The Effects of Concentric and Eccentric Contractions on Strength, Retention and Bilateral Transfer

A Thesis

Presented to

the Faculty of University Schools

Lakehead University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in the

Theory of Coaching

by

Calvin Edward McDonald

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TABLE OF CONTENTS

ABSTRACT

Title of Thesis:	The Effects of Concentric and Eccentric Contractions on Strength, Retention and Bilateral Transfer.
Calvin Edward McDonald:	Master of Science in the Theory of Coaching, 1978.
Thesis Advisor:	Dr. T. M. K. Song Associate Professor School of Physical Education and Outdoor Recreation Lakehead University.

The purpose of this study was to examine the effects of two different strength training methods, (concentric and eccentric) on strength, retention and bilateral transfer. Subjects were 22 male volunteers, aged 16 to 17. Subjects were randomly assigned to one of two treatment groups and to exercise the left or right elbow flexor - extensors. Following a preliminary training and safety period the subjects were pre-tested on the four dependent variables static flexion, static extension, dynamic flexion and dynamic extension at multiple angles of 90, 105, 120, and 135 degrees. The groups alternated each week training Monday, Wednesday and Friday while the other group trained Tuesday and Thursday. Both groups performed 3x6 RM at a velocity of 7.2 revolutions per minute. The instrumentation designed by the investigator was used for training and testing. The non-trained arm remained in a standardized position during training and testing. Subjects were assessed for strength at the beginning of a 6 week training program, at the conclusion of training and after a 4 week retention period. Data were analyzed with a four-way split plot ANOVA, t-tests and percentage changes. The statistical index was represented by the higher score of two trials. An alpha level of .05 was accepted for all statistical procedures. Results showed: (a) strength training methods (concentric and eccentric) improved static and dynamic strength, (b) a significant difference was demonstrated among test angles, (c) specificity between static and dynamic testing procedures was present on a percentage basis, (d) there was a wide range of response among subjects to the exercise regimen, (e) eccentric tension was greater than concentric or isometric tension, (f) neither strength training method was superior to the other, (g) following 4 weeks of detraining neither training procedure resulted in a significant loss of strength, (h) neither training procedure resulted in a significant transfer of strength and (i) the trained arm was superior to the non-trained arm on the 4 test items.

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My thanks are also extended to my subjects who gave a great deal of time and effort over the course of the experiment.

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LIST OF FIGURES

Figure		Page

LIST OF TABLES

Chapter 1

INTRODUCTION

Purpose of the Study

The purpose of this study was to examine the effects of concentric and eccentric training methods upon the acquisition and retention of strength, and bilateral transfer.

Significance

The effects of muscle conditioning programs upon static and dynamic strength have been the subject of extensive research; however, investigations have been limited almost exclusively to isotonic and isometric training methods. The concept of predominantly eccentric work and its effect on strength, and bilateral transfer has received comparatively little research attention.

Training programs employing eccentric contractions have resulted in strength increases. However, there have been few indications which show eccentric training to be more or less effective as a training stimulus than concentric training. The answer remains somewhat elusive since the results of studies using eccentric contractions are limited and those which do exist are somewhat contradictory. Although past research has made noteworthy contributions to the understanding of eccentric contractions their results have provided more new questions than answers to the purpose of the original research.

Several studies suggest that muscle soreness during eccentric contractions may severely inhibit strength gains. Alterations in the experimental design would attempt to minimize muscular soreness and differences between concentric and eccentric contractions associated with an increase in velocity. If this study were successful in eliminating the aforementioned concepts then it may clarify which type of contraction results in the greatest strength gains. If the training regimen proves superior to the conventional type of exercise it would appear that the present instrumentation and training methods do not lend themselves to optimal strength development.

The most efficient method of achieving strength in a short period of time remains a controversial and intriguing issue to the coach and athlete. Despite the prolonged and concentrated efforts there is still no generally accepted "best method" for increasing muscular strength. Consequently the emergence of a scientifically supported strength training method would be a valuable contribution to sports training.

Despite the interest in strength development, there has been remarkably little research dealing with the retention of newly acquired levels of strength once training has been terminated. The basic investigation of whether transfer of strength does occur in the contralateral appendage with an eccentric or concentric training program seems pertinent. The contradictory evidence regarding under what condition transfer occurs also indicates a need for further investigation. The specific nature of the cross transfer effect and the rate of retrogression are questions that have never been thoroughly answered at the experimental level.

It is the purpose of this study to determine the most effective type of muscular contraction for the acquisition and retention of strength and bilateral transfer. It could clarify several controversial and contradictory findings reported by previous studies. The prospective value of this investigation lies in its potential to add to existing knowledge by employing new training techniques and ultimately providing tenable answers to researchable questions.

The research to date, although extensive, is not conclusive with respect to any one of the aspects proposed in this study, it would seem justifiable to pursue the problems.

Limitations

The following are factors which limited this study:

1. Although standardized motivational procedures were provided, it is possible that these were ineffective or inconsistent and consequently, motivation must be considered a limiting factor.

2. Subjects understood training and testing methods thoroughly. They followed the investigator's instructions and did their best to exceed previous records.

3. The use of volunteers produced a nonrandomized sample and consequently, this becomes a limiting factor with respect to statistical analysis and subsequent generalizations.

4. The subjects' willingness to abide by instructions concerning extracurricular activities becomes a limiting factor.

5. An alpha level of .05 is established as the level of significance for statistical tests.

Delimitations

The following delimitations apply to this study:

1. Male High School students (N=22) at Port Arthur Collegiate

Institute constituted the subjects for this study.

2. The training period was restricted to (MWF) and (TTH) every other week for 6 weeks.

3. The two training methods were equated on range of motion, speed of movement, maximal effort, and rest intervals between sets and exercise periods.

4. The instrumentation devised by the investigator was used for training.

5. The testing or training procedure does not guarantee a physiological rather than a psychological end point of effort.

Definitions

1. Eccentric contraction: The contracting muscle is lengthened due to an externally imposed force.

2. Concentric contraction: A muscle develops tension sufficient to overcome a resistance so that the muscle actually shortens and moves a body part in spite of the resistance.

3. Maximal strength: The subject exerts force with one or more defined muscle groups when he is asked to contract the muscles as strongly as possible in a predetermined position under the specified conditions.

4. Retention strength score: The score represents the amount of newly acquired strength which remained following an inactivity period.

5. Decrement Score: The score refers to the amount of strength lost due to an inactivity period (Sysler & Stull, 1970).

6. Repetition Maximum (RM): The maximum load with which a given movement can be correctly executed for the given number of repetitions. A workload of 3x6 RM would imply 3 sets of 6 maximum repetitions, with adequate rest between each successive set.

7. Bilateral transfer: A phenomena in which there is a diffusion of motor impulses to both the exercised as well as the unexercised limbs. Bilateral transfer is synonomous with cross education and neuromuscular overflow.

8. Contralateral: The homologous unexercised muscle group on opposite side of the body.

9. Ipsilateral: Pertains to the appendage which receives exercise.

Chapter 2

REVIEW OF LITERATURE

The research reviewed in this chapter represents those investigations of particular relevance to the present study and those which best epitomize the findings of the majority of researchers.

For the purpose of greater convenience the literature relating to this problem has been summarized under the following headings: (a) Eccentric Exercise, (b) Retention of Strength, and (c) Bilateral Transfer.

Eccentric Exercise

It has been well documented that eccentric tension is greater than maximal concentric tension (Doss & Karpovich, 1965; Rasch, 1974; Singh & Danielson, 1975). Doss and Karpovich (1965) demonstrated that the elbow flexors have an eccentric force 13.5% and 39.7% greater than isometric and concentric forces respectively. Singh and Karpovich (1966) observed that when exercising the forearm extensors the isometric force was greater than the eccentric force in the range of 120 to 140 degrees.

The magnitude of this difference is determined by the force - velocity characteristics of the muscle in concentric and eccentric work (Komi, 1973; Asmussen, Lammert & Hansen, Note 1). Several investigators (Abbott, Bigland & Ritchie, 1952; Rogers & Berger, 1974) have verified or provided approximations of the inverted S-shape curve reported by

Hill (1938).

Hellebrandt and Houtz (1958) previously suggested that for increasing muscular force, work is not as important as the rate at which it is done. It seems apparent, therefore, that one means of increasing muscular torque through a specific range of motion is to apply resistance at a speed which produces optimal power output. The specific effects of various exercise speeds have been examined by Osternig, 1975; and Rogers and Berger, 1974.

Rogers and Berger (1974) employing isokinetic training methods found 7.5 revolutions per minute to produce optimal tension during concentric or eccentric contractions of the elbow flexors. The velocity effect was significant only during eccentric contractions. Osternig (1975) later reported maximum isokinetic torque occuring at different joint positions with increases in knee extension speed. Jones (1973) has claimed that for maximum response to eccentric training the movement should be slow enough to permit the subject to stop the stretching force if he is able. Previous research (Clarke & Clarke, 1963; Hellebrandt & Houtz, 1956; Hettinger, 1961) suggested that tension is the stimulus for strength, therefore, the type of contraction which induces the most tension should result in the greatest strength gains. Based on this premise several investigators (Johnson, Adamczyk, Tennoe, & Stromme, 1976; Laycoe & Martenuik, 1971; Mannheimer, 1969; Peterson, 1960; Singh & Danielson, 1975) initiated studies on the basis that eccentric contractions would result in superior strength gains when compared to concentric or static contractions capable of developing less tension. Tension as the stimulus for strength during voluntary contraction may be valid, but Laycoe and Martenuik (1971) and Johnson _et al_. (1976) question the validity of forced loading during eccentric work as a further stimulus for strength development.

Among the first investigators to compare eccentric training to other training methods were Peterson (1960), Boileau (Note 2) and Logan (Note 3). The investigators concluded that there were no significant differences in strength gains when performing concentric, eccentric or static contractions.

Singh and Karpovich (1967) attempted to determine the effects of training the elbow extensors of subjects eccentrically with a dynamometer for 20 contractions per day, 4 times a week for 8 weeks. Significant strength gains measured using concentric, eccentric and static tests of both the forearm flexors and extensors were observed. The mean increase measured eccentrically, concentrically and isometrically of the forearm extensors were 22.9%, 42.8% and 40.3% respectively.

Singh and Danielson (1975) compared isometric, concentric, and eccentric training methods on the leg extensor muscles of 30 subjects, 3 times per week for 8 weeks. A leg dynamometer (Singh, 1972) was used as a testing and training device for the leg extensors. Attempting to eliminate muscle soreness subjects began with 6 maximum contractions and increased 3 contractions per training session until subjects were performing 18 contractions per training session by the fifth week. Each contraction phase took 6.5 seconds to complete. The subjects were tested and trained isotonically from 60 degrees flexion to 150 degrees extension. The isometric training and testing were performed at knee angles of 75, 100 and 145 degrees. The concentric, eccentric, and isometric training methods resulted in an average weekly strength gain of 2.83%, 3.07% and 3.79% respectively. The concentric group showed significant strength improvement over isometric ($p<.05$) and eccentric ($p<.01$) training groups after 6 weeks. However, for the 2 week duration of the training period the concentric group showed no significant improvement while the eccentric group improved significantly ($p<.01$). Singh and Danielson (1975) support the findings of Mannheimer (1969) and Komi and Buskirk (1972) which suggest that there is a delayed tissue response to eccentric training.

A study on eccentric, concentric and static contractions by Talag (1973) found the group that trained utilizing eccentric contractions experienced a severe loss in strength initially due to muscle soreness. The appearance of muscle soreness during eccentric work has been well documented (Johnson & Adamczyk, 1975; Komi & Buskirk, 1972; Komi & Viitasalo, 1977).

Komi and Buskirk (1972) studied the effects of eccentric and concentric muscle conditioning on muscle tension by using a special electrical dynamometer as a testing and training apparatus. The instrumentation was designed to measure and record the concentric, eccentric and isometric forces of the forearm flexors throughout 105 degrees of movement (65 degrees - 170 degrees). Subjects were 31 college males who trained for 7 weeks, 4 times per week, performing 6 maximum contractions of the right forearm flexors. The eccentric group showed a significant increase ($p<.01$) in concentric, eccentric and isometric maximal tension. The concentric training caused a significant increase over the control group in eccentric ($p<.05$) and concentric ($p<.01$) maximal tension but not in isometric maximal tension. The upper arm girth of the eccentric group differed significantly from the control group ($p<.01$) while the concentric group did not attain statistical significance.

Johnson (1972) indicated that training eccentrically with one set of 10 repetitions using 80% of 1 RM performed 3 times weekly over an 8 week training period would produce a significant increase in strength. Four subjects trained by doing a bench press while 5 other subjects lowered a weight performing the eccentric phase of the bench press. The 9 subjects trained quadriceps concentrically by performing knee extensions with one leg. The same subjects trained with eccentric contractions by lowering a weight from a position of knee extension with the opposite leg. Neither training procedure was found superior to the other and contrary to Komi and Buskirk (1972) and Singh and Danielson (1975) week to week strength changes involving concentric or eccentric training methods were essentially the same.

Johnson and Adamczyk (1975) had 12 medical students, 6 experimental and 6 control, perform concentric and concentric-eccentric contractions for 6 weeks. During the knee extension, knee flexion and bench press, both limbs were employed to lift the weight concentrically while one limb lowered the weight eccentrically. While the strength gains of the limb exercised con-eccentrically were greater than the mean gains of the limb trained only concentrically, the difference between the two means was not significant. During the pre-test none of the subjects could execute one bar dip. While the results are somewhat biased by including one female subject, the strength increases and gains in test repetitions are quite modest, when concerned with the training state of the subjects.

Pletnev (1975) reported the combined regimen to be more effective than concentric, isometric, or eccentric training regimens for development of maximum dynamic and static strength. Other investigators (Bannister, 1966; Ferris, Note 4) also compared the combined regimen to conventional training methods.

Johnson et al. (1976) compared concentric and eccentric training methods by training the arm and the leg on one side of the body with concentric contractions while the contralateral limb performed eccentric exercise. Concentric exercise was against a resistance 80% of 1 RM for 2 sets of 10 repetitions. Eccentric exercise was against a resistance of 120% 1 RM for 2 sets of 6 repetitions. After training 3 times per week for 6 weeks neither training procedure produced dynamic or static strength gains significantly different from the other. The possible effects of cross education and central facilitation were not evaluated by Johnson (1972), Johnson and Adamczyk (1975) and Johnson et al. (1976).

Rasch (1974) presented a review of eccentric exercise and raises some doubt as to the practicability and practicality of the eccentric form of exercise. Hill (1951) suggested that the eccentric phase of reciprocal maneuvers may constitute a skillful method of making use of the optimum tension-producing ability of muscle providing an additional source of force for the production of power. Kinpara, Haruyama and Miura (1966) substantiated the theory of Hill by demonstrating the eccentric phase of reciprocal maneuvers before the concentric contraction begins facilitated performance, while jumping vertically from a measuring board or throwing the shot. Moore (1966) reported 25% - 30% facilitation of the flexor response could be attained by active resistive stretch just prior to maximum isometric contraction. Muller and Rohmert (1963) proposed that the duration and amount of stretch, which is a by-product of muscular contraction, is the principle stimulus for an increase in strength. The recent popularity of depth jumping (Scoles, 1978) is also based upon the stimulation of the myotatic reflex causing a powerful contraction to prevent over-stretching of the muscle. While Scoles failed to attain significant results utilizing the depth jumping technique, the author concluded that further manipulation of the experimental variables was required to support or refute the theory of depth jumping.

The following conclusions seem justified:

1. At most angles of the joints which have been tested eccentric tension is greater than isometric or concentric tension (Doss & Karpovich, 1965; Komi & Buskirk, 1972; Rasch, 1974; Singh & Danielson, 1975; Singh & Karpovich, 1966).

2. The optimal speed of movement appears to be 7.5 revolutions per minute to produce optimal tension during concentric or eccentric contractions of the elbow flexors (Rogers & Berger, 1974).

3. Tension is a prominent factor in the development of strength (Clarke & Clarke, 1963; Hellebrandt & Houtz, 1956; Hettinger, 1961).

4. Theories of strength development when applied within laboratory format have failed to attain data consistent with expected theoretical values.

5. The appearance of muscle soreness during eccentric work has been well documented (Johnson & Adamczyk, 1975; Komi & Buskirk, 1972; Komi & Viitasalo, 1977; Talag, 1973).

6. Research suggests that there is a delayed tissue response to eccentric training (Komi & Buskirk, 1972; Mannheimer, 1969; Singh & Danielson, 1975).

7. Stimulation of the myotatic reflex may enhance the optimal

tension producing ability of a muscle causing a greater summation of power (Hill, 1951; Kinpara et al., 1966; Moore, 1966).

Retention of Strength

Several investigators have reported significant retention of either strength or muscular endurance (Clarke, Shay, & Mathews, 1954; Shaver, 1973, 1975; Sysler & Stull, 1970) following varying periods of inactivity.

Shaver (1973) conducted a 6 week isotonic training program on relative muscular endurance at various levels of strength in the exercised and unexercised arms. The training program resulted in significant increases in maximum isometric strength and muscular endurance of ipsilateral and contralateral arms. While no significant amount of newly acquired isometric strength was lost despite 1 week of detraining, 3 and 5 weeks of inactivity resulted in a significant loss of strength in exercised and unexercised arms. Detraining of 5 weeks resulted in a significant loss of muscular endurance of exercised arm while 3 and 5 week inactivity periods resulted in a significant loss of muscular endurance in the unexercised arm. Shaver (1973) concluded that after the initial rapid drop-off between 3 and 5 weeks the absolute loss begins to decline appreciably.

Shaver (1975) later determined the effects of a 6 week high intensity, low repetition, isotonic training program on muscular strength in the conditioned and unconditioned arms. The retention of the newly acquired strength was tested after 1, 4, 6, and 8 weeks inactivity periods. Shaver (1975) found the decline in strength to subside after 5 and 6 weeks of detraining.

MacDougall, Ward, Sale, and Sutton (1977) attempted to determine whether the changes in muscle size and contractile strength which occurs with resistive training are reflected by changes in muscle energy stores, and if so, whether they are reversible with immobilization. Following 5 months training the 9 subjects showed an increase in upper arm girth and elbow extension strength of 11% and 28% respectively. The 5 week immobilization procedure where exercised limb was placed in a cast resulted in decreases in upper arm girth, and elbow extension strength of 5% and 35% respectively, below pre immobilization values.

Muller (1959) and Hettinger (1961) suggested that the loss of strength after training by daily contractions is at the rate which it was gained. The slower increase by weekly training leads to a more permanent acquisition of strength. Permanent increase in muscle strength may be maintained by long interval training or short interval training followed by maintenance of the trained state of one contraction daily. Rose, Radzyminski, and Beatty (1957) were unable to maintain the peak of maximum strength with decreasing frequency of exercise effort. Hettinger (1961) concluded that "normal" muscle strength shows slow steady improvement as training sessions are given. Intermittent type training resulted in a greater retention of strength each time training was resumed after a rest period.

Muller and Hettinger (1954) reported average decreases in strength to be approximately 3% per week following maximal isometric training for several weeks. Muller (1970) later suggested that in the complete absence of any contraction of a muscle by narcotising the nerve, strength decreases approximately 5% per day. Applegate and Stull (1969) concluded that the closer one comes to his maximum possible endurance attainment, the greater is his absolute loss following cessation of training. Shaver (1973, 1975) stated that this rule was also applicable when concerned with strength training.

Muller (1970) suggested that the findings of studies on retention of strength are distorted by comparing unequal states of training. When recording retention of strength the testing contraction constitutes a stimulus which interrupts the progressive loss of strength.

Based on the research completed to date the following conclusions seem justified:

1. The absolute loss of strength declines appreciably after 5-6 weeks of detraining (Shaver, 1973, 1975).

2. The loss of strength after training by daily contractions is at the rate which it was gained (Hettinger, 1961; Muller, 1959).

3. The closer one comes to his maximum possible strength or endurance attainment, the greater is his absolute loss following cessation of training (Applegate & Stull, 1969; Shaver, 1973, 1975).

4. Intermittent type training results in a greater retention of strength each time training is resumed after a rest period (Hettinger, 1961).

Bilateral Transfer

Research has demonstrated that overload exercise not only increases the capacity of the muscles subjected to direct training but has a significant effect on the power, endurance, and strength of the contralateral unpractised limbs.

The transfer effects of exercise has been studied by several early investigators (Davis, 1899; Scripture, Smith, & Brown, 1894). Scripture *et al*. (1894) were among the first investigators to report that the development of strength in one arm was accompanied by an increase in the contralateral limb. Davis (1899) theorized that the increase in strength was the result of an overflow of nerve impulses. Davis concluded that exercise producing a gain in endurance, strength or muscle girth in one arm would cause a similar though smaller gain in the contralateral limb.

Hellebrandt, Parrish and Houtz (1947) suggested that the widespread synergistic contraction manifested during contractions was responsible for the phenomena. Later, Hellebrandt (1951) attempted to explain the neuronal links which perpetuate motor impulse overflow to the contralateral appendage. Hellebrandt concluded that the phenomena was simply "a simultaneous discharge of identical efferent impulses over bilateral pathways differing only in volume" (142). The investigator further postulated that the bilateral transfer of nervous impulses may be less when the dominant limb is exercised due to the "more highly trained and discrete neural pathways of the dominant limb" (140).

Rasch and Morehouse (1957) contributed a large portion of the gain in strength of the contralateral limb to the training of anti-gravity muscles to compensate for the effect of body balance during the exercise. Slater-Hammel (1950) suggested an alternative explanation in that the transfer occurred due to an increase in the subject's tolerance to fatigue. The investigator suggested that psychological and physiological adaptations allow a greater effort influencing the performance of other muscle groups.

While controversy exists concerning the most effective means of developing cross transfer of strength, majority of investigators agree that cross transfer of strength is greatest when work has been performed in overload (Hellebrandt, Houtz, & Krikorian, 1950; Hellebrandt & Houtz, 1956; Hellebrandt & Waterland, 1962; Shaver, 1970).

Walters (1955) reported the clinical significance of cross education in immobilized, non functioning, normally, innervated muscles. Walters concluded that as much could be gained by indirect practice in overload as by direct practice in underload.

Zimkin (1957) examined the effects of irradiation on centres of symmetrical non-exercised muscles on the development of power, speed of movement, and endurance. It was found that in each experiment the gain in power, speed of movement or endurance was always accompanied by a gain in the untrained symmetrical muscles.

Coleman (1969a) compared the effectiveness of isotonic and isometric exercise on the development of strength and bilateral transfer. The experiment consisted of 63 college male volunteers enrolled in physical education. For the duration of the 12 weeks the isotonic group performed 2x5 RM for forearm flexors while the isometric group performed 2-20 second static contractions maintained at an elbow angle of 110 degrees with a weight that could be lifted only 5 repetitions. The isometric and isotonic testing were initiated at this same angle. While strength increases and bilateral transfer did occur, no significant differences were found between the two methods of training. Lawrence, Meyer and Matthews (1962) reported an increase in strength of the unexercised quadriceps ranging between 65% and 100% of the strength increases recorded for the exercised limbs of both the isometric and isotonic training groups.

Rose, _et al_. (1957) attempted to determine cross education effects by exercising leg extensors which had been immobilized in a cast. Once the cast was removed the limb was exercised until strength curve began to plateau. Training of the normal limbs resulted in strength increases while the contralateral limbs could only be maintained by cross education. The cross education effect was nullified when the unexercised limb was immobilized by a cast. The authors further concluded that cross education does not represent a balance between strength of two extremities but that the two strength curves continue to parallel one another.

Coleman (1969b) found isotonic contractions to produce significant increases in dynamic but not static strength of the contralateral limb, while isometric training resulted in both static and dynamic strength increases of the contralateral limb. Logan and Lockhart (1962) had previously reported a non specific transfer of strength to the contralateral limbs when training leg extensors isotonically.

Wagner (Note 5) attempted to determine the effects of isokinetic exercise upon the power, strength, and electromyographical activity of the elbow flexors of the contralateral limb. The experimental group consisted of 18 female non physical education students. The exercise program consisted of 6 different exercise speeds performed 3 times per week for 5 weeks. Results indicated that the ipsilateral elbow flexors of the experimental group increased significantly in strength at all speeds of contraction. The contralateral elbow flexors increased significantly in strength at all speeds except 20 and 25 revolutions per minute. The author concluded that transfer did not occur at these particular exercise speeds due to an insufficient level of facilitation due to the characteristics of spacial and temporal summation. Electromyographical facilitation to the contralateral limbs varied from 5 to 10 millivolts.

Investigators (Lagasse, 1974; Morris, 1974; Smith, 1970; Ashton, Note 6) attempted to evaluate the effectiveness of the myotatic reflex in augmenting an increase of muscular strength and contralateral transfer. Smith (1970) completed an extensive study on 82 male subjects comparing the effects of isometric training and myotatic stretch training on the quadriceps muscles to determine the facilitatory effects upon strength and contralateral transfer. The myotatic exercise consisted of an isometric contraction followed by a myotatic stretch which in turn was followed by an isotonic contraction and completed with an isometric contraction. The dominant stronger leg was used for experimental purposes. Following 6 weeks of myotatic stretch training the ipsilateral and contralateral limbs improved 23% and 16.4% respectively. Smith postulated that the facilitatory effect of the myotatic reflex initiated during stretch may achieve a neuromuscular threshold required to activate an irradiation overflow of neural impulses to the contralateral limb. The intrafusal tension and velocity of stretch may facilitate motor neuron activity emanating from the muscle spindles.

Based primarily upon the report of Smith (1970) Ashton (Note 6) investigated the effects of myotatic and isometric training on the ipsilateral leg and retention of strength of the contralateral limb immobilized in a cast subsequent to injury and surgery. The experimental design of myotatic stretch training initiated by Smith (1970) was modified by Ashton (Note 6). Three groups of 5 subjects trained 4 days per week for 3 weeks performing 6 isometric or 6 myotatic contractions. No significant difference was found between the two groups on acquisition of strength of ipsilateral limbs or retention of strength in the injured leg at completion of the training period. The myotatic group was significantly ($p<.05$) more effective than no training in helping retain static strength of the quadriceps of the contralateral limb.

Contradictory findings were reported by Lagasse (1974) who observed a loss of tension for the contralateral homologous muscles and Morris (1974) observed a gain in tension for the contralateral antagonist muscles after the myotatic stretch had been imposed on the ipsilateral limb. The facilitation of the extensor muscles of the stretched limb and the inhibition of the contralateral homologous muscle group are in agreement with the crossed extensor reflex theory (Carpenter, 1971). Other investigators who support the bilateral transfer phenomena are Carlson (1973), Hellebrandt and Waterland (1962), Shaver (1970), (1973), (1975) and Wellock (1958).

Bowers (1966) found isometric, static and autosuggested muscular contractions to elicit no cross transfer of strength or muscular girth from the exercised arm to the contralateral limb. Panin, Lindenauer, Weiss, and Ebel (1961) concluded from their studies that the amplitude and frequency of the potentials in the contralateral limb were of insufficient magnitude to constitute an exercise effect. Various other investigators (Gardner, 1963; Kaufmann, Note 7) also failed to substantiate the cross transfer phenomena.

Gregg, Mastellone and Gersten (1957) reported that during simple, non resistive and isometric exercises that there was no over-flow of neural impulses to the contralateral limb. However, when the subjects performed isotonic exercises overflow occurred as fatigue was approached and a cross exercise effect was apparent. Position of the unexercised arm and stabilizing of the body did not alter the results. Hellebrandt (1951) suggested that the facilitating mechanisms underlying cross education may be related to the effects of reciprocal and alternate exercise.

Melia (1958) utilizing an arm ergograph found that when the arms were working simultaneously to the point of exhaustion both arms performed less work than when they worked alone. When the work of one arm ceased the other showed an increase in the amplitude of the flexions. The increase was directly proportional to the fatigue of the arm that ceased work. If work was started with the left arm and after its cessation, was continued with the right, then regardless of the duration of the preceding work with the left arm, the performance of the right was reduced.

Davis (1899) concluded from the results presented by Patrizi (1893) that during simultaneous action more attention was paid to the right hand than to the left hand. During alternating contractions the right hand appeared to facilitate the work capacity of the left hand. Evidence of central facilitation due to the simultaneous contraction of bilateral muscle groups compared to the contraction of unilateral muscle groups has been reported by Hellebrandt, Houtz, and Eubank (1951) and Partridge (1954). Both Henry and Smith (1961) and Kroll (1965a, 1965b) reported contradictory results refuting the concept that simultaneous bilateral movements result in central facilitation effects.

Despite interstudy differences, a synthesis of the relevant research reveals some trends and facilitates conclusions regarding the phenomena of cross transfer.

1. Several investigators have offered theories to explain the

phenomena of cross transfer; (a) An overflow of nerve impulses (Davis, 1899); (b) The widespread synergistic contraction of muscle groups (Hellebrandt, et al., 1947); (c) Training of antigravity muscles to compensate for the effect of body balance during exercise (Rasch & Morehouse, 1957) and (d) Transfer occurs due to an increased tolerance to fatigue. Psychological and physiological adaptations allow a greater effort influencing the performance of other muscle groups (Slater-Hammel, 1950).

2. Transfer effects may be less when the dominant limb is exercised (Hellebrandt, 1951).

3. Cross transfer of strength is greatest during overload (Hellebrandt & Houtz, 1956; Hellebrandt, et al., 1950; Hellebrandt & Waterland, 1962; Shaver, 1970).

4. The myotatic stretch reflex may facilitate an overflow of neural impulses to the contralateral limb (Smith, 1970; Ashton, Note 6).

5. There may be a non-specific transfer of strength to the contralateral limb (Coleman, 1969b; Logan & Lockhart, 1962).

6. Cross transfer effects may be most prominent as the muscle approaches fatigue (Gregg, et al., 1957).

7. The facilitating mechanisms underlying cross transfer may be related to central facilitation (Hellebrandt, 1951).

8. Those studies which have failed to demonstrate a significant change in strength of the contralateral limb have generally incorporated isometric exercise (Bowers, 1966; Gardner, 1963).

Chapter 3

METHODOLOGY

This chapter presents the procedures used in the study in the following sequence (a) Subjects, (b) Testing, (c) Instrumentation, (d) Preliminary Training and Safety, (e) Training, and (f) Retention.

The agonist and antagonistic muscles of the elbow joint were selected for experimental use in this study. The specific muscle group under study allowed a direct comparison with other comparative studies in which the training of these muscles has predominated.

Subjects

The study consisted of 22 volunteer male students enrolled in the Grade 11 physical education class at Port Arthur Collegiate Institute, Thunder Bay. Following pretesting, the subjects were randomly assigned to one of two groups, a concentric and an eccentric group. One of each pair of the experimental group were assigned randomly to exercise the right arm and the other to exercise the left arm. Originally 28 subjects were to be used in this study, however due to sporadic attendance and injury 6 subjects did not complete the training program and consequently were not included in the total analysis.

Subjects were instructed to keep their daily activities as regular as possible in terms of sleep, diet and avoid any activities which were shown to have a specific conditioning affect on the flexor-extensors of the elbow joint. During the experimental period the subjects participated in instructional basketball, badminton and volleyball as well as the training program.

Testing Procedures

Due to the possible specificity effect of strength training the muscular strength of each subject was assessed by both dynamic and static contractions. The instrumentation designed by this investigator in comparison with the tensiometer on static flexion and static extension at multiple angles (Clarke, 1970) was found to have a validity of .80 to .97 (N =22). This was considered acceptable and therefore the instrumentation served as a training device and testing device for static and dynamic strength.

When testing or training on the dynamometer the subject's upper arm rested on a firm pad while the lateral condyle of the humerus was placed directly in line with the mechanical point of rotation. The wrist bar was positioned even with the styloid process of the radius. The point of force application was made directly from the elbow flexor-extensor bar which was graduated in centimetres.

While participating in any test the experimenter urged the subject to exert his maximum force, but also told the subject to avoid any positions which may jeopardize testing of the arm flexor-extensors. Subjects performed in a room with the investigator, one assistant and 11 subjects arbitrarily selected from both experimental groups. During testing an assistant was responsible for the motor operation and safety switches while the investigator was responsible for data collection. The Vishay/Ellis 20-A Digital Strain Indicator was allowed to warm up at least 20 minutes before testing. Power to the gauges was turned on only during the actual performance of the exercise to prevent overheating and prolong the life of the gauges. Feedback was provided about the exerted force after each trial. The statistical index was represented by the higher score of the two trials (Wilmore, 1974).

Two experimental periods of approximately 2.5 hours with 3-minute rest intervals between trials was required to complete the prescribed number of tests. To control possible diurnal variations in strength (Hislop, 1963; Wright, 1969) all testing and training was carried out at the same time each day for the duration of the experiment. All subjects in the experimental groups were re-tested on both arms in a manner patterned after the initial examination period. In addition to the major pre- and post-tests, recordings were taken periodically during the training portion of the study. The description of the strength tests are shown in Appendix A, and the testing and training instrument in Figures 1 and 2.

Static tests. Subjects exerted maximal efforts at angles of 90, 105, 120 and 135 degrees of elbow flexion and extension. Subjects were instructed to increase force steadily to their subjective maximum for not more than 5 seconds. The time period was chosen as sufficient to attain maximal force and yet short enough to be endured without perceptible muscle fatigue.

Dynamic tests. The tests recorded the sustained effort throughout the range of motion at the prescribed angles of 90, 105, 120 and 135 degrees. Eccentric contractions were performed from 75 degrees to 135 degrees extension and concentric contractions from 150 degrees to 90 degrees flexion.

Instrumentation

An electrical dynamometer similar in concept to that reported by Komi (Note 8) and Singh and Karpovich (1966), although different in design was constructed. The dynamometer measures and records the continuous dynamic (concentric and eccentric) and static forces of the elbow flexor-extensors.

Power to the dynamometer was provided by a Dayton model 5K250 1/4 h.p. electric motor which drove a Radicon AAUD200 gear reducer (250:1) connected via a chain drive to the lever arm system providing a constant speed of 7.2 revolutions per minute. A 2.25 inch (5.71 cm) sprocket was keyed and set to the bar with tap screws while an identical sprocket was applied to the gear reducer. Standard 40 gauge chain was used to connect the drive axis to the output shaft. The lever arm mechanism pivoted on two 1 inch (2.54 cm) stainless steel shafts 8 inches (20.32 cm) in length. The shafts were supported by four SKF pillow block bearings. The bearings were mounted on a platform of .375 inch (.95 cm) T-1 steel. The lever arm system was constructed from .5 inch (1.27 cm) #6061 aluminum plate which were bolted to 1 inch (2.54 cm) stainless steel collars keyed and tapped to the pivitol shafts. The general arrangement of the dynamometer is shown in Figures 1 and 2.

The resultant forces attempting to accelerate or decelerate the rate of movement of the lever arm were measured by two micro strain gauges[1] rated at 120 ohms. The gauges were prepared in the engineering laboratory under ideal conditions. The half-bridge transducer was tested and balanced on a Tinus Olsen Electro hydraulic load frame.

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[1]Micro-Measurements, gauge type EA-06-250BG-120, Romulus, Michigan.

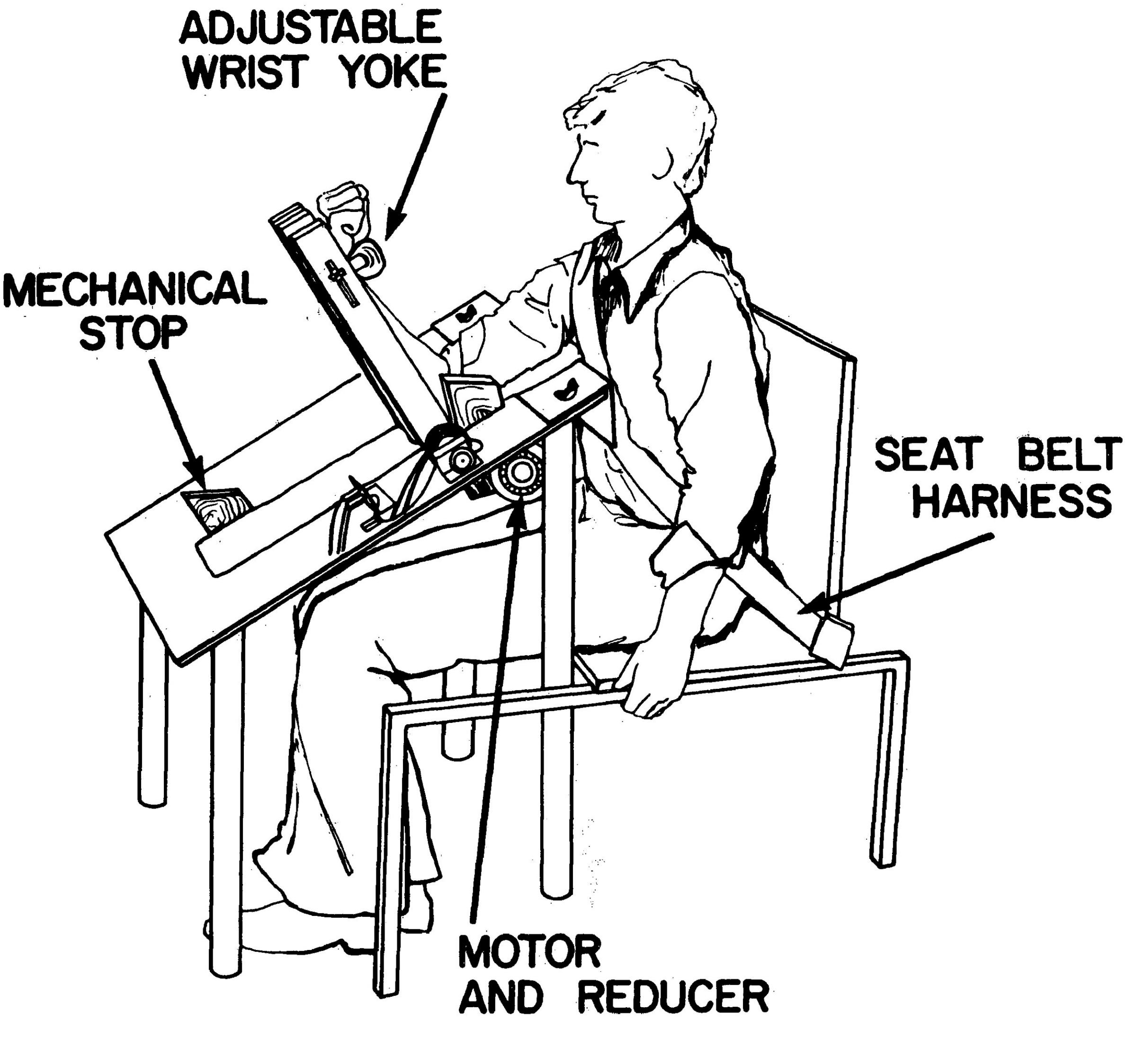


Figure 1. Dynamometer for Testing and Training.

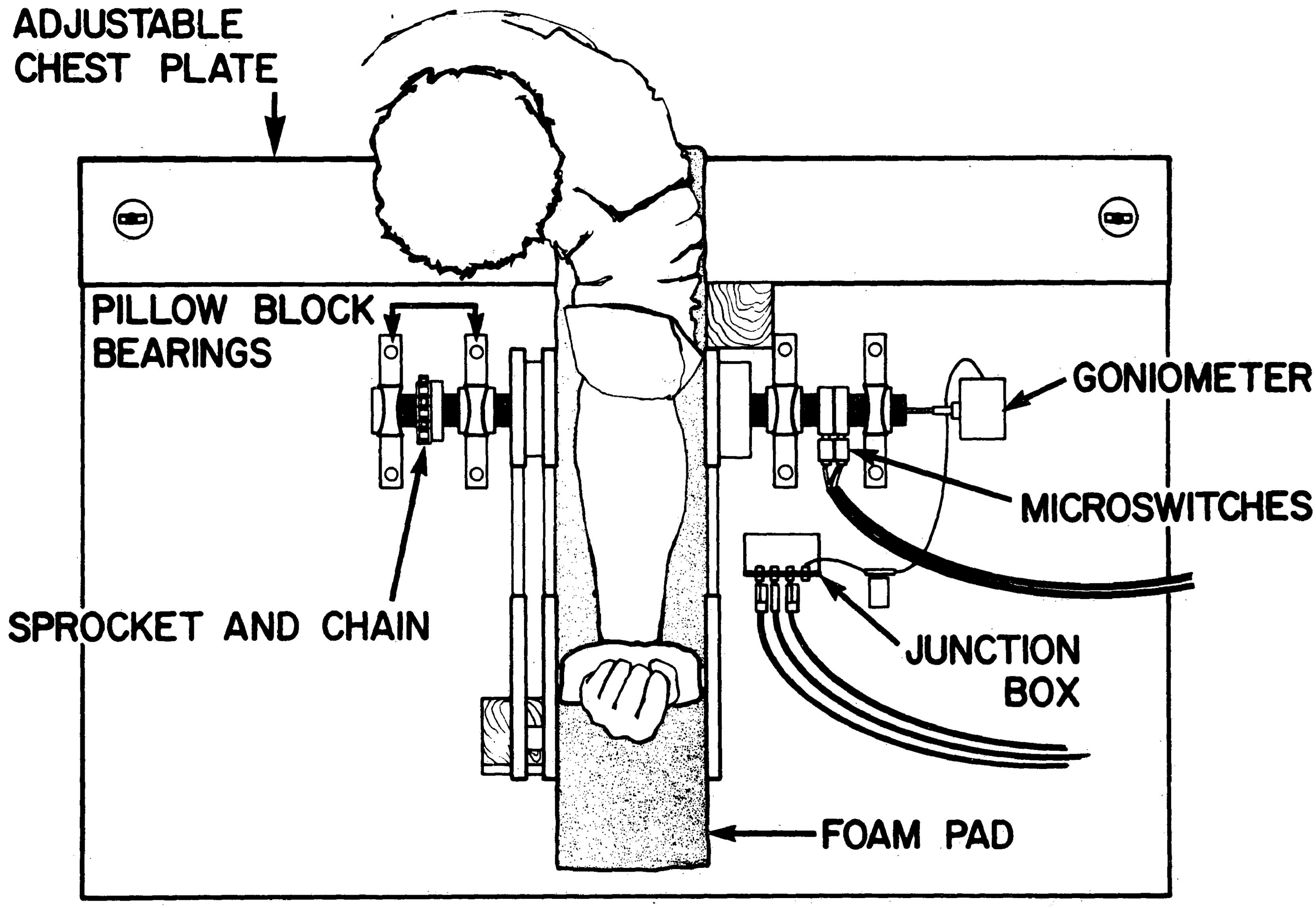


Figure 2. Dynamometer (top view).

The .5 inch (1.27 cm) aluminum lever arms were found adequate in that the distortion in the bar was found proportional to the force applied. This deformation was measured by the change in electrical resistance of two strain gauge elements attached to the lever arm. The hysteresis effect over the whole range of force applied was found to be minimal. Two strain gauges were installed 11 centimetres from the mean point of force application. This was considered the point of maximum moment and therefore optimal sensitivity. The strain gauge output was displayed on a Vishay/Ellis 20-A Digital Strain Indicator and amplified and recorded on a Beckman RS Dynograph. All recordings were taken with a paper speed of 25 mm/second. A schematic diagram of the recording system is shown in Figure 3.

Precision weights were used to calibrate strain in terms of the moment produced by suspending the weights on the wrist bar at 26, 27 and 28 cm. from the pivitol point. This range was found adequate to encompass the lever arm length of all the subjects. The lever arm was kept in a horizontal position throughout the calibration procedure. Recalibration of the strain gauges prior to the performance of each subject eliminated variables such as temperature, humidity, and permanent shaft deflection. Instrument precision was assessed by the repeatability of an output value for a particular input value and was shown by recalibration to be high on four separate occasions.

A 24 position rotary switch provided a method of recording the lever arm position every 15 degrees. Power for the rotary switch circuit was provided by a 1.5 volt dry cell battery. Electrical contact was made each time the lever arm moved through 15 degrees of motion, which generated a small impulse that was displayed on a Beckman RS

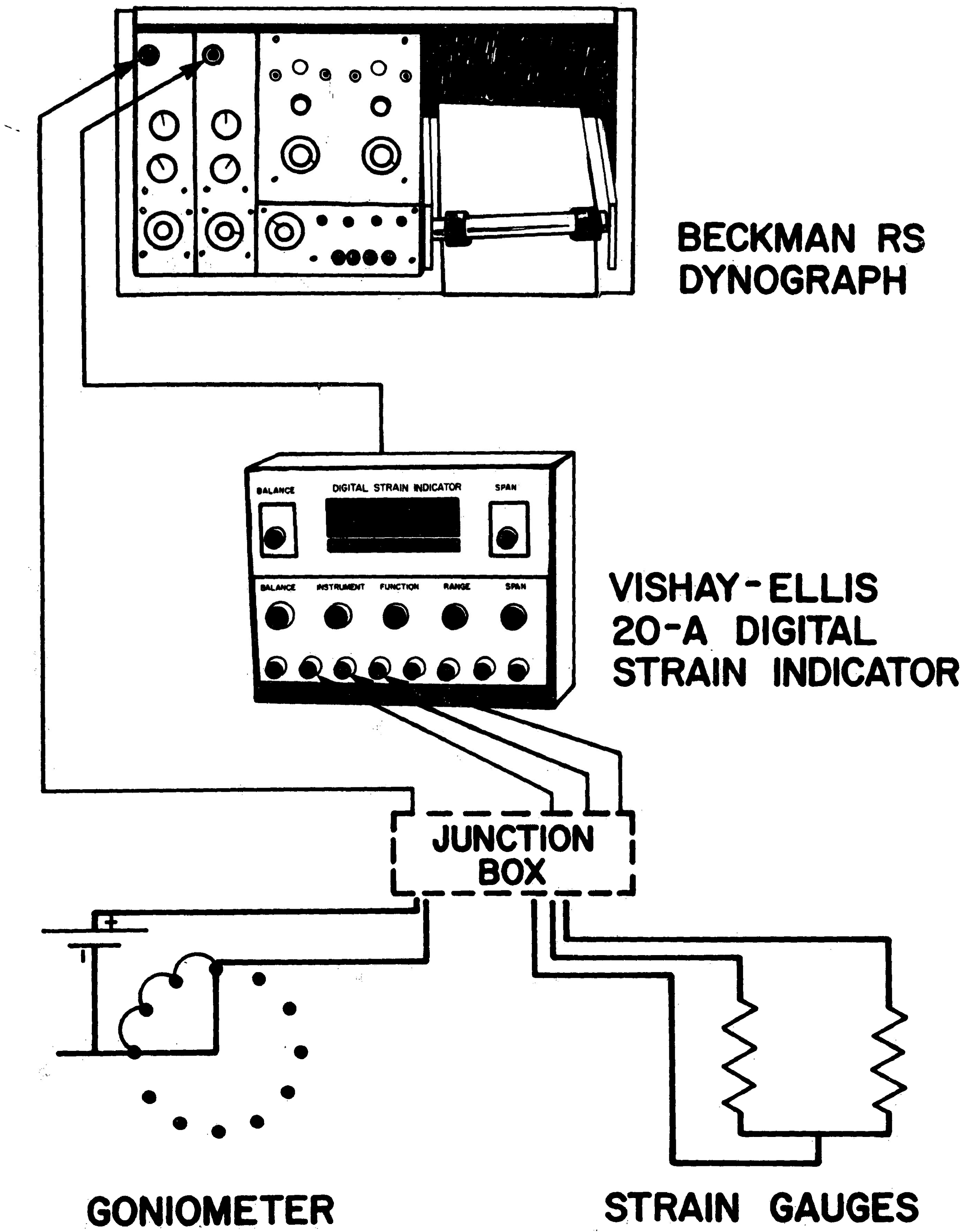


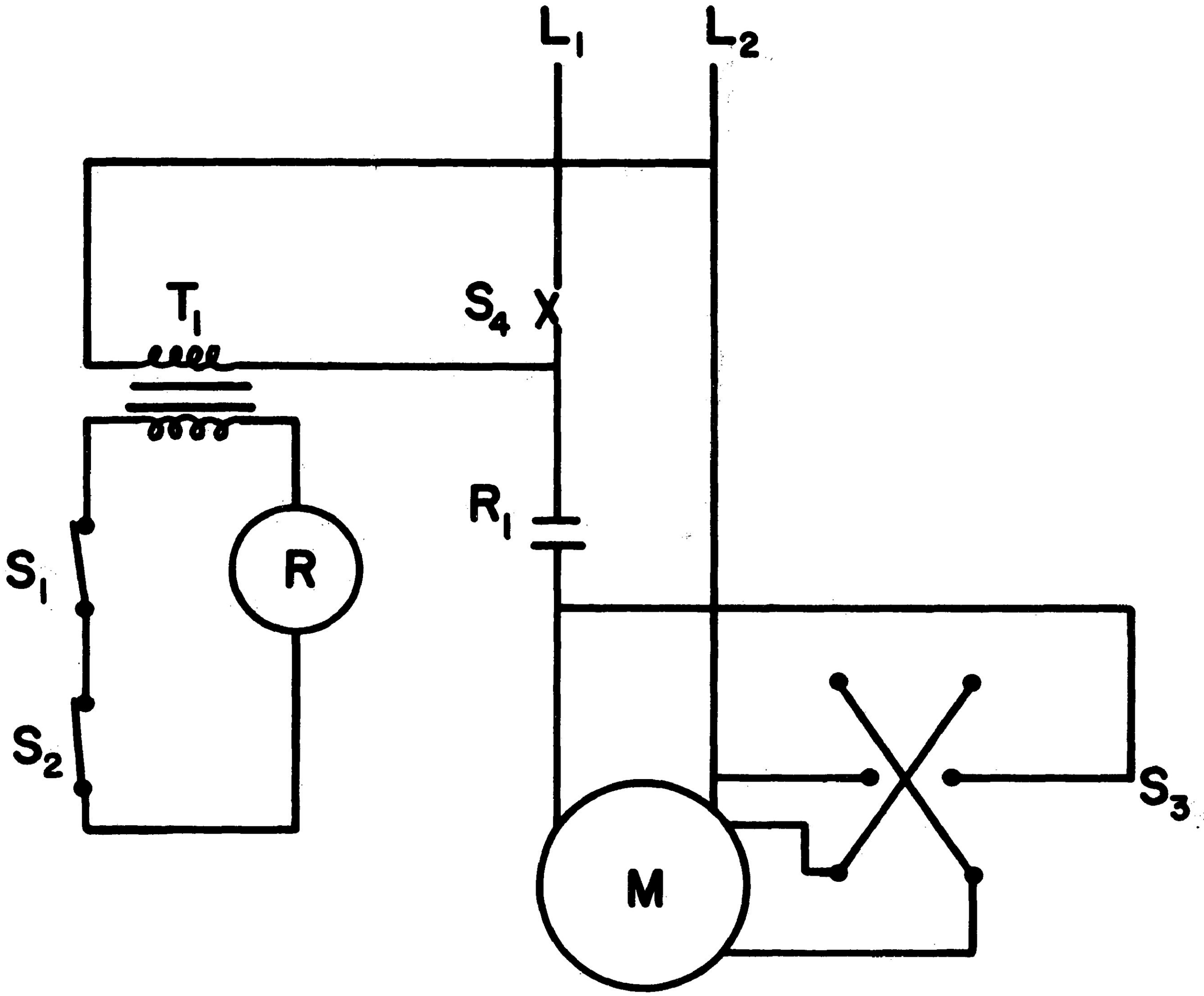
Figure 3. Recording System.

Dynograph. The rotary switch was calibrated with an international standard goniometer before each test. Microswitches were incorporated to stop the lever-arm automatically at the termination of each contraction. In the event that the micro-switch should fail to operate properly an in-line stop switch and mechanical stopping devices were installed to assure the safety of the subject. The subject could release his arm from the lever system at any time during the movement. A schematic diagram of the electrical system is shown in Figure 4.

The subject was seated in a chair with a high backrest and a seat belt across the shoulder being exercised to preclude the use of undesired muscles. The exercised arm was placed on an incline of 30 degrees with the elbow parallel to the sagittal plane of the body. The geometrical arrangement of the lever system and chest plate allowed adjustment for intersubject variability.

Preliminary Training and Safety

A preliminary training period was given one week prior to the initial training program. This training period served to familiarize both the subjects and the investigator with the procedures and instrumentation. During this time the subjects reported to the laboratory daily where the experimental procedures were explained, each subject learned how to exert maximum effort and adjustment and alterations were made to the instrumentation to accommodate each subject and avoid revisions during the actual period of investigation. The pilot test demonstrated in agreement with Merton (1954) that the sensation of effort by the subject is in no way related to the tension actually reached. It was anticipated that constant verbal encouragement and the objective evidence of the digital strain indicator may allow the subject to attain



M - Motor

T_1 - Transformer

S_1 - Limit switch (up)

S_2 - Limit switch (down)

S_3 - Reversing switch

S_4 - Emergency switch

R - Relay

R_1 - Relay contact

Figure 4. Motor Circuit Diagram.

his threshold of voluntary or involuntary contraction.

It became apparent that if a subject was allowed to bend his knees letting his body weight drop suddenly while performing concentric exercise a higher score was achieved. Non coplanar movement of the segment and apparatus also resulted in higher test scores. Precautionary measures were necessary to ensure that the subject contracted the elbow flexors rather than initiating the breaking strength response. In an attempt to standardize and account for intersubject variability a high backrest, seatbelts, incline of elbow rest, and adjustable chest plate, were incorporated to preclude the use of undesired muscle groups.

It was noted that the subject's limb may pass through several degrees of a desired arc of movement before the limb would attain the prescribed speed. This delayed reaction was accommodated for by having the subject begin his maximal effort 15 degrees before the flexion or extension of the elbow. This would allow the subject time to attain the predetermined velocity before the limb reached the beginning of the measured arc of joint motion.

Following the preliminary training period differences between pre-test and post-test scores would be more likely to reflect true gains in strength and less likely to be influenced by practise and learning effects.

<u>Training Procedure</u>

All subjects in the experimental groups underwent a training program for a period of 6 weeks. Subjects were restricted to the training capacity of the instrumentation. The experimental groups alternated each week training Monday, Wednesday and Friday (MWF) while the other group trained Tuesday and Thursday (TTh). Both groups performed 3x6 RM (Berger, 1962) at a velocity of 7.2 revolutions per minute. The speed of contractions was determined by using the force velocity relationship as defined by Rogers and Berger (1974) to minimize the increase in difference between concentric and eccentric contractions associated with an increase in velocity. The subjects were given a 3 minute recuperation interval between each set (Clarke, et al., 1954) and a 15 second rest interval between each contraction (Singh & Danielson, 1975). The workload was randomly assigned to the right or the left arm while the subjects were instructed to position the non-exercised limb at side while performing the exercise. The subjects were instructed to make a conscious effort to prevent the contralateral limb from contracting isometrically while the ipsilateral limb was training.

The range of motion for the concentric group was 150 to 90 degrees flexion while the eccentric group exercised from 75 to 135 degrees extension. During the performance of the actual exercise both the investigator and the subject monitored the digital strain indicator providing instantaneous feedback as to the intensity of effort. To enhance maximum effort the subject was encouraged to compete with his previous score and other individuals in his group.

Concentric group. Subjects performed 3x6 RM of concentric contractions. Maximum force was applied to the lever arm from 150 degrees to a flexion angle of 90 degrees. The subjects were instructed to isometrically contract their arm flexors before the beginning of each contraction. Each contraction was performed at a velocity of 7.2 revolutions per minute. Subjects trained MWF alternating to TTh every other week for the duration of the 6 weeks.

Eccentric group. Subjects performed 3x6 RM of eccentric contractions. Maximum resistance was applied to the lever arm from 75 degrees to an extension angle of 135 degrees. The subjects were instructed to maximally contract their flexors before the beginning of each extension. Each contraction was performed at a constant velocity of 7.2 revolutions per minute. Subjects trained TTh alternating to MWF every other week for the duration of the 6 weeks.

Retention

Complete restriction of activity was not advocated during the retention period. Subjects were requested not to engage in specific strength type training relative to the elbow flexor - extensors for the 4 weeks following the training program. The retention period was based on the assumption that routine daily activities do not result in an increase in muscular strength (Müller, 1970).

Analysis of Data

Descriptive statistics generated were computed from the program SPSS, while the split-plot four-way analysis of variance (Keppel, 1973; Winer, 1962) was computed from the program University of Alberta ANOVA 88. The significance testing was performed according to a model where the training method (concentric and eccentric) was considered a fixed factor and the trained and non-trained arm, multiple angles (90°, 105°, 120° and 135°) and test periods (T_1, T_2 and T_3) repeated measures.

Any variance component which was of experimental interest, and in which the treatment mean square was significant was further analyzed for significant differences using two-tailed *t*-tests. Percentage changes were also presented within each group to analyze strength gains and transfer and retention effects. The above procedure was repeated for each of the four test items.

Chapter 4

RESULTS

To facilitate interpretation the data was presented in the following subsections; (a) Reliability of Data, (b) Initial Comparison of Groups, (c) Strength, (d) Retention and (e) Bilateral Transfer.

Reliability of Data

The reliability of the data was assessed by a Pearson Product Moment Correlation Coefficient. The reliability coefficients were determined for the trained and non-trained arms for the four test items and three test periods. The range of the reliability coefficients was between .851 and .947 (refer to Appendix B, Table 1).

Initial Comparison of Groups

Using the initial scores, the two training groups were analyzed for differences which might exist prior to initiating the training program. The t-test procedure revealed no significant differences ($p>.05$) between groups on characteristics of subjects (refer to Table 1) or the four test items (refer to Appendix C, Table 1).

Strength

Static flexion. The results of the four way ANOVA revealed significant differences between the trained and non-trained arms ($F=31.74$, $p<.01$) among angles ($F=114.84$, $p<.01$) and among test periods ($F=175.84$, $p<.01$). No significant difference was found between methods

TABLE 1

CHARACTERISTICS OF SUBJECTS

GROUP	AGE (yr)	HEIGHT (cm.)	WEIGHT (kg.)
Concentric N=11	16.9 ±.3	173.9 ±6.9	70.9 ±6.6
Eccentric N=11	16.9 ±.5	173.4 ±5.3	72.9 ±7.3

Values presented are means ± standard deviations

No significant difference ($p>.05$) between groups

TABLE 2

SUMMARY OF THE ANALYSIS OF VARIANCE

FOR STATIC FLEXION

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
A (methods of training)	40.08	1	40.08	.15
Subjects within groups (S.W.G)	5204.39	20	260.22	
B (trained & non-trained arm)	509.96	1	509.96	31.73**
AB	31.57	1	31.57	1.96
B X S.W.G	321.38	20	16.07	
C (different angles)	4983.55	3	1661.18	114.84**
AC	58.80	3	19.60	1.35
C X S.W.G	867.89	60	14.46	
D (pre-post, & retention test)	678.10	2	339.05	175.84**
AD	24.57	2	12.28	6.37**
D X S.W.G	77.13	40	1.93	
BC	23.49	3	7.83	2.25
ABC	13.90	3	4.63	1.33
BC X S.W.G	208.57	60	3.48	
BD	223.06	2	111.53	57.99**
ABD	20.81	2	10.41	5.41**
BD X S.W.G	76.93	40	1.92	
CD	15.53	6	2.59	2.09*
ACD	8.11	6	1.35	1.09
CD X S.W.G	148.29	120	1.24	
BCD	5.04	6	0.84	.67
ABCD	4.34	6	0.72	.58
BCD X S.W.G	150.34	120	1.25	

* F ratio significant at .05 level.

** F ratio significant at .01 level.

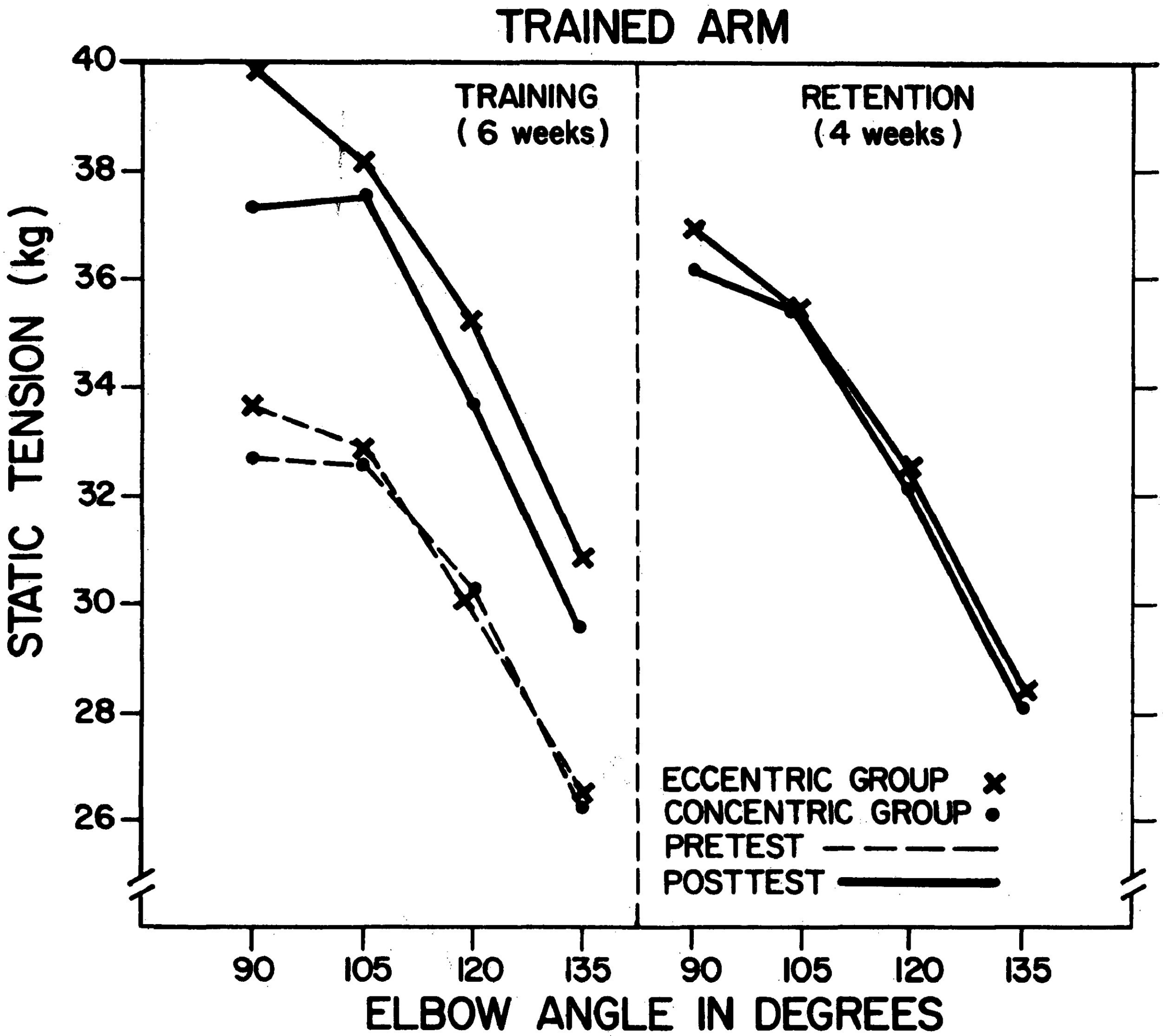


FIGURE 5. Static Flexion for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

of training (F=.15, p>.05). On a percentage basis the range of strength for the concentric group at multiple angles was 14.1 - 15.4%, with a total mean of all angles being 13.4% and standard deviation 1.7%. Comparatively the range of improvement for the eccentric group was 15.4 - 18.3%, with a mean of 16.7% and standard deviation 1.5%. Refer to Table 2 for summary of the analysis of variance and Figure 5 for graphic presentation of the data.

Static extension. The ANOVA revealed significant differences between trained and non-trained arms (F=4.24, p<.05) among angles (F=6.68, p<.01) and among test periods (F=85.91, p<.01). No significant difference (F=.11, p>.05) was found between groups on static extension. The range of strength gain for the eccentric group at multiple angles on a percentage basis was 12.9 - 18.4%, with a total mean of 15.7% and standard deviation 2.3%. Refer to Table 3 for summary of the analysis of variance and Figure 6 for graphic presentation of data.

Dynamic flexion. The ANOVA showed a significant difference between trained and non-trained arms (F=11.86, p<.01) among angles (F=77.87, p<.01) and among test periods (F=74.27, p<.01). The analysis indicated no significant difference between training methods on dynamic flexion (F=.33, p>.05). However, on a percentage basis the range of strength improvement for the concentric group was 18.6 - 26.2% with a total mean of 21.4% and standard deviation 3.4%. The eccentric group ranged from 36.7 - 41.7% with a total mean of 38.8% and standard deviation 2.1%. This represents a percentage superiority for the eccentric group of 12.6%. Comparing grouped means dynamic flexion increased 15% more than static flexion. The results of the above analysis are summarized in Table 4 and Figure 7.

TABLE 3

SUMMARY OF THE ANALYSIS OF VARIANCE
FOR STATIC EXTENSION

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
A (methods of training)	31.26	1	31.26	.11
Subjects within groups (S.W.G)	5463.97	20	273.20	
B (trained & non-trained arm)	52.85	1	52.85	4.24*
AB	4.91	1	4.91	.39
B X S.W.G	249.30	20	12.47	
C (different angles)	461.33	3	153.78	6.68**
AC	56.00	3	18.67	.81
C X S.W.G	1380.90	60	23.02	
D (pre-post, & retention test)	552.24	2	276.12	85.91**
AD	21.74	2	10.87	3.38
D X S.W.G	128.56	40	3.21	
BC	25.09	3	8.36	.96
ABC	14.48	3	4.83	.55
BC X S.W.G	523.58	60	8.73	
BD	217.78	2	108.89	44.21**
ABD	1.96	2	.98	.40
BD X S.W.G	98.52	40	2.46	
CD	12.29	6	2.05	.77
ACD	19.36	6	3.23	1.21
CD X S.W.G	320.95	120	2.67	
BCD	13.52	6	2.25	.92
ABCD	13.92	6	2.32	.95
BCD X S.W.G	293.13	120	2.44	

* F ratio significant at .05 level.

** F ratio significant at .01 level.

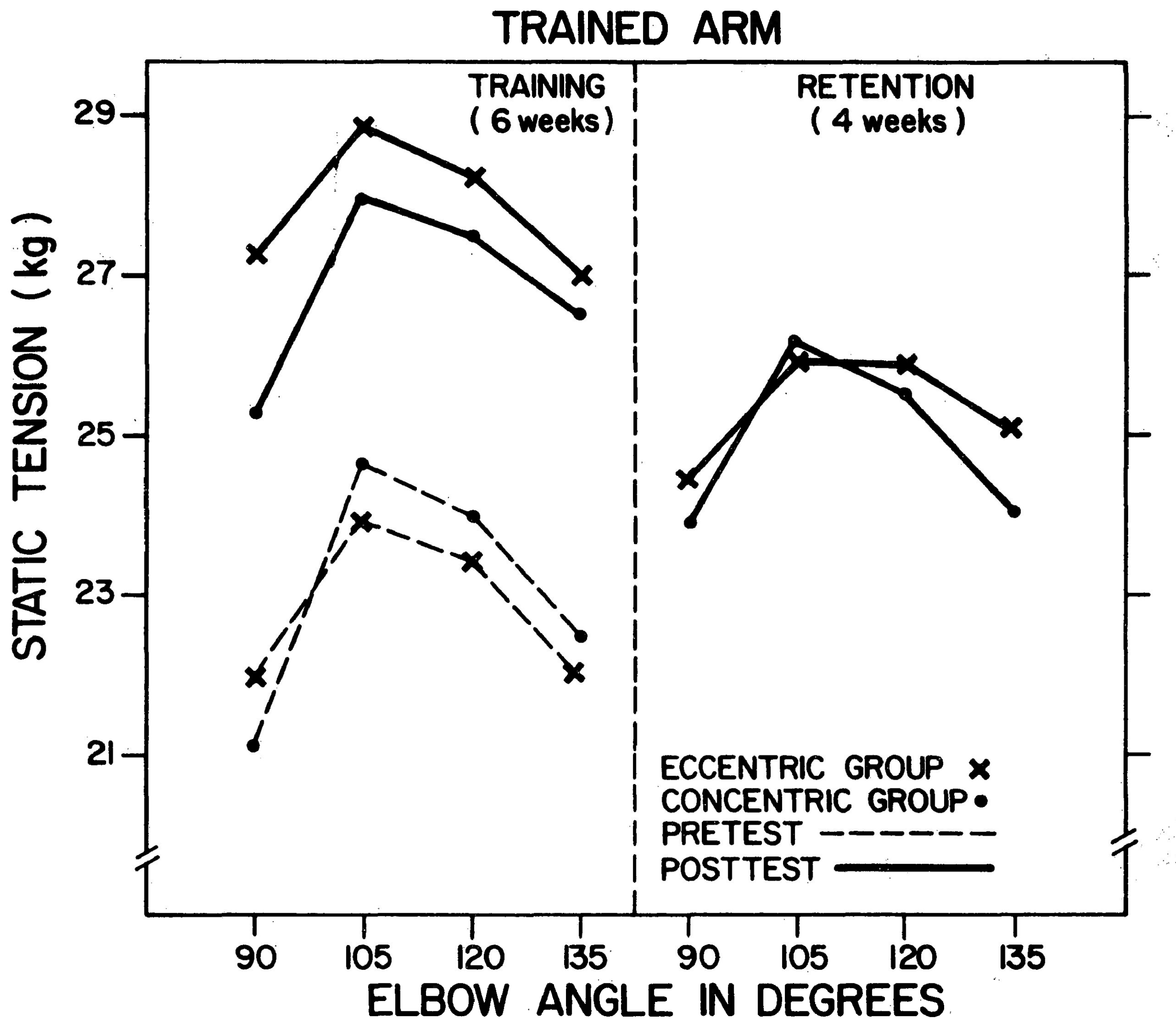


FIGURE 6. Static Extension for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

TABLE 4

SUMMARY OF THE ANALYSIS OF VARIANCE

FOR DYNAMIC FLEXION

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
A (methods of training)	114.15	1	114.15	.33
Subjects within groups (S.W.G)	6863.79	20	343.19	
B (trained & non-trained arm)	481.55	1	481.55	11.86**
AB	22.57	1	22.57	.55
B X S.W.G	811.68	20	40.58	
C (different angles)	1752.97	3	584.32	77.87**
AC	36.70	3	12.23	1.63
C X S.W.G	450.24	60	7.50	
D (pre-post, & retention test)	1203.50	2	601.75	74.26**
AD	46.03	2	23.01	2.84
D X S.W.G	324.11	40	8.10	
BC	6.90	3	2.30	.75
ABC	4.83	3	1.61	.53
BC X S.W.G	182.18	60	3.04	
BD	315.04	2	157.52	23.53**
ABD	15.29	2	7.65	1.14
BD X S.W.G	267.74	40	6.69	
CD	33.52	6	5.59	5.51**
ACD	2.92	6	0.49	.48
CD X S.W.G	121.70	120	1.01	
BCD	9.36	6	1.56	2.08
ABCD	4.02	6	0.67	.89
BCD X S.W.G	89.88	120	0.75	

* F ratio significant at .05 level.

** F ratio significant at .01 level.

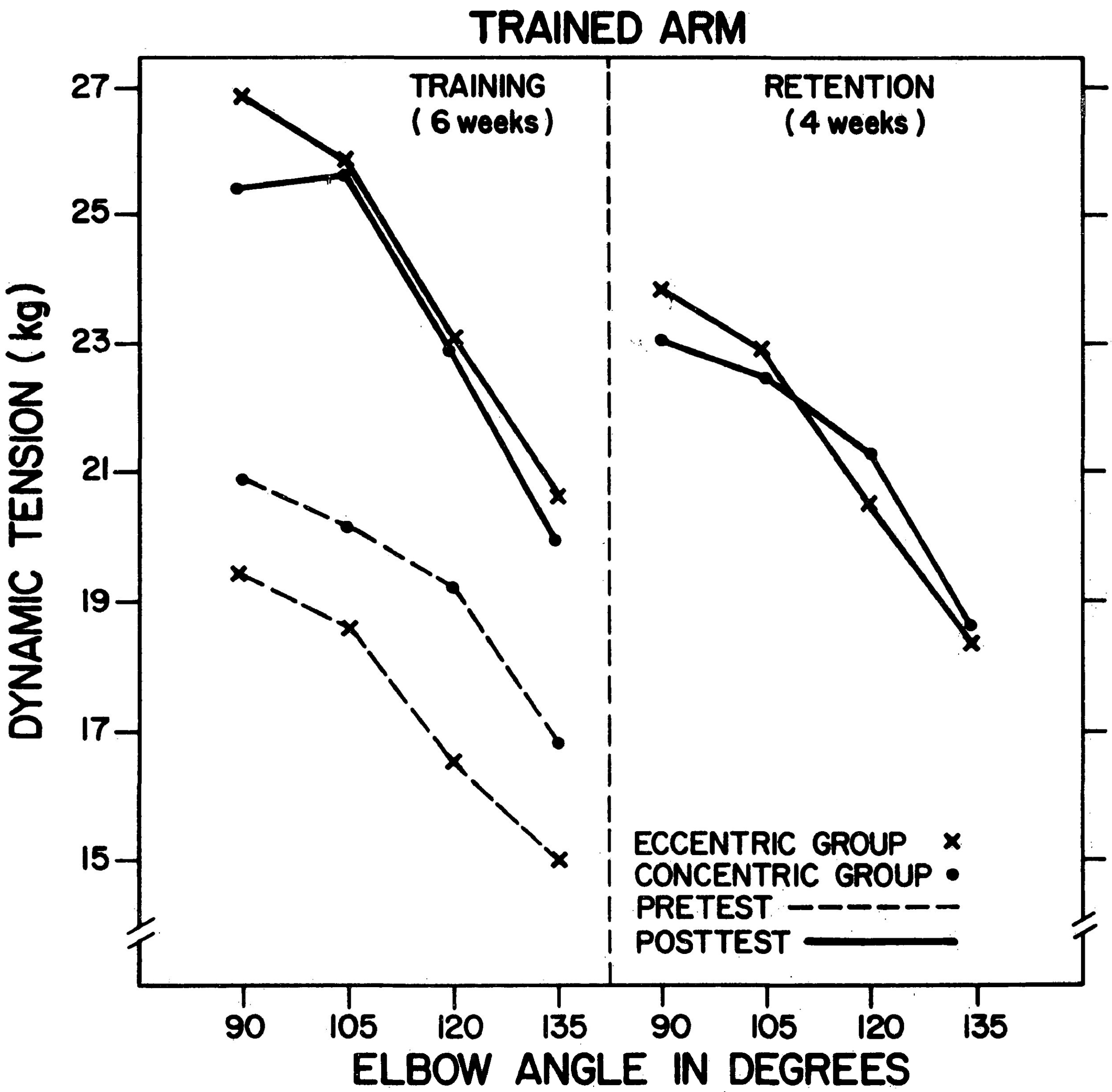


FIGURE 7. Dynamic Flexion for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

Dynamic extension. The ANOVA indicated a significant difference between trained and non-trained arm (F=16.50, p<.01) among angles (F=129.75, p<.01) and among test periods (F=80.31, p<.01). The comparison between training groups on dynamic extension indicated no significant difference (F=.13, p>.05). However, on a percentage basis the range of strength improvement for the concentric groups was 17.1 - 26.8% with a mean of 21.1% and standard deviation 4.2%. The eccentric group ranged from 30.8 - 39.5% with a mean of 35% and standard deviation 3.8%. This represents a percentage superiority of 13.9% for the eccentric group. Comparing grouped means dynamic extension produced 41.6% more tension than dynamic flexion. The results are summarized in Table 5 and Figure 8.

Retention

Neither the concentric nor eccentric group experienced a significant (p>.05) detraining effect over the 4 week retention period on any of the four test items. The retention score for the concentric group ranged from 88.2 - 97.7% of the post-test score. The retention score for the eccentric group ranged from 85.5 - 94.7% of the post-test score. The results of the above analysis are summarized in Tables 6 and 7 and Figures 5, 6, 7 and 8.

Bilateral Transfer

Strength. There was no significant (p>.05) strength gain by the non-trained arm on any of the four test items; static flexion, static extension, dynamic flexion and dynamic extension. The concentric group improved 2.9, 4.7, 8.0, and 11.1% respectively while the eccentric group improved 3.5, 5.8, 12.9, and 4.2% respectively on the four test items. Overall the concentric and eccentric groups improved 6.7 and 6.6% respectively. The results of the above analysis are summarized in Tables 6 and 7 and Figures 9, 10, 11, and 12.

Retention. The concentric and eccentric groups retained 97.3 and 96.4% of the post-test score respectively. The results of the above analysis are summarized in Tables 6 and 7 and Figures 9, 10, 11, and 12.

TABLE 5

SUMMARY OF THE ANALYSIS OF VARIANCE

FOR DYNAMIC EXTENSION

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
A (methods of training)	78.20	1	78.20	.13
Subjects within groups (S.W.G)	11969.16	20	598.46	
B (trained & non-trained arm)	1036.56	1	1036.56	16.50**
AB	16.88	1	16.88	.27
B X S.W.G	1256.23	20	62.81	
C (different angles)	14250.30	3	4750.10	129.75**
AC	27.77	3	9.26	.25
C X S.W.G	2196.50	60	36.21	
D (pre-post, & retention test)	3045.19	2	1522.59	80.31**
AD	34.59	2	17.29	.91
D X S.W.G	758.38	40	18.96	
BC	20.49	3	6.83	.53
ABC	8.80	3	2.93	.23
BC X S.W.G	775.72	60	12.93	
BD	991.31	2	495.65	28.29**
ABD	175.08	2	87.54	4.99**
BD X S.W.G	700.83	40	17.52	
CD	159.43	6	26.57	5.33**
ACD	4.78	6	.80	.16
CD X S.W.G	598.39	120	4.99	
BCD	83.57	6	13.93	3.33**
ABCD	22.12	6	3.69	.88
BCD X S.W.G	502.30	120	4.19	

* F ratio significant at .05 level.

** F ratio significant at .01 level.

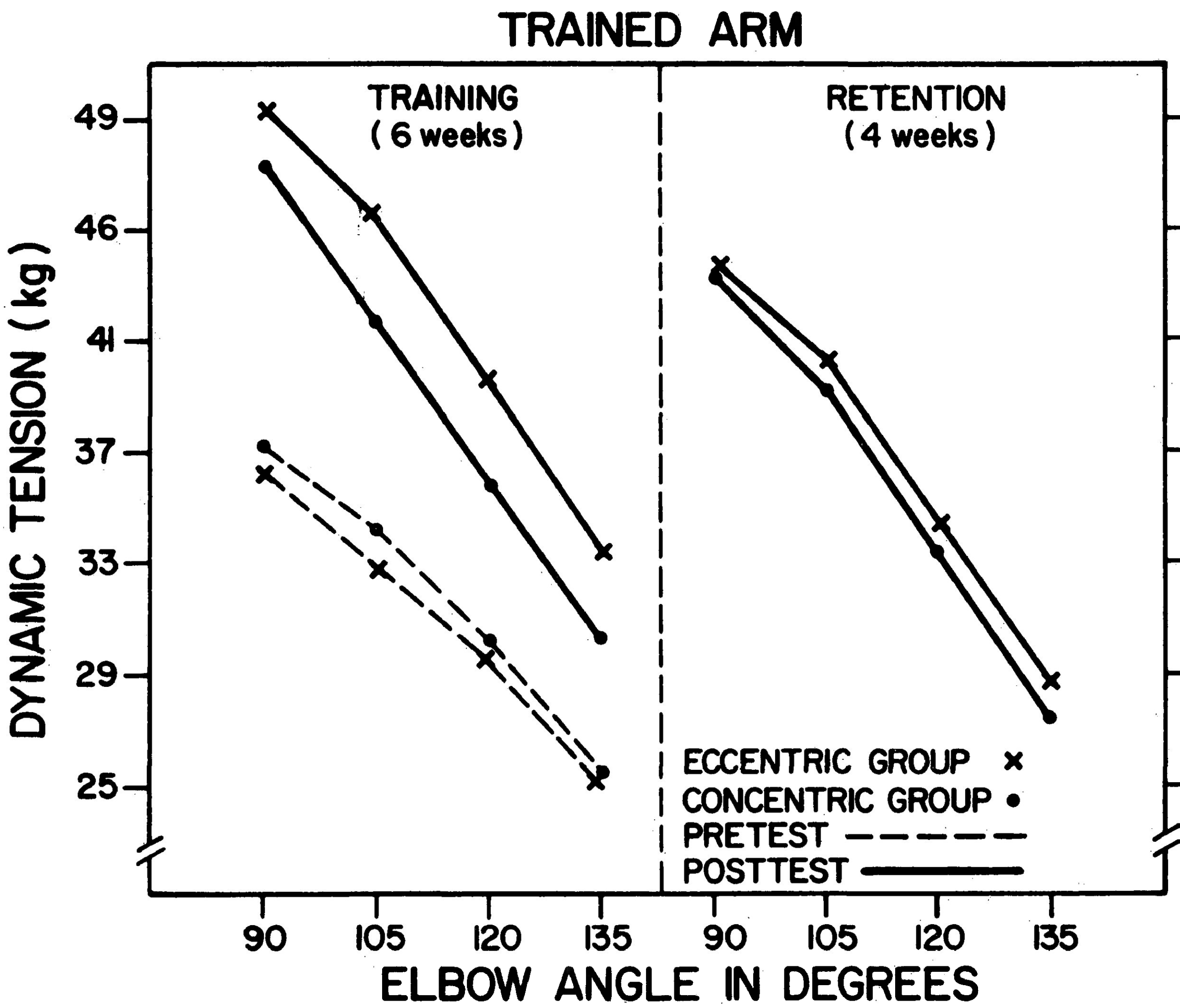


FIGURE 8. Dynamic Extension for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

TABLE 6

MEANS, STANDARD DEVIATIONS, PERCENTAGE INCREASES, RETENTION SCORES, AND t-VALUES FOR CONCENTRIC GROUP

TEST & STATISTICS \ ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
STATIC FLEXION												
TRAINED	32.7[a] ±2.8	37.3 ±3.6	36.1 ±2.9	32.5 ±3.4	37.5 ±3.7	35.3 ±3.0	30.2 ±2.7	33.6 ±2.8	32.0 ±2.8	26.1 ±3.0	29.5 ±3.2	28.0 ±2.8
% CHANGE		14.1[b]	97.0[c]		15.4	94.0		11.3	95.2		13.0	95.0
t-VALUE		3.19**	.82		3.14**	1.46		2.76*	1.28		2.46*	1.12
NON-TRAINED	33.1 ±3.5	34.1 ±3.7	34.0 ±3.6	31.8 ±4.1	32.8 ±3.9	32.3 ±3.6	29.5 ±3.1	30.2 ±3.1	29.7 ±2.8	26.4 ±4.8	27.2 ±4.7	26.9 ±4.4
% CHANGE		3.0	97.0		3.1	98.5		2.4	98.3		3.0	98.9
t-VALUE		.62	.06		.55	.30		.38	.51		.37	.15
STATIC EXTENSION												
TRAINED	21.2 ±4.6	25.1 ±3.7	23.7 ±3.4	24.7 ±3.6	27.9 ±3.3	26.1 ±3.2	23.9 ±3.4	27.5 ±3.0	25.4 ±2.8	22.7 ±1.9	26.4 ±2.6	24.2 ±2.5
% CHANGE		18.4	94.4		12.9	93.5		15.1	92.4		16.3	91.7
t-VALUE		2.10*	.88		2.08*	1.45		2.52*	1.61		3.66**	1.95
NON-TRAINED	21.8 ±3.5	23.1 ±3.6	22.7 ±2.9	25.7 ±2.9	26.6 ±3.0	26.1 ±3.0	25.1 ±3.1	26.3 ±3.3	25.7 ±3.2	24.4 ±4.3	25.5 ±4.2	24.7 ±3.8
% CHANGE		6.0	99.3		3.5	99.5		4.8	97.7		4.5	96.9
t-VALUE		.82	.27		.68	.37		.74	.41		.58	.45

TABLE 6 cont'd.

ANGLE & TEST PERIOD / TEST & STATISTICS	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
DYNAMIC FLEXION												
TRAINED	20.8[a] ±4.2	25.3 ±4.1	23.0 ±4.4	20.2 ±4.7	25.5 ±4.3	22.5 ±4.7	19.1 ±4.0	22.8 ±3.8	21.4 ±4.0	16.7 ±3.4	19.8 ±3.1	18.7 ±3.5
% CHANGE		21.6[b]	97.7[c]		26.2	88.2		19.4	93.9		18.6	94.4
t-VALUE		2.42*	1.21		2.62*	1.48		2.13*	.80		2.14*	.74
NON-TRAINED	20.8 ±3.3	22.4 ±3.7	21.1 ±3.4	20.3 ±4.3	21.8 ±4.2	20.5 ±3.6	18.8 ±4.8	20.4 ±4.6	19.9 ±4.0	16.9 ±3.5	18.3 ±3.5	17.9 ±2.9
% CHANGE		7.7	94.2		7.4	94.0		8.5	97.5		8.3	97.8
t-VALUE		1.02	.82		.79	.74		.76	.26		.89	.28
DYNAMIC EXTENSION												
TRAINED	37.3 ±6.8	47.3 ±6.8	43.1 ±5.3	34.3 ±5.6	41.7 ±5.9	39.1 ±4.6	30.1 ±4.8	35.8 ±4.4	33.4 ±3.9	25.7 ±4.8	30.1 ±3.4	27.3 ±4.4
% CHANGE		26.8	91.1		21.6	93.8		18.9	93.3		17.1	90.7
t-VALUE		3.29**	1.54		2.88**	1.10		2.77*	1.29		2.36*	1.60
NON-TRAINED	37.7 ±7.3	42.1 ±6.0	39.8 ±6.8	33.6 ±6.3	37.7 ±4.9	35.3 ±5.9	29.9 ±4.3	32.7 ±4.2	32.1 ±4.0	24.5 ±4.1	27.2 ±3.3	26.5 ±3.2
% CHANGE		11.7	94.5		12.2	93.6		9.4	98.2		11.0	97.4
t-VALUE		1.47	.80		1.63	.99		1.47	.33		1.61	.48

a: Values presented are means ± standard deviations.
Values presented in kilograms.
b: % difference between pre test and post test.

c: % of post test score retained after retention period.
t-value, $p<.05=2.08^{*}$, $p<.01$ 2.84^{**}
T_1: Pre test; T_2: Post test; T_3: Retention test.

TABLE 7

MEANS, STANDARD DEVIATIONS, PERCENTAGE INCREASES, RETENTION SCORES, AND t-VALUES FOR ECCENTRIC GROUP

TEST & STATISTICS / ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
STATIC FLEXION												
TRAINED	33.9[a] ±4.8	40.1 ±5.3	36.3 ±4.9	33.2 ±4.3	38.3 ±4.7	35.5 ±5.2	30.0 ±4.2	35.3 ±4.4	32.4 ±4.1	26.7 ±3.4	30.8 ±4.5	28.1 ±3.5
% CHANGE		18.3[b]	89.5[c]		15.4	92.1		17.7	91.8		15.4	90.4
t-VALUE		2.74*	1.67		2.52*	1.27		2.76*	1.53		2.30*	1.50
NON-TRAINED	34.6 ±4.3	36.2 ±4.9	35.2 ±4.1	32.4 ±3.6	33.5 ±3.9	32.7 ±3.6	29.4 ±3.9	30.1 ±3.5	29.4 ±3.8	25.4 ±2.8	26.4 ±2.6	26.0 ±2.4
% CHANGE		4.6	97.2		3.4	97.6		2.4	98.3		3.5	98.5
t-VALUE		.78	.49		.65	.48		.42	.43		.68	.32
STATIC EXTENSION												
TRAINED	22.4 ±4.1	27.2 ±4.3	24.4 ±3.9	23.8 ±5.2	28.7 ±4.6	25.9 ±4.9	23.7 ±4.9	28.2 ±4.2	25.9 ±4.3	22.1 ±3.1	26.9 ±4.6	25.1 ±4.2
% CHANGE		21.4	88.5		20.6	94.7		19.0	91.8		21.7	93.3
t-VALUE		2.55*	1.53		2.24*	1.32		2.20*	1.21		2.74*	.91
NON-TRAINED	22.0 ±4.8	23.4 ±4.5	22.7 ±4.8	25.2 ±3.7	26.8 ±3.5	25.9 ±3.7	25.1 ±5.5	26.3 ±5.7	25.3 ±5.4	23.7 ±5.4	25.1 ±5.0	23.9 ±5.0
% CHANGE		6.4	97.0		6.3	96.6		4.8	96.2		5.9	95.2
t-VALUE		.67	.34		.99	.56		.48	.40		.60	.53

TABLE 7 cont'd.

TEST & STATISTICS / ANGLE & TEST PERIOD	90° T_1	90° T_2	90° T_3	105° T_1	105° T_2	105° T_3	120° T_1	120° T_2	120° T_3	135° T_1	135° T_2	135° T_3
DYNAMIC FLEXION												
TRAINED	19.3[a] ±5.0	26.7 ±3.9	23.7 ±4.9	18.5 ±5.2	25.6 ±4.8	22.8 ±5.3	16.3 ±5.6	23.1 ±4.2	20.4 ±5.4	15.0 ±4.7	20.5 ±3.7	18.5 ±4.5
% CHANGE		38.3[b]	88.8[c]		38.4	89.1		41.7	88.3		36.7	90.2
t-VALUE		3.40**	1.52		3.17**	1.24		3.08**	1.25		2.91**	1.09
NON-TRAINED	19.7 ±5.0	22.2 ±4.3	20.4 ±5.1	18.8 ±5.1	21.7 ±4.2	19.9 ±4.8	16.3 ±4.2	18.3 ±3.8	18.0 ±4.3	14.9 ±3.8	16.6 ±3.5	15.9 ±3.9
% CHANGE		12.7	91.9		15.4	91.7		12.3	98.4		11.4	95.8
t-VALUE		1.20	.85		1.39	.89		1.12	.17		1.04	.42
DYNAMIC EXTENSION												
TRAINED	36.1 ±6.7	49.3 ±7.3	43.9 ±7.7	32.9 ±6.9	45.9 ±7.2	40.3 ±7.5	29.4 ±6.7	39.1 ±6.8	34.3 ±6.9	25.3 ±5.8	33.1 ±4.4	28.9 ±4.9
% CHANGE		36.6	89.0		39.5	88.5		33.0	86.0		30.8	85.5
t-VALUE		4.22**	1.61		4.13**	1.70		3.21**	1.57		3.39**	2.02
NON-TRAINED	38.4 ±9.5	40.1 ±8.6	39.0 ±8.4	35.4 ±8.0	36.8 ±8.7	36.1 ±7.9	31.0 ±5.4	31.8 ±5.6	31.5 ±5.3	26.0 ±2.9	27.5 ±2.9	26.8 ±3.1
% CHANGE		4.4	93.3		4.0	98.1		2.6	99.0		5.8	97.5
t-VALUE		.42	.29		.37	.19		.32	.12		1.15	.39

a: Values presented are means ±standard deviations.
Values presented in kilograms.
b: % difference between pre test and post test.

c: % of post-test score retained after retention period.
t-value, $p<.05=2.08^*$, $p<.01=2.84^{**}$
T_1: Pre test; T_2: Post test; T_3: Retention test.

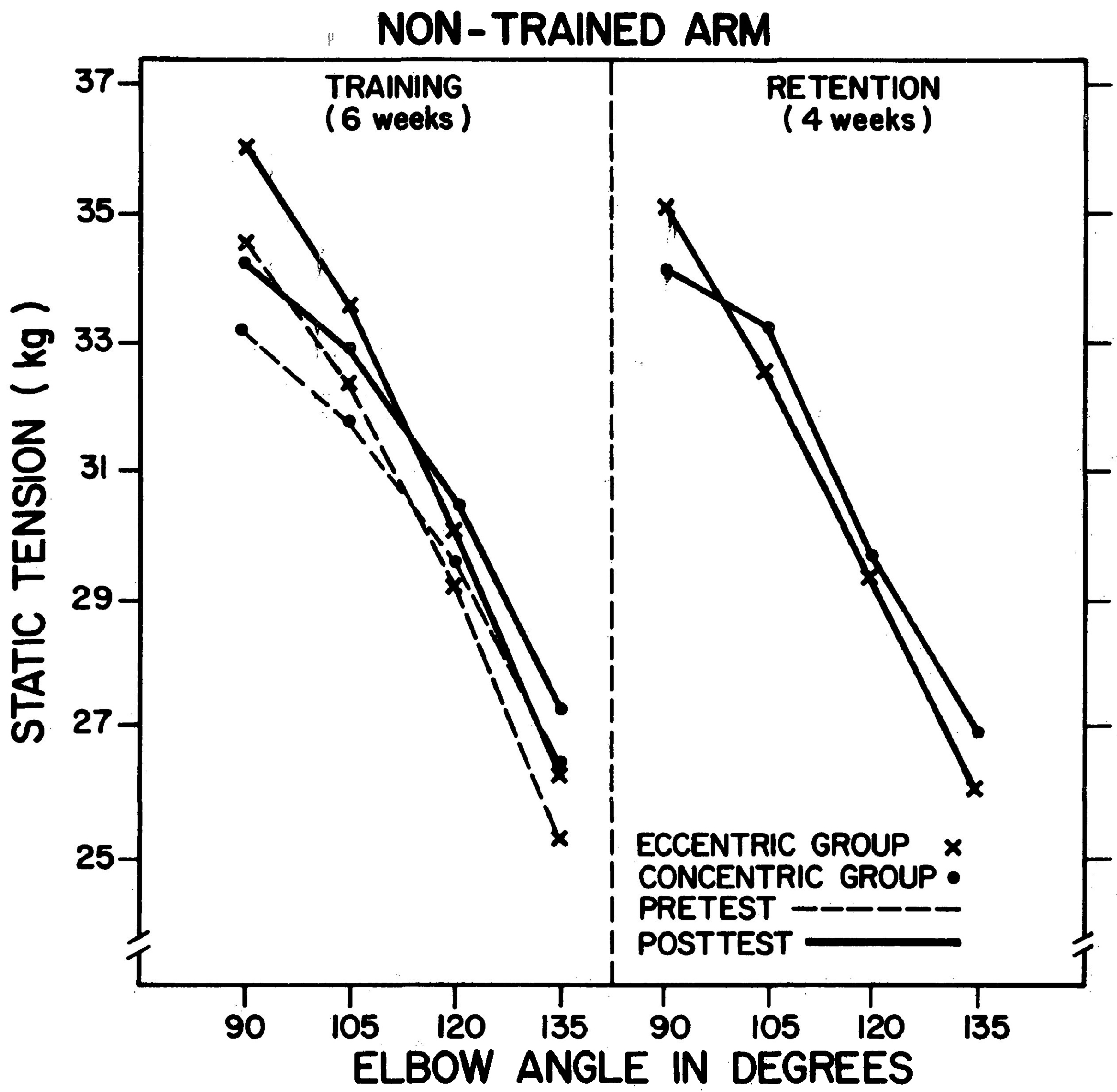


FIGURE 9. Static Flexion for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

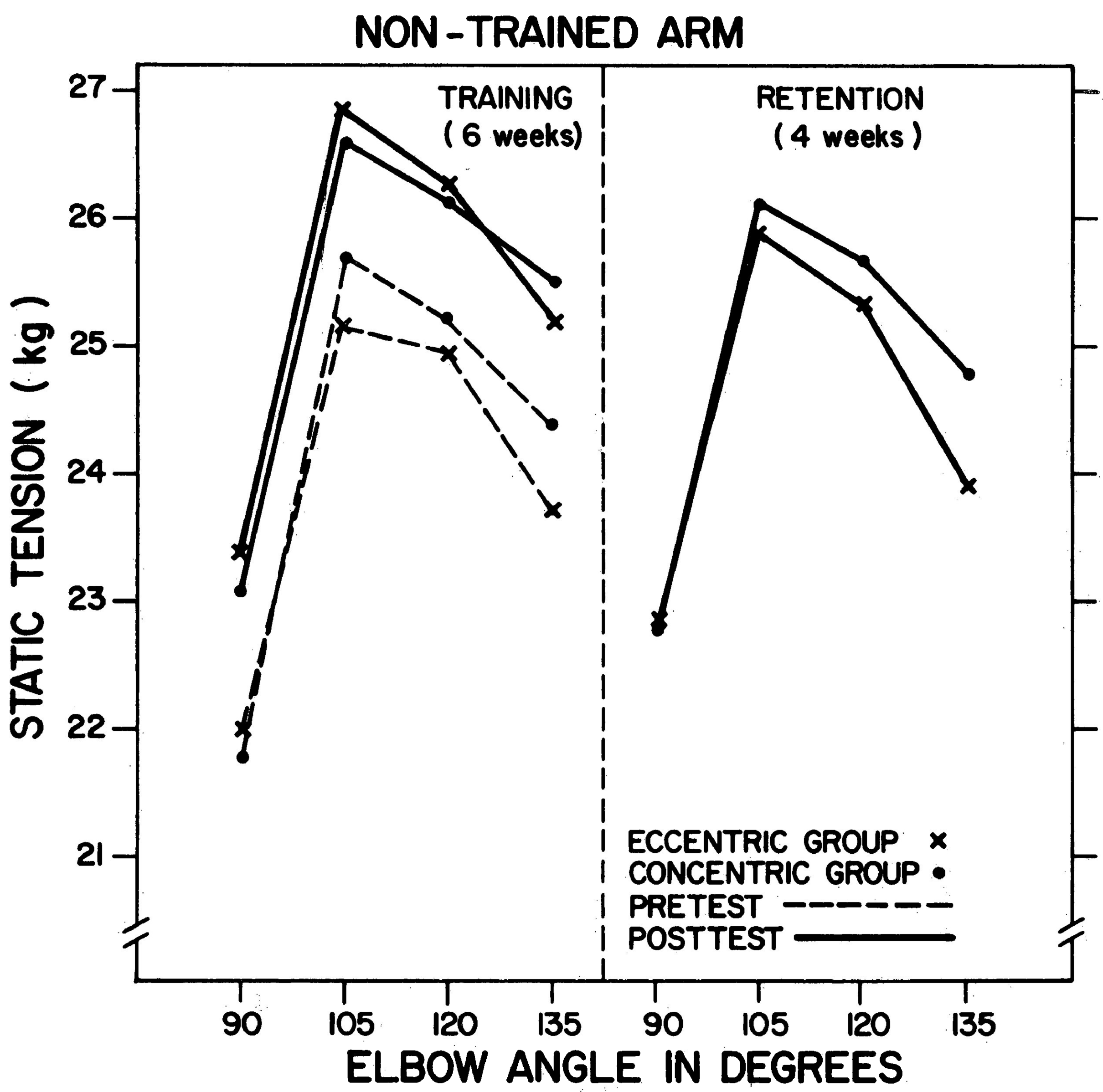


FIGURE 10. Static Extension for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

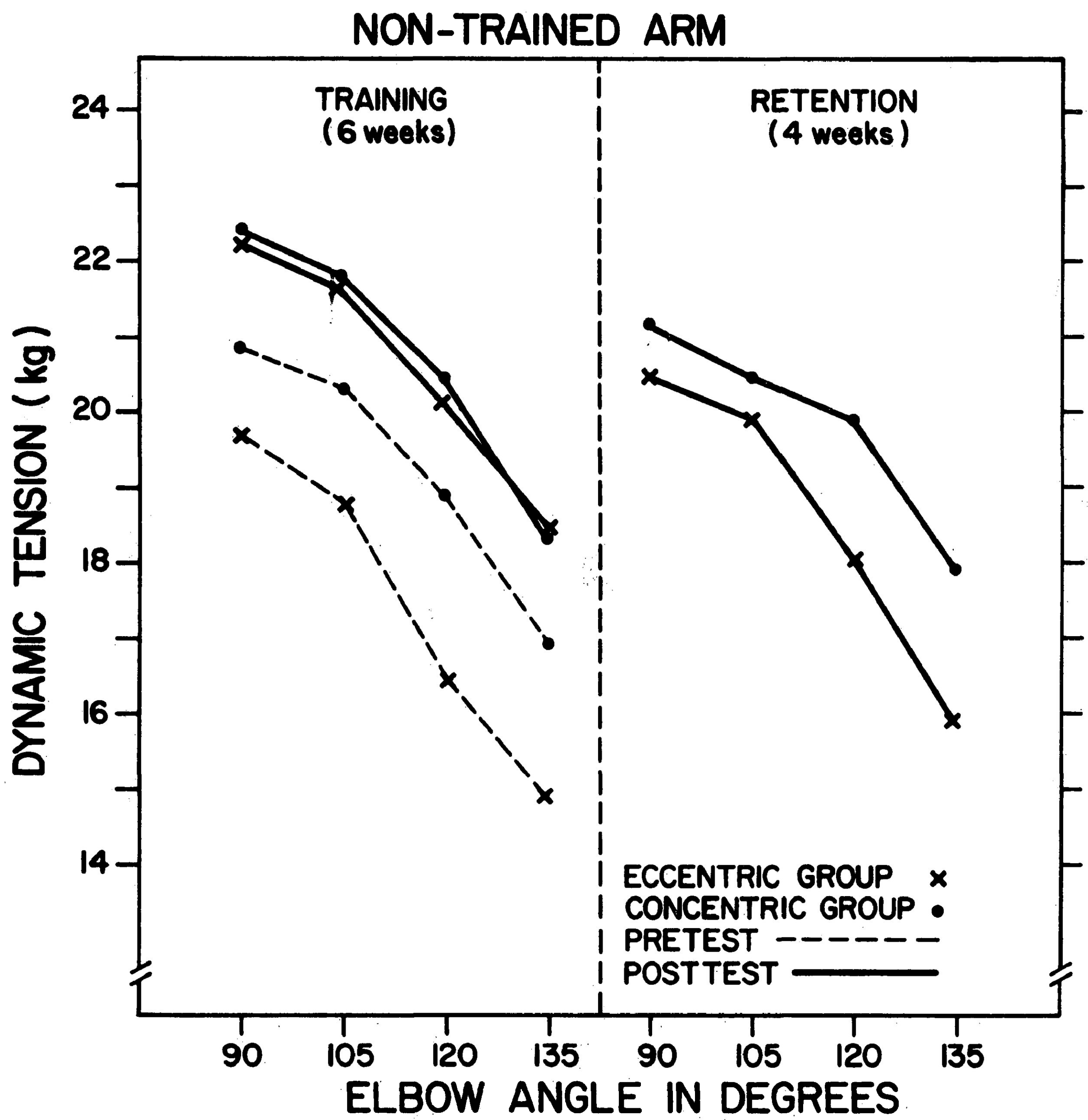


FIGURE 11. Dynamic Flexion for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

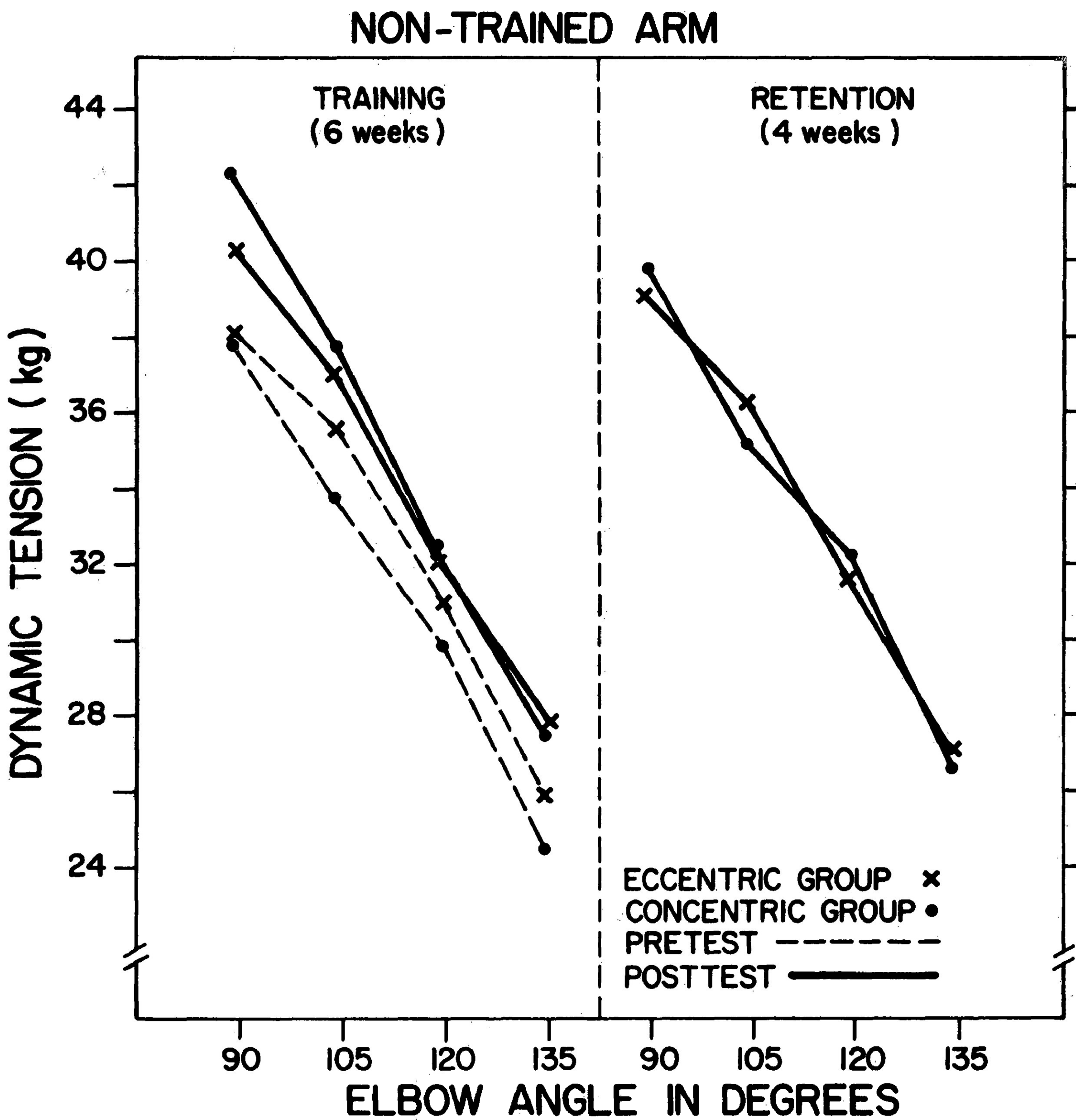


FIGURE 12. Dynamic Extension for the Concentric and Eccentric Groups Before and After 6 Weeks Training and 4 Weeks Retention.

Chapter 5

DISCUSSION

Like most previous studies the subjects of the present investigation were volunteers and therefore would limit extrapolations to the total population. Few studies reported in the literature employed a sample from this specific segment of the population and consequently this must be considered when discussing the results. To facilitate interpretation the discussion was presented in the following subsections; (a) Initial Comparison of Groups, (b) Strength, (c) Retention and (d) Bilateral Transfer.

Initial Comparison of Groups

The two groups did not differ significantly ($p > .05$) on characteristics and four test items. While the present study incorporated no formal control group, the minimal response of the non-trained arm indicates the stability of the various exercise responses in the absence of effective training. The logic of the control group design requires the assumption that the only additional variable experienced by the experimental groups is the training itself. Variables such as motivation to perform, attitudes regarding the experiment and the confounding of these variables with others would no doubt significantly alter the test score. To instill a similar attitude, interest and motivation in the control subjects is to say the least extremely difficult.

Strength

The results of this study support the findings of Johnson (1972), Johnson *et al*. (1976), Mannheimer (1969) and Singh and Danielson (1975) who had previously reported no significant difference between concentric and eccentric training methods. On the four test items; static flexion, static extension, dynamic flexion and dynamic extension the eccentric group showed a percentage superiority of 3.3%, 5.0%, 12.6%, and 13.9% respectively. Komi and Buskirk (1972) were one of few investigators to report the superiority of eccentric training when compared to concentric training.

Contrary to previous research the present investigation required both training groups to employ their maximum tension producing capability at a velocity of 7.2 revolutions per minute which was considered optimal. Regardless of rate, repetitions, resistance, or characteristics of subjects the results appear conclusive that forced loading during eccentric work is not a further stimulus for strength development (Johnson *et al*. 1976).

The trained arm showed a significant ($p<.01$) improvement when compared to the non-trained arm on static flexion, dynamic flexion, and dynamic extension. Static extension of the trained arm was also significant ($p<.05$) when compared to the non-trained arm. The significant difference among test angles ($p<.01$) may be due to the length-tension curve, leverage and the various muscles involved in producing tension at different angles throughout the range of motion (Bender & Kaplan, 1963; Williams & Stutzman, 1959). A summation of each test angle revealed 90 degrees to elicit 5%, 14.5%, and 22.3% more tension than 105 degrees, 120 degrees and 135 degrees respectively.

The magnitude of the difference between concentric and eccentric contractions (41.6%) was in agreement with the findings of Singh and Karpovich (1967) and Singh and Wiebe (1977). The state of training, constitution of the subject, and level of isometric strength may be contributing factors to differences between concentric and eccentric tension.

Both training programs resulted in significant ($p<.05$) strength gains during static and dynamic contractions of the agonists and antagonistic muscles. Singh and Karpovich (1967) reported eccentric training to improve the agonists substantially more than the antagonists. Electromyographical activity provided further evidence that both agonists and antagonists are active during maximal effort. The obvious difference in resisting and initiating maximum strength responses may be demonstrated by the substantial difference between dynamic extension and static extension. An interesting excursion would be the duplication of the foregoing experiment with the assessment of breaking strength at each of the four test angles.

Substantial individual differences in response to the exercise regimen were noted. This difference has been masked by the graphic presentation of the data and may be seen in Appendix D. The most marked improvement on the combined four test items was by subjects DD, BB, and BT of 42.2%, 61% and 50.9% respectively. Following the same training regimen, subjects SF, TZ, and GT improved 17.8%, 19.5%, and 17.7% respectively. The discrepancy may partially be explained by the postulation that regardless of state of training there is no common training method that should be used by all athletes. While quantitative evaluations of motivation were not included one may readily observe that the desire to excel is of primary importance for strength development. Other factors such as the ability to exert maximal effort and trainability contribute to a large portion of the strength gains.

While there was no significant difference between groups on height, weight and age the developmental age may have varied among subjects contributing to the wide range of responses to the exercise regimen (Carron, Stothart, & Bailey, 1976). The inclusion of somatotype as a characteristic of subjects may provide an index to the assessment of developmental age. Although all subjects underwent a thorough familiarization procedure it seems reasonable to conclude that at least part of the strength gain may be due to a specific increase in skill. However, Logan and Lockhart, (1962) suggested that increased skill is an expression of an ability to perform maximally and consequently should be considered part of strength development.

The present study found dynamic flexion to improve 15% more than static flexion. This finding was similar to that previously reported by Carlson (1970) who reported a discrepancy of 13%. Carlson (1970) concluded that if the purpose of the test was to discriminate between the strong and weak the substitution of dynamic or static testing methods was valid, however if the results are to determine the level of muscular strength the substitution is no longer tenable.

While it was not the purpose of this study to examine muscular soreness it was recognized that pain is a powerful inhibitor of muscular action, and consequently the experimental design incorporated a limited range of motion and variable resistance to accommodate the phenomena. The eccentric group experienced a "tightness" of the tendon insertion but no one complained of extreme muscular soreness and consequently muscle soreness was not considered a confounding factor when equating strength gains of both groups. One may postulate that stronger individuals should not train at maximal levels during eccentric work. The mechanical stress (Komi & Viitasalo, 1977) during maximal eccentric contractions may cause structural changes leading to muscle soreness and ultimately a detraining effect.

Perrine (1968) and Jones (1977) have made noteworthy contributions by introducing the isokinetic and Nautilus concepts to the sports sciences. However, controlled research has failed (Coleman, 1977) to substantiate the superiority of Nautilus training methods when compared to the techniques originally proposed by Delorme and Watkins (1948). In view of present research facts do not warrant the design of specific eccentric equipment as advertized by Nautilus.[2] Further studies are required to support or refute Pipes and Wilmore's (1975) findings that isokinetic training procedures are superior to the more traditional isotonic procedures. Within the limitations of concentric and eccentric training methods the present results and those of several others (Rasch, 1974) support the contention that at present there is no superior method of training. The discrepancy in the findings may be attributed to lack of standardization, ambiguity in terminology, experimental procedures, and statistical treatment of the data (Caldwell, Chaffin, Dukes-Dobos, Kroemer, Laubach, Snook, & Wasserman, 1974).

It becomes apparent that we must alter our empirical and theoretical approach to strength training and no longer rely on speculative findings. One alternative approach rather than manipulating rate,

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[2]Nautilus Instruction Manual, Nautilus Sports Medical Industries, Deland, Florida, 32720.

repetitions and resistance may be to examine the world class power and Olympic lifter. The histochemical, morphological, biochemical, and neuromuscular modifications of specific training techniques would no doubt scientifically substantiate the most efficient and effective strength training program with the most enduring effects (MacDougall et al., 1977; Prince, Hikida, & Hagerman, 1976; Raitsin, 1974; Milner-Brown, Note 9). The knowledge gained may allow a predictable pattern of strength acquisition and retention to be formulated.

Retention

Neither training group experienced a significant loss ($p>.05$) of strength following the 4 week retention period. One cannot exclude the possibility that a longer retention period may have revealed a significant increase in the detraining process. MacDougall et al. (1977) reported a 35% loss of strength for the exercised limb immobilized in a cast for a period of 5 weeks. Hislop (1963) reported training effects to persist after one year detraining while Thorstensson (1976) monitoring one subject found the training effects to subside after 5 months detraining.

One must recognize the contingency that routine daily activity may not increase strength as proposed by Muller (1970) but may alter retention of newly acquired levels of strength. The majority of studies no doubt employed highly trained, cooperative subjects familiar with the disciplined behavior required for controlled research; however, to objectively verify the retention effects of various training regimens it becomes apparent that one must immobilize the limb during the detraining period. The decrement score may be dependent upon how much of the increased test score reflects increased muscular force rather than decreased neuromuscular inhibition. Further research is required to support or refute the concept that the same neuromuscular principles are involved with the acquisition and retention of strength.

While an abundance of literature exists pertaining to maximum strength, few experimentalists (Houtz, Parrish & Hellebrandt, 1946; Peterson, Gaudal, Hanson, & Huid, 1961) have made note of the tremendous increase in dynamic work capacity as opposed to the modest increases in dynamic strength. The diversity within the literature when determining work capacity has resulted in non-standardized testing procedures (Smith & Edwards, 1968). It may be of interest to determine the retention effects of the work capacity of one set as opposed to the one repetition maximum (RM).

Bilateral Transfer

The non-trained arm failed to elicit significant ($p > .05$) strength gains on any of the four test items. Overall the concentric and eccentric groups improved 6.6% and 6.7% respectively. Evidence contradictory to these findings has been presented by several authorities (Coleman, 1969a, 1969b; Hellebrandt & Houtz, 1956; Shaver, 1970). Discrepancies between the results obtained in this study and those reported by other investigators may be attributed to differences in experimental design.

While several studies have reported a substantial transfer of strength to the contralateral limb the causes responsible for these changes are speculative and cannot be determined due to the limitations of the experimental designs. Within the limitations of this study the statistical evidence has failed to indicate any quantitatively important function that can be called bilateral transfer, and therefore the phenomena is non-tenable.

The prime movement was limited to one appendicular joint. Visual observation during the training period suggested that with both training methods there tended to be some tension in the contralateral arm during unilateral exercise. It is difficult to conceive this tension as sufficient to result in significant strength gains. One may suggest that a 6% increase over a 6 week training period by the non-trained arm is certainly within the limitations of motivation and the ability to exert maximal effort as suggested by Slater-Hammel (1950). Conversely, if one were to except the strength gain as primarily due to transfer the effect was inconsistent among subjects and test items, lending further support to Slater-Hammel's original theory. The within subject design incorporated by Johnson et al. (1976) may be the common denominator for equating training methods.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

From both a practical and theoretical perspective, one needs to discern which training method is most effective and efficient in terms of achieving the greatest strength gains in the shortest period of time with the most enduring effects. The present study was designed to determine the effects of concentric and eccentric training methods upon the acquisition of strength of the elbow flexor - extensors. Other problems investigated were (a) the retention of strength in the trained and non-trained arm and (b) the change, if any, in strength of the contralateral elbow flexor - extensors.

Subjects were 22 male volunteers enrolled in the Grade 11 physical education class at Port Arthur Collegiate Institute, Thunder Bay, Ontario. The subjects were randomly assigned to one of two groups and to exercise the right or left arm.

Both training groups participated in a preliminary training and safety program and were familiar with the testing and training procedure. The instrumentation designed by the investigator was used for testing and training strength. The test procedure consisted of static flexion, static extension, dynamic flexion and dynamic extension measured at angles of 90, 105, 120 and 135 degrees. The statistical index was represented by the higher score of two trials.

The subjects trained Monday, Wednesday, and Friday alternating to Tuesday and Thursday every other week for the duration of the 6 week training period. The retention period was the 4 weeks following the post-test. The training program consisted of 3x6 RM at a velocity of 7.2 revolutions per minute on trained arm while non-trained arm remained in a standardized position.

Data were analyzed using a four-way split plot ANOVA and *t*-tests in which an alpha level of .05 was accepted for statistical significance. Percentage changes and graphic illustration of the data was presented to provide further clarification of the data.

Conclusions

The results of this study indicated that within the limitations and delimitations of this thesis, the following conclusions could be made:

1. Strength training methods (concentric and eccentric) improve static and dynamic strength.

2. A significant difference was found among test angles.

3. Specificity between dynamic and static testing procedures was present on a percentage basis.

4. There was a wide range of response among subjects to the exercise regimen.

5. Eccentric tension was superior to concentric and isometric tension.

6. Neither strength training method was superior to the other.

7. Following 4 weeks of detraining neither training procedure resulted in a significant loss of strength.

8. Neither training procedure resulted in a transfer of strength.

9. The trained arm was superior to non-trained arm on the four test items.

Recommendations

Further research in this area may be warranted by the following recommendations.

1. When specifically concerned with rapid strength gains it may be of interest to determine if a correlation exists between the speed of strength increase and the end point up to which increase is possible.

2. Electro stimulation techniques may provide a new avenue to explore concerning acquisition, retention and transfer of strength.

3. Further research utilizing larger samples, longer training periods, more frequent test periods, and more efficient isolation of experimental variables may provide additional information concerning various training methods.

4. By incorporating a within subject design and altering the present instrumentation by incorporating a reversing gear so while one lever arm goes up the other goes down, one may control multiple treatment effects, eliminate intersubject variability and reduce statistical manipulation of the data.

5. If one were to replicate the present instrumentation it is recommended that straps be implemented to insure that a force increase was not the result of a change in mechanical advantage.

6. Further research in the area of bilateral transfer would no doubt be warranted by including electromyographical techniques and immobilizing contralateral limb in a plaster cast.

7. Recognition of the important role of motivation and the desire to excel as major contributing factors to strength gains warrants further study involving psychological preparation and endocronological responses and their effects on strength gains.

8. When equating groups the results are often obscured by the variability in trainability among subjects. Fibre type classification may provide an additional index when equating groups.

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APPENDIX A

TABLE 1

STRENGTH MEASUREMENT TECHNIQUE

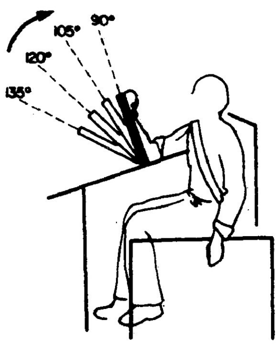
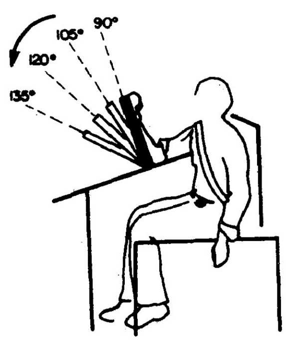
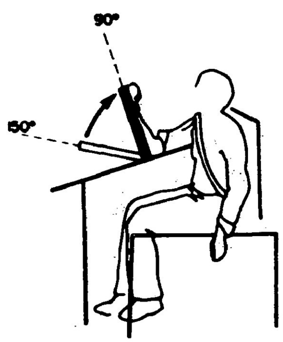
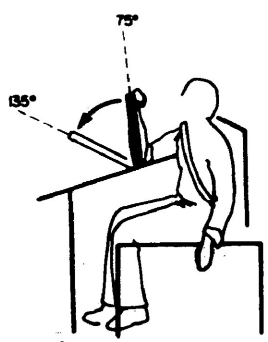
Test Items	Starting Position	Movement	Caution
 Static Flexion	1. Chest plate adjusted to insure that joint axis coincides with instrument axis. 2. Upper arm on the pad and fore-arm at the desired angle. 3. Wrist yoke adjusted to the styloid process of the radius. 4. Chair adjusted to prevent movement between chest plate and high back rest. 5. Opposite arm extended at side. 6. Seat belt placed across the shoulder being exercised.	1. Subject increases force steadily to their subjective maximum for not more than 5 seconds. 2. Subject relaxes and reading is taken. 3. Alternate between arms.	1. Hand must remain in the supinated position. 2. Avoid non coplanar alignment of the joint axis and the instrument axis. 3. Wrist yoke locked and the forearm length recorded. 4. Allow 3 minute rest interval between test angles.
 Static Extension	1. Chest plate adjusted to insure that the joint axis coincides with the instrument axis. 2. Upper arm on the pad and fore-arm at the desired angle. 3. Wrist yoke adjusted to the styloid process of the radius. 4. Chair adjusted to prevent movement between chest plate and high back rest. 5. Opposite arm extended at side. 6. Seat belt placed across the shoulder being exercised.	1. Subject exerts force steadily to their subjective maximum for not more than 5 seconds. 2. Subject relaxes and reading is recorded. 3. Alternate between arms.	1. Hand must remain in the supinated position. 2. Avoid non coplanar movement of the joint axis and the instrument axis. 3. Wrist yoke must be adjusted to the styloid process of the radius. 4. Allow 3 minute rest interval between test angles.

TABLE 1 cont'd.

Test Items	Starting Position	Movement	Caution
 Concentric Contraction	1. Chest plate adjusted to insure that the joint axis coincides with the instrument axis. 2. Upper arm on the pad and lever arm adjusted to 150°. 3. Wrist yoke adjusted to the styloid process of the radius. 4. Chair adjusted to prevent movement between chest plate and high back rest. 5. Opposite arm extended at side. 6. Seat belt placed across the shoulder being exercised.	1. On command "flex" subject isometrically contracts at 150°. 2. Machine activated and subject applies force to the 90° position. 3. Subject relaxes and the lever arm is returned to the starting position.	1. Hand must remain in the supinated position. 2. Avoid non coplanar movement of the joint axis and the instrument axis. 3. Subject must respond to the command "flex" to insure maximal flexion.
 Eccentric Contraction	1. Chest plate adjusted to insure that the joint axis coincides with the instrument axis. 2. Wrist yoke adjusted to the styloid process of the radius. 3. Upper arm on the pad and lever arm adjusted to 75°. 4. Chair adjusted to prevent movement between chest plate and high back rest. 5. Opposite arm extended at side. 6. Seat belt placed across the shoulder being exercised.	1. On command "resist" subject isometrically contracts at 75°. 2. Dynamometer activated and subject resists to 135° position. 3. Subject relaxes and the lever arm is returned to starting position.	1. Hand must remain in the supinated position. 2. Avoid non coplanar movement of the joint axis and the instrument axis. 3. Subject must respond to the command "resist" to insure maximal tension.

APPENDIX B

TABLE 1

RELIABILITY COEFFICIENTS FOR THE PRE TEST, POST TEST AND RETENTION TEST

ANGLE & TEST PERIOD / TEST & T, N-T ARM		90°			105°			120°			135°	
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
STATIC FLEXION T	926[a]	936	931	926	903	901	931	884	913	913	886	885
STATIC FLEXION N-T	913	901	920	900	897	907	897	900	901	901	900	893
STATIC EXTENSION T	896	890	883	863	890	883	851	861	880	885	882	881
STATIC EXTENSION N-T	900	901	893	884	878	871	864	871	897	900	901	877
DYNAMIC FLEXION T	862	888	893	902	896	892	870	861	873	870	858	873
DYNAMIC FLEXION N-T	897	879	893	900	891	920	880	892	886	891	867	879
DYNAMIC EXTENSION T	947	893	853	926	886	874	852	863	850	910	886	930
DYNAMIC EXTENSION N-T	920	910	901	899	903	892	841	863	859	889	880	897

a: $p<.05=423$; $p<.01=537$. $\underline{N}=22$.
T: Trained arm, N-T: Non-Trained arm.
* Rounded to three digits and decimals omitted.
T_1: Pre test; T_2: Post test; T_3: Retention test.

APPENDIX C

TABLE 1

INITIAL COMPARISON BETWEEN GROUPS

TEST ITEM & T, N-T ARM \ TEST ANGLE		90°	105°	120°	135°
STATIC FLEXION	T	33.9±4.8 E 32.7±2.8 C	33.2±4.3 32.5±3.4	30.0±4.2 30.2±2.7	26.7±3.4 26.1±3.0
		.77	.45	.13	.42
	N-T	34.6±4.3 33.1±3.5	32.4±3.6 31.8±4.1	29.4±3.9 29.5±3.1	25.4±2.8 26.4±4.8
		.95	.38	.07	.64
STATIC EXTENSION	T	22.4±4.1 21.2±4.6	23.8±5.2 24.7±3.6	23.7±4.9 23.9±3.4	22.1±3.1 22.7±1.9
		.72	.54	.12	.48
	N-T	22.0±4.8 21.8±3.5	25.2±3.7 25.7±2.9	25.1±5.5 25.1±3.1	23.7±5.4 24.4±4.3
		1.11	.44	.00	.40
DYNAMIC FLEXION	T	19.3±5.0 20.8±4.2	18.5±5.2 20.2±4.7	16.3±5.6 19.1±4.0	15.0±4.7 16.7±3.4
		.88	.96	1.61	1.06
	N-T	19.7±5.0 20.8±3.3	18.8±5.1 20.3±4.3	16.3±4.2 18.8±4.8	14.9±3.8 16.9±3.5
		.68	.87	1.48	1.31
DYNAMIC EXTENSION	T	36.1±6.7 37.3±6.8	32.4±6.9 34.3±5.6	29.4±6.7 30.1±4.8	25.3±5.8 25.7±4.8
		.58	.70	.37	.22
	N-T	38.4±9.5 37.7±7.3	35.4±8.0 33.6±6.3	31.0±5.4 29.9±4.3	26.0±2.9 24.5±4.1
		.30	.84	.63	1.01

Values presented are means ± standard deviations and t-values. ($p<.05=2.08$).

T: Trained arm, N-T: Non-Trained arm.

C: Concentric Group.

E: Eccentric Group.

APPENDIX D RAW DATA

TABLE 1

CHARACTERISTICS OF SUBJECTS

SUBJECT	AGE (yr)	HEIGHT (cm)	WEIGHT (kg) T_1	T_2	T_3
CONCENTRIC GROUP					
PA	17.1	173.0	82.9	83.4	83.6
PP	16.7	180.0	77.9	80.0	79.1
LJ	16.8	189.0	77.9	79.5	80.9
DF	16.4	173.0	71.8	74.5	74.5
BF	17.6	171.5	69.8	71.2	72.3
BT	17.2	170.5	67.6	68.9	69.5
DK	17.2	166.5	63.2	63.7	64.1
LR	16.8	173.0	68.2	70.0	69.1
IM	17.0	181.0	74.2	73.3	73.8
MM	16.5	171.0	64.3	65.0	65.0
MF	16.8	166.0	62.7	64.2	64.9
MEAN	16.9	173.9	70.9	72.1	72.4
S.D.	±.3	±6.9	±6.6	±6.7	±6.7
ECCENTRIC GROUP					
SF	17.3	174.0	83.0	83.5	83.8
TZ	17.4	168.5	86.0	86.2	86.8
DD	16.2	175.0	76.0	81.5	80.7
GT	16.4	170.0	74.7	73.1	72.7
UB	16.3	185.0	71.2	72.0	75.2
PC	16.8	171.0	62.4	62.2	63.6
BB	17.6	171.0	67.5	67.5	67.5
BW	16.9	178.0	63.8	63.8	65.0
BT	17.3	173.5	68.9	68.9	68.2
RK	17.3	165.0	74.2	74.2	74.3
RM	16.3	176.5	74.2	74.2	72.3
MEAN	16.9	173.4	72.9	73.4	73.6
S.D.	±.5	±5.3	±7.3	±7.8	±7.6

T_1: Pretest; T_2: Posttest; T_3: Retention test

TABLE 2

STATIC FLEXION (CONCENTRIC GROUP)

ANGLE & TEST PERIOD / ARM & SUBJECT	90° T_1	90° T_2	90° T_3	105° T_1	105° T_2	105° T_3	120° T_1	120° T_2	120° T_3	135° T_1	135° T_2	135° T_3
TRAINED ARM												
RA (L)	36.6	40.7	39.7	38.7	41.7	40.7	33.6	37.7	34.6	31.6	33.6	31.6
PP (R)	31.7	35.9	35.3	31.7	36.1	33.5	29.9	31.7	31.7	24.7	26.5	26.5
LJ (L)	34.4	45.0	40.6	33.5	43.2	36.1	30.9	34.4	32.6	27.3	29.9	27.3
DF (R)	34.0	39.7	37.7	38.7	41.6	37.7	34.0	36.9	34.0	30.2	34.0	33.1
BF (L)	33.1	35.9	34.0	31.2	34.0	33.6	29.3	32.1	31.2	24.6	27.4	26.5
BT (L)	32.4	35.6	35.6	29.5	35.6	39.4	31.6	34.6	33.6	28.5	33.6	30.6
DK (R)	36.6	39.7	39.7	33.6	40.7	39.7	30.5	36.6	35.8	24.4	30.5	27.5
LR (L)	31.5	34.6	34.6	31.6	36.9	33.6	28.5	31.6	29.5	26.5	29.5	29.5
IM (L)	27.5	33.6	32.6	29.5	32.6	30.6	27.5	31.6	27.5	21.4	26.5	25.5
MM (R)	29.3	33.1	32.6	29.3	34.0	33.6	24.4	28.5	27.5	23.6	24.4	25.5
MF (R)	32.6	36.6	34.4	30.5	35.6	34.4	31.6	34.4	32.6	24.4	28.5	24.6
MEAN	32.7	37.3	36.1	32.5	37.5	35.3	30.2	33.6	32.0	26.1	29.5	28.0
S.D.	±2.8	±3.6	±2.9	±3.4	±3.7	±3.0	±2.7	±2.8	±2.8	±3.0	±3.2	±2.8
NON-TRAINED ARM												
PA (R)	37.7	38.7	38.7	37.7	38.7	37.7	35.6	35.6	34.6	31.6	32.6	32.6
PP (L)	31.7	32.1	31.7	27.3	28.2	28.2	27.3	28.2	27.5	23.8	22.6	23.8
LJ (R)	37.9	39.8	38.8	37.9	38.8	38.8	32.6	33.5	32.6	29.9	27.3	29.9
DF (L)	34.9	35.5	36.6	34.9	35.5	36.6	32.1	33.1	32.1	32.1	34.0	31.2
BF (R)	33.1	36.9	36.8	34.0	34.0	35.6	28.4	30.2	29.5	23.6	25.5	23.4
BT (R)	33.6	33.6	32.6	32.6	33.6	32.6	30.4	31.5	30.4	34.6	35.6	34.6
DK (L)	35.6	36.6	36.6	32.6	33.6	33.6	30.5	30.5	30.5	24.4	25.5	25.5
LR (R)	31.6	32.6	32.6	29.5	31.6	30.6	28.5	28.5	28.5	26.5	26.5	26.5
IM (R)	28.5	30.4	29.5	28.5	30.5	28.5	27.5	28.5	29.5	22.4	23.4	23.4
MM (L)	26.5	29.5	28.5	24.6	27.5	31.6	24.6	26.5	24.6	21.4	23.4	22.4
MF (L)	32.6	29.3	32.6	31.6	28.5	32.6	27.5	25.5	27.5	20.4	22.4	22.7
MEAN	33.1	34.1	34.0	31.8	32.8	32.3	29.5	30.2	29.7	26.4	27.2	26.9
S.D.	±3.5	±3.7	±3.6	±4.1	±3.9	±3.6	±3.1	±3.1	±2.8	±4.8	±4.7	±4.4

T_1: Pretest; T_2: Posttest; T_3: Retention Test. R: Right Arm; L: Left Arm. (Values presented in kilograms)

TABLE 3

STATIC FLEXION (ECCENTRIC GROUP)

ANGLE & TEST PERIOD / ARM & SUBJECT	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
TRAINED ARM												
SF (L)	39.7	41.7	40.7	35.6	45.8	38.5	32.6	40.7	36.6	26.5	35.6	30.6
TZ (R)	40.7	50.9	42.8	42.7	45.8	45.8	36.6	42.8	37.7	30.6	36.7	32.6
DD (L)	35.6	43.8	38.7	34.4	36.6	34.4	30.6	34.4	31.6	27.5	31.6	29.5
GT (L)	30.6	36.6	35.6	30.6	35.6	34.4	24.5	30.6	26.5	21.4	25.5	22.4
UB (R)	32.6	35.6	31.6	33.6	36.6	35.6	31.6	33.6	32.6	25.5	27.5	25.5
PC (R)	31.6	40.7	32.6	33.6	36.6	35.6	28.5	33.6	31.6	24.4	26.5	26.5
BB (L)	27.5	34.4	33.6	27.5	35.5	30.6	24.5	31.6	27.5	22.4	26.5	24.4
BW (R)	30.6	38.7	31.6	31.6	34.4	30.6	30.6	33.6	31.6	27.5	28.5	28.5
BT (L)	28.5	33.6	30.6	26.5	32.6	28.5	24.5	29.5	27.5	25.5	28.5	25.5
RK (R)	40.7	46.8	44.8	35.5	44.8	43.8	33.6	40.7	37.7	31.6	36.6	32.5
RM (R)	35.6	39.8	37.7	34.4	37.7	33.6	33.6	37.7	35.9	31.6	35.6	31.6
MEAN	33.9	40.1	36.3	33.2	38.3	35.5	30.0	35.3	32.4	26.7	30.8	28.1
S.D.	±4.8	±5.3	±4.9	±4.3	±4.7	±5.2	±4.2	±4.4	±4.1	±3.4	±4.5	±3.5
NON-TRAINED ARM												
SF (R)	38.7	40.7	37.7	33.6	32.6	33.6	31.6	34.4	33.6	23.4	25.5	25.5
TZ (L)	41.7	44.8	42.8	39.7	41.7	40.7	36.6	34.4	35.6	28.5	30.6	28.5
DD (R)	37.7	39.8	38.7	35.6	36.6	35.6	27.5	30.6	29.5	26.5	27.5	26.5
GT (R)	33.6	34.4	36.6	34.4	32.6	33.6	28.5	25.5	28.5	21.4	22.4	23.4
UB (L)	29.5	31.6	31.6	29.5	32.6	31.6	28.5	28.5	27.5	24.5	25.5	24.5
PC (L)	29.5	30.6	30.6	29.5	30.6	29.5	24.5	27.5	25.5	22.4	22.4	22.4
BB (R)	34.4	34.4	33.6	29.5	29.5	29.5	26.5	29.5	26.5	24.5	27.5	28.5
BW (L)	32.6	32.6	31.6	29.5	31.6	29.5	28.5	29.5	28.5	28.5	28.5	28.5
BT (R)	28.5	30.6	29.5	27.5	29.5	28.5	24.5	24.5	23.4	24.5	25.5	24.5
RK (L)	38.7	41.7	38.7	34.4	38.7	35.6	32.6	32.6	31.6	30.6	29.5	30.6
RM (L)	36.6	37.7	36.6	33.6	33.6	32.6	34.4	34.4	33.6	25.5	26.5	26.5
MEAN	34.6	36.2	35.2	32.4	33.5	32.7	29.4	30.1	29.4	25.4	26.4	26.0
S.D.	±4.3	±4.9	±4.1	±3.6	±3.9	±3.6	±3.9	±3.5	±3.8	±2.8	±2.6	±2.4

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)

TABLE 4

STATIC EXTENSION (CONCENTRIC GROUP)

ANGLE & TEST PERIOD / ARM & SUBJECT	90° T_1	90° T_2	90° T_3	105° T_1	105° T_2	105° T_3	120° T_1	120° T_2	120° T_3	135° T_1	135° T_2	135° T_3
TRAINED ARM												
PA (L)	24.4	27.5	24.4	33.6	36.1	33.6	32.6	35.5	32.6	23.4	30.5	26.5
PP (R)	20.4	24.7	21.4	22.9	25.6	23.4	24.4	25.6	25.6	22.4	25.6	22.4
LJ (L)	16.7	21.2	21.4	23.8	26.4	23.4	23.4	26.4	24.4	19.3	23.8	22.4
DF (R)	24.6	27.5	24.6	26.5	29.3	28.4	25.5	28.4	25.5	24.6	27.4	26.5
BF (L)	17.9	23.6	22.4	19.8	24.5	22.4	18.3	25.5	22.4	24.6	26.5	24.6
BT (L)	23.4	26.5	24.4	27.5	30.5	28.5	24.4	26.5	25.5	21.4	22.4	21.4
DK (R)	30.5	33.6	32.6	23.4	27.5	25.5	23.4	29.5	26.5	21.4	28.5	23.4
LR (L)	14.3	24.4	23.4	23.4	27.5	25.4	22.4	28.5	23.4	21.4	27.5	24.4
IM (L)	18.9	21.4	20.4	24.6	28.5	25.4	22.4	25.5	26.5	25.5	28.5	27.5
MM (R)	18.9	20.8	20.8	24.6	26.5	26.5	22.4	25.5	22.4	24.5	27.5	24.5
MF (R)	23.4	25.5	25.5	21.4	24.4	24.4	23.4	25.5	24.4	21.4	22.4	22.4
MEAN	21.2	25.1	23.7	24.7	27.9	26.1	23.9	27.5	25.4	22.7	26.4	24.2
S.D.	±4.6	±3.7	±3.4	±3.6	±3.3	±3.2	±3.4	±3.0	±2.8	±1.9	±2.6	±2.0
NON-TRAINED ARM												
PA (R)	29.5	31.7	28.5	32.4	33.6	32.4	33.6	35.5	34.4	29.5	29.5	29.5
PP (L)	21.2	22.9	21.4	24.4	25.6	23.4	27.5	29.5	27.5	17.6	20.4	18.3
LJ (R)	21.2	24.7	29.4	24.4	24.4	24.4	24.4	25.5	27.5	21.4	20.4	21.4
DF (L)	22.7	23.6	22.4	27.5	27.5	27.5	25.5	24.5	25.5	25.5	26.5	24.6
BF (R)	20.8	21.7	21.7	24.6	25.5	24.6	23.4	24.6	24.6	23.6	24.6	23.4
BT (R)	22.4	23.4	23.4	25.5	26.5	26.5	22.4	24.4	22.4	20.4	21.4	21.4
DK (L)	25.5	24.4	25.5	26.5	26.5	27.5	22.4	23.4	23.4	26.5	28.5	27.5
LR (R)	18.3	20.4	20.4	20.4	21.4	21.4	25.5	24.4	25.5	29.4	28.5	27.5
IM (R)	20.8	20.4	21.4	23.6	25.5	24.4	25.5	26.5	25.5	30.2	31.6	30.2
MM (L)	16.1	17.3	17.3	27.4	29.3	29.3	25.5	26.5	25.5	25.5	28.5	26.5
MF (L)	22.4	23.4	23.4	25.5	26.5	26.5	23.4	24.4	24.4	19.3	20.4	21.4
MEAN	21.8	23.1	22.7	25.7	26.6	26.1	25.1	26.3	25.7	24.4	25.5	24.7
S.D.	±3.5	±3.6	±2.9	±2.9	±3.0	±3.0	±3.0	±3.1	±3.2	±4.3	±4.2	±3.8

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (values presented in kilograms)

TABLE 5

STATIC EXTENSION (ECCENTRIC GROUP)

ARM & SUBJECT \ ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
TRAINED ARM												
SF (L)	27.5	33.6	30.6	32.6	34.4	33.6	27.5	32.6	27.5	26.5	31.6	31.6
TZ (R)	29.5	34.4	29.5	32.6	36.6	32.6	32.6	34.4	34.4	26.5	33.6	32.6
DD (L)	20.4	29.5	25.5	25.5	31.6	27.5	26.5	31.5	29.5	20.4	27.5	24.4
GT (L)	24.4	27.5	25.5	25.5	26.5	26.5	22.4	24.4	24.4	20.4	24.4	22.4
UB (R)	19.8	23.7	20.4	18.9	26.5	21.4	22.4	26.5	24.4	19.8	23.6	20.4
PC (R)	21.7	23.4	20.4	22.7	25.5	23.6	21.4	26.5	23.6	20.8	26.5	24.4
BB (L)	18.3	24.4	23.4	20.4	27.5	24.4	24.4	23.4	23.4	20.8	23.4	22.4
BW (R)	19.3	22.4	19.3	16.3	20.4	17.3	12.2	21.4	17.3	17.3	19.3	19.3
BT (L)	19.3	23.4	21.4	19.3	26.5	22.4	24.4	27.5	26.5	21.4	24.4	25.5
RK (R)	27.5	30.6	28.5	26.5	31.6	30.6	24.4	30.6	26.5	24.4	28.5	27.5
RM (R)	18.9	27.5	24.4	22.7	28.4	25.5	22.4	32.2	27.5	25.5	33.6	25.5
MEAN	22.4	27.2	24.4	23.8	28.7	25.9	23.7	28.2	25.9	22.1	26.9	25.1
S.D.	±4.1	±4.3	±3.9	±5.2	±4.6	±4.9	±4.9	±4.2	±4.3	±3.1	±4.6	±4.2
NON-TRAINED ARM												
SF (R)	27.5	28.5	28.5	28.5	30.5	30.5	29.5	29.5	29.5	29.5	31.5	28.5
TZ (L)	29.5	28.5	29.5	30.5	31.6	31.6	34.4	35.8	34.4	32.4	35.5	32.4
DD (R)	21.4	22.4	22.4	24.4	26.5	25.5	28.5	29.5	29.5	21.4	24.4	22.4
GT (R)	22.4	25.5	25.5	23.4	24.4	23.4	22.4	22.4	21.4	21.4	21.4	22.4
UB (L)	17.9	23.4	21.4	23.6	25.5	24.4	23.6	23.6	23.6	22.7	22.4	22.7
PC (L)	20.8	18.3	21.4	22.7	24.4	23.6	24.4	26.5	23.6	19.8	22.4	20.4
BB (R)	19.3	23.4	19.3	26.5	27.5	26.5	27.5	29.5	27.5	20.4	23.4	21.4
BW (L)	14.3	14.2	14.3	17.3	19.3	18.3	12.2	13.2	13.2	13.2	16.3	13.2
BT (R)	22.4	24.4	20.4	25.5	27.5	25.5	24.4	28.5	26.5	25.5	27.5	25.5
RK (L)	28.5	28.5	28.5	29.5	30.5	29.5	24.4	26.7	24.4	26.5	27.5	26.5
RM (L)	17.9	20.4	18.9	25.5	27.5	26.5	24.4	24.4	24.4	28.4	26.5	27.5
MEAN	22.0	23.4	22.7	25.2	26.8	25.9	25.1	26.3	25.3	23.7	25.1	23.9
S.D.	±4.8	±4.5	±4.8	±3.7	±3.5	±3.7	±5.5	±5.7	±5.4	±5.4	±5.0	±5.0

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)

TABLE 6

DYNAMIC FLEXION (CONCENTRIC GROUP)

ARM & SUBJECT / ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
TRAINED ARM												
PA (L)	20.4	25.5	23.4	20.4	24.4	22.4	20.4	28.5	25.5	17.3	24.5	24.4
PP (R)	22.9	27.3	26.5	18.5	26.4	25.6	20.3	24.6	24.6	17.6	21.2	19.4
LJ (L)	19.4	25.6	20.4	17.6	23.8	20.4	17.3	21.4	20.4	16.7	19.4	17.6
DF (L)	27.5	31.2	27.5	25.5	27.5	25.5	21.7	24.5	23.6	21.7	24.6	23.6
BF (L)	22.7	25.5	24.4	22.7	25.5	23.4	20.8	24.4	20.8	17.0	19.8	18.8
BT (L)	23.4	27.5	25.5	24.4	27.5	25.5	22.4	26.5	23.4	18.3	19.3	19.3
DK (R)	24.4	28.5	28.5	26.5	29.5	29.5	24.5	26.5	25.5	18.3	21.4	20.4
LR (L)	15.3	19.3	17.3	15.3	19.3	16.3	15.3	18.3	15.3	14.2	16.3	14.3
IM (L)	19.3	25.5	20.4	19.3	24.4	20.4	18.3	22.4	19.3	17.3	19.3	18.3
MM (R)	12.3	16.3	14.3	10.4	14.3	13.3	9.6	15.3	13.3	7.6	13.2	11.2
MF (R)	21.4	26.5	24.4	21.4	26.5	25.5	19.3	23.4	24.4	17.3	19.3	19.3
MEAN	20.8	25.3	23.0	20.2	25.5	22.5	19.1	22.8	21.4	16.7	19.8	18.7
S.D.	±4.2	±4.1	±4.4	±4.7	±4.3	±4.7	±4.0	±3.8	±4.1	±3.4	±3.3	±3.7
NON-TRAINED ARM												
PA (R)	23.4	25.5	29.4	24.4	24.4	22.4	22.4	25.5	23.4	20.4	22.4	22.4
PP (L)	17.6	22.9	18.5	16.7	20.8	18.5	16.7	18.8	16.7	14.9	15.9	15.9
LJ (R)	22.9	25.6	23.4	22.9	24.7	23.4	21.2	23.4	22.0	19.4	19.4	18.3
DF (L)	19.8	21.4	20.4	18.9	20.4	20.4	17.3	23.6	22.7	17.3	21.7	20.4
BF (R)	23.6	24.6	23.6	18.9	21.7	18.9	17.3	17.3	17.3	17.3	17.3	17.3
BR (R)	25.5	27.5	26.5	24.4	27.5	25.5	29.4	25.5	24.4	19.3	21.4	20.4
DK (L)	23.4	24.4	23.4	25.5	26.5	24.4	25.5	25.5	25.5	18.3	19.3	18.3
LR (R)	19.3	19.3	19.3	19.3	19.3	19.3	17.3	18.3	18.3	19.3	19.3	19.3
IM (R)	21.4	21.4	20.4	21.4	22.4	20.4	18.3	16.3	17.3	17.3	19.3	17.3
MM (L)	14.2	15.3	15.3	10.4	12.2	12.2	7.6	11.2	12.2	7.6	10.2	11.2
MF (L)	18.3	18.3	17.3	20.4	20.4	20.4	19.3	19.3	19.3	15.3	15.3	16.3
MEAN	20.8	22.4	21.1	20.3	21.8	20.5	18.8	20.4	19.9	16.9	18.3	17.9
S.D.	±3.3	±3.7	±3.4	±4.3	±4.2	±3.6	±4.8	±4.6	±4.0	±3.5	±3.5	±2.9

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)

TABLE 7

DYNAMIC FLEXION (ECCENTRIC GROUP)

ANGLE & TEST PERIOD / ARM & SUBJECT	90^{0} T_1	T_2	T_3	105^{0} T_1	T_2	T_3	120^{0} T_1	T_2	T_3	135^{0} T_1	T_2	T_3
TRAINED ARM												
SF (L)	23.4	27.5	27.5	23.4	26.5	26.5	20.4	23.4	23.4	19.3	22.4	22.4
TZ (R)	26.5	30.5	29.5	27.5	30.5	29.5	24.4	29.5	27.5	18.3	24.4	22.4
DD (L)	19.3	34.6	32.6	17.3	34.6	32.6	15.3	30.5	30.5	16.3	26.5	25.4
GT (L)	24.4	28.5	25.5	23.4	29.5	23.4	22.4	24.4	21.4	19.3	20.4	19.3
UB (R)	19.3	23.4	22.4	17.3	23.4	19.3	14.3	22.4	18.3	11.2	18.3	15.3
PC (R)	12.3	25.5	18.3	11.3	19.9	16.3	10.4	18.3	14.3	12.3	16.3	13.3
BB (L)	13.2	24.4	18.3	13.2	22.4	17.3	10.2	21.4	16.3	10.2	19.8	15.3
BW (R)	16.1	19.3	17.0	15.1	18.3	16.3	12.3	16.3	13.2	10.4	14.2	12.3
BT (L)	13.2	27.5	21.4	13.2	29.4	23.4	8.1	22.4	16.3	8.1	18.3	14.3
RK (R)	23.4	26.5	24.4	23.4	27.5	23.4	21.4	29.4	21.4	18.3	21.4	21.4
RM (R)	21.7	26.5	29.4	18.9	24.6	23.4	19.8	21.7	21.7	21.7	23.6	22.4
MEAN	19.3	26.7	23.7	18.5	25.6	22.8	16.3	23.1	20.4	15.0	20.5	18.5
S.D.	±5.0	±3.9	±4.9	±5.2	±4.8	±5.3	±5.6	±4.2	±5.4	±4.7	±3.7	±4.5
NON-TRAINED ARM												
SF (R)	26.5	27.5	25.5	24.4	26.5	26.5	21.4	23.4	24.4	18.3	18.3	18.3
TZ (L)	23.4	25.5	22.4	24.4	26.5	24.4	20.4	21.4	21.4	14.3	16.3	16.3
DD (R)	19.3	22.4	20.4	20.4	23.4	21.4	17.3	20.4	19.3	15.3	17.3	16.3
GT (R)	21.4	25.5	24.4	23.4	24.4	24.4	22.4	22.4	21.4	18.3	20.4	18.3
UB (L)	15.3	18.3	16.3	13.2	17.3	15.3	12.2	14.3	14.3	10.2	13.2	11.2
PC (L)	10.4	14.4	12.2	9.5	15.7	11.2	8.5	11.2	10.2	8.5	10.2	10.2
BB (R)	19.3	22.4	20.4	17.3	23.4	18.3	16.3	18.3	17.3	14.3	16.3	15.3
BW (L)	14.2	17.0	1s.3	14.2	16.3	15.3	12.3	14.2	12.3	11.3	14.2	1s.3
BT (R)	19.3	20.4	19.3	17.3	18.3	17.3	16.3	18.3	19.3	14.3	14.2	13.2
RK (L)	26.5	27.5	27.5	23.4	25.5	23.4	16.3	19.3	17.3	19.3	20.4	21.4
RM (L)	21.7	23.6	23.6	18.9	21.7	21.7	16.3	18.3	20.8	19.8	21.7	21.7
MEAN	19.7	22.2	20.4	18.8	21.7	19.9	16.3	18.3	18.0	14.9	16.6	15.9
S.D.	±5.0	±4.3	±5.1	±5.1	±4.2	±4.8	±4.2	±3.8	±4.3	±3.8	±3.5	±3.9

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)

TABLE 8

DYNAMIC EXTENSION (CONCENTRIC GROUP)

ARM & SUBJECT / ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
TRAINED ARM												
PA (L)	43.8	60.1	49.9	41.7	50.9	45.8	37.7	40.7	38.7	31.6	33.6	32.6
PP (R)	30.9	43.2	39.7	29.9	39.7	36.1	30.9	36.1	30.9	30.9	33.5	29.9
LJ (L)	38.8	46.7	46.2	35.3	39.7	39.7	30.9	34.4	34.4	24.7	29.1	29.1
DF (R)	47.3	50.1	48.2	42.5	44.8	42.5	37.8	39.8	37.7	33.1	34.0	34.0
BF (L)	31.2	47.3	37.8	27.5	39.7	34.9	24.6	34.9	29.3	21.7	29.3	23.6
BT (L)	41.7	54.9	48.9	38.7	49.9	44.8	31.6	40.7	36.6	25.5	27.5	25.5
DK (R)	47.8	52.9	48.9	40.7	44.8	43.7	32.6	38.7	36.7	28.5	30.5	30.5
LR (L)	31.6	42.8	40.7	29.5	40.7	39.7	28.5	36.6	34.6	24.4	32.6	28.5
IM (L)	30.5	44.8	38.7	31.6	40.7	36.7	28.5	35.6	32.6	23.4	31.6	23.4
MM (R)	34.0	40.7	39.7	29.3	33.6	33.6	23.6	28.5	28.5	17.9	23.4	22.4
MF (R)	32.6	36.6	35.8	30.5	33.6	32.6	26.5	27.5	27.5	21.4	26.5	20.4
MEAN	37.3	47.3	43.1	34.3	41.7	39.1	30.1	35.8	33.4	25.7	30.1	27.3
S.D.	±6.8	±6.8	±5.3	±5.6	±5.9	±4.6	±4.8	±4.4	±3.9	±4.8	±3.4	±4.4
NON-TRAINED ARM												
PA (R)	46.8	48.9	47.8	44.8	46.7	45.8	38.7	40.7	39.8	28.5	30.5	29.5
PP (L)	25.6	29.9	27.5	24.7	29.9	26.5	26.4	31.7	28.2	28.2	27.3	28.2
LJ (R)	43.2	48.5	44.8	36.1	39.8	37.7	30.9	32.7	32.7	25.6	29.1	26.7
DF (L)	42.5	45.4	43.7	38.8	39.7	39.7	33.1	34.0	34.0	25.5	26.5	26.5
BF (R)	33.1	38.7	35.6	26.5	31.6	28.5	28.4	30.6	29.5	30.2	32.1	32.5
BT (R)	42.8	46.8	44.8	37.7	42.8	40.7	32.6	35.6	33.6	27.5	30.5	27.5
DK (L)	46.8	47.9	47.9	38.7	40.7	39.8	32.6	36.7	34.4	17.3	26.7	23.4
LR (R)	29.5	38.7	32.6	26.5	35.6	30.6	25.5	27.5	25.5	21.4	24.4	22.4
IM (R)	31.6	36.7	32.6	30.5	37.7	31.6	28.5	33.6	35.6	24.4	27.5	28.5
MM (L)	37.8	41.7	39.8	33.1	35.6	33.1	23.4	25.5	30.5	19.8	20.4	24.4
MF (L)	34.6	39.7	40.7	32.6	34.6	34.6	28.5	31.6	29.5	21.4	24.4	22.4
MEAN	37.7	42.1	39.8	33.6	37.7	35.3	29.9	32.7	32.1	24.5	27.2	26.5
S.D.	±7.3	±6.0	±6.8	±6.3	±4.9	±5.9	±4.3	±4.2	±4.0	±4.1	±3.3	±3.2

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)

TABLE 9

DYNAMIC EXTENSION (ECCENTRIC GROUP)

ARM & SUBJECT / ANGLE & TEST PERIOD	90°			105°			120°			135°		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
TRAINED ARM												
SF (L)	43.8	52.9	49.9	40.7	51.9	46.8	37.7	41.7	38.7	28.5	31.6	29.5
TZ (R)	46.8	61.1	54.9	44.8	58.0	52.9	39.7	49.9	47.8	35.6	43.8	38.7
DD (L)	37.7	60.0	50.9	36.6	56.0	40.7	35.6	46.8	35.6	32.6	36.6	32.6
GT (L)	39.7	47.8	43.8	32.6	42.7	39.7	30.5	37.7	22.4	22.4	30.5	29.5
UB (R)	36.8	43.7	42.5	33.6	40.7	41.6	21.7	25.5	24.6	19.8	27.5	24.5
PC (R)	33.6	46.8	46.8	30.5	43.8	41.7	30.5	37.7	37.7	29.5	33.6	33.6
BB (L)	25.5	54.9	47.8	23.4	49.9	46.8	20.4	45.8	37.7	17.3	32.6	28.5
BW (R)	26.5	37.7	28.5	23.4	34.6	26.5	21.4	33.6	24.5	19.3	30.6	22.4
BT (L)	34.6	45.8	39.7	30.5	41.7	35.6	26.5	36.6	31.6	21.4	30.6	24.5
RK (R)	40.7	48.9	44.8	38.7	44.8	40.7	32.6	37.7	32.6	26.5	35.6	30.6
RM (R)	31.6	42.8	33.6	27.5	40.7	30.5	26.5	36.6	28.5	25.5	30.6	24.5
MEAN	36.1	49.3	43.9	32.9	45.9	40.3	29.4	39.1	34.3	25.3	33.1	28.9
S.D.	±6.7	±7.3	±7.7	±6.9	±7.2	±7.5	±6.7	±6.8	±6.9	±5.8	±4.4	±4.9
NON-TRAINED ARM												
SF (R)	48.8	48.8	47.8	44.8	48.8	44.8	38.7	39.7	38.7	31.6	30.6	32.6
TZ (L)	48.8	49.9	48.8	46.8	48.8	45.8	38.7	38.7	37.7	27.5	30.6	28.5
DD (R)	40.7	42.7	41.7	39.7	41.7	39.7	33.6	35.6	34.6	26.5	28.5	26.5
GT (R)	39.7	38.7	38.7	34.6	37.7	35.6	29.5	30.6	31.6	22.4	24.5	22.4
UB (L)	34.6	34.6	35.6	30.5	31.6	35.6	29.5	29.5	29.5	24.4	25.5	25.5
PC (L)	31.6	34.6	33.6	29.5	30.5	30.5	26.5	26.5	26.5	23.4	24.5	25.5
BB (R)	36.6	37.7	36.6	33.6	37.7	34.6	28.5	31.6	28.5	26.5	29.5	27.5
BW (L)	19.3	22.4	22.4	21.4	20.4	20.4	21.4	22.4	22.4	22.4	22.4	21.4
BT (R)	37.7	41.7	38.6	33.6	34.6	33.6	29.5	31.6	31.6	24.4	27.5	26.5
RK (L)	52.9	52.9	51.9	45.8	43.8	46.8	36.6	37.7	37.7	28.5	28.5	28.5
RM (L)	31.6	37.7	33.6	29.5	29.5	29.5	28.5	26.5	27.5	28.5	30.6	29.5
MEAN	38.4	40.1	39.0	35.4	36.8	36.1	31.0	31.8	31.5	26.0	27.5	26.8
S.D.	±9.5	±8.6	±8.4	±8.0	±8.7	±7.9	±5.4	±5.6	±5.3	±2.9	±2.9	±3.1

T_1: Pretest; T_2: Posttest; T_3: Retention test. R: Right arm; L: Left arm. (Values presented in kilograms)