

CSP-2

THE EFFECTS OF ELECTRICAL STIMULATION
ON KNEE REHABILITATION

by Claudia Cardarelli



Thesis presented to the School of Graduate Studies
in partial fulfilment of the requirements for the
degree of Master of Science in Kinanthropology

UNIVERSITY OF OTTAWA
OTTAWA, CANADA, 1977

UMI Number: EC55665

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI[®]

UMI Microform EC55665
Copyright 2011 by ProQuest LLC
All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

DEDICATION

I wish to thank my husband, Sebastian, for his support and encouragement.

ACKNOWLEDGEMENTS

I wish to thank Dr. Don Johnson and Phil Ashcroft of the Sports Medicine Clinic, University of Carleton for their helpfulness and co-operation in this study.

Chapter

IV. RESULTS AND DISCUSSION	48
Introduction	48
Homogeneity of Treatment Groups	48
Absolute Strength Gain Comparison Between the Electrical Stimulation and the Isokinetic Group	49
Percentage Strength Gain Comparison Between the Electrical Stimulation and Isokinetic Group	59
Individual Injured Leg Percent Strength Gains Relative to Pre-test Healthy Leg Score	61
Strength Gains in Injured Leg Relative to Pre-test Healthy Leg	67
Comparison on Rate of Strength Gain in Healthy and Injured Leg Relative to their Own Pre-test Values	71
Summary of Discussion	75
V. CONCLUSIONS AND RECOMMENDATIONS	78
Introduction	78
Conclusions	78
Recommendations	79
.	
Appendices	
A. ILLUSTRATIONS OF EQUIPMENT	81
B. RAW DATA	84
C. BACKGROUND QUESTIONNAIRE	86
REFERENCES	88

LIST OF ILLUSTRATIONS

Figure

1.	The Format of the Pre-tests and Post-tests and the Number of Treatment Sessions	43
2.	A Three Dimensional Block of the Statistical Design	46
3.	Mean Group Strength and Standard Deviation of Injured Leg on Isokinetic Test	54
4.	Mean Group Strength and Standard Deviation of Injured Leg on Isometric Test	55
5.	Mean Group Strength and Standard Deviation of Healthy Leg on Isometric Test	56
6.	Mean Group Strength and Standard Deviation of Healthy Leg on Isokinetic Test	57
7.	Comparison of the Two Treatments on the Magni- tude of the Strength Gain of the Injured Leg Expressed as a Percentage of the Pre-test Injured Leg	60
8.	Comparison of the Two Treatments on the Magni- tude of the Healthy Leg Expressed as a Percentage of the Pre-test Healthy Leg	62
9.	Percentage Strength Gains of Isokinetic Treated Leg on Isokinetic Test Relative to Pre-test Healthy Leg	64
10.	Percentage Strength Gains of Isokinetic Treated Injured Leg on Isometric Test Relative to Pre-test Healthy Leg	65
11.	Percentage Strength Gains of Electrically Stimu- lated Injured Leg on Isometric Test Relative to Pre-test Healthy Leg	66

Figure

12.	Percentage Strength Gains of Electrically Stimulated Injured Leg on Isokinetic Test Relative to Pre-test Healthy Leg	68
13.	Percent Changes in Strength Increase Between Each Test on the Injured Leg Relative to the Pre-test Healthy Leg, Over Time	69
14.	Comparison Between Healthy and Injured Leg on Percent Change in Strength Over Time During Electrical Stimulation Treatment	72
15.	Comparison Between Healthy and Injured Leg on Percent Change in Strength Over Time During Isokinetic Treatment	73
16.	Electrical Stimulation Apparatus	82
17.	Isokinetic Treatment Apparatus	83

LIST OF TABLES

Table

1. Description of Subjects' Sports Injuries . . .	34
2. Hartley F Max Test on Strength Percent Difference Between the Healthy and Injured Leg on the Static and Isokinetic Test Between the Two Treatment Groups	50
3. Hartley F Max Test on Pre-test Scores of Healthy and Injured Knee of the Two Treatment Groups on Static and Isokinetic Tests	51
4. ANOVA Results on the Electrical Stimulation and Isokinetic Groups	52
5. Raw Data in Units of Pound Force	85

CHAPTER I

THE PROBLEM

Introduction and Rationale

Participation in sports at all levels, from recreational to international, exposes the participant to the possibility of becoming involved in some form of injury. Knee injuries account for one quarter to one third of the sport injuries that occur (Williams, 1971). This may be due in part to the vulnerability of the knee joint to lateral displacement. Consequently, a great deal of rehabilitative effort is expended on the knee joint and related musculature.

When the knee joint does become injured, a reflex inhibition of the quadriceps occurs (Smillie, 1962). The result is loss of tone, volume and control, causing the joint to become inadequately protected from the strains and twists of weight bearing activities. Williams (1962) stated that "the degree of disability resulting from a knee injury is inversely proportional to the power of the quadriceps and therefore the active restoration and maintenance of power in this muscle is the key to early recovery from knee injuries."

At present, the rehabilitation of the knee joint using the conventional types of exercises, for example, resistive weights and isometrics, entails an average time period of four to six weeks for recovery. This time period can exact a heavy toll on the progress of an international or professional athlete during a competitive period. The provision of superior rehabilitative methods directed at decreasing recovery time would therefore be desirable.

Recently there has been an increase in the use of electrical stimulation as a supplementary part of a strength training program for Russian athletes of international calibre (Wise, 1974). However, Russian studies of this nature have not been published in North America to date. Studies on electrical stimulation in Canada and the United States have mainly focused on the denervated human muscle for the purpose of preventing further atrophy and enabling the movement of orthostatic equipment (Smith, 1968; Steinberger, 1968). The "trophic influence" of an innervated muscle promotes a different response to muscle stimulation, preventing the comparison between responses of the innervated and denervated muscle to electrical stimulation (Astrand, 1970).

Those few studies that have been conducted on the effects of electrical stimulation on contractile efficiency in man and animal using healthy, innervated musculature have demonstrated an increase in strength (Massey, 1965; Nowakowska, 1962). The increase of strength in these

investigations on healthy humans and animals was shown to be less than the strength developed through voluntary effort (Massey, 1965; Nowakowska, 1962; and de Vries, 1970). A standard method for the electrical stimulation procedure was not established in these studies. The frequency, amplitude and duration of electrical stimulation described in each study varied significantly obscuring identifiable trends of electrical stimulation.

Electrical stimulation is presently used as an aid in such therapeutic situations as relaxation of muscle spasm following trauma; muscle re-education; decreasing the rate of atrophy of denervated muscles; preventing disuse atrophy of innervated musculature and inhibiting development of orthostatic disturbances of muscles in chronic hypokinesia (Hurevych, 1973). A study to quantify the benefit of using electrical stimulation versus voluntary effort on weakened, human musculature may result in a new significant role for electrical stimulation.

The rehabilitation of a knee joint generally involves the application of static exercises during the phase of swelling, pain and general immobility of the knee joint. When the swelling has subsided and full range of movement is permitted by the knee joint, dynamic types of exercises involving both resistive and isokinetic exercises are employed. Static exercises promote increase of strength specific to that angle at which the exercise is carried out (de Vries, 1970) and dynamic exercise develops

strength mainly at the point of initial maximum resistance (Moffroid, 1969), therefore, it is necessary that both forms of exercise be undertaken during the proper phase for strength development throughout full range of knee movement. Unlike dynamic exercise, electrical stimulation can be applied to the quadriceps during the phase of knee immobility due to pain, swelling or casting. Perhaps the strength gained from electrical stimulation would be adequately distributed throughout the range of motion eliminating the need for additional dynamic training. In order to identify the translation of strength, if any, throughout the full range of movement, a comparison between an electrical stimulation trained group and an isokinetic (dynamic) group tested on both isometric and dynamic strength measurements is necessary.

Electrical stimulation is of a non-volitional nature permitting the progress of rehabilitation to be less influenced by the daily fluctuation of the individual's attitude. Therefore, intensity and frequency of the contractions would adhere more closely to the overloading of the musculature during each session. Hundal (1972) observed that local excitatory stimulation significantly increased the performance of a fatigued muscle as opposed to verbal encouragement indicating the potential of a greater training overload being placed on the muscles with stimulation. The progress of a subject's rehabilitation using electrical stimulation may be less inhibited with the factor of skill

learning generally associated with volitional activities such as weight training.

It, therefore, appears necessary to examine any possible significant effects that electrical stimulation compared to static and dynamic forms of exercise may have on the rate and magnitude of change in strength for rehabilitation.

Statement of the Problem

The purpose of this study was to determine any differences in the effects of an electrical stimulation and an isokinetic program on the rate and magnitude of strength development in normally innervated but weakened quadriceps following a knee injury.

Sub-Problems

The sub-problems of this study were:

1. To determine if there was a difference in the time course for strength increase in healthy and unhealthy quadriceps.
2. To determine if the strength gain resulting from electrical stimulation could be similarly demonstrated in both dynamic and static strength testing.
3. To compare the effects of electrical stimulation versus isokinetic training on the magnitude of strength gain in healthy, normal quadriceps.

Delimitations of the Study

The study was delimited to a group of human, male and female subjects varying in age from 18 years to 27 years of age. The subjects within the groups came from a variety of sport backgrounds and were homogeneous only in the presence of a unilateral knee joint injury and secondary weak quadriceps. The subjects were the patients of the same orthopedic specialist.

Limitations of the Study

The inferences of the study were limited by the following experimental problems:

1. A control group was not included in the study due to humanitarian reasons which would not allow a subject to be deprived of therapy. The subject's healthy leg was used as a control.
2. The subjects in the isokinetic treatment group were using the same equipment for their treatment as they were tested on dynamically. This provided an imbalanced learning situation between the two treatment groups on dynamic testing.
3. Motivation and daily activities of the subjects were not controlled other than a verbal explanation of what to do or not to do.

4. Due to individual pain thresholds, the intensity of exercise and measurements of strength were subject to individual variation.
5. The cause for knee injury was not of a homogeneous nature nor was the type of knee injury.
6. The elapsed time from the injury to the beginning of rehabilitation was uncontrolled.
7. The time of day and period of sessions varied for the subjects due to the number of subjects and limited pieces of equipment.
8. The study was conducted in the summer making it conducive for more physical activity and thus perhaps supplementation of the treatment.
9. The Neurotron 627, an electrostimulation unit, had a maximum current output of 60mA. Many subjects reached this intensity and were not able to add more progression to their treatment.
10. As a result of the limited number of subjects, the power of statistical analysis was low (Campbell and Stanley, 1963).
11. Individual body type differences influenced the fixed 40 degree angle of the knee joint.

Definition of Terminology

1. Atrophy: The decrease in fiber size and strength due to inactivity of the muscle or when the muscle is used only for weak contractions.
2. Chondromalacia Patella: The causative factor may be traumatic or idiopathic resulting in an erosion of the cartilage covering the underside of the knee cap causing pain in and around the front of the knee followed by an inhibited use of the quadriceps.
3. Dynamic Contraction: Contraction of the muscle varies its length when activated causing external work to be done. The human muscle is never purely isotonic, meaning constant tension, and thus the term dynamic contraction is employed.
4. Injury: For the purpose of this study the injury involved sport accidents causing the impairment of the knee joint and secondary inhibited use of innervated quadriceps resulting in a 20 percent or more muscular weakness.
5. Isokinetics: An electro-mechanical device providing regulation of the speed of the dynamic contraction and offering resistance equal and opposite to the exerted force recorded as torque.

6. Isometric Contraction: When both ends of a muscle are fixed and no movement occurs in the joint involved during muscle contraction, the contraction is called isometric. In human muscle, the isometric contraction causes a slight shortening of the muscle upon initiation of the contraction, thus it is more appropriately called static. The terms were used interchangeably in this experiment.
7. Motor Point: An anatomical entity and not a physiological property of muscle fiber. It is the area of the skin which is especially sensitive to electrical stimulation to produce the greatest contraction with the least current.
8. Muscular Weakness: Identified by a 20 percent or greater decrease in voluntary maximal isometric strength in the injured leg compared to the normal leg.
9. Strength: Refers to static strength involving maximal force in pounds exerted by the muscles in a single effort on a cable tensiometer and dynamic strength expressed in pounds of force moved on an isokinetic machine.
10. Torque: Torque is a force which acts about an axis of rotation. It represents the interaction between the lever arm of motion and muscular forces as they

act about a joint.

CHAPTER II

REVIEW OF LITERATURE

The review of literature emphasizes the role of the quadriceps in the knee joint and the various methods of strength training on normal as well as injury weakened quadriceps. Areas of particular concern are the specificity of strength training and the most effective types of strength training.

The Role of the Quadriceps in the Knee Joint

The knee joint is classified as a diarthrosis joint in terms of a hinge joint allowing flexion and extension (Rasch and Burke, 1967). Helfet (1974) described the knee joint as being spiral in character performing a screw action which creates more stability for the knee joint than that of a true hinge joint which permits movement in only one plane. The spiral action can be observed when the knee is fully flexed and the tibial tubercle points to the inner half of the patella and upon extension of the knee the tubercle points in line to the outer half of the patella. The other components of a knee joint that accompany the bony structure are the quadriceps, ligaments and tendons.

The quadricep muscle group is comprised of the vastus medialis, vastus lateralis, vastus intermedius and

the rectus femoris and performs the function of knee extension and stabilization enabling man to stand, walk and run. Strong quadriceps are the knee joint's first line of defense against extreme ranges of movement such as abduction and adduction (Goldfuss et al., 1973) and possible dislocation (Rasch and Burke, 1967). It is the stretch of a normal ligament which is proprioceptive in nature that stimulates the contraction of surrounding musculature to support the function of the joint resulting in knee joint stabilization and prevention of ligament damage by abnormal stress (Allman, 1974).

A study by Klein (1962) related the strength of quadriceps to knee injuries of 537 football players. Approximately one-quarter of all football injuries involved the knee joint and surrounding ligaments (Clarke, 1976). Klein found that knee injury was often associated with a strength imbalance between right and left quadriceps. Severe weakness of the quadriceps can hinder the individual's ability to climb stairs, walk up an incline and rise and lower from a sitting position (Ince, 1974). The weakness of quadriceps found when tested at one joint angle appeared common to other joint angles when tested (Brewerton, 1956; Mendler, 1967).

Thus a great emphasis must be placed on strength training of the quadriceps for the benefit of increased joint stability and as a preventative measure for possible knee injury. An increase of strength has been shown to

also influence ligament strength (Adams, 1966; Tipton, 1975) which acts as the knee joint's second line of defense against dislocation.

A controversy prevails over the relevance of the vastus medialis in completing the last 10 to 15 degrees of knee extension and giving the greatest stability to the knee joint. Proponents of the vastus medialis performing the select action of terminal extension of the knee (Williams, 1962; Smillie, 1962; Rasch and Burke, 1967) have influenced the format of knee rehabilitation procedures in terms of placing strengthening emphasis on the vastus medialis. Strengthening the full range of knee motion plays a secondary role to the strengthening of the vastus medialis (Wise, 1977). Anatomically fibres of the vastus medialis control the synchronous spiral movement of the patella and prevent lateral dislocation (Helfet, 1974). Reinforcement for the importance of the vastus medialis comes from the observation that it is this particular muscle which atrophies more quickly than the rest of the quadriceps (Edstrom, 1970) and hypertrophies the greatest amount when strength training occurs at full knee extension (Francis, 1974). Williams (1976) observed that after knee injury, the vastus medialis was most affected by co-ordination and proprioceptive functions. Apparently, the normal synchrony of the vastus medialis was altered so that it contracts last instead of being the first to contract in extension (Williams, 1976).

Contrary to the belief of the select role of the vastus medialis in the last few degrees of knee extension are those studies involved in EMG (electromyography) testing of the quadriceps. Although EMG studies are only able to qualify rather than quantify readings, it was observed that the vastus medialis was found to react throughout knee extension as did the other muscles of the quadriceps (Hallén, 1967; Bos, 1970).

Although it is agreed that quadricep strength is necessary for increased knee joint stability, there is a disagreement on the role of the vastus medialis in knee extension. This controversy influences the rehabilitative treatment for increasing knee joint stability. At present, the initial emphasis is placed on strengthening the vastus medialis with straight leg contractions (Brewerton, 1956) and secondly on increasing strength throughout full range of movement.

Joint Specificity in Strength Training of Quadriceps

The capacity of a muscle to overcome a counterforce can be measured in different dimensions such as torque, power, force, tension or work done. The types of counterforce and units of quantitative measurement dictates the applicable terminology and the angle at which the muscle is most efficient. In knee extension strength can be defined as the maximal torque of the quadriceps measured at a

40 degree angle of flexion (Haffajee, 1972). Minimum torque is found in the nearly extended position of zero degrees of flexion where torque is reduced by 50 percent (Haffajee, 1972). Torque relates to the moment of force the quadriceps can produce about the axis of the knee joint. When an isometric counterforce is offered, the angle of optimal muscle efficiency changes to 60 degrees of knee flexion and the weakest at 30 degrees (Mendler, 1967). Isotonically the greatest force is exerted in midrange where the muscle is biomechanically at its optimum (Rasch and Burke, 1967). In that position the muscle is acting to rotate the bony lever around its axis with its entire force (Rasch and Burke, 1967). The muscle tension produced at the optimal stretch of 20 percent above resting length decreases when the muscle is shortened or further elongated (Walmsley, 1976). Thus the assessment of muscle strength capacity is dependent not only on the amount and angle of the external counterforce applied, but also on the bony lever system and the length of the muscle (Walmsley, 1976).

Strength training and the resultant strength increase is considered by some investigators to be specific to that angle or range of movement in which the muscle was overloaded (Gardner, 1963; Moffroid, 1969). Observations made by other investigators contend that strength increase is not specific to the angle at which training occurred (Bates, 1967). A third view is that there is some type of

strength transfer throughout the range of movement but this is dependent on the angle at which training was initiated (Raitsin, 1976). A Russian investigator, Raitsin (1976), found that static training at small angles in the range of motion produced a greater strength increase but less strength transfer to the full range of motion than training at wider angles. Gardner (1963) suggested that diffusion of strength possibly occurred at angles of less than 20 degrees apart.

The greatest strength increment appears to be specific to the angle or range in which the muscle is overloaded with possible strength increases within a limited range of non-trained angles. Reference made to the specificity of strength gain relates to the response of various integrated systems of the individual. Involvement of the central nervous system, motor unit recruitment as well as muscular activity must be considered.

Static Strength Training Versus Dynamic Strength Training

There are basically two types of strength training, static and dynamic. Static training involves a resistance which overloads the muscle maximally one length at a time with the muscle remaining at one length with no external work done (Walmsley, 1976). Dynamic training provides an overload of an intensity to permit movement of the musculature through an arc of motion in overcoming the imposed resistance. Both static (isometric) and dynamic

(isotonic) forms of training have provided significant strength gains but the results, when compared between the two methods, have indicated differences in the amount and type of strength gains (Bergeron, 1966; Gardner, 1963; Berger, 1962; and Thorstenson, 1976).

When static and dynamic strength training results have been compared it has been shown that dynamic training provided the greater strength increase throughout the range of motion (Hellebrandt, 1956; Morris, 1969). Gardner (1963) theorized from his study of static strength specific only to the angle trained that isometric techniques were not ideal for improving dynamic skill. A study by Morris (1969), of runners supplementing their 880 yard running program with isometric and dynamic training, indicated that both types of training improved running times significantly but isotonic training provided the greatest strength and running time improvement. Rasch (1957) compared the two types of training on a static test involving arm press and flexion and found isotonic to be the superior of the two methods for strength improvement. He did make note of the fact that the subjects were less motivated in their isometric training than isotonic due to the lack of quantitative feedback. Training dynamically compared to static training at 13 angles through the same range of motion provided an increase of muscular endurance rather than the greatest strength increase according to Muller (1970).

Muller (1970) found that dynamic contractions of one second duration produced less tension than isometric

contractions. He concluded that the hardest dynamic work was less effective than isometric training for increased strength. Muller's findings concurred with Friedebold (1968) and Mathews (1957) who classified isometric training as favouring strength increment and dynamic training as favouring an increased muscle endurance. However, Mathews' (1957) experimental format involved a variance in overloading procedures in the two methods. Static training was carried out with a maximum overload compared to a very low sub-maximum load used in isotonic training. Since Muller (1970) showed that the stronger the contraction, which is dependent on the load, the quicker the increase in strength then Mathews' results may be explained by the use of different load intensities over the same period of time.

Another proponent of the superiority of static training for greatest strength increment is Berger (1962). He compared static and dynamic training and found those subjects who trained dynamically improved dynamic strength significantly more than isometric training and conversely isometric training when tested isometrically gave greater strength increase than dynamic training. Berger (1962) observed that all the improvements were significant but an even greater improvement was realized in static training and testing as opposed to dynamic training and testing. Shaver (1963) tested the relationship between maximum absolute isometric strength and relative isotonic endurance and found that a positive relationship existed. He noted that those subjects with the greatest maximum isometric strength could

maintain a higher percentage of that strength during a relative isotonic endurance bout before and after a 6 week isotonic training program.

Many of the experimental studies comparing static and dynamic training on strength increase concluded that there were no significant differences between the two methods on strength training (Chui, 1964; Bergeron, 1966). Bates (1967) found that isometric and isotonic training were equally effective in significant strength gains as well as endurance and speed of movement. He also stated that significant gains in strength occurred at any position in the range of motion and the relative effects of isometric and isotonic exercises remained constant regardless of the portion of range of motion in which the exercise was performed. Coleman (1972) compared weekly strength changes in isometric and isotonic training and found changes in strength were of similar magnitude.

Another attempt to establish the best training method for strength improvement was the combining of static and dynamic training together as one training method. It was found that the combination of these two methods provided the most effective method (Dobrovolski, 1972 and Patterson, 1977). The purpose of combining the two methods into one program was an attempt to override some of the disadvantages inherent in each method and capitalize on the advantages of each.

Dynamic training provides direct feedback through immediate quantification of the applied effort as well as

promoting a greater translation of strength into the production of movement throughout the range of motion and improved endurance. In comparison to static training, dynamic training requires greater energy expenditure and cardiovascular loading which necessitates more time and rest.

Training statically may be more beneficial in ballistic dynamic training as suggested by Gardner (1963). Muller (1970) contends that static training recruits a greater number of motor units than dynamic which is associated with a greater increase of strength. It has been suggested that static training involves more frustration and perhaps less motivation on the part of the subject thus influencing the rate of strength gain (Rasch, 1957).

The greatest area of difficulty in deciding the most favourable type of strength training based on the literature reviewed is the lack of standardization of important basic principles which can have profound implications on the results of the experimental design and conclusions. A low correlation, .62, exists between the static testing of dynamic training and conversely static training tested dynamically (De Vries, 1970). Numerous strength studies have used only one type of testing for both types of training perhaps resulting in a camouflage of the true results (Rasch, 1957; Chui, 1964; Bates, 1967).

The degree of overloading the musculature was not consistent within and between studies. Many of the experiments involved static training at maximum loads and comparing the results with an isotonic group trained at a submaximum load over the same duration of time (Mathews, 1957). It is understood that training at a maximum load will require less time than a submaximum load to realize a significant increment of strength (Muller, 1970). Duration of strength training programs varied considerably between studies extending anywhere from 6 weeks (Johnson, 1975) to 12 weeks (Berger, 1962; Coleman, 1972). Duration and frequency within the exercise format varied extensively. In static exercises, the duration and frequency would vary from 3 sets of 6 second repetitions with a 2 minute rest (Berger, 1962 & 1963) to 3 repetitions of 15 second contractions and a 3 minute rest between each repetition (Rasch and Morehouse, 1957). Dynamic training altered between 8 to 10 repetitions with maximum effort (Berger, 1962 & 1963) to 3 sets of 5 repetitions (Rasch and Morehouse, 1957).

An important consideration in measuring strength increase is knowledge of the individual's limiting strength (Muller, 1970). The rate of strength increase that can be achieved by maximum effort is approximately 12 percent per week increasing nearly linearly to 75 percent of the subject's limiting strength. Above 75 percent the rate of increase diminishes progressively to become zero at

limiting strength. Thus it is necessary to state the level of physical conditioning as accurately as possible of the subject chosen for the strength training program.

It is mandatory that standardization of the optimum frequency, duration and intensity of static and dynamic exercise be established before a final decision can be made on the best type of strength training for the greatest strength increment. Training statically and dynamically appear to be related specifically to the purpose of the study, whether it is to provide increased strength at a specified angle or promote strength throughout a range of motion thus requiring static or dynamic training, respectively. If the intention of the study is to provide strength at a specific angle as well as increased strength throughout the range of movement, then it appears necessary to apply a combination of the two types of training into one exercise format.

Isokinetic Strength Training

The traditional form of dynamic training is associated with the development of strength through weight training. More recently another method of dynamic training has been introduced in the form of isokinetic strength training. The main feature of isokinetic training is that when force is being exerted against a lever arm of the apparatus more resistance is encountered by the limb and movement occurs at a predetermined velocity. The external

resistance offered by the apparatus is able to accommodate the changing force of the internal musculature characterized by the changes in lever length. In weight training, the external load remains constant resulting in the tension demand on the musculature being maximum only during a small portion of any range of motion, usually at the weakest angle in the motion (Moffroid, 1969; Hislop, 1967). As a result the total work done with weights is significantly less than the maximum capacity of the muscle. In isokinetic training on the other hand, the accommodating load is able to provide maximal output of the muscle throughout the range of motion.

There are other advantages of the isokinetic training method as opposed to regular weight training. The control of speed in isokinetic movement prevents acceleration normally associated with dynamic training. As a result most of the energy is not dissipated with acceleration but is converted to a resisting force proportional to the magnitude of input (muscular force) (Hislop, 1967). Muscular soreness is often associated with initial weight training bouts, however this does not occur with isokinetic training procedures because of the passive period of recovery (Pipes and Wilmore, 1975). Controlling the speed of movement permits specificity of speed training whereas the speed in weight training varies considerably due to individual differences.

Moffroid (1969) compared the training effects of isokinetics, isotonics and isometrics for 4 weeks of daily

training on the quadriceps. All the subjects were tested isokinetically at 45 and 90 degree angles. It was found that the isokinetic group, trained at low speeds (Moffroid and Whipple, 1970) increased the muscular work (force) more rapidly than isometric or dynamic training at both angles. The isokinetic training furnished an effective means of increasing muscular torque throughout the full arc of motion whereas the other methods increased muscular torque through a partial range of motion corresponding to the range and angle the muscle was overloaded.

A comparison of isometric, isotonic and isokinetic maximal contraction recorded through electromyography revealed that the isokinetic contraction elicited significantly greater muscle action potentials than either isotonic or isometric contractions (Rosentsweig and Hinson, 1972). Isotonic contraction did not produce muscular activity that was significantly different from either of the other two types of contractions. Isometric contraction produced the smallest mean action potential which is contrary to the motor unit recruitment expected of an isometric contraction (Muller, 1970). It was suggested that the EMG apparatus was not capable of recording the results in the same way for all 3 types of exercise (Rosentsweig and Hinson, 1972).

A Russian investigator, Kusakin (1971) cited the possible disadvantage of the isokinetic training being that it was not specific enough for skilled performance. He explained that physical skills require maximum effort for

the greatest speed generating a movement that does require acceleration.

In rehabilitation of knee injuries the controlling of speed is of vital importance (Coplin, 1971). In the knee joint rehabilitation of soft tissue, other than muscle, is the first consideration followed by increased muscular strength after the occurrence of a knee injury. The muscle is usually not involved in the injury and thus can sustain more weight than the affected ligaments. Thus, in order to prevent further damage, it is vital that a proper balance between joint stress and increase of muscle strength be met in the rehabilitative program. The isokinetic method of training is able to provide the necessary qualifications through its controlling of speed and accommodating resistance (Coplin, 1971). It enables the regulation of muscular force and promotes improved coordination in relation to the joint position. The rehabilitation of an injured leg is completed when there is equality of torque output between normal and affected extremities at all speeds of exercise (Coplin, 1971).

Isokinetic exercise appears to have resolved some of the inherent disadvantages of traditional dynamic work with weights. It supplies continuous variable resistance throughout the range of motion eliminating the mechanical influence of change in lever length on the muscle work capacity. The isokinetic form of exercise seems to be more suited for knee rehabilitation where the effort is under

more control (speed) and progression is readily quantified.

Electrical Stimulation and Strength Training

A nerve impulse can be initiated by an electrical stimulus of sufficient intensity (Scott, 1969). The impulse travels distally in the nerve resulting in contraction of all those motor units innervated by the nerve (Wise, 1977). The strength of the contraction depends on the number of muscle fibers stimulated and the threshold current. Threshold current is dependent on the rate of change in current (frequency), duration and wave form of the current. A frequency of 30 to 50 Hertz (cycles per second) requires less current intensity than a frequency of 60 to 100 Hertz which requires greater intensity and is less comfortable for the subject to endure because of a burning sensation. A square wave form as opposed to a triangular wave introduces a greater current intensity due to a decrease in the time taken to depolarize the nerve resulting in a greater action potential.

The effects of a muscle contraction electrically stimulated are similar to a voluntary, active contraction (Scott, 1969). There is an increase in metabolism, a greater demand for oxygen and foodstuffs and an output of waste products and metabolites resulting in vasodilation and an increased blood supply (hyperemia) in post-contraction. Through chronic stimulation an increase in muscle strength does occur similar to traditional forms of strength

training (Scott, 1969). Unlike voluntary muscle contraction the frequency of electrical stimulation can influence the type of motor unit recruitment, hyperemia and changes of one muscle fiber type to resemble that of another in skeletal musculature.

Petté (1972), Cotter (1973) and Van Der Meulen (1974) observed in animals that the speed of contraction of a fast muscle could be slowed by adding a frequency pattern simulating that of a motorneuron supplying slow muscle fibers at a frequency of 10 Hertz. Histochemical changes of the fast fibers resembling the slower fiber type were also reported.

The refractory period of an individual muscle fiber is 10 milliseconds thus with a frequency of 30 Hertz or more a tetanic contraction results. A frequency of 50 Hertz can cause a complete mechanical fusion of fast muscle contractions developing a tension four to five times greater than that exerted during a single twitch (Astrand, 1970). A tetanic frequency maintained for a short period of time results in a decrease of tension due to the frequency's effect on ionic displacements (Gillis, 1964), and glycogen depletion with a rapid rise in lactic acid (Corsi, 1969).

Blood flow and vasodilation are also affected by different levels of frequencies. At higher frequencies there is a decrease in blood flow during contraction and greater hyperemia in postcontraction. This indicates a

need for an optimal ratio between the contraction and relaxation phase for maintaining an adequate electrical training stimulus for increased tension (Manvelyan, 1970; Skinner, 1967).

It was observed by investigators and physiotherapists that electrical stimulation is more functional as a supplementary training method secondary to other types of voluntary, active strength training stimuli (Scott, 1969; Wise, 1977; Massey, 1965; Nowakowska, 1962). Nowakowska (1962) studied the effects of electrical stimulation on intact muscles of rats immobilized in special cages for detection of possible changes in excitability and working ability. The format of his study included maximum flexion in all joints of the right hind extremity stimulated at a frequency of 11 Hertz for 1 hour daily extended over 35 days. It was observed that electrical stimulation caused an increased working ability when measured over a 6 hour duration stimulated at a frequency of 180 Hertz. However, the increased working ability was much less than those rats permitted voluntary, active movement. He concluded that where voluntary movements are hampered the application of contraction produced by electrical excitation would be appropriate.

Immobilization of the rats may have caused a degree of muscular atrophy to occur. Characteristic of atrophied musculature is a decrease in tetanic contraction tension and a faster fatiguing effect when induced to contract electrically for prolonged periods of time (Van Der Meulen,

1974). It may be that the intensity of stimulation in Nowakowska's study was insufficient to counteract the immobilizing effects of the special cages.

The effects of a high frequency electrical stimulation, 1,000 Hertz, interrupted direct current on the size and strength of skeletal human muscle was investigated by Massey (1965). The experimental design included weight training, static training, electrical stimulation training and a control group. The subjects trained 3 times per week for a total of 24 workout sessions. Muscles of the upper extremities were trained and tested in flexed and extended positions. However, testing on the dynamometer occurred at midrange of the motion (90 degrees) perhaps nullifying some of the strength increment that may have occurred specific to the angle overloaded. Observations revealed that weight training provided the greatest strength increase followed by static training the least effective was electrical stimulation. The amount of time spent training each session corresponded to the order of the strength training methods and their increments, that is, most time was spent on the weight training and the least on electrical stimulation. Massey concluded that traditional methods promoted the greatest strength increment.

The applied frequency of 1,000 Hertz for a normal muscle is of questionable physiological significance considering that it exceeds the upper limit of frequency of axonal impulse propagation in humans (Basmajian, 1967).

The duration of electrical stimulation ranged from only 10 to 15 seconds total time per session in Massey's study providing a very brief stimulation exposure and perhaps inducing very little muscle fatigue.

Contrary to Massey's findings of static training being superior to electrical stimulation, a Russian investigator, Raitsin (1976), found that electrical stimulation proved to be more efficient than static training when both used a 10 second contraction and 50 second rest for a total of 10 sets at 70 percent of maximum for a training format.

Electrical stimulation may be a more efficient alternative to traditional forms of static training whereas isokinetic training may provide a better alternative to traditional forms of dynamic training in a rehabilitative program. A comparison of these two types of training may promote a better understanding of the functional role played by static and dynamic strength training in a program of rehabilitation.

CHAPTER III

RESEARCH METHODS

Introduction

This chapter of methods of research includes a detailed description on the topics of subjects; methods and equipment; protocol and the methods for statistical analysis.

Subjects

The subjects were young men and women numbering 15 and ranging in age from 18 to 27 years of age, an age range selected for its physiological peak and adaptability towards physiological stress.

The subjects' background entailed participation in various sports at a recreational level. It was the involvement of the subjects in sports such as skiing, running and football where they experienced an injury. Injuries to the knee involved torn ligaments, pulled ligaments or damaged cartilage which resulted in 2 menisectomies, 1 surgical repair of ligaments and 9 chondromalacia patella. All subjects were diagnosed and treated by the same orthopedic physician.* The time between the injury and

* Dr. D. Johnson, Sports Medicine Clinic, University of Carleton.

physiotherapy treatment spanned from 1 month to a year. The subjects were treated over a 4 month summer period.

Selection of the subjects was made on the basis of a unilateral knee injury causing the development of a 20 percent or greater quadriceps weakness in the injured leg. This was determined by strength measurements taken on both legs tested isometrically on a cable tensiometer and the results compared. The injured leg's strength measurements were made relative to the individual's healthy leg. A difference of equal to or greater than 15 percent measured isometrically in symmetrical muscle groups was considered by Damholt (1972) to be pathological. An additional 5 percent difference was required for a greater strength discrimination between the injured and healthy leg. This ensured that the cause of the weakened musculature was due to the injury rather than left or right leg dominance exercised in a sport or day to day fluctuations in voluntary, maximal strength contractions.

The subjects also had to be capable of voluntarily exercising the injured knee throughout its full range of movement on the isokinetic device, the orthotron, without causing inhibitive pain. When put in a treatment group, the subject was requested to fill out a background questionnaire stating name, age and occupation; cause of injury; the time duration between the injury and the treatment and diagnosis by the doctor; level of sports participation and the sports participated in; the post

rehabilitation goal of the subject in reference to the activities the knee must be able to resume (Appendix C). Preceding each treatment a brief report concerning the subject's state of well being was recorded to provide information on the knee strength progression each session.

The electrical stimulation group was comprised of 5 females and 3 males for a total of 8 subjects. There were 4 females who suffered from chondromalacia patella following a sport injury and 1 female who had a menisectomy following a cross-country running accident. The 3 males involved 1 male with a football injury resulting in a menisectomy and chondromalacia of patella. One male experienced chondromalacia from a hockey injury while the remaining male subject pulled ligaments in the knee playing handball.

The isokinetic group had 7 subjects, 4 were female and 3 were male. Three of the 4 females suffered from chondromalacia and the other had torn a ligament. Two of the 3 males had symptoms of chondromalacia and one male had pulled ligaments from a ski accident (Table 1).

Method and Equipment

The subjects were divided into 2 rehabilitative treatment groups, an electrical stimulation group and an isokinetic group. The subjects were randomly assigned to their treatment groups. The period of time between the occurrence of the injury and the pretest varied depending

TABLE 1

DESCRIPTION OF SUBJECTS' SPORTS INJURIES

Group	Sex	Sport Injury	Chondro- malacia	Torn or Pulled Ligaments	Meni- sectomy
Iso- kinetic Group	F	Motor Cycle		✓	
	F	Alpine Skiing	✓	✓	
	F	Tennis	✓		
	F	Running	✓	✓	
	M	Alpine Skiing		✓	
	M	Football	✓		
	M	Alpine Skiing			✓
Elec- trical Stimu- lation	F	Basketball	✓		
	F	Walking	✓		
	F	Track & Field	✓		
	F	Running			✓
	F	Running	✓		
	M	Football	✓		✓
	M	Hockey	✓		
M	Handball			✓	

upon the knee problem; the time taken by the subject to seek medical attention; and medical authorization to commence rehabilitation in one of the groups. Thus, the selection of subjects occurred over a period of 4 months.

The pretest, to qualify the subjects, consisted of two types of strength measurements conducted on both the injured leg and the normal leg of each subject. The purpose was to identify the degree of muscular weakness and to establish the maximum resistance achieved isometrically and dynamically for each leg at a 40 degree angle.

The isometric strength was measured by a calibrated cable tensiometer and the dynamic strength by a calibrated electromechanical device, known as an orthotron. The 40 degree knee joint angle from a horizontal knee flexion of 0 degrees was designated as the measured angle since it is the angle generally used in climbing stairs and hills as well as providing the greatest maximum torque as observed by Haffajee (1972). Those subjects whose injured leg measured a minimum of 20 percent less than their normal leg on the cable tensiometer were randomly assigned to a treatment group.

The healthy leg of all subjects was exposed to the identical rehabilitative treatment employed on the injured leg. The objective of training the normal leg was to use it as a control for the injured leg as well as examine its response to the effects of electrical stimulation versus isokinetic training relative to the weakened musculature.

Treating the healthy leg as a control for the injured leg aided in relating the possible effects of illness, daily physical activity and motivation or individual strength performance fluctuations throughout the 6 week treatment period.

Electrical Stimulation Group Method

A Siemen's Neurotron 627, an electrostimulation unit, was used to provide the source of the stimulating current. It supplied exponentially progressive currents and diadynamic currents for galvanization, faradization and surge current treatment. The pulse duration had a range of 0.1 to 1,000 milliseconds and resting intervals of 20, 500 and 2,000 milliseconds. The current intensity had controlled measuring ranges of 12 and 60 milliamperes and a voltage, measured with a voltmeter, of 7 and 9 volts, respectively. An automatic blocking device associated with a measuring range button protected the patient from incorrect setting.

The current used for electrostimulation was an interrupted direct current which commences and ceases at regular intervals known as faradization, a recommended current for healthy, but weak muscles (Scott, 1969). The current was calibrated on an oscilloscope and recorded by photograph. A rectangular wave form with a pulse duration of .8 milliseconds and a resting interval of 20 milliseconds to produce a frequency of 50 cycles per second was used to

elicit a tetanic contraction (Astrand, 1970; Basmajian, 1967). A rectangular wave form provided a shorter impulse duration resulting in a steeper current rise and a greater intensity of muscular contraction as opposed to the alternative triangular wave form. The investigator decided the intensity of the current based on the subject's pain threshold and timed the stimulating format of 10 seconds on and 50 seconds off for recovery for a repeat of 10 sets (Wise, 1974).

The size of the electrodes employed were 6.5 cm. by 8 cm. flat metal plates placed inside of viscose sponge pockets measuring 11 cm. by 9 cm. and 1 cm. thick. The 2 electrodes were placed with a bipolar technique where one electrode was placed at each end of the quadricep muscle region. The anode electrode was placed proximal and the active electrode, the cathode, was distally placed over the combined motor point areas of the rectus femoris, vastus lateralis and medialis. The cathode was placed distally since it requires less current than the anode (Scott, 1969). The electrodes were kept in place with a 1½ inch adjustable rubber band.

The subject's lower leg was strapped for greater resistance and prevention of injury at a 40 degree angle. A 4 inch adjustable strap was placed 2 inches above the ankle securing the back of the heel against the 40 degree angled board. The board was divided into 3 pieces, held together by movable hinges in the shape of a triangle, with the posterior side of the knee at the top of the triangle

measured at 40 degrees. A stop watch and manual manipulation of the current switch was used to regulate the electrostimulation pattern (Appendix A). The subject remained in a supported sitting position with a back angle greater than 110 degrees for better stabilization during the treatment (Currier, 1977).

Isokinetics Group Method

An orthotron machine* was employed in the treatment of the isokinetic group. The speed of movement could be controlled from a range of 1, simulating an isometric contraction, to a high speed of 10. Each muscular contraction provided an instant visible reading on a dial with a scale range of 20 to 600 foot-pounds. The orthotron was calibrated by dropping weights from a horizontal position of the lever arm and recording peak torque.

The lower leg of the subject, with the knee joint aligned with the input axis of the orthotron, was attached parallel to the steel 1.5 foot lever arm of the machine by an adjustable, padded, 4 inch strap placed just above the ankle. The heel of the subject's foot rested on a 3 inch wide, 3 foot long board positioning the knee in a 40 degree angle. The board had a 5 inch long segment attached to it by a hinge for the purpose of clamping the board in position to the table. The subject remained in a supported sitting

*Manufactured by Lumex, Bay Shore New York.

position with the back at greater than 110 degrees and the hands grasping the side of the table for better stabilization (Mendler, 1967).

The subjects began their contractions to full extension at a regulated speed of 3 representing a velocity of 10 revolutions per minute to emphasize muscular strength (Coplin, 1971). The orthotron provided a passive recovery allowing a greater time to rest between each contraction. The design of the machine eliminated any erratic or unstable muscular movement (Appendix A). The resistance offered was the function of the force applied occurring throughout the course of full natural movement. The resulting torque obtained from muscular action on the skeletal lever makes it possible to obtain the functional capability of a specific joint (Coplin, 1971).

Protocol

The pre-test, post-test and the format of the treatment used in the electrical stimulation and isokinetics are described in the following.

Pre-test and Post-test Protocol

The setting for the treatment and testing sessions was a clinical physiotherapy room at a constant room temperature of 21 degrees centigrade. The time of each treatment and testing session was scheduled for the same time of day throughout the 6 weeks for the individual

subject. Major emphasis was given to morning testing and rehabilitation to reduce the possibility of fatigue from daily activities.

The pre-test and post-tests followed identical procedures. The isometric part of the testing involved the subject, dressed in shorts, T-shirt and socks, sitting on a therapeutic table with the edge of the table meeting the middle of the back of the knee and the heel of the foot supported on a 40 degree angled board. A 3 inch strap attached to a calibrated cable tensiometer was placed around the lower leg, 2 inches above the ankle, and adjusted to securely immobilize the subject's heel to the supporting board used in the isokinetic method.

There was one instructor for all tests and treatments who explained the action of contracting the quadriceps in the isometric test. The contraction involved simulating trying to pull the strap away from its fixed position through a gradual maximum strength increase without a "jerk" motion (Kroemer, 1970). The foot remained flexed and the hands grasping the edge of the table to provide a bracing action for increased maximal effort (Mendler, 1967).

An oral command was given as the signal to begin contraction. The healthy leg was always tested first for the benefit of providing a practise and learning situation. A maximum of 3 tries with a 3 minute recovery between each maximal effort (Funderburk, 1974) was given. The 3 readings were recorded in pounds of force and the highest was used

in the analysis of data. A time interval of 3 minutes after the last maximal effort of the healthy leg was allowed before the injured leg was tested in the same manner. A 5 minute delay occurred before the subject was tested dynamically on the orthotron for recovery and an explanation of the isokinetic test.

The subject duplicated the same position as in the isometric 40 degree test, using the wooden support, for the isokinetic test. The subject was given 1 trial with very little resistance for practise and any necessary corrections. The subject was expected to contract the quadriceps at a speed of 10 revolutions per minute and bring the knee to a lockout position of knee extension. The subject was permitted 3 maximal efforts with a 3 minute recovery between each maximal effort. The injured leg was tested using the same procedure.

The subjects were not aware that the procedures were of an experimental nature but were made to feel that it was part of their normal rehabilitation program. This approach was desirable for maintaining a positive attitude by the subjects towards their treatment.

A pre-test was administered to both legs on the same day to determine the degree of muscular weakness. In order to account for eliminating practice, illness, pain and day to day fluctuations on maximal strength measurements a second pre-test was conducted 2 days following the first pre-test. The measurement of maximal strength had been shown to

change as much as 10 to 15 percent from day to day (Berger, 1962). Treatment sessions were begun immediately following the 2nd pre-test. The first post-test was administered after the 6th treatment session with the two measurements given on the same day in order to avoid undue interruption of the treatment protocol. The second post-test was given after the 12th treatment session. The final post-tests were given in the same manner as the pre-tests with a two day interval. The same rationale used for the 2 pre-tests was applied to the final 2 post-tests. The highest measurements for the 2 pre-tests and final post-tests for both legs were recorded. The period of rehabilitation for the 2 treatment groups spanned 6 weeks, 3 times a week on alternate days with a 35 minute treatment session numbering a total of 18 sessions; see Figure 1.

Electrical Stimulation Group Protocol

The viscose sponge pockets in which the electrode plates were placed were rinsed under tap water several times to remove any buildup of electrolytes from previous stimulations. Excess electrolytes in the sponge caused a burning sensation directly underneath the electrode when the current was applied. A wet sponge also acted as a conductor for the current. The cathode electrode was placed distally, approximately 2 inches above the patella and slightly medially and the anode electrode was positioned in the center, 2 inches from the point of hip flexion, on the quadriceps. A rubber

	<u>Weeks</u>																		
	1		2			3			4			5			6			7	
Sessions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Pre-test	1	2																	
Post-tests						1						2						3	4

* Tests precede treatments.

Figure 1:- The Format of the Pre-tests and Post-tests and the Number of Treatment Sessions

band secured each electrode in place. The subject was in a supported sitting position on a bed with one leg fastened securely to a board angled at 40 degrees and the other leg in an extended relaxed position. The subject's legs were alternately stimulated each treatment session to avoid a set patterning.

The first treatment involved determining for each leg the amount of milliamperage the subject was capable of training at just below pain threshold. Each session thereafter began at the intensity of current for each leg of the previous workout and adjusted according to the subject's perception of pain on that particular day. The subject, under the supervision of the researcher, controlled the electrical stimulation for 10 sets of 10 seconds on and 50 seconds recovery. This amounted to a total of 100 seconds of maximal contractions interspersed with 50 seconds of rest. The milliamperage reading remained fixed throughout each session of 10 sets and changed only at the next session.

Isokinetic Group Protocol

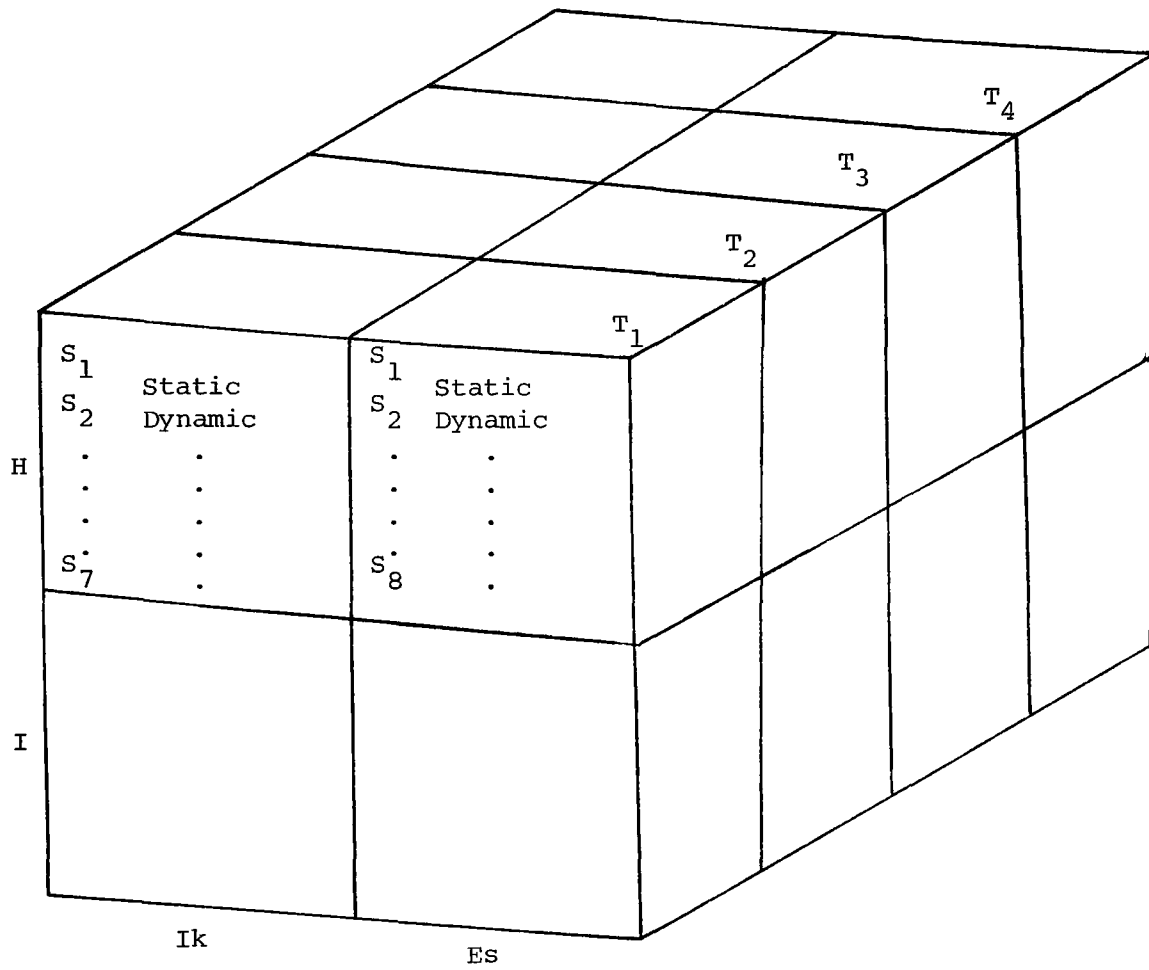
The same position and equipment as the dynamic part of the pre-test and post-tests was simulated by the subjects on the orthotron. It was emphasized and explained to the subjects that a fast, continuous quadricep contraction without an initial jerking action was required. The legs were alternated each session to avoid development of a set patterning. The treatment format on the orthotron included

3 sets of 15 repetitions with a 3 minute recovery time in between each set. The subject performed maximal contractions each repetition. The total time of all maximal contractions was approximately 30 seconds. If there was more than a 20 foot-pound drop off in the repetitions, the treatment was terminated due to fatigue. In order to avoid racing through the repetitions causing incomplete knee extensions and improper quadricep contractions a 3 second count by the subject between each repetition was required. The highest reading achieved in each set was recorded in pounds of force.

The duration of maximal stimulation differed between electrical stimulation and isokinetic treatment based on an approximate 3:1 ratio for electrical stimulation. As a result it might be assumed that a greater strength gain could be expected from electrical stimulation due to the longer duration of maximal contractions. However, force of contraction was a function of patient acceptance of the stimulation procedure in the electrical stimulation group and a function of apprehension in the isokinetic group. Therefore, there is no way of knowing if the 3:1 ratio of stimulation time resulted in any difference between the actual volume of work done by each group.

Method for Statistical Analysis

A Hartley F max test was conducted on the percent difference in strength between the healthy leg and the injured leg measured on the cable tensiometer and the isokinetic pre-test for homogeneity within the treatment groups. A Hartley F max test was also performed on the actual scores of the healthy



H --Healthy Leg
 I --Injured Leg
 Ik --Isokinetic Treatment
 Es --Electrical Stimulation Treatment
 S --Subjects
 T --Time (Tests)

Figure 2:- A Three Dimensional Block of the Statistical Design

and injured leg in the pre-test scores.

A 2 way ANOVA was carried out on 4 groups of randomized, fixed factors at a significance level of $\alpha.05$. The 4 groups evolved out of the 2 treatment groups when the injured and healthy leg results were separated and analyzed within the 2 treatment groups for the effect of treatment on strength gain and strength gain over time (see Figure 2).

Due to the low statistical power of this design, descriptive statistics were applied in percentages and graphs to indicate the potential of possible trends within the results.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The results of the effect of the 2 treatment groups, electrostimulation and isokinetic, on the rate and magnitude of strength gain when tested statically and dynamically on injured and healthy legs are presented in this chapter. This is accomplished by discussion of the homogeneity of the treatment groups; the absolute strength gain comparison between the treatment groups; percentage strength gain comparison between the electrostimulation and isokinetic groups; individual injured leg percent strength gains relative to pre-test healthy leg score; strength gains in injured leg relative to pre-test healthy leg over time; comparison of strength gain in healthy and injured leg relative to their own pre-test values over time and a summary of the discussion.

Homogeneity of Treatment Groups

The criterion of 20 percent or greater in strength difference between the healthy and injured leg for selection of subjects in both treatment groups, measured on a static (cable tensiometer) and a dynamic test (orthotron),

was checked for homogeneity between the 2 groups by a Hartley F max test. It was observed in these results (Table 2) that both groups were homogeneous in static and dynamic strength differences between the healthy and injured leg. The subjects with different degrees of quadricep weakness appeared to be uniformly distributed in both types of treatment groups.

A Hartley F max test was also carried out on the pre-test scores of the healthy and injured leg tested statically and dynamically for homogeneity between the strength scores in each treatment group (Table 2). It was observed that there was homogeneity between the two treatment groups on both legs and both types of strength tests when the Hartley F max value was less than the F ratio.

Absolute Strength Gain Comparison Between
the Electrical Stimulation and the
Isokinetic Group

A 2-way ANOVA was conducted on each of the following 4 conditions: A (electrical stimulation and isokinetic group tested statically on the injured leg); B (electrical stimulation and isokinetic group tested dynamically on the injured leg); C (electrical stimulation and isokinetic group tested statically (isometrically) on the healthy leg) and D (electrical stimulation and isokinetic group tested dynamically on the healthy leg). This resulted in a significant difference found only in gain of strength over time in 3 of 4 conditions (Table 4).

TABLE 2

HARTLEY F MAX TEST ON PERCENT DIFFERENCE
IN STATIC AND ISOKINETIC STRENGTH
BETWEEN HEALTHY AND INJURED LEG

Pre-test	H F Max Value	F-Ratio
Static	2.48	.95 F (2,7) = 4.99
Isokinetic	1.45	.95 F (2,7) = 4.99

TABLE 3

HARTLEY F MAX TEST ON PRE-TEST SCORES OF HEALTHY
AND INJURED KNEE OF THE TWO TREATMENT GROUPS
ON STATIC AND ISOKINETIC TESTS

Conditions	Test	H F Max Value	F-Ratio
Isokinetic and Electrical Stimulation on Healthy Leg	Isometric	2.28	4.99
Isokinetic and Electrical Stimulation on Healthy Leg	Isokinetic	1.26	4.99
Isokinetic and Electrical Stimulation on Injured Leg	Isometric	3.34	4.99
Isokinetic and Electrical Stimulation on Injured Leg	Isokinetic	1.52	4.99

TABLE 4
ANOVA RESULTS ON THE ELECTRICAL STIMULATION
AND ISOKINETIC GROUPS

Condition	Source	Degrees of Freedom	Sums of Squares	Mean Squares	F- Ratio
A					
Isometric	Treatment	1	3296.3	3296.3	1.98
Test on	Time	3	39025.2	13008.4	7.84*
Injured Leg	Interaction	3	960.8	320.2	.193
B					
Isokinetic	Treatment	1	930.0	930.0	.899
Test on	Time	3	28317.4	9439.1	9.12*
Injured Leg	Interaction	3	1612.1	537.3	.51
C					
Isometric	Treatment	1	8531.3	8531.3	2.96
Test on	Time	3	22989.1	7663.0	2.66
Healthy Leg	Interaction	3	798.4	266.1	.092
D					
Isokinetic	Treatment	1	180.5	180.5	.232
Test on	Time	3	19896.3	6632.1	8.53*
Healthy Leg	Interaction	3	2810.9	936.9	1.20

*Significant at the level of $p \leq 0.05$.

Condition C showed no significant difference with gain of strength over time at a $p < 0.05$ level. There was no significant difference found between the two treatment groups on the magnitude of strength gained over 6 weeks. A similar observation was made by Bates (1967), Chui (1964) and Bergeron (1966) who discovered that static and dynamic testing were equally effective in promoting significant strength increments. The results in Table 4 also demonstrated that quadriceps weakened to varying extents were influenced by the treatments similarly to normal quadriceps.

Figures 3, 4, 5 and 6 show that strength was consistently gained when repeatedly measured at 2 week intervals. There appeared to be no plateauing of strength increment in either the healthy or injured leg during the 6 week training session. Muller (1970) stated that strength gained above 75 percent of the individual's maximum strength capacity diminished progressively to become zero at limiting strength. Figures 3, 4, 5 and 6 appeared to indicate that the subjects may have been close to or below 75 percent of their maximum strength capacity at 6 weeks. It may be that if the treatment groups had carried on past the 6 weeks that a difference in treatments may have been recognized at a time when strength gains were more difficult to achieve.

Figures 4 and 5 showed that static strength improvement was greater when trained and tested isometrically on both the normal and weakened quadriceps. The same trend was observed in Figures 3 and 6 for dynamic strength gain.

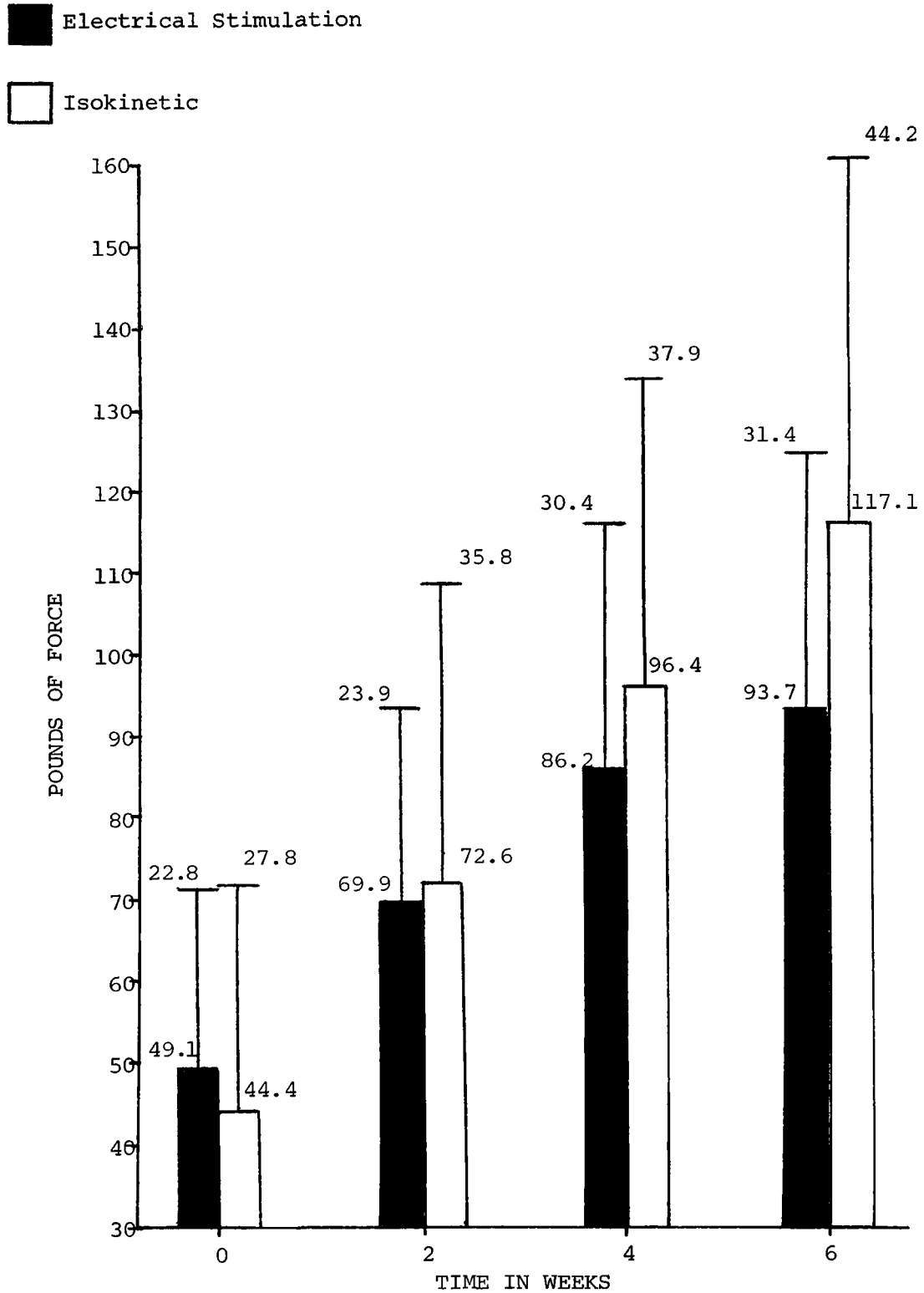


Figure 3:- Mean Group Strength and Standard Deviation of Injured Leg on Isokinetic Test

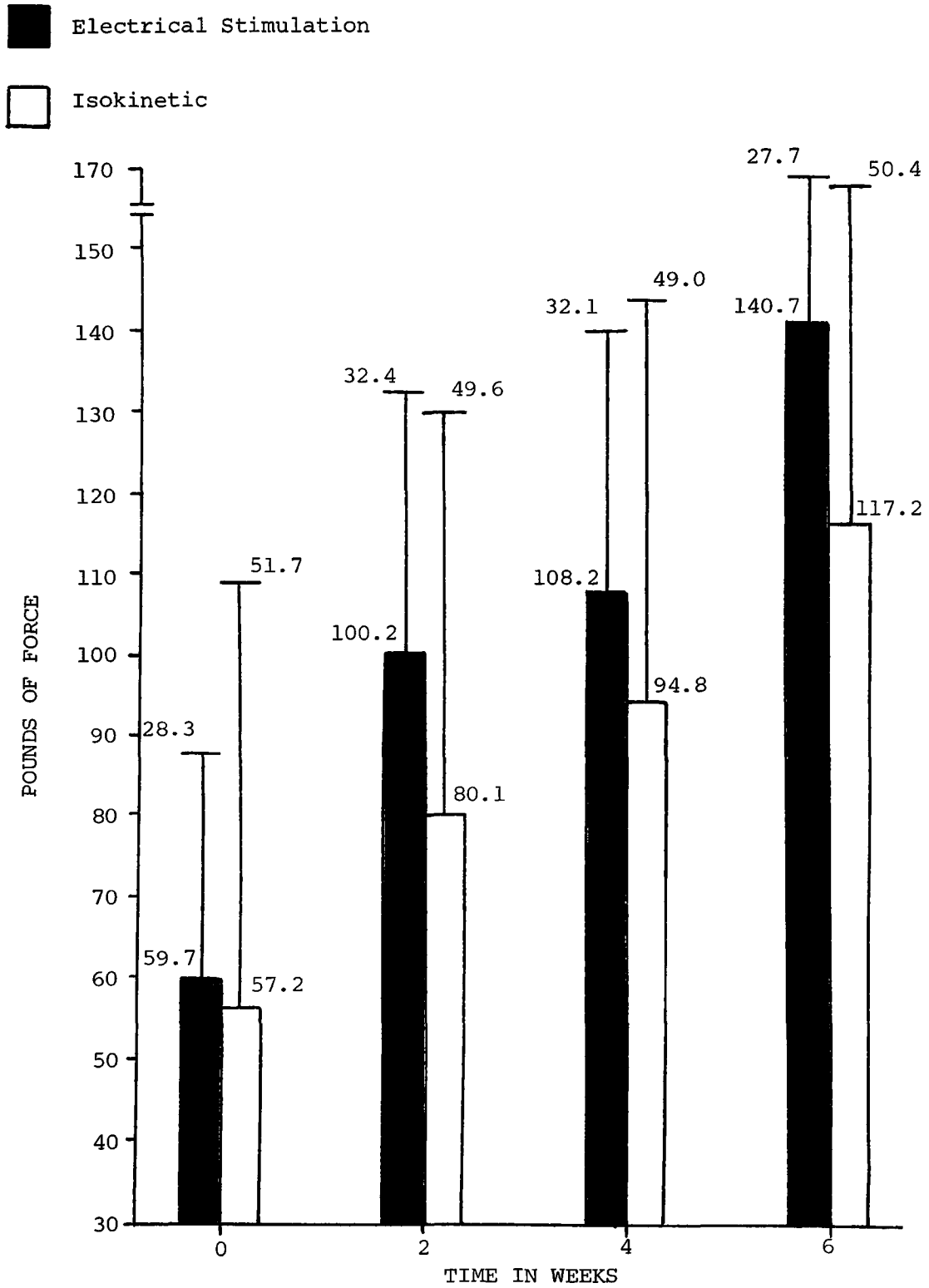


Figure 4:- Mean Group Strength and Standard Deviation of Injured Leg on Isometric Test

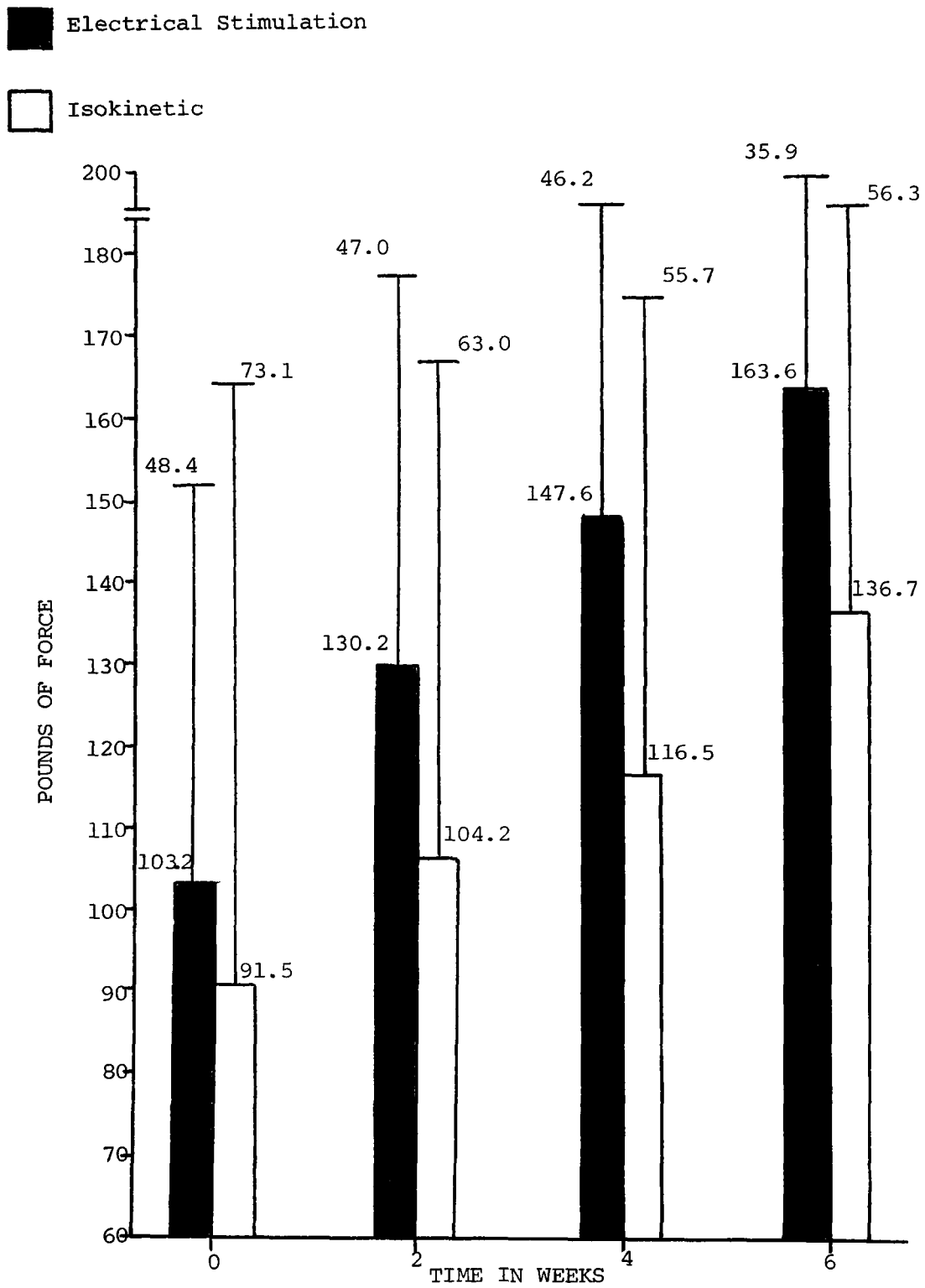


Figure 5:- Mean Group Strength and Standard Deviation of Healthy Leg on Isometric Test

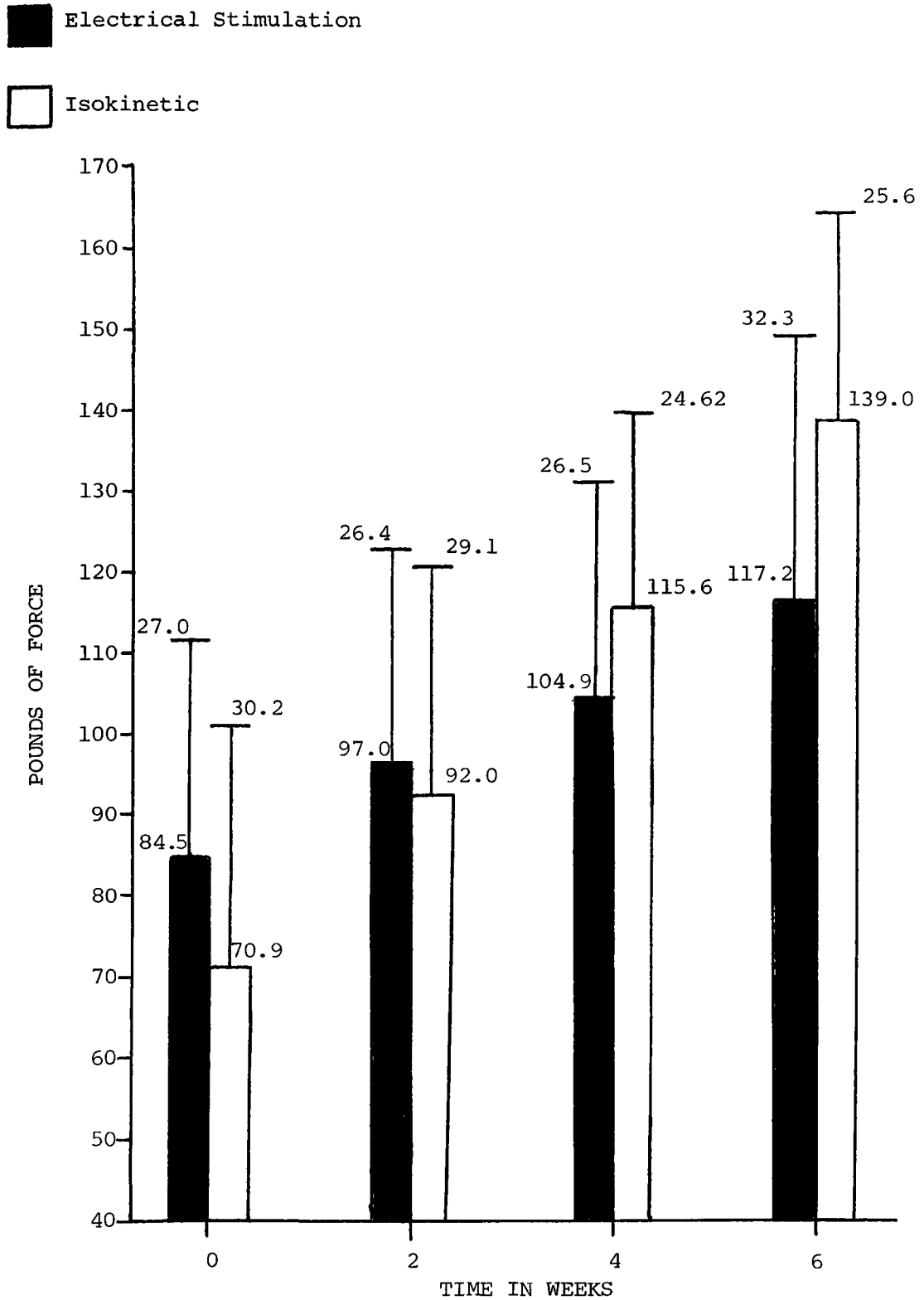


Figure 6:- Mean Group Strength and Standard Deviation of Healthy Leg on Isokinetic Test

Thus the combination of treatment and test that provided the greatest measurement of strength gain was the use of the same treatment procedure in the test design (static treatment, static test and dynamic treatment and dynamic test). An observation that was found to be in agreement with studies of Berger (1962) and de Vries (1970).

The lack of significant difference found between the 2 treatment groups in Table 4 demonstrated that there may be a considerable strength transfer from electrostimulation at a specific midrange angle to dynamic strength over a range of motion. Raitsin (1976) concluded from his study that static training at a wide joint angle provided the greater amount of strength transfer throughout full range of motion compared to static training at small angles of range of motion. In the present study a similar reaction may have occurred with training at a midrange angle but the strength transfer was within a restricted range of motion.

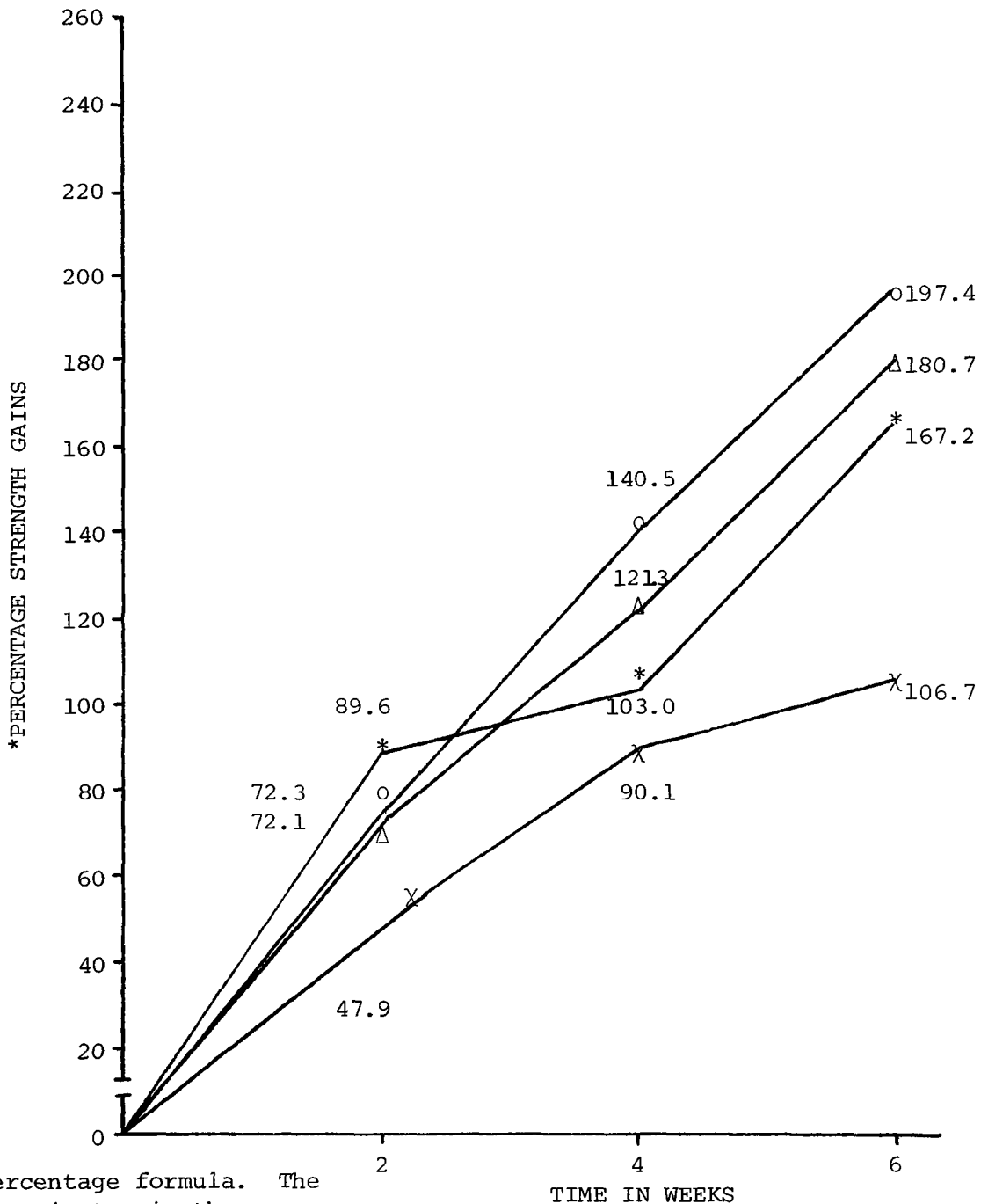
Isometric results of the electrical stimulation and isokinetic training did not show a significant rise in strength gain on the healthy leg (Figure 5). It may be related to a low correlation of dynamic training and static testing (de Vries, 1970) for the isokinetic group. The electrical stimulation group may have had insufficient overload (Hellebrandt, 1956) due to equipment being designed for physiotherapy and not normal muscle conditions. All of the subjects trained at the stimulator's maximal current for the last 2 to 3 weeks of their training program on their healthy leg. In reference to

this phenomenon, it appears that electrical stimulation may have had its greatest influence on strong quadriceps for the first 3 weeks only. In contrast to the static test results, the electrostimulation group tested dynamically on the healthy leg (Figure 6) showed a significant strength gain. It may have been attributed to the factor of skill learning and improved co-ordination (Schenck, 1965; Rasch, 1969) on the orthotron apparatus combined with a degree of strength transfer. The subjects may have also indirectly supplemented their dynamic strength with an increased level of physical activity due to the summer season and a feeling of increased strength from the electrostimulation treatments. The healthy leg isokinetic group demonstrated a significant strength increase on the dynamic test perhaps due to the specificity of the strength test (Berger, 1962).

Percentage Strength Gain Comparison Between
the Electrical Stimulation and
Isokinetic Group

In Figure 7 the greater percent strength increase was realized by the isokinetic group tested dynamically followed by the isokinetic group examined statically. The least gain in strength occurred in the electrical stimulation group tested dynamically. The trend indicated that isokinetic training had the greater strength transfer as opposed to electrical stimulation and was contrary to the observations made by some investigators (Muller, 1970; Mathews, 1957; Friedebold, 1968) that static training provided the greatest

- * --Electrical Stimulation on Injured Leg on Isometric Test
 Δ --Isokinetic Treated Injured Leg on Isometric Test
 o --Isokinetic Treated Injured Leg on Isokinetic Test
 X --Electrical Stimulation on Injured Leg on Isokinetic Test



*Percentage formula. The denominator is the measurement of the Pre-test injured leg
 0% = Pre-test injured leg.

Figure 7:- Comparison of the Two Treatments on the Magnitude of the Strength Gain of the Injured Leg Expressed as a Percentage of the Pre-test Injured Leg

strength increase. Dynamic training promoting the greatest strength increase was in accordance with Moffroid (1969), Hellebrandt (1956) and Morris (1969).

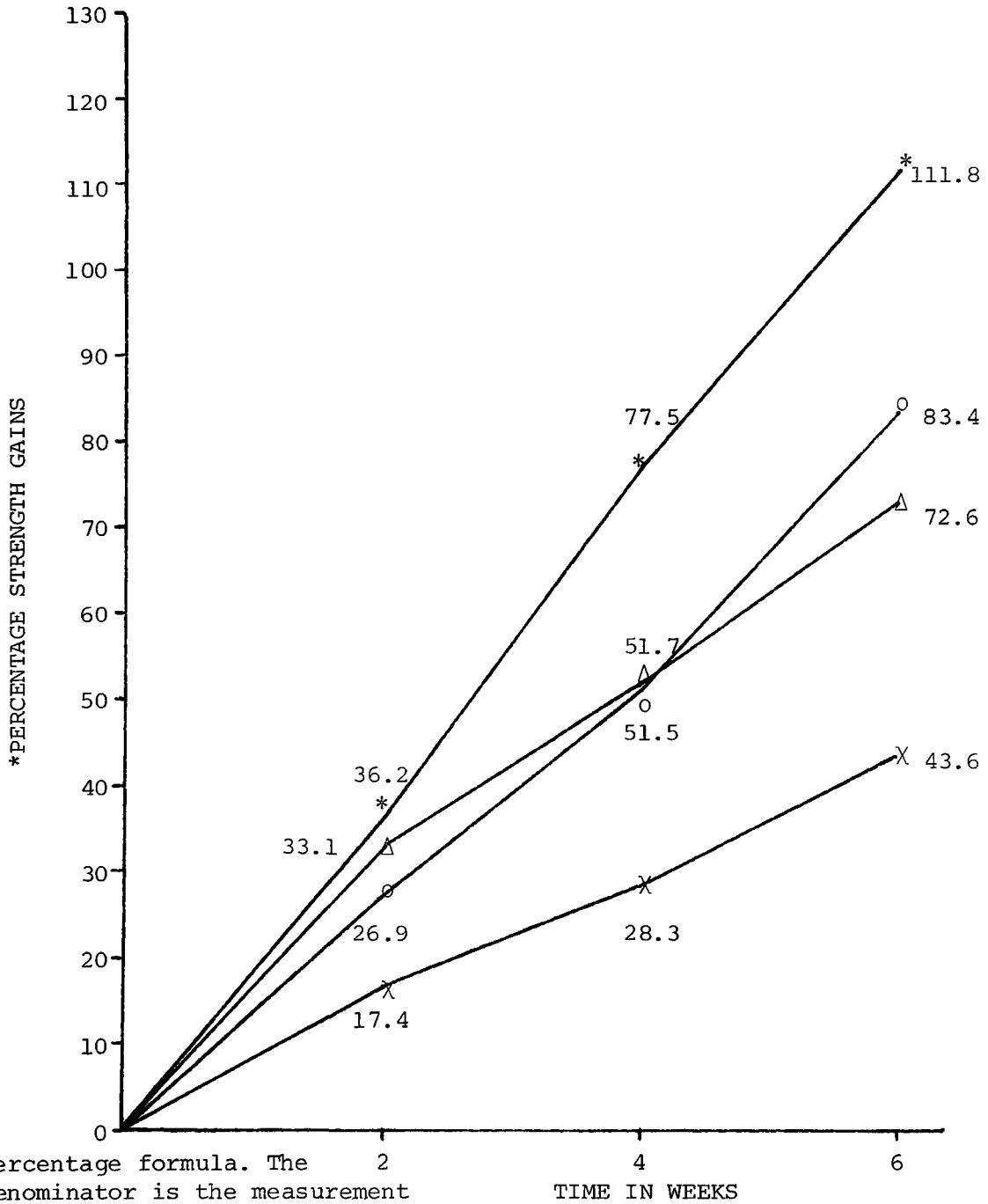
The resulting values in Figures 7 and 8 for the electrostimulation group seemed to indicate the need for dynamic training supplementation due to the decrease of strength transfer throughout the range of motion in comparison with isokinetic training strength transfer to a specific angle.

The above trends as illustrated in Figure 7 were also identifiable in Figure 8 for the healthy leg but to a lesser degree. The injured leg, treated isokinetically and tested dynamically, in Figure 7 compared with the healthy leg in Figure 8, had the highest reading. This finding concurred with Royce's (1964) observation that the closer the muscle is to maximal strength the slower is the gain of strength. The trend of strength gain over time in the injured leg (Figure 7) appeared to be less uniform than the healthy leg (Figure 8). Perhaps the injured leg was more affected by co-ordination initially and improved through repetitive action (Schenck, 1965) supplementing the strength increase and causing a wider variation of the strength gaining trend.

Individual Injured Leg Percent Strength Gains
Relative to Pre-test Healthy Leg Score

Rehabilitation of the subject in this study was considered complete when there was no longer a strength imbalance between the quadriceps since an imbalance was known to be closely associated with knee injuries

- * --Isokinetic Treated on Healthy Leg on Isokinetic Test
- Δ --Electrical Stimulation on Healthy Leg on Isometric Test
- o --Isokinetic Treated on Healthy Leg on Isometric Test
- χ --Electrical Stimulation on Healthy Leg on Isokinetic Test

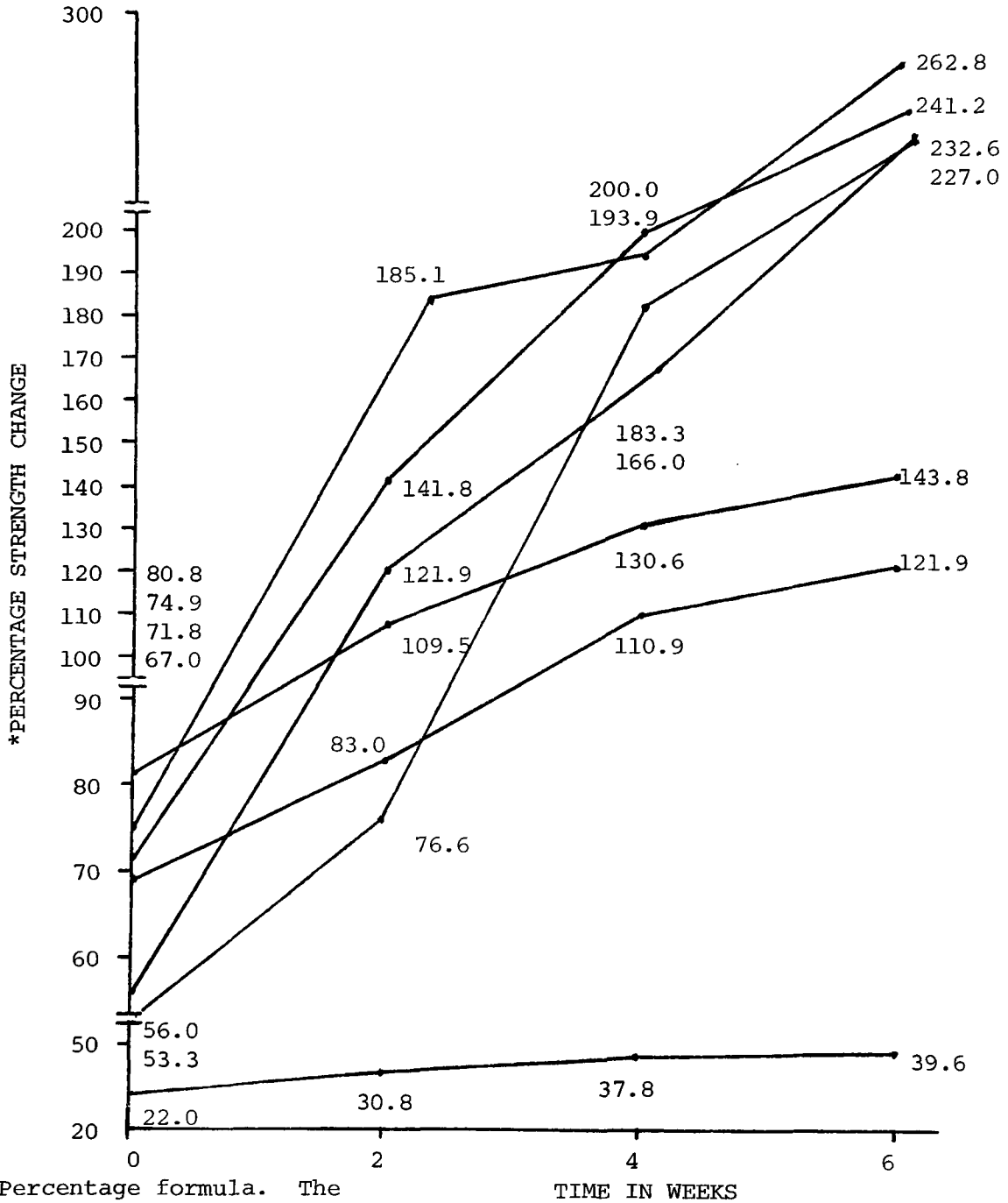


*Percentage formula. The denominator is the measurement of the Pre-test healthy leg
 0% = Pre-test healthy leg.

Figure 8:- Comparison of the Two Treatments on the Magnitude of the Healthy Leg Expressed as a Percentage of the Pre-test Healthy Leg

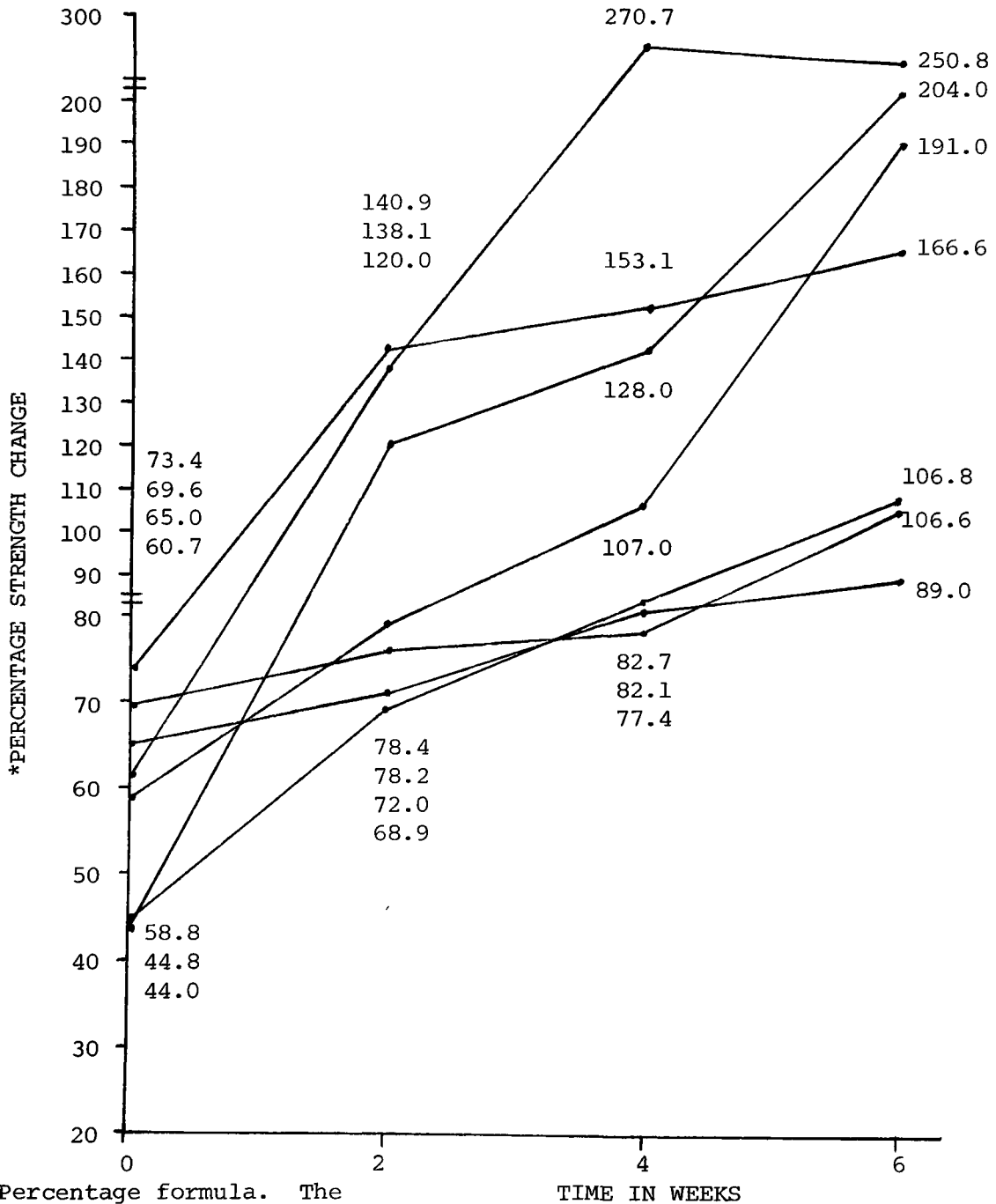
(Klein, 1962). The achievement of strength balance in the range of motion over the shortest period of time is the optimum expectation of an athlete returning to competition. The isokinetic group in Figure 9 accomplished the greatest gain in strength when tested dynamically. It was also interesting to note that a greater number of subjects acquired more than double the strength of the pre-test healthy leg score than did the subjects in the other groups. There were 6 out of 7 subjects who equalled or were greater than the healthy leg score after 4 weeks of isokinetic treatment. When the isokinetic group was tested statically, the subjects required the full 6 weeks of training in order to have 6 out of 7 subjects rehabilitated (Figure 10). It appeared that specificity of strength training, isokinetic tested dynamically, required less time to gain a balance of leg strength than the isokinetic group tested statically.

The electrically stimulated group tested statically required the least amount of time, 2 weeks (Figure 11), to rehabilitate subjects at a specific angle, 6 out of 8 subjects. Electrical stimulation may provide the most expedient training method for initial strength gain at a specific angle. Proponents (Scott, 1969; Williams, 1970) of the vastus medialis functioning as the knee's main joint stabilizer and emphasizing its rehabilitation in the initial phase of quadriceps strengthening, may be able to utilize electrical stimulation as opposed to isokinetic training in the early stages for the fastest gain of vastus



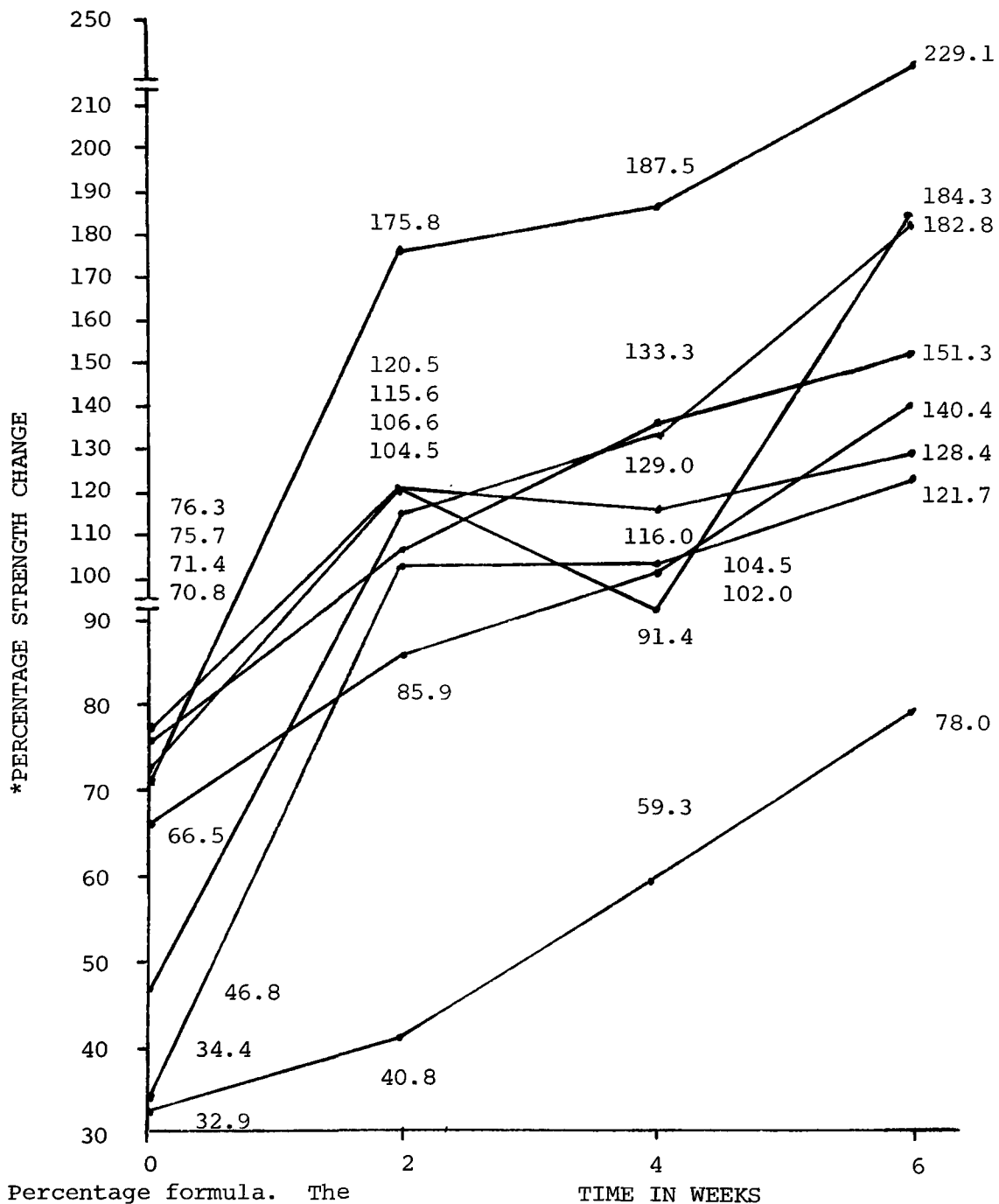
* Percentage formula. The denominator is the individual's Pre-test healthy leg measurement 100% = Pre-test healthy leg.

Figure 9:- Percentage Strength Gains of Isokinetic Treated Injured Leg on Isokinetic Test Relative to Pre-test Healthy Leg



* Percentage formula. The denominator is the individual's Pre-test healthy leg measurement 100% = Pre-test healthy leg.

Figure 10:- Percentage Strength Gains of Isokinetic Treated Injured Leg on Isometric Test Relative to Pre-test Healthy Leg



* Percentage formula. The denominator is the individual's Pre-test healthy leg measurement 100% = Pre-test healthy leg.

Figure 11:- Percentage Strength Gains of Electrically Stimulated Injured Leg on Isometric Test Relative to Pre-test Healthy Leg

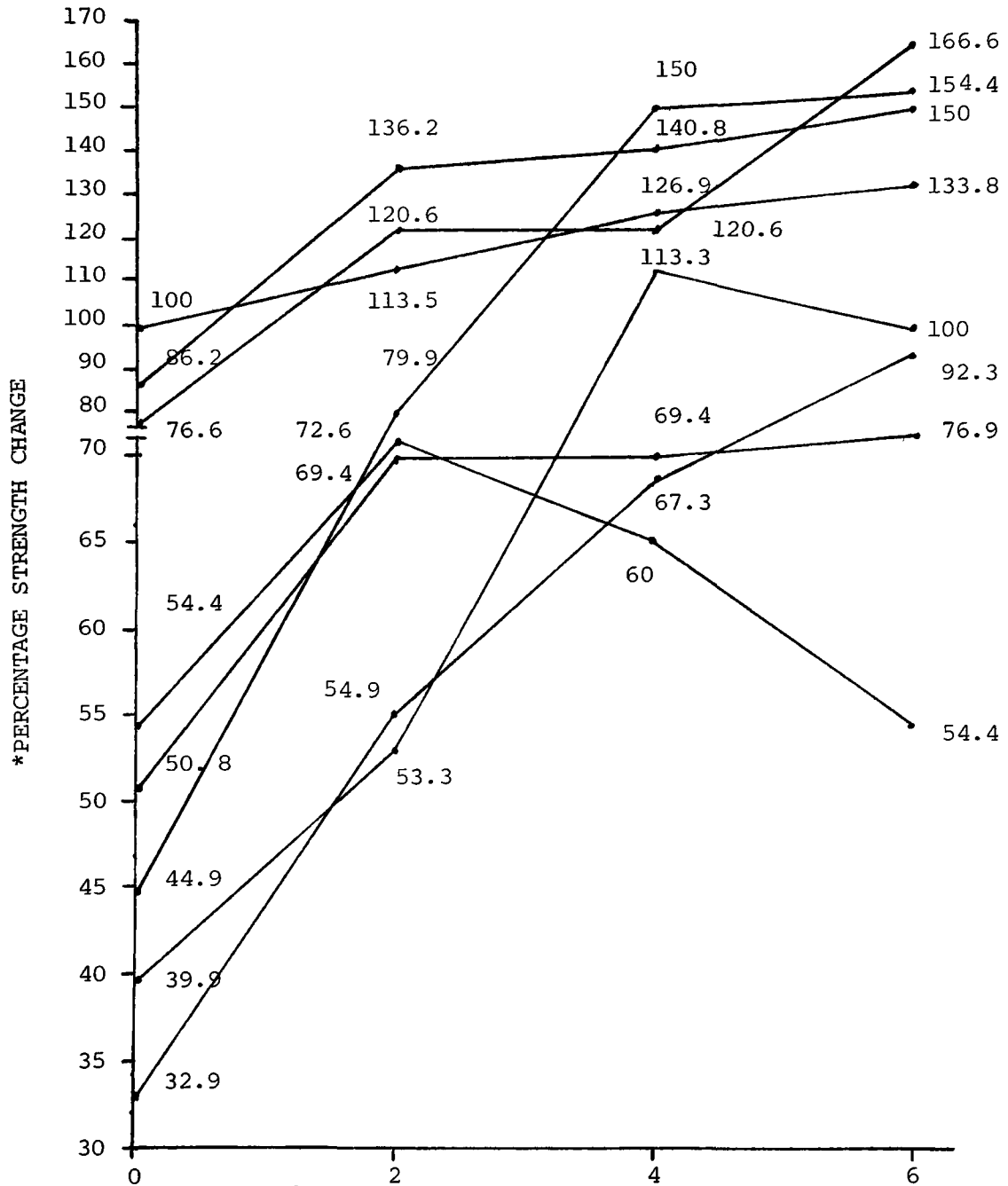
medialis strength.

The electrical stimulation group was least effective when examined dynamically for strength gains (Figure 12). There were 5 out of the 7 subjects who acquired scores equal to or greater than their healthy leg pre-test scores. Electrical stimulation appeared to have a degree of strength transfer but there was an indication that a supplementary dynamic training program was required in the latter phase of rehabilitation for improved strength throughout the range of motion.

The trend of strength increase in Figures 9, 10, 11 and 12 showed that 6 weeks may be optimal for rehabilitation at 3 times a week but the minimum appeared to be 4 weeks if using the isokinetic treatment for improved strength throughout the range of motion.

Strength Gains in Injured Leg Relative
to Pre-test Healthy Leg

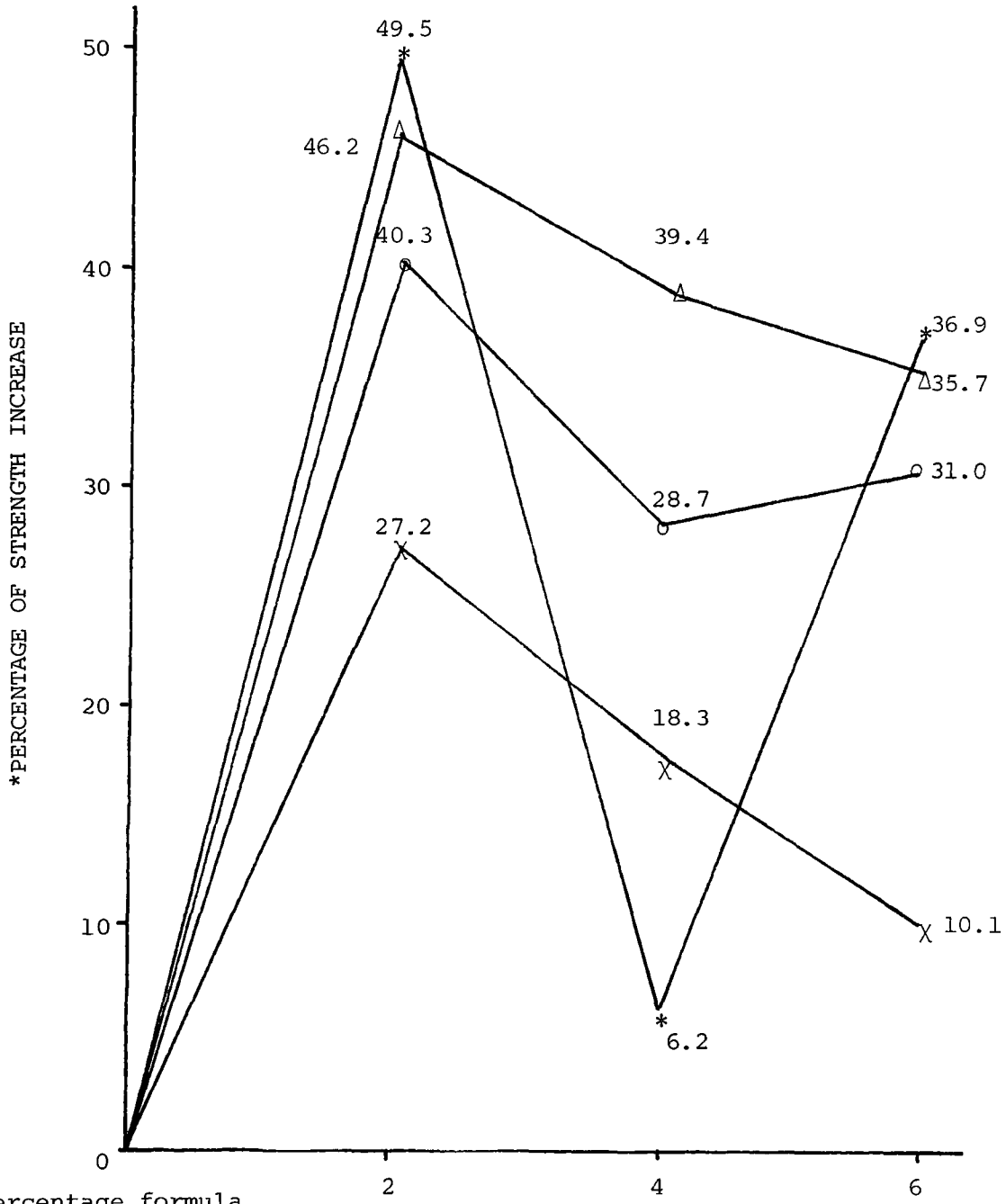
The strength gains made during the 6 week training session by the injured leg were linear (Figure 7) however, the rate of strength gain varied considerably during each 2 week tested interval (Figure 13). Generally both treatments when measured statically and dynamically had a marked increase of strength in the first 2 weeks with an emphasis placed on strength specificity in terms electrostimulation tested statically and isokinetic tested dynamically.



* Percentage formula. The denominator is the individual's Pre-test healthy leg measurement 100% = Pre-test healthy leg.

Figure 12:- Percentage Strength Gains of Electrically Stimulated Injured Leg on Isokinetic Test Relative to Pre-test Healthy Leg

- * --Electrical Stimulation Isometric Test
- Δ --Isokinetic Treated Isokinetic Test
- --Isokinetic Treated Isometric Test
- χ --Electrical Stimulation Isokinetic Test



*Percentage formula denominator is Pre-test Measurement

Figure 13:- Percent Changes in Strength Increase Between Each Test on the Injured Leg Relative to the Pre-test Healthy Leg, Over Time

A similar trend was apparent between the rates of strength increase on the static as well as the dynamic tests. Static strength gains, whether electrically stimulated or isokinetically trained, peaked at 2 weeks, declined in the 4th week and increased at the 6th week, simulating 2 phases, a trend especially noted in the electrical stimulation group. This may be interpreted as a need to allocate more time for a substantial static strength gain in a rehabilitative program.

The dynamic rate of strength gain was more uniform throughout the 6 week training session compared to the rate of static strength gain. The dynamic rate of strength gain appeared to decline between the 4th and the 6th week. Perhaps the subjects were closer to their limiting strength, suggested by the fact that the isokinetic group tested dynamically had the highest strength gains, thus affecting the rate of strength increment (Royce, 1964).

The differences in rate of strength gain between static and dynamic training were not consistent with Coleman's (1972) observations. He noted that static and dynamic training had an increment of similar magnitude each week for 12 weeks on normal legs. The weakened quadriceps of the injured knees may differ in their response to static and dynamic training compared to normal quadriceps.

Comparison on Rate of Strength Gain in Healthy
and Injured Leg Relative to their Own
Pre-test Values

Figure 14 indicated that electrical stimulation had a greater effect on the rate of strength increase for the injured leg on both static and dynamic testing in the first 2 weeks when compared with the healthy leg. The difference of rate of strength gain between the two legs may be attributed to the strength variation between the healthy and injured leg upon the initiation of the training program. The weaker the muscle the faster the strength gain is made up to 75 percent of the muscle's maximum strength (Muller, 1970).

Consideration of the difference existing between that of weak musculature, studied by Muller, 1970, and that of weak musculature secondary to a knee joint injury must be recognized in terms of the measurement of rate of strength gain. The presence of a joint injury can adversely affect the individual's capacity to exert a maximal volitional contraction. Fear concerning the re-occurrence of pain, apprehension of one's ability to move the joint through its full range of motion and a general sense of protectiveness can inhibit the motor unit recruitment and co-ordination necessary for an initial strength test. However, these negative factors appeared to have less importance as the number of treatment sessions increased over an extended period of time and positive feedback was realized.

The results depicted in Figure 15 showed that the isokinetic treatment similarly influenced the healthy and

- * --Electrical Stimulation of Injured Leg on Isometric Test
- Δ --Electrical Stimulation of Injured Leg on Isokinetic Test
- o --Electrical Stimulation on Healthy Leg on Isometric Test
- χ --Electrical Stimulation on Healthy Leg on Isokinetic Test

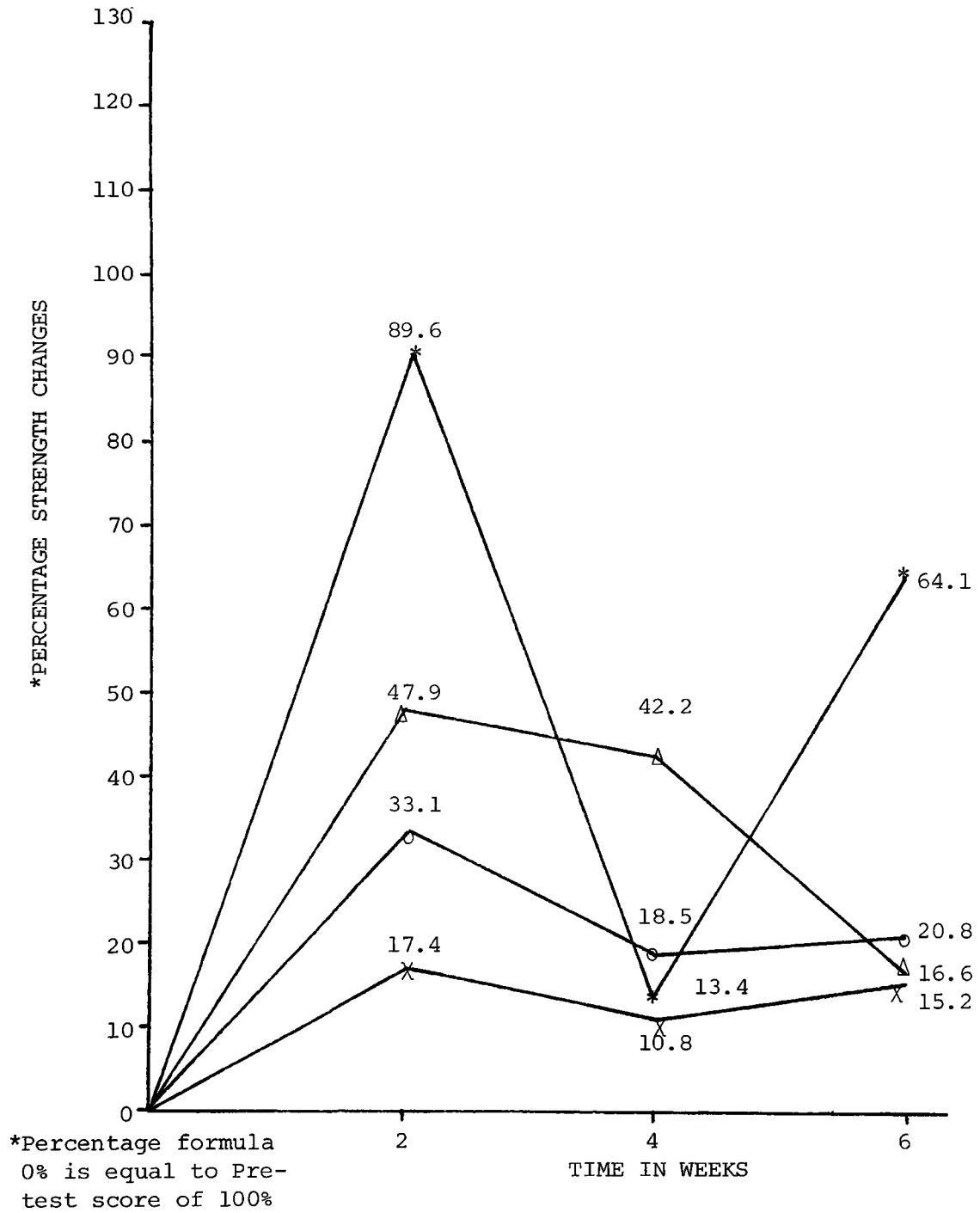
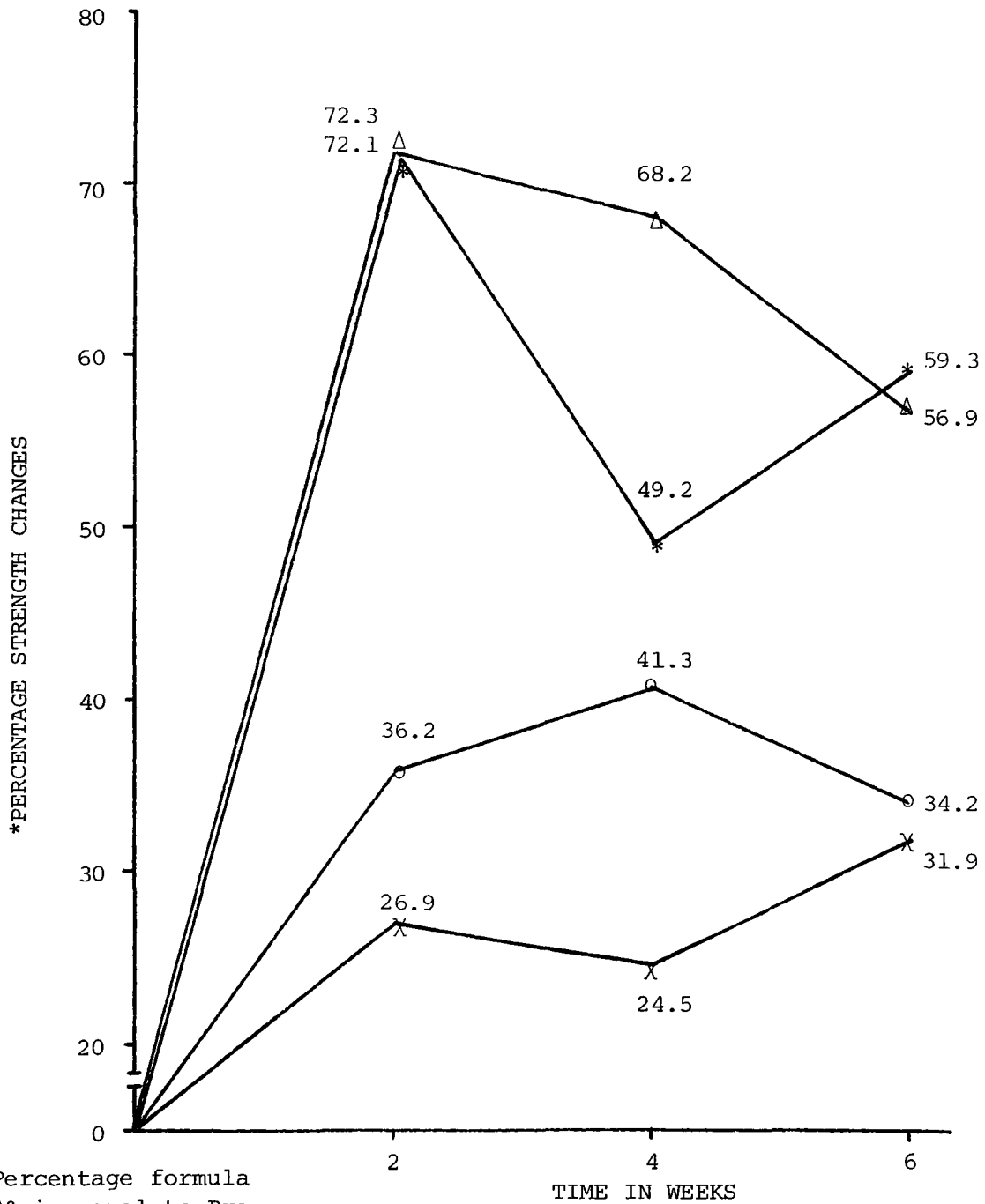


Figure 14:- Comparison Between Healthy and Injured Leg on Percent Change in Strength Over Time During Electrical Stimulation Treatment

- * --Isokinetic Treatment on Injured Leg on Isometric Test
- Δ --Isokinetic Treatment on Injured Leg on Isokinetic Test
- o --Isokinetic Treatment on Healthy Leg on Isokinetic Test
- χ --Isokinetic Treatment on Healthy Leg on Isometric Test



*Percentage formula
 0% is equal to Pre-
 test score of 100%

Figure 15:- Comparison Between Healthy and Injured Leg on Percent Change in Strength Over Time During Isokinetic Treatment

injured leg on the rate of strength increment throughout the 6 weeks although the absolute rate of increase was higher for the injured leg. In the first 2 weeks the injured leg demonstrated a similar strength gain both statically and dynamically whereas the healthy leg realized a greater strength gain dynamically at the testing and training angle of 40 degrees. Perhaps the 40 degree knee joint angle in the healthy leg was closer to its limiting strength due to daily activities such as climbing stairs and inclines which require strength development at this angle (Haffajee, 1972) and therefore may be less influenced by the rate of static strength gain.

It was interesting to note that when the results were combined from one type of treatment with different types of testing that certain trends were shown. Electrical stimulation treatment when tested statically appeared to have the greatest influence on the rate of strength measured on the injured leg in the 2nd and 6th week. The healthy and injured leg were least influenced by electrical stimulation when tested isokinetically. Thus the combination of static treatment (electrical stimulation) and static (isometric) testing appeared to be most effective on the injured leg particularly during the early phase of rehabilitation. The isokinetic treatment whether evaluated by an isokinetic test or an isometric test seemed to influence the healthy and injured leg similarly on the rate of strength measured. The importance of combining the same type of treatment and test did not appear

to be as emphasized in the isokinetic treatment and dynamic test on both legs as electrical stimulation and static testing on the injured leg.

Summary of Discussion

The electrical stimulation and isokinetic training groups significantly increased both static and dynamic strength of the injured leg in the 6 week session. However, there was no significant difference found between the 2 treatment groups on the strength measured. This may be an indication that there was some strength transfer from electrical stimulation at a 40 degree angle to a partial range of motion from 40 to 0 degrees knee extension in the in-vivo condition. A similar statement can be made of isokinetic training affecting the static force exerted at an angle of 40 degrees.

Trend differences between the 2 treatment groups on rate and magnitude of the injured leg's strength gain when measured statically and dynamically were observed. Electrical stimulation provided the injured leg with the greater static force gains in rate, magnitude and number of subjects achieving their pre-test healthy leg score within the first 2 weeks. Conversely, electrical stimulation produced the least effect on dynamic force in terms of the above mentioned parameters in the 6 week training period. In comparison the isokinetic training elicited the greater dynamic force, rate of strength gain and dynamic strength balance with the pre-test healthy leg in the 4th and 6th week. It is also noteworthy that

isokinetic training resulted in a higher static force gain than the electrical stimulation group at the end of 6 weeks. This occurrence may be attributed to insufficient muscle overloading due to the limitations of the electrical stimulating apparatus or to the inherent characteristics of electrical stimulation which may provide its greatest impact on short term static force development and decrease in its effectiveness over a longer period of time on stronger musculature.

The healthy and injured leg were affected similarly by the 2 treatments on the final post-test at the end of 6 weeks. The greatest strength gain was stimulated by the isokinetic method tested dynamically followed by isokinetic treatment measured statically then electrical stimulation tested statically and finally by electrical stimulation measured dynamically. The same parallelism was not observed when comparing rates of strength gains between the healthy and injured leg as a result of the 2 treatment groups. The healthy leg was not affected by electrical stimulation to the same extent as the injured leg in the first 2 weeks when examined statically. In fact it was generally noted that the healthy leg developed static and dynamic strength better with isokinetic training than electrical stimulation, although it took longer to achieve.

The fundamental role of electrical stimulation in knee rehabilitation may be to produce an increased static force of the vastus medialis at an appropriate angle for improved knee stabilization more rapidly than that possible

with isokinetic training. Electrical stimulation may also be applied when the subject is unable to complete a range of motion voluntarily without pain due to swelling. In certain knee conditions such as chondromalacia of the patella where knee stabilization is a problem, electrostimulation may provide a better alternative than isokinetic strength therapy. Isokinetic treatment seems to be more applicable when the subject is required to increase strength throughout the full range of movement in order to balance the strength in both legs. Thus, the combination of electrostimulation and isokinetic training may comprise the optimum training format for a complete knee rehabilitation program.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The purpose of this study was to determine if there was a difference between an electrical stimulation and an isokinetic training program on the rate and magnitude of strength development in normally innervated, but weakened quadriceps following a knee injury. The effect that these two types of training would have on normal, healthy quadriceps compared with the weakened quadriceps was also investigated.

Conclusions

The conclusions made within the scope of this study are.

1. The electrical stimulation and isokinetic treatments significantly increased the strength of the injured leg.
2. There was no significant difference found between the two treatments on the final magnitude of strength measured. However, descriptive statistics showed that the isokinetic treatment produced a greater increase in measurement of strength expressed as a

percentage of the pre-test values than did electrical stimulation. This trend was not supported statistically but was shown in both healthy and injured legs.

3. The electrical stimulation treatment produced a greater rate of percentage strength gain by the injured leg when compared to the isokinetic method of treatment earlier in the treatment program.
4. The electrical stimulation had less effect on both rate and magnitude of strength measured on the healthy leg than the isokinetic treatment.
5. The two treatments promoted a faster rate of strength gain in the injured leg than in the healthy leg when expressed as a percentage of pre-test values.

Recommendations

1. Further investigation with a larger number of subjects with varying degrees of muscular weakness electrically stimulated at various angles should be examined for the effect that stimulation may have on dynamic strength.
2. Further study into the electrical stimulation format of frequency and duration should be made in order to develop an optimum program for knee rehabilitation.

3. A further examination of the effects that electrical stimulation may have on different degrees of quadricep weakness should be considered since this study has indicated a difference between healthy and weakened quadriceps on rate and static strength gain as the result of electrical stimulation.
4. Further study should be carried out on the effects that electrical stimulation may have on the vastus medialis in terms of improving knee stabilization in the shortest duration after a knee injury should be made.
5. Further investigation of the effects that electrical stimulation may have on static strength gain with a stimulating apparatus capable of overloading muscles of different strength ranges should be undertaken.
6. Electrical stimulation in a knee rehabilitation program should be used as a method for greater static strength gain in the least amount of time during the initial phase of the program but should be supplemented with isokinetic training in the latter part of the program in order to achieve a static and dynamic strength balance with the healthy leg.

APPENDIX A

ILLUSTRATIONS OF EQUIPMENT



Figure 16:- Electrical Stimulation Apparatus



Figure 17:- Isokinetic Treatment Apparatus

APPENDIX B

RAW DATA

TABLE 5
RAW DATA IN UNITS OF POUND FORCE

SUBJECT	T ₁				T ₂				T ₃				T ₄			
	H		I		H		I		H		I		H		I	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
ISOKINETIC																
1	40	43.3	24	23.3	60	53.3	55	33.3	89	103.3	107	80.0	98	110.0	100	100.0
2	49	53.3	36	40.0	68	101.3	69	98.6	70	106.6	74	103.3	81	133.3	81	140.0
3	54	46.6	24	33.3	81	80.0	66	66.6	83	110.0	70	93.3	132	110.0	112	113.3
4	45	60.0	26	33.3	56	66.6	35	73.3	74	103.3	48	100.0	98	143.3	85	140.0
5	63	66.6	28	14.6	81	86.6	43	20.0	110	86.6	52	25.3	119	133.3	68	26.6
6	165	120.0	115	80.0	162	123.3	118	100.0	180	146.6	128	133.3	198	176.6	175	146.6
7	225	106.6	148	86.6	222	133.3	175	116.6	210	153.3	185	140.0	231	166.6	200	153.3
ELECTRICAL STIMULATION																
1	52	43.3	37	33.3	82	56.6	93	53.3	90	66.6	98	53.3	115	86.6	120	73.3
2	148	100.0	113	100.0	218	113.3	178	113.3	214	126.6	171	126.6	214	146.6	190	133.3
3	77	73.3	55	40.0	118	96.6	93	53.3	145	83.3	70	43.3	151	86.6	140	40.0
4	70	86.6	32	43.3	115	73.3	81	60.0	113	83.3	91	60.0	140	86.6	130	66.6
5	78	100.0	27	40.0	100	110.0	81	53.3	115	140.0	81	113.3	136	160.0	95	100.0
6	98	73.3	75	63.3	96	96.6	105	100.0	170	100.0	132	103.3	162	113.3	150	113.3
7	103	66.6	69	30.0	128	86.6	89	53.3	124	106.6	105	100.0	178	101.3	145	100.0
8	200	133.3	70	43.3	185	143.3	82	73.3	210	133.3	118	90.0	213	156.6	156	123.3

T --Time
H --Healthy Leg
I --Injured Leg
S --Static Test
D --Dynamic Test

APPENDIX C

BACKGROUND QUESTIONNAIRE

BACKGROUND QUESTIONNAIRE

Date: _____

Name: _____

Age: _____

Sex: _____

Occupation: _____

Address: _____

Telephone: _____

Sports Actively Participated In Within the Last 2 Years:

Level of Sports Participation: a) Recreational

b) National

c) International

Cause of Injury: a) Sport Accident--Name Sport _____

b) Non-Sport Activity--Name Activity

Time Interval from Injury to Treatment: _____

Doctor's Diagnosis for Knee Injury: (To be filled in by
the Doctor)

Reason for Rehabilitation: a) To Resume Normal Everyday
Activity.

b) To Return to Sport Competition.

c) The Doctor Advised Rehabilitation.

REFERENCES

- Adams, Advan. "Effects of Exercise upon Ligament Strength," Research Quarterly, 37:163, May, 1966.
- Allman, Fred, L. Rehabilitation of the Injured Athlete, in Sports Medicine. New York: Academic Press, 1974, 311 pp.
- Astrand, Per-Olof and Kaare, Rodahl. Textbook of Work Physiology. New York: McGraw-Hill Book Company, 1970, 69 pp.
- Basmajian, J. V. Muscles Alive. Baltimore: Williams and Wilkins Company, 1967.
- Bates, James D. "The Effects of Static and Dynamic Strength Training and Position of Exercise on the Acquisition of Strength Speed of Movement Reaction Time and Endurance," 1967. Microcard Doctoral Dissertation.
- Berger, R. A. "Comparison Between Resistance Load and Strength Improvement," Research Quarterly, 33:637, 1962.
- _____. "Comparison of Static and Dynamic Strength Increases," Research Quarterly, 33:329-33, 1962.
- _____. "Comparison Between Static and Various Dynamic Training Programs," Research Quarterly, 34:131, May, 1963.
- _____. "Comparison of the Effect of Various Weight Training Loads on Strength," Research Quarterly, 36:141-46, 1965.
- Bergeron, Philip C. "The Effects of Static Training at Various Positions and Dynamic Strength Training Through a Full Range of Motion on Strength, Speed Movement and Power," Microcard Doctoral Dissertation, 1966.
- Bos, R. R. and T. G. Blosser. "An Electromyographic Study of Vastus Medialis and Vastus Lateralis During Selected Isometric Exercises," Medicine Science in Sports, 2:218-23, Winter, 1970.

- Brewerton, D. "Discussion on an Evaluation of the Methods of Increasing Muscle Strength," Proceedings from the Royal Society of Medicine, 49:1006-1008, 1956.
- Chui, Edward F. "Effects of Isometric and Dynamic Weight-Training Exercises Upon Strength and Speed of Movement," Research Quarterly, 35:246, October, 1964.
- Clarke, H. Harrison (ed.). "Isometric Versus Isotonic Exercises," Australian Journal of Sports Medicine, 4(5), February, 1972.
- _____. "Exercise and Knee Joint," Physical Fitness Research Digest, No. 1, January, 1976.
- Coleman, A. E. "A Comparison of Isotonic and Isometric Exercises Performed on Contralateral Limbs," American Corrective Therapy Journal, November, 1969.
- _____. "Comparison of Weekly Strength Changes Following Isometric and Isotonic Training," Journal of Sports Medicine and Physical Fitness, 12:21, March, 1972.
- Coplin, Thomas H. "Isokinetic Exercise: Clinical Usage," Journal of National Athletic Trainers Assoc., 6:222, 1971.
- Corsi, A. et al. "In Situ Utilization of Glycogen and Blood Glucose By Skeletal Muscle During Tetanus," American Journal of Physiology, 216:1534-41, 1969.
- Cotter, M. O. et al. "Changes of Capillary Density and Enzyme Pattern for Fast Rabbit Muscles During Long-Term Stimulation," Journal of Physiology, 230:34-35, 1973.
- Currier, D. P. "Positioning for Knee Strengthening Exercises," Physical Therapy, 57(2), February, 1977.
- Damholt, V and Danilo Zoravkovic. "Quadriceps Function Following Fractures of the Femoral Shaft," ACTA Orthopedics Scandinavia, 43:148-56, 1972.
- de Vries, Herbert. Physiology of Exercise. Iowa: W. M. C. Brown Co. Pub., c 1966, 1970.
- Dobrovolski, I. "New in Strength Development," Yessis Review of Soviet Physical Education and Sports, 7(3), September, 1972.
- Edstrom, L. "Selective Atrophy of Red Muscle Fibres in the Quadriceps in Long-Standing Knee-Joint Dysfunction. Injuries to the Anterior Cruciate Ligament," Journal of Neurological Sciences 11(6):551-58, 1970.

- Francis, R. S. and D. E. Scott. "Hypertrophy of the Vastus Medialis in Knee Extension," Physical Therapy 54(10):1066-1070, October, 1974.
- Friedebold, Guenter et al. "Strength and Endurance in the Training of Normal and Atrophic Muscles in Man," American Corrective Therapy Journal, 22(2):39-42, March-April, 1968.
- Funderburk, C. F. et al. "Development of and Recovery From Fatigue Induced by Static Effort at Various Tensions," Journal of Applied Physiology, 37(3):392-96, September, 1974.
- Gardner, G. W. "Specificity of Strength Changes of the Exercised and Nonexercised Limb Following Isometric Training," Research Quarterly, 34:98-101, 1963.
- Gillis, J. M. "Ionic Displacements In Isolated Striated Muscle After Repeated Tetanization [frog]," Archives International Physiological Biochemistry, 72(1): 124-53, 1964.
- Goldfuss, A. J. et al. "Effect of Muscular Tension on Knee Stability," Medicine and Science in Sports 5(4):267-71, 1973.
- Grimby, G. et al. "Muscle Strength and Endurance After Training With Repeated Maximal Isometric Contractions," Scandinavian Journal of Rehabilitative Medicine, 5: 118-1233, 1973.
- Guyton, Arthur C. Textbook of Medical Physiology. Toronto: W. B. Saunders Co., 1971.
- Haffajee, D. et al. "Isometric Knee Extension Strength, As a Function of Joint Angle, Muscle Length and Motor Unit Activity," ACTA Orthopedic Scandinavia, 43:138-49, 1972.
- Hallén, L. G. and O Lindahl. "Muscle Function in Knee Extension, 38(4):434-44, 1967.
- Helfet, Arthur J. Disorders of the Knee. Toronto: J. B. Lippincott Co., c 1974.
- Hellebrandt, F. A. and S. J. Hontz. "Mechanism of Muscle Training in Man: Experimental Demonstrations of the Overload Principle," Physical Therapy Review, 36:371, 1956.

- Hellebrandt, F. A. "Application of the Overload Principle To Muscle Training in Man," American Journal of Physical Medicine, 37:278, October, 1958.
- Hislop, H. J. and J. J. Perrine. "The Isokinetic Concept of Exercise," Physical Therapy, 47(2):114, 1967.
- Hundal, P. S. and Surishtha Gill. "A Comparative Study of the Effects of Electrical and Psychological Stimulation On Muscular Fatigue," Psychophysiology, 9(3): 368-72, 1972.
- Hurevych, M. I. and Y. O. Dukhin. "Effect of Muscle Electrostimulation on Hemodynamic Shifts During Chronic Hypokinesia," FIZIOL ZH (AKADNAUK UKR RSR) 19(1):45-51, 1973.
- Ince, L. P. The Rehabilitation Medicine Services. Illinois: Charles C. Thomas Pub, 1974.
- Johnson, B. L. and J. W. Adamczyk. "Program of Eccentric and Concentric Strength Training," American Corrective Therapy Journal, 29(1):13-16, Jan. - Feb., 1975.
- Johnson, B. L. et al. "A Comparison of Concentric and Eccentric Muscle Training," Medicine and Science In Sports, 8(1):35-38, 1976.
- Kessler, H. H. Principles of Rehabilitation. Philadelphia: Lea and Febiger, 1950.
- Klein, Karl K. "An Instrument of Testing the Medial and Lateral Collateral Ligament Stability in Man," American Journal of Surgery, 104(11):768, November, 1962.
- Kroemer, K. H. and J. M. Howard. "Towards Standardization of Muscle Strength Testing," Medicine and Science for Sports, 2:224-30, Winter, 1970.
- Kusakin, A. "A New Method For Strength Preparation," Yessis Review of Soviet Physical Education and Sports, 6(4), December, 1971.
- Liberson, W. T. "Experiment Concerning Reciprocal Inhibition of Antagonists Elicited by Electrical Stimulation of Agonists in a Normal Individual," American Journal of Physical Medicine, 44:306-308, December, 1965.
- Licht, S. (ed.) Electrodiagnosis and Electromyography. Baltimore, Maryland: Waverly Press, Inc., c 1961.

- Manvelyan, L. R. et al. "Relationship Between Blood Flow in Auxotonically Contracting Gastrocnemius Muscle and Frequency of Stimulation," Experimental Biology and Medicine, 69(5):490-94, May, 1970.
- Massey, B. H. et al. "Effects of High Frequency Electrical Stimulation on the Size and Strength of Skeletal Muscle," Journal of Sport Medicine and Physical Fitness, 5:136-44, September, 1965.
- Mathews, D. K. and R. Kruse. "Effects of Isometric and Isotonic Exercises on Elbow Flexor Muscle Groups," Research Quarterly, 28(1):26, March, 1957.
- Mendler, H. M. "Knee Extension and Flexor Force, Following Injury," Physical Therapy, 47(1):35, 1967.
- _____. "Effect of Stabilization on Maximum Isometric Knee Extensor Force," Physical Therapy, 47 (5), May, 1967.
- Milner, M. "Force, Pain and Electrode Size in the Electrical Stimulation of Leg Muscle," Nature, 233:645, August, 1969.
- Moffroid, Mary et al. "A Study of Isokinetic Exercise," Physical Therapy, 49:735-46, 1969.
- _____. "Specificity of Speed of Exercise," Journal of American Physical Therapy, 50:1699, December, 1970.
- Morris, William M. "The Effects of Isometric and Isotonic Weight Training Exercises Upon Quadriceps Strength and Performance in Middle Distance Running Events," Microcard Doctoral Dissertation, 1969.
- Muller, Erich A. "Influence of Training and Inactivity on Muscle Strength," Archives Physical Medicine Rehabilitation, 51(8):449-62, 1970.
- Nowakowska, A. "Influence of Experimental Training By Electric Current Stimulation of Skeletal Muscle," ACTA Physiologica Polonica, 13:32-38, 1962.
- Patel, A. N. et al. "Disuse Atrophy of Human Skeletal Muscles," Archives of Neurology, 20 (4):413-21, 1969.
- Patterson, Paul R. "The Effect of Electro-Stimulation and Isokinetic Training Techniques on Strength and Hypertrophy of the Quadriceps Muscle," Unpublished Master's Thesis, University of Western, February, 1976.

- Pette, D. et al. "Physiological and Biochemical Changes Induced By Long Term Stimulation of Fast Muscle," Naturwissenschaften, 59:469-70, 1972.
- Pipes, T. V. and J. H. Wilmore. "Isokinetic Versus Isotonic Strength Training in Adult Men," Medicine and Science in Sports, 7(4):262-74, 1975.
- Quigley, T. "Knee Injuries Incurred in Sport," Journal of American Medical Assoc., 171(2):142-46, November, 1959.
- Raitsin, L. M. "The Effectiveness of Isometric and Electro-Stimulated Training on Muscle Strength at Different Joint Angles," Yessis Review of Soviet Physical Education and Sports, 11(2), June, 1976.
- Rasch, Philip J. and L. E. Morehouse. "Effect of Static and Dynamic Exercises on Muscular Strength and Hypertrophy," Journal of Applied Physiology, 11:29-34, 1959.
- Rasch, P. J. and R. K. Burke. Kinesiology and Applied Anatomy. Philadelphia: Lea and Febiger, c 1967.
- Rosentswieg, Joel and M. M. Hinson. "Comparison of Isometric, Isotonic and Isokinetic Exercises by Electromyography," Archives of Physical Medicine and Rehabilitation, 53:42-44, June, 1972.
- Royce, Joseph. "Re-Evaluation of Isometric Training Methods and Results, A Must," Research Quarterly, 35(2), May, 1964.
- Schenck, Jeanne and E. Forward. "Quantitative Strength Changes with Test Repetitions," Physical Therapy, 45(6), June, 1965.
- Scott, P. Clayton's Electrotherapy and Actinotherapy. London: Bailliere, Tendall and Cassell, 6th ed., 1969.
- Shaver, L. G. "The Relationship Between Maximim Isometric Strength and Relative Isotonic Endurance of Athletes with Various Degrees of Strength," Journal of Sports Medicine and Physical Fitness, 13 (4):231, December, 1973.
- Skinner, N. Sheldon and W. John Powell. "Regulation of Skeletal Muscle Blood Flow During Exercise," Supplement I to Circulation Research, 20, March, 1967.

- Smillie, I. S. Injuries of the Knee Joint. London: E. and S. Livingstone Ltd., 1962.
- Smith, E. M. and W. Steinberger. "Effect of Stimulus Parameter Variation on Recruitment in Denervated Rabbit Muscle," Archives of Physical Medicine and Rehabilitation, 49:566-71, 1968.
- Steinberger, W. W. and E. M. Smith. "Maintenance of Denervated Rabbit Muscle With Direct Electrostimulation," Archives of Physical Medicine and Rehabilitation, 49:573-77, 1968.
- Stillwell, D. M. et al. "Atrophy of Quadriceps Muscle Due to Immobilization of the Lower Extremity," Archives of Physical Medicine and Rehabilitation, 48(1):289, January, 1967.
- Thompson, C. W. Kranz Manual of Kinesiology. Saint Louis: C. V. Mosby Co., 5th ed., 1965, 74 pp.
- Thorstensso, Alf et al. "Effect of Strength Training on Enzyme Activities and Fibre Characteristics in Human Skeletal Muscle," ACTA Physiologica Scandinavia, 96:392-98, March, 1976.
- Tipton, Charles M. et al. "The Influence of Physical Activity on Ligaments and Tendons," Medicine and Science in Sports, 7 (3):165, Fall, 1975.
- Van Leeuwen, H. J. "Strength in Therapeutic Exercise," Progressive Physical Therapy, 1:346-52, 1970.
- Van Der Meulen, J. P. et al. "Use and Disuse of Muscle," Annals New York Academy of Sciences, 228:177-89, 1974.
- Walmsley, Roy P and Ianna Swann. "Biomechanics and Physiology of Muscle Strengthening," Physiotherapy Canada, 28(4), October, 1976.
- Williams, J. (ed.) Sports Medicine. London, England: Edward Arnold Pub. Ltd., 1962.
- Williams, J. G. P. "Diagnostic Pitfalls in the Sportsman's Knee," Proceedings of the Royal Society of Medicine, 277:640-41, June, 1971.
- Williams, J. G. P. and Marilyn Street. "Sequential Faradism in Quadriceps Rehabilitation," Physiotherapy 62(8), August, 1976.
- Wise, David. "A New Day for Faradic Stimulation," Physiotherapy Newsletter, 8(3), October, 1974.

Wise, David, Physiotherapist, Ottawa Athletic Club.
Personal Communications, 1977.

ABSTRACT

The purpose of this study was to determine if there was a difference between an electrical stimulation and an isokinetic training program on the rate and magnitude of strength development in normally innervated, but weakened quadriceps following a knee injury. The effect that these 2 types of training would have on normal, healthy quadriceps compared with the weakened quadriceps was also investigated.

There were 15 male and female subjects with unilateral knee joint injuries and secondary quadricep strength imbalance of 20 percent or greater. The subjects varied in age from 18 to 27 years with backgrounds of recreational sports participation. They were randomly assigned to the 2 treatment groups to be trained at a 40 degree angle of knee flexion from horizontal on both injured and healthy legs for a half-hour, 3 times per week, for 6 weeks. A pre-test and 3 post-tests at 2 week intervals on a static (cable tensiometer) and a dynamic (isokinetic) test were given also at a 40 degree angle on both injured and healthy legs recording the best of 3 attempts. The electrical stimulation group trained at a milliamperage adjusted at each session to just below the individual's pain threshold for 10 sets of a 10 second contraction with a 50 second rest. The isokinetic group trained at 3 sets

of 15 repetitions of maximal contractions on an orthotron at 10 revolutions per minute with a 2 minute rest between sets.

A statistical 2-way ANOVA showed a significant difference of strength increase over 6 weeks on both static and dynamic tests of the injured leg however, there was no significant difference between the treatment groups. The two treatments did not produce a significant strength increase on the healthy leg when tested statically, whereas when tested dynamically there was a significant strength increase. The rate of strength increase was greater for the injured leg than the healthy leg. Electrical stimulation provided the fastest rate and magnitude of static strength in the first 2 weeks on the injured leg. The greater percentage strength gain was realized by isokinetic training tested both statically and dynamically on the injured leg as well as the healthy leg.