*	42*
02	100	78	85	74	74	70	56	67	59	56	44	56	48	48	52	48	44	44	44	52	44
03	94	94	81	72	72	72	63	72	69	56	63	63	66	63	59	59	59	59	56	50	50
04	100	93	74	67	56	52	48	48	33	41	44	33	22	30	30	37	30	37	22	26	26
05	100	77	94	65	82	77	82	82	71	77	94	71	77	77	88	71	82	65	65	71	59
06	100	65	41	27	47	31	30	34	37	28	28	34	37	24	28	27	41	31	31	57	34
07	92	81	73	69	96	73	73	77	73	69	46	62	69	69	50	46	54	54	54	46	65
08	100	71	81	67	67	62	71	43	62	52	43	43	52	33	43	33	43	33	33	29	29
09	100	53	53	47	80	63	60	53	57	47	53	60	60	40	47	40	40	43	47	43	47
10	100	55	50	39	48	41	34	39	34	32	30	27	27	23	16	16	11	09	40*	37*	42*
11	83	71	63	46	38	33	33	33	25	29	29	17	21	21	25	25	21	17	21	21	29
12	100	77	58	45	55	42	39	48	45	36	48	45	39	32	29	32	36	29	29	29	39

Note: * group mean substituted for missing data.

DECLINE IN CONCENTRIC FORCE OUTPUT AS A PERCENT OF INITIAL MAXIMUM FOR MALE SUBJECTS

	Number of Contractions																				
Subject	1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
01	100	67	50	54	50	46	42	42	33	42	42	33	33	33	29	33	29	38	33	33	33
02	91	59	64	55	64	73	55	50	46	46	50	59	46	55	32	46	46	41	36	36	46
03	100	86	77	68	68	77	64	73	64	73	68	64	68	64	55	59	59	55	50	50	55
04	93	67	53	53	47	53	47	47	47	40	47	40	40	40	47	47	33	33	33	33	33
05	100	82	71	59	59	53	59	59	59	47	47	41	41	35	41	35	41	35	47	35	41
06	94	67	86	61	64	67	72	67	78	64	67	81	58	111	61	75	58	103	94	100	75
07	95	91	76	76	81	95	99	71	95	76	67	71	81	67	67	71	67	62	57	48	62
08	87	87	87	60	87	47	67	53	47	60	67	73	100	60	53	67	60	67	47	67	67
09	100	65	60	80	85	65	60	70	65	60	55	45	50	55	55	45	60	50	50	50	50
10	100	68	64	50	57	61	57	61	64	07	50	43	50	43	54	64	57	36	36	46*	49*
11	100	64	68	59	64	55	55	46	46	46	36	50	46	27	32	41	36	27	18	18	36
12	100	62	65	54	46	42	39	46	54	50	31	46	42	35	35	23	31	31	31	31	39

Note: * group mean substituted for missing data.

DECLINE IN ECCENTRIC FORCE OUTPUT AS A PERCENT OF INITIAL MAXIMUM FOR FEMALE SUBJECTS

	Number of Contractions																				
Subject	1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
13	100	70	65	57	57	52	48	48	52	39	52	44	35	44	44	44	39	44	39	52	52
14	100	50	67	67	117	92	92	108	83	99	117	100	108	100	100	117	75	83	83	92	67
15	80	60	50	50	40	40	40	40	50	40	40	40	40	30	30	30	20	49*	50*	57*	53*
16	100	55	64	64	36	55	46	46	46	36	46	46	46	46	36	36	36	36	46	46	36
17	88	88	75	75	75	75	75	99	75	88	100	100	100	88	88	75	75	75	88	100	88
18	100	71	62	62	57	48	43	48	43	38	43	33	33	33	29	29	29	29	33	33	38
19	96	91	73	64	59	46	50	50	32	23	27	18	18	23	52*	51*	45*	49*	50*	57*	53*
20	100	69	75	50	63	50	63	56	63	69	56	50	44	38	38	50	44	38	38	50	63
21	88	94	75	75	69	69	63	56	56	50	44	38	38	38	38	38	38	38	44	38	38
22	100	75	67	75	75	58	58	58	50	58	58	58	50	58	50	42	42	58	50	58	50
23	100	67	75	83	83	92	83	75	67	58	58	67	68	67	67	58	58	58	50	58	67
24	85	85	85	80	65	75	65	60	45	40	35	40	30	40	55	40	35	30	30	40	30

Note: * group mean substituted for missing data.

DECLINE IN CONCENTRIC FORCE OUTPUT AS A PERCENT OF INITIAL MAXIMUM FOR FEMALE SUBJECTS

Subject	Number of Contractions																				
	1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
13	100	64	64	64	57	50	50	43	43	50	50	50	43	43	43	36	43	43	50	43	36
14	100	79	64	64	50	57	57	36	43	64	57	50	57	50	50	57	43	57	50	50	50
15	100	67	67	78	78	67	78	56	56	56	56	56	44	56	44	44	22	68*	64*	63*	61*
16	86	86	99	99	86	86	114	99	86	86	86	86	86	86	86	100	100	86	71	71	71
17	100	99	99	86	71	86	86	71	57	71	57	71	57	57	57	57	57	57	57	57	57
18	80	60	60	70	60	80	60	60	70	70	60	60	50	60	80	60	80	80	70	80	80
19	100	71	64	64	57	50	57	57	57	57	43	43	50	43	43	43	50	50	43	43	43
20	86	99	99	86	99	71	86	99	71	71	86	71	86	100	100	100	86	86	71	71	71
21	100	73	64	64	64	73	64	64	73	73	82	82	82	82	82	82	82	73	73	73	82
22	80	80	80	70	80	80	70	80	80	80	80	80	80	100	80	80	80	90	80	80	70
23	100	78	89	89	78	78	67	67	67	67	67	56	78	56	44	44	44	44	56	44	44
24	100	99	99	90	99	99	99	90	90	99	99	90	99	80	99	80	90	80	80	80	70

Note: * group mean substituted for missing data.

APPENDIX F

EXAMPLE OF QUESTIONNAIRE

QUESTIONNAIRE ON EXPERIMENTATION

1. Did you perform concentric contraction before eccentric? Y _ N _
2. After completion of concentric contraction did you experience pain? Y _ N _
3. After completion of eccentric contraction did you experience pain? Y _ N _

Rate pain experienced on a scale where 0 no pain and 10 extreme pain.

Concentric	0 1 2 3 4 5 6 7 8 9 10	Eccentric	0 1 2 3 4 5 6 7 8 9 10
During		During	
_ hrs after		_ hrs after	
Day 1 after		Day 1 after	
Day 2 after		Day 2 after	
Day 3 after		Day 3 after	
Day 4 after		Day 4 after	
Day 5 after		Day 5 after	
Day 6 after		Day 6 after	
Day 7 after		Day 7 after	
Day 8 after		Day 8 after	

FURTHER COMMENTS:

[redacted]