THE EFFECT OF ELECTRICAL STIMULATION
AND ISOKINETIC EXERCISE ON
MUSCULAR POWER OF THE QUADRICEPS

by

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to the required standards

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ABSTRACT

Power and strength training, using conventional techniques, has been studied by several researchers. Investigations into the use of different training methods and their effect on power and strength development are continually being studied and re-assessed. Recently, the use of faradic or electrical stimulation has become an interesting alternative method, although much controversy surrounds this technique. It has been reported by Johnson et al. (1977) and Kots (1977) that faradic stimulation is used with success as part of a strengthening program by elite Soviet athletes. The combined effects of a program consisting of exercise as well as electrical stimulation was undertaken to determine the muscular power and strength potentials. The main objective of this study was to compare power and strength changes between equated groups employing the following training techniques: electrical stimulation plus isokinetic exercise, isokinetic exercise and electrical stimulation, respectively.

Twenty-seven, moderately trained, female subjects, nine per group, were tested on three separate occasions. During the first session, height, weight, left and right quadriceps power evaluation, time to peak tension of the muscle contraction at the four velocities (30, 100, 180 and 300 degrees per second) and two thigh girth measurements were determined. The three groups were equated for power after the pretest was conducted.
The second and third testing sessions assessed the power and time to peak tension of the non-dominant leg at the four velocities and patellar and gluteal thigh girths.

A significant difference for power was found between the pre and post tests and the pre and mid tests for the combined groups during the six week period of training. Although no difference was found between each of the three groups, the results indicated that programs involving electrical stimulation and isokinetic exercise, isokinetic exercise and electrical stimulation only, are potentially effective in improving muscular power and strength in normal subjects. The study revealed that one method was not superior to another after six weeks of training.

There was significant power differences between the pre and post tests and pre and mid tests at the slow isokinetic speeds of 30° and 0° per second. Since the training was conducted at the speeds of 30° and 0° (isometric) per second, the slow testing speeds reflected neural adaptation and muscular recruitment when the specificity of training theory is considered. These findings imply that power and strength training benefits are limited to speeds used during training.

During the six week training period, time to peak maximal torque and hypertrophy of the quadriceps muscle group did not alter significantly when examining the means of all three groups.
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CHAPTER I

INTRODUCTION

Exercise training utilizing either isotonic, isometric or isokinetic techniques is generally considered the most important means of developing power and strengthening muscles. Recently, interest has developed in the use of tetanic electrical stimulation, although it is a somewhat controversial alternative to improving muscular strength and power.

Isokinetic exercise controls angular velocity and allows for maximal accommodating resistance throughout the full range of limb motion. Isokinetic resistance training procedures are significantly better in bringing about changes in muscular strength, power, body composition and motor performance tasks than are standard weight training procedures (Pipes and Wilmore, 1975). Pipes and Wilmore (1975) stated that isokinetic training achieves greater gains in muscular strength and power not only in exercise patterns that are similar to the training activity but also at limb speeds that are typical of those found in athletic and sports activities when training at a specific speed. Lesmes et al. (1978) demonstrated that isokinetic training velocity is an important consideration in improving peak torque. Due to the greatly decreased time required for developing power and strength, isokinetic exercise has been suggested for use in rehabilitation and athletic training over isotonic or isometric exercises (Moffroid et al. 1972).
The purpose of electrical stimulation is to produce a maximal muscular contraction, as similar to a normal maximal voluntary contraction, by stimulating all the motor units (Astrand, 1977). Kots (1977) theorized that under normal conditions, a maximal voluntary contraction is ten to thirty percent lower in strength than an involuntary contraction that can be obtained with electrical stimulation because of a force deficit. The force deficit can be explained by the fact that the current is able to recruit more peripheral motor units than an individual can with a maximal voluntary contraction.

Much controversy still exists over the use of electrical stimulation as an adjunct to enhancing muscular strength and power. However, recent improvements in equipment and techniques have made electrical stimulation a more viable strengthening mode through research.

Nowakowska (1962) and Ikai et al. (1967, 1969), claimed that faradic stimulation increases muscular strength, endurance, working capacity and excitability of the muscle groups trained. But Massey et al. (1965) indicated that the conditioning of muscle by means of electrical stimulation was not as effective for increasing strength than were traditional, isometric and isotonic, methods of exercise.

In another study by Munsat (1976), electrical stimulation applied for long durations (days or weeks) appears to alter the pattern of activity of muscle to increase the size of fast
glycolytic and slow oxidative fibers. His study suggests that the neural component of the motor unit may be acting in a passive manner as a conduit for central nervous system information. Although electrical stimulation for short periods of time is not likely to cause histological and biochemical changes of muscle, these changes were not investigated in this study.

The traditional use of electro-stimulation has been for muscle re-education, supplementing exercise. However, Johnson et al. (1977) states that it is only in recent years that faradic stimulation has been used as part of a strength training program by elite Russian athletes. This was particularly evident when it was reported that they had used the "Russian technique" of electro-stimulation to hypertrophy selected normal muscles in athletes competing in the 1972 Olympic Games. It has been observed that along with increased power and strength of large muscle groups, the time to accomplish these gains was significantly shorter as compared with the time required for increases to occur with normal weight training programs (Kots, 1977). However, these reports are questionable because the Russian clinical studies have not been published in North America.

Williams (1976), Johnson et al. (1977) and Halbach and Straus (1980) reported that electrical stimulation increases girth and strength of the quadriceps femoris muscle group. Some of the specific claims made by Kots (1977), with respect to electrical stimulation, were that improvements in strength, velocity and endurance training could be achieved. Johnson and
co-workers (1977), using faradic stimulation as the only treatment mode, found significant strength gains among patients having mild and severe chondromalacia, respectively. There was a much greater improvement in the severe group, as compared to the mild chondromalacia group. This is not totally due to a specific benefit of faradism in this disorder. Rather, the greater improvement of the severe group probably reflects the more profound quadriceps atrophy present initially.

When muscle is exercised strenuously at a maximum work intensity it adapts to the stress by hypertrophying and enhancing its ability to generate force (tension). Gollnick (1980) found that in high intensity exercise, both types of motor units (fast glycolytic or type IIb fibers and slow oxidative or type I fibers) may contribute to the effort, and such exercise may train both fiber types. High speed by itself does not appear to activate the fast twitch motor units. The main point is that it does not appear to be physiologically possible to activate only fast twitch units during power activities or stimulation sessions by "jumping over" the slow twitch units. However, electrical stimulation of normal fast glycolytic and slow oxidative muscles have indicated a tendency for slow oxidative muscle to increase contraction speed when chronically stimulated with impulse patterns similar to fast glycolytic muscles, while the opposite occurs in fast glycolytic muscle stimulated with impulse patterns of slow oxidative muscle (Ianuzzo, 1976). Support for the motor impulse theory has come from experiments that have imposed different patterns of
stimulation on fast glycolytic and slow oxidative muscles (Ianuzzo, 1976). Ianuzzo (1976) states that the time taken to reach peak contraction changes with electrical stimulation such that slow oxidative muscles increase contraction speed when chronically stimulated with impulse patterns similar to fast glycolytic muscle stimuli. Kots' (1977) findings also support the research of Ianuzzo.

Kots (1977) further explained that the recruitment order of muscle fibers with his electrical stimulator, was larger (fast glycolytic) fibers first followed by smaller (slow oxidative) fibers, which is opposite to the "normal" voluntary contraction sequence.

Williams (1976) found that electrical stimulation combined with active muscular contraction was superior to exercises alone in restoring the function of the knee joint. However, Currier et al. (1970) discovered that electrical stimulation combined with maximum isometric contractions had no greater effect on enhancing strength than did conventional static exercise. Halbach and Straus (1980) found that both isokinetics and electro-myo stimulation increased muscle power of the knee extensor muscles in healthy subjects.

Therefore, a controversy exists about the combined effect of electrical stimulation and exercise for developing muscular strength and power. At present, rehabilitation for increasing power and strength of muscle groups is basically done with isometric, isotonic and isokinetic exercises that usually
involve eight to ten weeks (Johnson et al. 1977). Since electrical stimulation reduces the time to accomplish muscle power and strength gains, a reduction in time output would benefit the athlete.

Although recent work has broadened the understanding of the effects of isokinetic exercise and electro-stimulation of the quadriceps on producing muscular power and strength, there remains a need to compare the effectiveness of these techniques clinically in rehabilitating and training muscles.

The purpose of this study, employing the quadriceps muscle group, is to determine whether a training regimen consisting of electrical stimulation applied concurrently with maximum, isokinetic muscular contractions increases power more than does an exercise program consisting of only isokinetic contractions, or a program of only electrical stimulation.

Significance of the Study

To date, research involving muscle power training has not elucidated whether a regime consisting of electrical stimulation applied concurrently with maximum isokinetic muscular contractions increases power more than does an exercise program consisting of maximum isokinetic contractions or a program of electrical stimulation, respectively. This study intends to examine the value of such programs and extend the knowledge of electrical stimulation for future training of muscle power and rehabilitation of musculature after injury.
Hypotheses

Group I - Electrical Stimulation and Isokinetic Exercise (ES + IE)
Group II - Isokinetic Exercise (IE)
Group III - Electrical Stimulation (ES)

Following a six week training program:

1. Power

Measured at $0^\circ$ per second (isometric), $30^\circ$ per second, $100^\circ$ per second and $180^\circ$ per second for each of the three groups, respectively.

The increase in muscular power produced by ES + IE $>\text{the}$ increase in muscular power produced by IE, which is $>\text{the}$ increase in muscular power produced by ES (ES + IE $>\text{IE} > \text{ES}$).

Rationale: The increase in power produced by electrical stimulation is primarily caused by increased recruitment of peripheral nerves (motor units) and also caused by increased cross-sectional area of muscle. Peripheral recruitment is an important contributing power factor, as both fiber types are innervated within the stimulated muscle. Dynamic isokinetic exercise provides a greater form of resistance than static, electrical stimulation contractions. This implies that isokinetic exercise increases power more than electrical stimulation alone. In addition, isokinetic training procedures are significantly better in bringing about changes in muscular power than are standard resistance training methods. Since additional muscle fibers are recruited to increase power with electrical stimulation and
isokinetic exercise training, there should be power gains evident when isometrically contracting (0° per second) and at slow (30° per second) and fast (100° and 180° per second) speeds of movement.

2. Time to peak tension
Measured at 0° per second (isometric contraction) 30° per second, 100° per second and 180° per second for each of the three groups, respectively.

Time to peak tension produced by ES + IE < the time to peak tension produced by IE which is < the time to peak tension produced by ES (ES + IE < IE < ES).

Rationale: The increase in contraction velocity (decrease in contraction time) during electrical stimulation is attributed to a change in the firing rate of fast twitch and slow twitch fibers. Because slow twitch motor units require twice the time to reach peak tension as fast twitch motor units, it is possible for the fast twitch units to be activated later but still reach peak tension in time to make major contributions to the effort. The fast twitch fibers react to a higher firing frequency signal than those which innervate slow twitch fibers. However, when slow twitch fibers are chronically stimulated with impulse patterns similar to fast muscle stimuli the slow twitch fibers increase contraction speed. So, both fast twitch and slow twitch fibers speed up their velocity. This explains why there is an increased ability to reach peak contraction time for a muscle when an action potential
is produced. Isokinetic exercise increases muscular power, and since power training is based on short, high intensity work bouts then fast and slow twitch fibers are recruited for performance. Since both fiber types increase their velocity with electrical stimulation and isokinetic exercise training, there should be a decreased time to peak tension when isometrically contracting (0° per second) and at slow (30° per second) and fast (100° and 180° per second) speeds of movement.

3. Thigh circumference
The thigh circumference produced by ES + IE > the thigh circumference produced by IE which is > the thigh circumference produced by ES (ES + IE > IE > ES).

Rationale: The muscle hypertrophy that results from resistance training programs is due to an increase in the cross-sectional area of individual muscle fibers. Body composition changes following a resistance training program consist of a loss of relative body fat and a gain in muscle mass. Therefore, the combination of electrical stimulation and isokinetic exercise should produce an increase in thigh circumference due to hypertrophy of the quadriceps.

Delimitations

1. Inferences from this study are limited to moderately active female subjects, ages 19 to 27 years, with normally innervated skeletal muscle.
2. The effects of electrical stimulation and isokinetic exercise are assessed over a six week period.

3. The subjects are free to engage in daily activities but they must not be on an athletic team or participate in strenuous physical activity.

Limitations

1. Superficial muscles are stimulated to a greater degree than deep muscles and thus, equal increases in strength of the quadriceps are not possible using electrical stimulation.

2. Each subject's tolerance level to electrical stimulation is different due to the variations in skin resistance and pain thresholds.

Definitions

Contraction velocity - the speed at which a muscle can contract or develop tension as it shortens.

Electrical stimulation - the electrical stimulation to be used in the study is a faradic current. The current is produced by a faradic coil which consists of a rise and fall of unidirectional current impulses. The essential features are that the stimuli, with a duration of .1-1 millisecond, are repeated 50-100 times per second. The rapid recurrence of these impulses holds a normal muscle in
continued tetanic contraction until the current is terminated.

**Fast twitch fibers** - white, type IIb muscle fibers having a high anaerobic capability (glycolytic) and recruited during power exercises.

**Muscle power** - the rate of work; the capability for which maximum muscle tension is developed in a brief time span. Exercises for power are designed to increase strength of muscles. Performance of muscular work is expressed as work per unit of time. Power is expressed as Newton-meters per second in this study.

**Muscle strength** - the force that a muscle or muscle groups can exert against a resistance in one maximal effort.

**Muscle hypertrophy** - acquired increase in the size of a normally developed tissue.

**Newton-meters per second** - a measure of power; that is, a load of work is the product of force and distance. Performance of work is expressed as $1N = 1kg \times m \times s^{-2} =$ the force which gives the mass of $1kg$ an acceleration of $1m \times s^{-2}$. The unit for force is $N$ (Newton) and the unit for distance is $m$ (meter); therefore, the unit for work in a given
period of time is N·m per second (Appendix C).

Thigh girth - The distance around the thigh at the point of greater muscle mass.

Time to peak tension - the period of time it takes from the initial force exerted by a contracting muscle to the maximal force exerted by the contracting muscle.

Torque - a power or strength force through a range of motion.

Slow twitch fibers - red, type I muscle fibers having an aerobic capacity (oxidative) and recruited during long-term endurance types of activities.

Speed selection - (degrees per second) the speed or velocity at which limb movement can be controlled over the full range of motion on isokinetic equipment.
CHAPTER II

REVIEW OF LITERATURE

A library search revealed a lack of literature concerning the effects of electrical stimulation on the development of muscular strength and power in normally innervated human skeletal muscle. Two areas of literature which are essential in understanding this study will be examined. The two areas are: isokinetic training and electrical stimulation.

Isokinetic Training

Athletes and non-athletes have always been interested in techniques to increase strength and power of muscles. Isokinetic programs have been suggested for use in rehabilitation and athletic training due to the greatly decreased time required for developing muscular power and strength, and the absence of injury. Isokinetic training is relatively new and has not been the subject of many studies. Therefore, much controversy exists regarding the etiology of isokinetic strength gains, and in addition, what combination of method and protocol provide the most efficient power gains. However, isokinetic training is a viable technique for obtaining substantial strength gains based on the few studies conducted so far (Pipes and Wilmore, 1975; Moffroid, 1969 and Thistle et al., 1967).

Isokinetic or accommodating resistance exercise is a new dimension in the field of resistance exercise and muscle evaluation. The underlying principle is motion at a constant.
speed. This prevents acceleration, which results in increased resistance. The resistance developed is in proportion to the exerted muscle force. Isokinetic exercise not only controls the angular velocity but it allows for maximal resistance throughout the full range of limb motion.

In theory, isokinetic exercises should lead to the greatest improvement in muscular performance. As mentioned earlier, the isokinetic principle permits development of maximal muscular tension throughout the full range of joint movement. In other words, a greater number of motor units are activated (Rosentsweig and Hinson, 1972). As a result, a greater work load than was previously possible can be placed on the muscles being exercised (Hislop and Perrine, 1967).

One of the most important features of isokinetic training as related to muscular training or therapeutic exercise, since, in most sports activities and progressive stages of rehabilitation, muscular force is applied during movement at varying speeds. The relationship between muscular force and speed of movement becomes evident in the force-velocity curve. Moffroid and Whipple (1970) demonstrated that the force-velocity curve can be shifted upward and to the right after a fast speed (108° per second) training routine was completed. Training at fast speeds of movement produced increases in strength at all speeds of contraction at and below the training speed. Whereas slow speed (36° per second) training produced the greatest increase in strength only at slow speeds of
movement.

In another study, Pipes and Wilmore (1975) investigated two different training speeds. Training was conducted three days per week for eight weeks. The slow speed (24° per second) group did eight repetitions during each of three sets, while the fast speed (136° per second) group did fifteen repetitions during each of the three sets. The findings of Pipes and Wilmore (1975) demonstrated that training at a fast speed increased strength at both fast and slow speeds of movement. However, training at a slow speed produced increases in strength only at slow speeds of movement. In two subsequent studies, Thistle et al. (1967) and Moffroid et al. (1969) found that high power (fast velocity, low load) exercise produced an increase in muscular force at all speeds of contraction at and below the training speed.

Thistle et al. (1967) provided a comparison of isokinetic, isotonic and isometric programs. The subjects in this study were patients with varying degrees of rehabilitative problems. The training frequency and duration were four days per week for eight weeks. In this case, it was concluded that the isokinetic program was clearly superior to the other programs in both strength and endurance gains.

In Pipes and Wilmore's (1975) comparative study of isokinetic versus isotonic strength training, it was shown that the isokinetic resistance programs are significantly better in bringing about changes in muscular strength, body composition
and selected power tasks than are standard isotonic resistance training procedures. These researchers also demonstrated that isokinetic training achieves greater gains in muscular strength not only in exercise patterns that are similar to the training activity but also at limb speeds that are typical of those found in athletic and sports activities as evidenced by substantial improvements in the power performance tasks.

Although the contractile properties of skeletal muscle appear to be unaltered by resistance training, major changes do occur with training in the metabolic potential of the muscle and the individual fibers. Gollnick (1980) stated that in the slow twitch fibers the most dramatic evidence of metabolic adaptation is the increased concentration of mitochondria and the enzymes for oxidative metabolism with endurance training. The increased oxidative potential of muscle with training would appear to increase its capacity for using its energy reserves – both those stored intracellularly and those transported to it by the blood – through oxidation to carbon dioxide and water. In the case of carbohydrates, this process yields large energy supplies from ATP than when lactate is produced by the anaerobic pathway. The increased aerobic capacity would increase the muscle's ability to use fatty acids provided to it by the blood. The combination of these processes would exert a glycogen-sparing effect on the muscle and result in greater endurance capacity, because there is a relationship between the depletion of intracellular glycogen reserves of muscle and the termination of moderately severe exercise.
The influence of training on the anaerobic capacity of skeletal muscle is not as clear as that of the aerobic capacity. However, the fast twitch fibers have a fast speed of contraction but they rapidly fatigue as they exhaust their internal supply of glycogen. Associated with the fast twitch fibers' low oxidative capacity is a poor blood supply, which fails to provide these fibers with the additional glucose required to maintain contraction.

It has been asserted by Pipes and Wilmore (1975) that fast or slow training causes selective recruitment of fast and slow twitch motor units, respectively. However, the foregoing is not in agreement with a considerably body of scientific evidence. MacDougall et al. (1980b) and Prince et al. (1976) showed that bodybuilders and power lifters have enlarged fast twitch as well as slow twitch fibers. Further, conventional slow velocity weight training and slow isokinetic training causes hypertrophy of both fiber types (MacDougall et al. 1980a). In fact, the fast twitch fibers are enlarged to a greater extent than the slow twitch fibers in the bodybuilders and power lifters; similarly, slow velocity training causes greater hypertrophy of the fast twitch fibers (MacDougall et al. 1980a and Thorstensson et al. 1976). This does not mean that the fast twitch motor units were recruited more but may indicate that fast twitch fibers are more adaptable in relation to hypertrophy. Electromyographic studies undertaken by Desmedt and Godaux (1979) and Maton (1980) indicate that provided the degree of voluntary effort is maximal, the motor unit activation
is similar regardless of the velocity of contraction. Gollnick et al. (1974) and Warmolts and Engel (1972) have shown that fast twitch motor units are activated during isometric contractions. In addition, a positive correlation between isometric strength and the percentage of fast twitch fibers within a muscle has been demonstrated by Tesch and Karlsson (1978). Therefore, it can be concluded that there is no basis for the claim that slow twitch motor units are preferentially recruited during maximal slow velocity contractions. The misleading notion may have arisen from the assumption that fast twitch muscle fibers could only be involved in fast contractions; however, fast twitch fibers are also designed to contribute force, regardless of velocity. Also, slow twitch motor units can contribute force to very rapid contractions.

As far as the specificity of a training effect is concerned, the fact that the nervous control plays a decisive role for the development of strength is important (Eccles, 1973). The specificity is related to the organization of movements by neural adaptation rather than to selective recruitment of motor unit types (Desmedt and Godaux, 1979). The central nervous system continuously receives messages from peripheral receptors about joint positions, muscle length and tension, movements, environment and so on. When a call for a movement is reported to the brain, the nervous system has all the necessary requirements for execution and control of the movement. Therefore, the strength training program designed for "speed" and "power" athletes should include fast movements to
train the nervous system and slow movements to train the muscles. In other words, the athlete should train the muscles and learn to execute the desired movements through neural control.

Commonly associated with strengthening programs is muscle soreness. Frequently, in resistance training programs there is an initial loss of strength due to muscle soreness as evidenced by Talag (1973). At present there are three different explanations for the problem of delayed muscle soreness according to Abraham (1977). The "torn tissue" hypothesis suggests that the pain results from structural damage in the muscle. Alternatively, the spasm theory proposes that the delayed soreness is caused by tonic spasms in localized motor units. The hypothesis that overstretching the muscles' elastic components, i.e., the connective tissue among the fibers and fibrils, especially during eccentric types of work, results in delayed post-exercise pain. Abraham (1977) states that by correlating the appearance of delayed soreness with breakdown products from muscle cells and/or connective tissue, it would be possible to determine if the "connective tissue damage" theory exists. The "connective tissue damage" proposal can be studied by monitoring urinary hydroxyproline (OHP) levels. Since OHP has been shown to be a specific breakdown product of connective tissue, assays for urinary OHP would be useful in studying collagen metabolism.

Abraham's (1977) investigative work revealed that strenuous exercise resulted in injury to the connective tissue in and around the muscle. Thus, it may be that when the level of
exercise became sufficiently severe, a reduction in the physical strength of the collagen allowed it to be damaged. This theory would suggest that increased degradation was responsible for the higher urinary OHP levels. In addition, hypoxia is known to stimulate collagen synthesis. Since mechanical stress and local tissue hypoxia may result from exercise, it is conceivable that the increased OHP excretions are indicative of more rapid collagen synthesis. The answer as to which mechanism resulted in the increased OHP excretion during this investigation could not be obtained. However, what was concluded from these results was that the delayed muscle soreness observed after exercise was most likely correlated to alterations in the muscle connective tissue.

On the other hand, Thistle et al. (1967) and Pipes and Wilmore (1975) observed that isokinetic training subjects did not report muscle soreness. It is suggested that isokinetic resistance procedures employ only positive, concentric contractions with little or no resistance during the recovery phase of the exercise. It has been demonstrated that the application of eccentric contractions in training has no advantage compared with the concentric. During an isokinetic contraction, the muscle is not lengthened as in a negative, eccentric movement. This explains the absence of connective tissue damage and lack of soreness associated with isokinetic training.

It appears that the superiority of the isokinetic programs is probably due to the nature of the isokinetic contraction,
i.e., maximal resistance through the total range of motion. The apparent superiority of the high speed exercise over the low speed exercise is presently unexplainable and requires further investigation.

In viewing the limited literature on isokinetic training with respect to muscular power and strength, one would conclude that it is still a relatively unexplored training mode. It appears that Pipes and Wilmore (1975) and Moffroid and Whipple's (1970) work have been the most extensive in terms of developing an isokinetic training regime.

Electrical Stimulation

The majority of the research examining the effect of electrical stimulation on the development of muscular strength or power has dealt with either animal studies or denervated muscles of humans. Traditionally, electrical stimulation has been used for muscle re-education, supplementing exercise.

Faradic or electrical stimulation is developed from a faradic coil and has two essential features: the stimuli must last for a duration of .1-1 millisecond and be repeated 50-100 times per second. Current of this type can stimulate the motor nerves and the muscle itself with sufficient current to elicit a muscle contraction. Because the stimuli are repeated 50-100 times per second, the contraction is tetanic.

If this type of contraction is maintained for a period of
time, muscle fatigue is produced, so the current is usually surged or interrupted to allow for muscle relaxation. When the current is surged the contraction increases and decreases in strength, similar to a voluntary contraction (Scott, 1975 and Stillwell, 1967). The muscle contraction produced by this type of current has been found to be similar to a voluntary contraction (Scott, 1975).

Stillwell (1967) mentioned that electrical stimulation comparable to the method used in this experiment stimulates sensory nerves, motor nerves and the entire muscle. Electrical stimulation to a muscle causes similar vascular changes as associated with voluntary contraction. An increase in the requirement for nutrients occurs, as well as an increase needed for removal of waste products. Stillwell (1976:127) states:

"If a muscle contracts a sufficient number of times against a resistance of an adequate load there is an increase in the bulk of the muscle fibers and the muscle is strengthened. There is some doubt whether the muscle contraction caused by faradic stimulation can produce these effects, but presumably if sufficient contractions are produced against a resistance of an adequate load it should be possible to do so."

Stillwell (1976) was skeptical as to the effects of electrical stimulation pertaining to strength increments in skeletal muscle. There has been little information gathered to suggest that muscle power can increase by electrical stimulation (Nicols, 1976 and Stillwell, 1967). This is because the discomfort of the stimuli is such that a contraction produced is rarely more than thirty percent of a maximal
contraction (Nichols, 1976). In the study conducted by Halbach and Straus (1980), as individual treatment sessions progressed with electro-myo stimulation, the maximum amount of faradic current that could be tolerated increased significantly. However, following treatments of maximum tolerance, there was a decrease in the amount of faradic current that could be tolerated, due to the resultant muscle soreness.

Recently, new equipment has been introduced overcoming the uncomfortable sensory stimulation associated with electrical current. In the study by Curwin et al. (1980) it was demonstrated that modulation of sinusoidal currents used for muscle stimulation produces medium frequency currents capable of blocking superficial nerve endings. This permits the more comfortable use of high intensities. Faradic currents utilizing spiked pulses with a duration of 50 to 500 microseconds and a fast rise time similarly decrease resistance reducing sensory effects and allowing use of high intensities. Cummings (1980) states that the currents with a fast rise time avoid accommodation by the motor nerve, producing required tetanic contraction at a lower intensity.

The use of electrical stimulation as a stimulus for atrophy retardation has been studied by many investigators. Guttmann and Guttmann (1942) reported that denervated rabbit muscle atrophies less when exposed to electrical stimulation. Osbourne (1951) found a decrease in atrophy in humans with lesions of peripheral nerves after receiving electrical stimulation.
Jackson and Seddon (1945) studied patients with denervated muscles of the hand and found that electrical stimulation retarded atrophy during the first one hundred days of denervation and subsequently, the stimulation was responsible for preventing further atrophy after this time.

Not only can atrophy be controlled, but other researchers have demonstrated that hypertrophy within the muscle can be influenced by electrical stimulation. Osbourne et al. (1950) stimulated subjects with poliomyelitis using a sinusoidal wave for ten minutes a day, and the results showed significant increases in the circumferences of the limbs. More recent literature by Peckham (1976) illustrated significant strength gains in quadraplegic patients when subjected to electrical stimulation. An intramuscular electrode was planted within the muscle nerves which stimulated the muscle at fifty percent of its maximal force. The contraction was primarily by excitation of intramuscular nerves and it was estimated that only five percent of the muscular force was from direct muscle stimulation. The current remained on for 2.5 seconds and off for the same duration. The hand was in a locked position and finger flexors were stimulated for two to three hours per day for thirty weeks. Significant strength gains were observed after only four weeks of stimulation.

As reported by Johnson et al. (1977), the Russians aroused renewed interest by using electrical stimulation to hypertrophy selected normal muscles in athletes competing in the 1972
Olympic Games. The Russian clinical studies have not been published in North America to date. Consequently, little is known about the standardization or efficiency of the technique.

In a Canadian-Soviet exchange symposium, Kots (1977) outlined the "Russian technique" and results of the Soviet research. Precise details of this method and description of the apparatus are not available.

Kots (1977) utilized electrical muscle stimulation to rehabilitate soft and hard tissue injuries, as well as a strengthening mode for healthy muscles. He also has found that electrical stimulation produces better results than traditional exercise regimes alone, and can be specifically used to isolate particular muscles for individual sports.

The Russian electrical stimulator produced overall strength gains that were similar, whether treatments were on alternate days or for an equivalent number of sessions on a daily basis. The important factors appear to be the total number of treatments and an adequate rest period following each treatment.

The Russian technique has demonstrated optimal strength benefits following four to five weeks, or twenty to twenty-five training sessions (Kots, 1977). As is the case with traditional voluntary strength training techniques, the rate of strength gain decreases as the number of treatment sessions increases. Strength is maintained at near maximum for three months and ninety percent for ten months. Kots (1977) attributes the
strengthening effect to two factors. Firstly, muscle cross-section is increased with an associated decrease in subcutaneous fat as measured by ultrasound techniques. Secondly, there is greater recruitment of peripheral nerves. This accounts for retained strength after hypertrophy decreases and is the primary benefit of electrical stimulation for muscle strengthening. He stated that a change in velocity or rate of muscle contraction may be a result of percent fast-twitch fibers to percent of slow-twitch fibers remaining the same but the quality of recruitment may tend to be more specific to the fast-twitch fibers, even though both fiber types increase their velocity.

Johnson et al. (1977) found that electrical stimulation was beneficial in improving strength and muscle size using the Russian regimen during rehabilitation. They studied fifty patients suffering chondromalacia patella, each patient was measured for leg strength and thigh girth initially and after twenty sessions of faradic stimulation. The treatment consisted of ten maximum tetanic contractions with a fifty second rest period between each contraction. The Soviet technique is capable of producing a medium frequency current of sufficient intensity to activate all available motor units at maximal tetanus frequency, but at the same time minimizes the skin sensory discomfort. The contractions were isometric in nature with the knee at five degrees of flexion. The results showed a 25.3 percent increase in quadriceps strength in the mild chondromalacia group and a 36.2 percent increase in the severe chondromalacia group. There was also a similar increase in
thigh girth of 4.3 percent in the mild group and 6.8 percent in the severe group. Johnson et al. (1977) concluded that faradic stimulation is an effective form of therapy for chondromalacia patella and has its greatest benefit in the initial stages, to prevent the loss of voluntary control of quadriceps contraction.

Other studies have shown that electrical stimulation was advantageous in obtaining strength increments (Currier et al., 1979 and Godfrey et al., 1979). The purpose of the studies was to compare the effectiveness of electrical stimulation as a mode of exercise and treatment, respectively. Currier et al. (1979) took two groups of healthy subjects; one group performed isometric exercise while simultaneously receiving electrical stimulation and the second group engaged in isometric exercise only. The knee extensor muscles of both groups increased in strength, however the strength gains for both groups were equivalent. In a comparison study by Godfrey et al. (1979), it was reported that a program of electrical stimulation is as effective as a program of isometric quadriceps strengthening for development of muscle power following surgery or injury to the knee. These researchers concluded that by using electrical stimulation a physical restoration program is started immediately because of the ability to maintain a voluntary full contraction.

In a recent study, Halbach et al. (1980) compared electrical stimulation to isokinetic training in order to increase
muscular power. It was demonstrated that both isokinetics and electrical stimulation increase muscle power of healthy knee extensor muscles, however the isokinetics proved to be superior in increasing power as compared to electrical stimulation. It was concluded that more study needs to be undertaken with electrical stimulation and its effect on increasing power, particularly when the subject can tolerate over twenty-five milliamperes.

Several authors (Curwin et al., 1980 and Stanish et al., 1980) have shown that patients undergoing muscle stimulation as part of their rehabilitation program did not have a decrease in myofibrillar ATPase activity, as determined by muscle biopsies, normally associated with an immobilization period. It was concluded that electrical stimulation was able to prevent the decrease in myofibrillar ATPase and atrophy that accompanies immobilization, but the findings do not necessarily lead to the conclusion that the use of electrical stimulation for the improvement of muscle function is superior to conventional training programs or physiotherapy techniques. It can be employed as a means of maintaining myofibrillar ATPase levels of the quadriceps group while the knee joint is immobilized.

Eriksson et al. (1979) worked with patients in a similar study concerning enzymes connected with muscle activity. They examined the effects that post-surgical immobilization had upon succinated dehydrogenase (SDH) activity. This particular
enzyme was singled out because it has been found to be well correlated with the ability of muscle to perform everyday tasks and strenuous sports. The results showed that the patients who received electrical stimulation had less muscle atrophy and better muscle function than did the patient group that did isometric training. When the biochemical analysis of the muscle biopsy was carried out it was found that the increase in SDH in the stimulated group was significant and the decrease in SDH in the isometrically trained group was also significant.

Eriksson et al. (1981) in a subsequent study evaluated the acute and adaptive effects of electrical stimulation of the quadriceps muscle on healthy human skeletal muscle. The acute effects, such as depletion of phosphagen and glycogen stores and formation of lactate as well as decreases in certain enzyme activities, were similar to those found for intense muscular exercise. Intermittent electrical stimulation for four to five weeks did not cause any significant changes in enzyme activities, muscle fiber characteristics, or mitochondrial properties. The findings indicated that a four week period of electrical stimulation resulted in improvements of muscle strength comparable to the results of a corresponding program of voluntary training. The electrically stimulated leg had the greatest increase in strength at small joint angles, whereas the voluntary trained leg seemed less specific in this respect. An opposite pattern was observed when the training response was compared in relation to speed of contraction. In
this case, the voluntarily trained leg showed the largest increments in strength at the speed corresponding to that used in training, whereas the electrically stimulated leg appeared less speed specific. So, the effects of electrical stimulation appeared more "position-specific" and less "speed-specific" than those of voluntary training with slow isokinetic contractions.

The findings of Goldberg et al. (1975) are supported by Eriksson's et al. (1981) research. Specificity of training is important and should be considered when developing a resistance training program, whether it be for improvement of athletic performance or muscle function after trauma.

Ianuzzo (1976) explains velocity training through the use of electrical stimulation. His work on contractile characteristics found that in mammalian skeletal muscles the time required to reach peak tension was determined to be two to four times quicker in fast-twitch fibers than slow-twitch fibers. Ianuzzo (1976) states that this peak time reaction has been shown to change with electrical stimulation such that slow muscles increase contraction speed when chronically stimulated with impulse patterns similar to fast muscle stimuli.

Summary

Isokinetic training is a relatively new technique for developing muscular power and strength. Isokinetic resistance training procedures are significantly better in bringing about
changes in muscular strength, body composition, and power tasks with little muscular soreness than are standard weight training procedures (Pipes and Wilmore, 1975).

The limited amount of research published in this area has demonstrated several important findings with normal subjects. Firstly, isokinetic exercise is an effective means with which to increase muscular tone throughout an arc of motion. It has been shown to increase the work a muscle can do more so than does isometric or isotonic exercise. Finally, power and strength responses are specific to the joint angle and velocity at which the muscle group is trained (Moffroid et al., 1969 and Pipes and Wilmore, 1975).

Electrical stimulation techniques have been effective as a form of therapy in restoring muscle size and strength of the injured or denervated limb during rehabilitation. The use of electrical stimulation for the purpose of improving normal muscular strength has not been an important concern in rehabilitation. However, athletic training presents a situation beyond simple rehabilitation. Lately, electrical stimulation has become a complement and even a substitute for the ordinary strength training program of many athletes involved in strength and power events (Kots, 1977). On the other hand, there has been no conclusive research to indicate that electrical stimulation has positive effects on muscle tissue.

Therefore, by using electrical stimulation and isokinetic training simultaneously as a physical restoration program and/or
strengthening regime, it could be substituted for conventional and time-consuming rehabilitative and training techniques. Since electrical stimulation and isokinetic exercise reduces the time to accomplish muscle strength and power gains, a reduction in time output would benefit the athlete in particular, with his competitive character and tight training routine, as well as the recovering patient.
CHAPTER III

METHODS AND PROCEDURES

Subjects

Twenty-seven female, University of British Columbia students, between the ages of 19 to 27 years, participated in this study. The subjects were measured for power at 30° per second speed in both quadriceps muscle groups. The purpose of this initial measurement was to equate the three groups for power and to determine the non-dominant muscle group, which was the preferred quadriceps group for the study. The subjects were ranked one to twenty-seven, from highest to lowest quadriceps' power. Subjects, in order of power ranking, were placed into the three training groups of nine subjects per group. This technique for achieving constancy between the three groups is termed "matching by equating subjects". The subjects were not on an athletic team or participating in strenuous physical activity or muscle strengthening regimes. Subjects were also screened for patellar femoral joint disorders, internal derangement of the knee, history of knee surgery and any general disease or pathology contraindicating strength training of the quadriceps.

Time and Duration of the Study

There were eighteen training sessions for each group, held three times per week (Monday, Wednesday, Friday) for
six weeks. The pretest was carried out, before any training, on the initial visit during the first week of the study. The midtest was substituted for the training session held at the end of the fourth week. The eighth week, after six weeks of training, consisted of the posttest. Subjects were encouraged to perform maximally during the three testing sessions.

Testing Protocol

The Cybex II Isokinetic dynamometer was used for testing quadriceps power and strength. The force was recorded in foot pounds and calculated to Newton-meters per second (N-m \cdot \text{s}^{-1}). The subjects were tested in the exercise position with the knee moving freely against the Cybex arm, through a 90° to 0° knee angle (0° = straight leg). The test used for measuring muscular strength, power and joint integrity was the preferred protocol as outlined in the Cybex II Testing Protocol Manual (Cybex Division). This method uses a testing speed of 30° per second and a paper speed of 5 millimeters per second. Two additional fast speeds, 100° and 180° per second, and an isometric measurement, were utilized to determine power. The test called for three sub-maximal trials at 30° per second to familiarize the subject with required movement and then three test curves were recorded, with the highest torque reading being accepted as the measure of maximum power.

During the pretest, each subject had both legs measured for maximal quadriceps power to determine which was the weaker
or non-dominant limb. Once the non-dominant leg was known then the remaining pretest variables, time to peak tension, thigh circumference, weight, height and age, were measured. The contralateral or non-stimulated leg will be assessed again on completion of the study to determine if cross-education of the central nervous system or physical activity outside of the study influenced the power gains of the training limb.

The thigh girth was calculated by use of a Wyteface steel tape at one centimeter distal to gluteal line and twenty centimeters superior to the base of the patella. The subject stood erect with feet slightly apart, while the two circumference measurements were taken on the horizontal plane. Each site was measured twice and the two average values were recorded for the non-dominant leg.

After the pretest measurements were complete and the subjects were assigned to the three groups, the two groups receiving electrical stimulation (ES + IE and ES) were given one introductory session with the stimulator. The introduction was used to explain briefly the nature of the training and sensations to be experienced.

Training Procedures

The three groups were training on a Cybex II Isokinetic Dynamometer in the exercise position: sitting, thighs fully supported on a quadriceps bench, back supported with hips at 90°, use of thigh belt, and lower leg stabilized by the Cybex
lever arm. The non-dominant leg received the training in each group.

The electrical stimulation group (ES) received faradic stimulation from the Multitone Multifaradic Unit (Model F283). This unit was chosen because of its availability and capability of producing the desired prolonged tetanic contraction necessary for this technique. The electrical stimulator has a maximum current of 198 milliamperes. Rectangular wave stimuli were used to elicit a tetanic response. The rectangular waveform provided maximum activation of the motor units and brought about greater tension than voluntary effort alone (Johnson et al., 1977). Subjects were expected to tolerate 10-20 milliamperes of faradic current. The subjects received a ten second contraction at a frequency of sixty cycles per second with a fifty second rest period and ten repetitions per treatment. The intensity was adjusted according to each subject's variable tolerance under the tester's supervision. This was repeated three times per week for six weeks. A monopolar method using a medium size active electrode (9 x 14 cm) was placed over the femoral nerve trunk proximally and a large size dispersive electrode ('S' shaped pattern) was placed over the motor points of the vastus medialis, rectus femoris and vastus lateralis. The shape of the latter electrode was to produce a contraction of the whole quadriceps group and to ensure inclusion of the deeper vastus intermedius. During the actual stimulation period the subject was urged to take the maximal current tolerable.
The subjects were treated in the exercise position, however the knee was supported at 45° flexion (Halbach and Straus, 1980), and prevented from further extension by the Cybex II lever arm. The use of the Cybex II at zero velocity, as used in isometric testing, provided an accommodating resistance to any force exerted by the quadriceps, without joint movement. This provided the subject with visible feedback of attained torque for motivation during each training session.

The isokinetic exercise group (IE), using the same exercise position, were instructed to maximally extend the knee against the Cybex arm from 90° to 0°. The workouts consisted of six maximal contractions per set at a slow speed/high resistance setting of 30° per second; this procedure was repeated three times.

The electrical stimulation plus isokinetic exercise group (ES + IE) performed the same exercise routine as the IE group, but in addition, the subjects received electrical stimulation concurrently with each volitional maximum isokinetic contraction. The electrical stimulation protocol was the same as that for the ES group. The faradic current was applied for three seconds which was the approximate duration of each volitional maximum isokinetic contraction. The tester turned the faradic current to the subject's maximum tolerance simultaneously as she extended her knee, using maximum effort, from 90° to 0° on the Cybex II bench. At approximately 20°, prior to complete extension, the tester turned the faradic current down to zero
intensity. This procedure was repeated six times for three sets.

Experimental Design and Data Analysis

This study adopted an experimental method using equated groups with a pretest, midtest and posttest design. The dependent variables were leg power and time to peak tension measured at 0°, 30°, 100° and 180° per second, and thigh circumference measured at patellar and gluteal sites. The experimental design used in this study was a repeated measures design on the second and third factors, with the three groups, ES + IE, IE and ES, being the three levels of the independent variable.

The data was analyzed using a multivariate analysis of variance. This was accomplished using the computer program BMD P4V: General Univariate and Multivariate Anova (Davidson and Toporek, 1981) at the computing centre of the University of British Columbia. The P4V is a general purpose analysis of variance and covariance program. It handles both univariate and multivariate analyses. Both univariate and multivariate tests are given for repeated measurement of several different dependent variables. Each variable was tested at an alpha level of 0.05.

A significant overall multivariate F (p<0.05) was followed by pairwise comparison of groups (nonorthogonal) to get a between groups multivariate F, in conjunction with the univariate
F's for each dependent variable. Each significant variable was tested at an alpha level of \( p < 0.01 \) or \( p < 0.05 \), with Tukey's multiple comparison test of means, as this was the criterion measure for acceptance or rejection of the null hypothesis.
CHAPTER IV

RESULTS AND DISCUSSION

Results

The twenty-seven subjects were tested according to the testing protocols and their physical characteristics are summarized in Table I. The power measurements are represented in Table II, while the time to peak tension and thigh girth parameters are represented in Appendix A (Tables III, IV, V, VI). The results of the statistical analysis for the power measurement are displayed in Tables IIIa and IIIb. Appendix A (Tables Ia, Ib and II) illustrates the statistical analysis for the remaining power variables, time to peak tension and thigh girth parameters.

A multivariate statistical analysis revealed significant differences on several power, time to peak tension and thigh girth measurements. As well, a univariate statistical analysis of the three parameters was performed as part of the multivariate statistical program.

The multivariate statistical analysis was followed up by pairwise comparison to obtain the univariate analyses and probabilities for each groupwise contrast. The power, time to peak tension and thigh girth analyses that did not contribute to the relevancy of the study are represented in Appendix A (Tables I to VI). The power, time to peak tension and thigh
girth analyses that exemplified significance, and subsequently, were important to the hypotheses, were followed through with a post hoc comparison. Tukey's multiple comparison of means test was used to determine the location of significance.

The following univariate values for power were found not to be statistically significant as shown in Table IIIa and Appendix A (Table II): there was no significant power differences between each of the three groups; no significant power differences for interactions (tests x groups, tests x speeds, speeds x groups and tests x speeds x groups); and, no significant power differences for pairwise comparisons could be identified.

Appendix A (Table IV) revealed that several of the univariate values for time to peak tension were not significant. There was no significant differences between the groups; no significant time to peak differences between the tests were prevalent; and, no significant time to peak differences for interactions (tests x groups, speeds x groups, tests x speeds and tests x speeds x groups) existed.

The univariate value for the thigh girth analysis (Appendix A - Table VI) displayed no significant patellar girth differences between the groups, tests or interaction (tests x x groups).

Tukey's post hoc comparison of means revealed significant differences (p<0.01 and 0.05) on several power, time to peak tension and thigh girth parameters. The post hoc treatment of the power data established that the pre to mid and pre to post tests and 30° and 0° per second speeds were statistically
significant, as evident in Tables IIIa and IIIb. While the post hoc comparison of the time to peak tension parameter in Appendix A (Table IV) identified the four speeds ($30^\circ$, $100^\circ$, $180^\circ$ and $0^\circ$ per second) as being significant. Tukey's comparison of means also revealed, from the two thigh girth measurements (patellar and gluteal), that only the gluteal thigh girth in Appendix A (Table VI) was statistically significant between the ES + IE and ES groups.

Table V summarizes the results of the hypotheses testing.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ES + IE GROUP*</th>
<th>IE GROUP*</th>
<th>ES GROUP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE (years)</td>
<td>X 21.22</td>
<td>22.67</td>
<td>20.89</td>
</tr>
<tr>
<td></td>
<td>S.D. ± 2.11</td>
<td>± 3.12</td>
<td>± 1.54</td>
</tr>
<tr>
<td>WEIGHT (kgs)</td>
<td>55.44</td>
<td>57.98</td>
<td>58.58</td>
</tr>
<tr>
<td></td>
<td>± 5.17</td>
<td>± 6.64</td>
<td>± 6.77</td>
</tr>
<tr>
<td>HEIGHT (cm)</td>
<td>163.38</td>
<td>165.10</td>
<td>167.78</td>
</tr>
<tr>
<td></td>
<td>± 6.12</td>
<td>± 7.26</td>
<td>± 7.08</td>
</tr>
<tr>
<td>PRETEST EQUATING (N-m per second)</td>
<td>70.08</td>
<td>70.68</td>
<td>69.90</td>
</tr>
<tr>
<td></td>
<td>± 12.52</td>
<td>± 10.63</td>
<td>± 13.59</td>
</tr>
<tr>
<td>NUMBER IN EACH GROUP</td>
<td>9</td>
<td>9</td>
<td>9</td>
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</tbody>
</table>

ES + IE - Electrical Stimulation and Isokinetic Exercise Group
IE - Isokinetic Exercise Group
ES - Electrical Stimulation Group
TABLE II

COMPARISON OF POWER BETWEEN
ELECTRICAL STIMULATION AND ISOKINETIC EXERCISE (ES + IE), ISOKINETIC EXERCISE (IE)
AND ELECTRICAL STIMULATION (ES) GROUPS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ES + IE GROUP</th>
<th>IE GROUP</th>
<th>ES GROUP</th>
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<tr>
<td></td>
<td>PRE</td>
<td>MID</td>
<td>POST</td>
</tr>
<tr>
<td>POWER</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>30° x s⁻¹</td>
<td>70.08*</td>
<td>78.84</td>
<td>82.88</td>
</tr>
<tr>
<td>100° x s⁻¹</td>
<td>201.60</td>
<td>200.27</td>
<td>204.80</td>
</tr>
<tr>
<td>S.D.</td>
<td>+37.83</td>
<td>+33.75</td>
<td>+39.25</td>
</tr>
<tr>
<td>180° x s⁻¹</td>
<td>234.95</td>
<td>227.04</td>
<td>250.08</td>
</tr>
<tr>
<td>S.D.</td>
<td>+68.09</td>
<td>+42.00</td>
<td>+46.85</td>
</tr>
<tr>
<td>0° x s⁻¹</td>
<td>119.48</td>
<td>132.21</td>
<td>139.68</td>
</tr>
<tr>
<td>S.D.</td>
<td>+30.00</td>
<td>+29.18</td>
<td>+28.81</td>
</tr>
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*Newton-meters per second
### TABLE IIIa

MULTIVARIATE ANALYSIS OF VARIANCE FOR POWER PARAMETER

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>BETWEEN GROUPS PROBABILITY (p &lt;)</th>
<th>BETWEEN TESTS PROB.</th>
<th>INTERACTION T X G PROBABILITY</th>
<th>BETWEEN SPEEDS PROB.</th>
<th>INTERACTION S X G PROBABILITY</th>
<th>INTERACTION T X S PROBABILITY</th>
<th>INTERACTION T X S X G PROBABILITY</th>
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<tr>
<td>POWER</td>
<td>0.8678</td>
<td>0.0004</td>
<td>0.1350</td>
<td>0.0000</td>
<td>0.5450</td>
<td>0.4952</td>
<td>0.0490</td>
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</table>

UNIVARIATE F VALUE

- 0.14
- 9.18
- 1.85
- 311.28
- 0.84
- 0.90
- 1.83

POST HOC ANALYSIS: (TUKEY)

- .01 PRE-POST
- .05 PRE-MID
- NO SIG.
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<tr>
<th>DEPENDENT VARIABLE</th>
<th>BETWEEN GROUPS PROBABILITY</th>
<th>BETWEEN TESTS PROBABILITY</th>
<th>INTERACTION T X G PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER</td>
<td>(p&lt;)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEED 30° x s⁻¹</td>
<td>0.8132</td>
<td>0.0000</td>
<td>0.6219</td>
</tr>
<tr>
<td>MULTIVARIATE F</td>
<td>0.21</td>
<td>24.53</td>
<td>0.66</td>
</tr>
<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.01 PRE-POST</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.05 PRE-MID</td>
</tr>
<tr>
<td>SPEED 0° x s⁻¹</td>
<td>0.7813</td>
<td>0.0000</td>
<td>0.5689</td>
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<tr>
<td>MULTIVARIATE F</td>
<td>0.25</td>
<td>19.25</td>
<td>0.74</td>
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<td>0.05 PRE-MID</td>
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## TABLE IV

### COMPARISON OF MID AND POST POWER GAINS

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<th>GROUPS</th>
<th>MID GAINS</th>
<th>POST GAINS</th>
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<tr>
<td></td>
<td>(Mid Test - Pre Test)</td>
<td>(Post Test - Pre Test)</td>
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</tr>
<tr>
<td></td>
<td>30</td>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td>ES + IE</td>
<td>$X$ 8.76*</td>
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</tr>
<tr>
<td></td>
<td>$\pm$ 6.73</td>
<td>$\pm$ 24.97</td>
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<td>IE</td>
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<td>$\pm$ 11.52</td>
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</tr>
</tbody>
</table>

* Newton-meters per second
FIGURE I

PRE, MID AND POST POWER MEASUREMENTS

AT 30° x s⁻¹

POWER (N·m·s⁻¹)

PRE, MID, POST

ES + IE
IE
ES
FIGURE II

PRE, MID AND POST POWER MEASUREMENTS AT $100^\circ \times s^{-1}$
FIGURE III

PRE, MID AND POST POWER MEASUREMENTS AT $180^\circ \times s^{-1}$

POWER
($N\cdot m\cdot s^{-1}$)

280-
275-
270-
265-
260-
255-
250-
245-
240-
235-
230-
225-
220-
$\angle 215$-

PRE MID POST

TESTS

ES + IE •
IE ○
ES △
FIGURE IV

PRE, MID AND POST POWER MEASUREMENTS AT $0^\circ \times s^{-1}$

PRE TESTS  MID TESTS  POST TESTS

POWER  (N-m·s$^{-1}$)
TABLE V

SUMMARY OF HYPOTHESES TESTING

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLES</th>
<th>PROPOSED GROUP RELATIONSHIPS</th>
<th>RESULTS</th>
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<td>1. POWER (N-m \cdot s^{-1}) at 30, 100, 180 and 0 degrees per second, respectively</td>
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<td>2. TIME TO PEAK TENSION (seconds) at 30, 100, 180 and 0 degrees per second, respectively</td>
<td>ES + IE &lt; IE &lt; ES</td>
<td>NONSUPPORTED</td>
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<tr>
<td>3. THIGH Girth (centimeters) at patellar and gluteal sites</td>
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</table>
Discussion

The main objective of this study was to compare the effect of specific training regimens (ES + IE, IE and ES) on the power of the quadriceps muscle group at velocities of 30°, 100°, 180° and 0° per second. It was also the intention of this research to compare the effect of training on the velocity of muscle contraction and muscle hypertrophy. The comparison was designed to determine if there exists a difference in muscle power and time to peak tension variables at the four velocities in these three groups.

There was a significant difference between the pretest and midtest, as well as between the pretest and posttest with respect to the power measurement when all three groups were combined. As represented in Tables IIIa, IIIb (between tests) and IV (mid and post gains), the three groups improved muscular power during the six week training period, although there was no particular group which had the greatest power gains. The significance between the tests indicated that it is possible to improve muscular power and strength, but which is the best training method remains questionable.

It was postulated that the ES + IE and IE groups were responsible for the improvement in muscular power, more so than the ES group. The increases in muscular power and strength may have resulted from the isokinetic resistive training alone. This finding is in partial agreement with the research of Halbach and Straus (1980) and Eriksson et al. (1981) with respect to improvements in muscle power and strength in healthy
quadriceps muscle. Halbach and Straus (1980) and Eriksson et al. (1981) demonstrated that voluntary isokinetic exercise and electrical stimulation increase muscle power and strength, however the isokinetics proved to be superior for increasing power as compared to electrical stimulation. The isokinetic resistance programs are significantly better in bringing about changes in muscular strength and selected power tasks than isometric or isotonic programs, as shown by Pipes and Wilmore (1975); Moffroid (1969) and Thistle et al. (1967). To date, it has not been shown that a combined effect of stimulation and exercise can increase muscular power and strength. Consequently, there may be no summation effect of power associated with electrical stimulation, when given concurrently with isokinetic exercise.

Muscle power did not demonstrate a significant difference between each of the three groups after receiving eighteen training sessions. Kots (1977) states that the optimal effect on power and strength occurs between twenty and twenty-five sessions with stimulation. Whereas Halbach and Straus (1980) and Eriksson et al. (1981) obtained results after fifteen and twenty training sessions, respectively. Perhaps, if the treatment groups had received several more sessions, a significant muscular power effect may have occurred. Generally, the greater the frequency of the training program, the greater will be the improvements.

There was a significant difference in power between the
velocities of $30^\circ$, $100^\circ$, $180^\circ$ and $0^\circ$ per second. As the velocity of the contraction increases, the force that can be generated decreases, despite maximal effort. Associated with increased velocities is a proportionate increase in Newton-meters per second. Newton-meters decrease with an increase in isokinetic velocity, however when time (seconds) is introduced there is a multiplication factor with Newton-meters at the fast speeds ($100^\circ$ and $180^\circ$ per second). This was confirmed as the slow velocity increased to a fast velocity on the isokinetic dynamometer, the Newton-meters increased. The post hoc analysis revealed that power was significantly different between the four speeds (Table IIia), however it was not an acceptable significant effect because of Newton-meters' numerical variation with speeds.

The subjects in the ES + IE and IE groups trained at $30^\circ$ per second, while the subjects in the ES group trained isometrically. According to Pipes and Wilmore (1975) and Moffroid and Whipple (1970), the specificity of training theory was responsible for the significant power gains at speeds of $30^\circ$ and $0^\circ$ per second. These researchers showed that training at a slow speed produces increases in strength only at slow speeds of movement. Whereas, training at fast speeds of movement produces increases in strength at all speeds of contraction at and below the training speed. Therefore, it is important to realize that it is possible to increase low velocity strength with specific training and also, low velocity training has a better transfer effect to low velocities
rather than to high velocities (Moffroid and Whipple, 1970). Specific slow velocity training regimes were clearly a positive factor in developing muscular power in this study.

The three groups produced gains in power at angular velocities equal to or slower than the training velocities (Table IIIb and Figures I to IV). At the high or fast velocities no significant changes were observed. It is not possible to recruit similar motor units that have been trained slowly in a situation requiring fast muscle movement (Moffroid and Whipple, 1970). These findings imply that the power training benefits may be limited to the speeds used during training. This is of practical consideration to the athlete as it suggests that the athlete should train at speeds approximating or exceeding those used during his or her actual sport. These observations are supported by the findings of Pipes and Wilmore (1975).

Tables IIIa and IIIb indicate that power between tests for the combined groups, specifically between the pre and mid tests and between the pre and post tests at the isokinetic speed of 30° per second and isometrically, was significantly different. These results indicate that by training at a slow speed (30° per second), the same muscle fibers are recruited for power and strength at even slower speeds (0° per second). There is evidence that slow twitch motor units (MacDougall et al., 1980a and Thorstensson et al., 1976) are recruited along with the fast twitch motor units (Gollnick et al., 1974
and Warmolts and Engel, 1972), despite the differences in contractile properties and energy systems. The slow twitch, type II fibers have a long time interval between activation and reaching peak tension, in addition to having a high capacity for aerobic or oxidative metabolism and a low capacity for anaerobic metabolism. Conversely, the fast twitch, type IIb fibers attain peak tension rapidly by having a low capacity for aerobic metabolism and a high capacity for anaerobic or glycolytic metabolism. MacDougall et al. (1980a) have demonstrated that slow velocity training, whether it is isotonic or isokinetic, causes hypertrophy of both fiber types. This does not imply that the fast twitch motor units were recruited more but may indicate that fast twitch fibers are more adaptable in relation to hypertrophy. Hence, slow training at 30° per second and isometrically activated both slow and fast twitch motor units. Consequently, velocity-specific adaptation within the nervous system is established. Based on the evidence presented by Desmedt and Godaux (1979), the brain organizes and initiates fast, ballistic movements differently than slow movements. The mechanism responsible is primarily neural organization of movements by the central nervous system rather than selective recruitment of motor unit types.

The nervous control plays a decisive role for the development of power, as far as the specificity of a training effect is concerned. It appears as if power and strength, developed over a period of time, are maintained by the same motor units (Eccles, 1973). An increase in the developed force in the
same activity means that the same motor units become engaged with greater frequency and that new motor units are recruited in addition. Only at maximal effort are the motor units representing the "last reserve" thrown into play. Eccles (1973) stated that these reserve units may become more easily engaged as the result of training. Thus, one explanation for the specificity of adaptation to a specific training program is that a given type of exercise requires a specific combination of motor units that are best adapted for that demand. The existence of motor unit types is an example of built-in adaptation or specificity. When a call for a movement is reported to the brain, it has all the necessary requirements from the peripheral receptors for execution and control of the movement. The athlete trains the muscles and learns to execute specific movements through the intervention of the central nervous system. Therefore, the physiological basis for the specificity effect is explained by the fact that neural adaptations play an important role in the response to power training.

It is interesting to note that with the ES + IE and ES subjects, as individual training sessions progressed, the maximum amount of faradic current that could be tolerated increased significantly (Appendix B - Figure IV). Following training with maximum tolerance, however, there was generally a decrease in the amount of faradic current a subject could tolerate, due to muscle soreness. During several sessions it was reported by subjects that physical fatigue was responsible for a limited tolerance. The average dosage of electrical
stimulation for the ES group during the latter part of the training period began to level off as shown in Appendix B (Figure IV). This was an indication that the subjects in the ES group had reached the maximum amperage that could be sustained without unbearable pain. The ES + IE group did not plateau at the same level as the ES group. Instead the ES + IE group continued to tolerate a greater amperage throughout the study.

Possibly, the reason for the ES + IE group being able to tolerate a greater dosage of stimulation, may be attributed to their participation in voluntary dynamic contractions while simultaneously receiving electrical stimulation. It was reported by Thistle et al. (1967) and Pipes and Wilmore (1975) that isokinetic training did not induce muscle soreness. The concentric contractions of isokinetic movements during the recovery phase of exercise were an advantage in limiting and preventing muscle soreness while electrical stimulation was applied concurrently. Whereas the ES group reported feeling delayed muscle soreness one to two days after receiving the stimulation. Abraham (1977) concluded that alterations in muscle connective tissue were responsible for delayed, post-exercise muscle soreness. When exercise became severe enough to damage the connective tissue, it caused an increased degradation of collagen. Thus, increased breakdown of collagen would be evident in the high urinary hydroxyproline levels. This process caused an imbalance in collagen metabolism requiring a compensatory increase in collagen synthesis.
Therefore, there is a strong possibility that stimulation, particularly in untrained muscle, causes either muscle cell injury and/or connective tissue damage resulting in localized soreness 24-48 hours later.

The ES group also complained about the pain and burning sensation associated with the electrical stimulation more than the ES + IE group. It appears that exercising the muscle through the full range of motion prevented or reduced the uncomfortable sensation and muscle soreness affiliated with electrical stimulation.

It is important to note that most of the subjects were physically active during the study, however it was revealed that no significant cross-education effect from the non-dominant training leg to the dominant leg occurred (Appendix B - Figure V). Power gains in the contralateral limb were not evident between the pre and post tests, therefore no physical factors outside of the study influenced the power increments of the trained leg. Thus, the training produced effects, if any, on the peripheral motor units of the trained limb and not the neural system of the opposite limb.

The primary hypothesis of the study stated that power could be increased to a greater degree by using electrical stimulation in combination with isokinetic exercise, more so than with isokinetic exercise or electrical stimulation (ES + IE > IE > ES). This hypothesis was not accepted. There was no significant difference between the three groups for
muscular power gains. However, the rationale stating that increased power results from a greater recruitment of slow and fast motor units with electrical stimulation, and when isokinetic exercise is jointly involved, was partially evident by reasoning of the significant tests effect. The fact that the combined groups did improve muscular power and strength between the tests, although no one group had greater increases in power than the others, indicates that this physiological rationale may exist. Perhaps if the training sessions had been extended for a longer period of time significant power increments may have occurred in the ES + IE group, as they were receiving two types of strength training modalities. Muscle power is closely related to the cross-sectional area of a muscle. Evidence shows that power training increases the cross-sectional area of the fast twitch fibers of human muscle (Gollnick, 1980). Theoretically, the ES + IE group's muscles should have hypertrophied to a larger size and at a faster rate than the IE and ES groups because it was assumed that more slow and fast motor units were being activated.

Time to peak tension, the second dependent variable of this study, was the period of time it took from the onset of muscular contraction to the peak maximal muscular contraction. It was hypothesized that the time to peak tension produced by the ES + IE group would be less than the time to peak tension for the IE and ES groups (ES + IE < IE < ES). However, no significant difference between the three groups resulted in a change in the time to peak muscular tension as shown in [formula].
The rationale behind this theory suggests that the decrease in contraction time during electrical stimulation is attributed to a change in numbers of fast twitch and slow twitch fibers that are recruited. The quality of recruitment may tend to be more specific to fast twitch fibers (Kots, 1977). However, this was not demonstrated in the study and, in fact, Gollnick (1980) has shown that it is not possible to activate only fast twitch units during exercise by "jumping over" the slow twitch units. The fast twitch motor units, which contain many fibers and produce large amounts of force and are innervated by large motoneurons, are activated only after the slow twitch units are engaged. This pattern of motor unit recruitment leads to an orderly increase in the force developed by muscle and results in a smooth control over motor activity.

Conventional slow velocity training and slow isokinetic training causes hypertrophy of both fiber types (MacDougall et al., 1980a). It has been shown that the fast twitch fibers are enlarged to a greater extent that the slow twitch fibers in the power movements; similarly, slow velocity training causes greater hypertrophy of the fast twitch fibers (MacDougall et al., 1980a and Thorstensson et al., 1976). This does not mean that the fast twitch motor units were recruited more but may indicate that fast twitch fibers are more adaptable in relation to hypertrophy. Therefore, there is no basis for the claim that slow twitch motor units are preferentially recruited during
maximal slow velocity contractions. The misconception may have arisen from the assumption that fast twitch muscle fibers could only be involved in fast contractions; however, fast twitch fibers are also designed to contribute force, regardless of velocity. Similarly, slow twitch motor units can contribute force to very rapid contractions (slow twitch fibers can develop their peak force within 0.1 second or less).

As is clearly evident in Appendix B (Figure I), training with electrical stimulation and isokinetic exercise produced a speeds effect with respect to time to peak tension. As expected, the time to peak tension between the four speeds was significantly different. The time to peak tension was directly influenced by the testing velocities and numerical variance of the Newton-meters, rather than being influenced by the training methods. This created a false significant effect between the speeds.

To summarize, the time to peak tension did not significantly decrease over the six week training period. The decrease in contraction time during training is attributed to a change in the firing rate of fast twitch and slow twitch fibers. Both fiber types were hypothesized to speed up their velocity, however this was not proven during the study. Perhaps, the slow and fast twitch fibers did not adapt to faster velocity and faster contraction patterns because the training period was not of sufficient duration for a training change to occur. Thus, a change in time to peak tension was not evident after
receiving a program of electrical stimulation and isokinetic exercise.

The third dependent variable, thigh girth (patellar and gluteal), was hypothesized to be greater in the group receiving the combination of stimulation and exercise than the exercise or electrically stimulated group after training for six weeks (ES + IE > IE > ES). According to the results, Appendix A (Table VI), there was a significant difference between the three groups for gluteal thigh girth. The post hoc location of the significance was determined to be between the ES + IE and ES groups. However, the significance was not related to a training change. The fact that these two groups had different pretest gluteal thigh measurements was probably because of their difference in size (Appendix B - Figure III). The groups were equated only for power and no other equating factors were taken into consideration. The ES + IE group, as listed in Table I, was smallest in stature and weight, conversely the ES group was the tallest in stature and heaviest in weight. The difference in size would account for the variation in the mean gain values, particularly at the gluteal site in the ES + IE and ES groups.

The univariate analysis of the patellar thigh girth between the groups was also significant as shown in Appendix A (Table VI). Tukey's comparison test did not display sufficient significance to cause a difference in thigh girth. The lower leg circumference was not significantly different between the
groups, even though the upper leg circumference did reflect a size differential, despite an obvious size discrepancy between the groups.

As shown in Appendix B (Figure II), the patellar girth measurement increased for the ES group, but the measurement decreased mid way through the study and then increased to initial or better girth size at the posttest for the ES + IE and IE groups. Kots (1977) states that a decrease in subcutaneous fat and a corresponding increase in muscle hypertrophy should be apparent after ten training sessions. Unfortunately, this physiological effect was not exhibited in the study.

Appendix B (Figure III) indicates that the gluteal measurement increased steadily for the ES group, while the gluteal measurement for the ES + IE and IE groups increased up to the midtest and then began to decrease slowly. The gluteal measurement was a much better indicator of girth size because there is more muscle tissue in this region of the leg. A postulated reason exists for the increase and then sudden decrease in the latter two groups' thigh girth. The primary explanation was related to the fact that the two groups were physically active and thereby had well-developed gluteal muscles to begin with, so that only a small change in hypertrophy was possible.

It was hypothesized that the resistance training from the combination of stimulation and exercise would increase the cross-sectional area of the individual muscle fibers
(Eriksson et al., 1981; Halbach and Straus, 1980 and Kots, 1977). It has been shown that body composition changes consist of a decrease in relative body fat and a gain in muscle mass when following a regular routine of resistance training. Subsequently, if the study had been conducted for a longer period of time and had the groups been equated for the thigh circumference as well as power, the muscle hypertrophy may have been greater.

In summary, the ES + IE group was hypothesized to have the greatest improvements in power, time to peak torque and thigh girth relative to the IE group, which was postulated to have the next best results, followed by the ES group, which was to show the least improvements. Although voluntary isokinetic training has been used as a strength training technique successfully, the use of electrical stimulation as a method of increasing strength has long been a question in the eyes of various researchers. Stillwell (1967) had some doubt whether muscle contractions caused by faradic stimulation could produce strength increases. The findings of this study reflect a trend for yields in muscular power and strength of the total groups, by using the combination of electrical stimulation and isokinetic exercise, as well as isokinetic exercise and electrical stimulation, respectively, after six weeks. Although it was not proven statistically that power gains were obtained between each group. It should be noted that one method of training was not significantly better than another. Training the three groups at slow speeds, demonstrated that specificity of velocity
is associated with power and strength development. Neural
adaptation through training of the central nervous system played
an important role in the response to power training. Further
studies need to be conducted on larger groups of untrained
subjects for longer durations using electrical stimulation as
a supplement to isokinetic exercise, or even as a substitute
to conventional strength training, to determine the advantages
and disadvantages of this technique for power and strength
events.
Summary

Power and strength training, using conventional techniques, has been studied by several researchers; generally the type of exercise performed reflects the training effects. Investigations into the use of different training methods and their effect on power and strength development are continually being studied and re-assessed. Recently, the use of faradic or electrical stimulation has become an interesting alternative method, although much controversy surrounds this technique. It has been reported by Johnson et al. (1977) and Kots (1977) that faradic stimulation was used with success as part of a strengthening program by elite Soviet athletes. The combined effects of a program consisting of exercise as well as electrical stimulation was undertaken to determine the muscular power and strength potentials. The main objective of this study was to compare power and strength changes between equated groups employing the following training techniques: electrical stimulation plus isokinetic exercise, isokinetic exercise and electrical stimulation, respectively.

Twenty-seven, moderately trained, female subjects, nine per group, were tested on three separate occasions. During the first session, height, weight, left and right quadriceps power evaluation, time to peak tension of the muscle contraction
at the four velocities and two thigh girth measurements were determined. The three groups were equated for power after the pretest was conducted and the results are shown in Table 1. The second and third testing sessions assessed the power and time to peak tension of the non-dominant leg at the four velocities and patellar and gluteal thigh girths.

A significant difference for power was found between the pre and post tests and the pre and mid tests for the combined groups during the six week period of training. Although no difference was found between each of the three groups, the results indicated that programs involving electrical stimulation and isokinetic exercise, isokinetic exercise and electrical stimulation only are potentially effective in improving muscular power and strength in healthy subjects. The study revealed that one method was not superior to another after six weeks of training.

There was significant power differences between the pre and post tests and pre and mid tests at the slow isokinetic speeds of 30° and 0° per second. Since the training was conducted at the speeds of 30° and 0° (isometric) per second, the slow testing speeds (30° and 0° per second) should reflect neural adaptation and muscular recruitment when the specificity of training theory is considered. These findings imply that power and strength training benefits are limited to speeds used during training.
The thigh girth between the ES + IE and ES groups was significant. This significance was related to the fact that the ES group had slight height and weight advantages as compared to the ES + IE group, which accounted for their greater gluteal proportions. So, the size difference between the groups was present at the start of the study, contributing to false statistical significance.

Conclusions

The following conclusions can be reached:

1) ES + IE, IE and ES used in the methods of this experiment are possible methods for increasing power and strength of healthy quadriceps muscles.

2) One method of training was not significantly better than another. Electrical stimulation combined with isokinetic exercise, used as a form of power and strength training, is not a better form of training than a program of isokinetic exercise or electrical stimulation training as used in this experiment over six weeks.

3) Training effects are specific to the velocity at which the exercise is performed. Power increments in the ES + IE, IE and ES groups were limited to the velocities used during training.
(4) Time to peak muscular tension does not decrease with ES + IE training more than the time to peak tension with IE or ES training as used in this study.

(5) Girth measurements showed no relationship to increasing power in the quadriceps muscle group.

(6) Pain and burning sensations were the major limiting factors in the amount of amperage that could be tolerated with ES + IE and ES.

Recommendations for Further Research

(1) Training sessions of greater frequency and duration would be beneficial in determining which method, ES + IE, IE or ES, is better for improving muscular power and strength.

(2) The use of sedentary subjects in larger training groups would assist in determining which method is superior for muscle power and strength development.

(3) Additional research is needed to determine whether the techniques used in this study would benefit patients with atrophied muscle and knee joint disorders. Re-education following weakness caused by trauma or surgery, may demonstrate maximal benefits using these training methods instead of traditional rehabilitation techniques.
(4) More studies need to be conducted with ES and its effect on increasing power, especially when the participant can tolerate a high amperage.

(5) Clarification is needed on the capabilities of the stimulating devices presently available.
BIBLIOGRAPHY


APPENDIX A

(Tables for Power, Time to Peak Tension and Thigh Girth Parameters)
<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>BETWEEN GROUPS PROBABILITY (p &lt;)</th>
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### TABLE 1b

#### MULTIVARIATE ANALYSIS OF VARIANCE FOR POWER PARAMETER

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<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td>MIDTEST</td>
<td>0.9284</td>
<td></td>
<td></td>
<td>0.0000</td>
<td>0.3191</td>
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<td></td>
</tr>
<tr>
<td>MULTI. F</td>
<td>0.07</td>
<td>189.49</td>
<td>1.19</td>
<td></td>
<td></td>
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<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
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<tr>
<td>POSTTEST</td>
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<tr>
<td>MULTI. F</td>
<td>0.76</td>
<td>145.13</td>
<td>1.73</td>
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<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
</tr>
</tbody>
</table>
## TABLE II

### MULTIVARIATE ANALYSIS OF PAIRWISE COMPARISON FOR POWER VARIABLE

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>( Tx(GR1&amp;2)^* )</th>
<th>( Tx(GR2&amp;3) )</th>
<th>( Sx(GR1&amp;3) )</th>
<th>( TxSx(GR1&amp;2) )</th>
<th>( TxSx(GR2&amp;3) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Tx(GR1&amp;3) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Sx(GR1&amp;2) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Sx(GR2&amp;3) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( TxSx(GR1&amp;3) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( p < \)

**POWER**

- \( 0.0448 \)
- \( 0.3591 \)
- \( 0.0938 \)
- \( 0.5467 \)
- \( 0.4983 \)
- \( 0.3983 \)
- \( 0.2139 \)
- \( 0.2179 \)
- \( 0.0237 \)

**UNIVARIATE F VALUE**

- \( 2.01 \)
- \( 1.05 \)
- \( 2.49 \)
- \( 0.71 \)
- \( 0.80 \)
- \( 1.00 \)
- \( 1.41 \)
- \( 1.54 \)
- \( 2.52 \)

**TUKEY'S POST HOC ANALYSIS:** NO SIG.

*GR1 - ES + IE Group

GR2 - IE Group

GR3 - ES Group
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ES + IE GROUP</th>
<th>IE GROUP</th>
<th>ES GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME TO PEAK TENSION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30° x s⁻¹</td>
<td>X: .73*</td>
<td>.48</td>
<td>.55</td>
</tr>
<tr>
<td></td>
<td>S.D.: ±.38</td>
<td>±.13</td>
<td>±.11</td>
</tr>
<tr>
<td>100° x s⁻¹</td>
<td>.25</td>
<td>.29</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>±.07</td>
<td>±.05</td>
<td>±.09</td>
</tr>
<tr>
<td>180° x s⁻¹</td>
<td>.40</td>
<td>.15</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>±.07</td>
<td>±.04</td>
<td>±.06</td>
</tr>
<tr>
<td>0° x s⁻¹</td>
<td>2.10</td>
<td>3.06</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td>±1.11</td>
<td>±1.46</td>
<td>±1.36</td>
</tr>
</tbody>
</table>

* seconds
## TABLE IV

**MULTIVARIATE ANALYSIS OF VARIANCE FOR TIME TO PEAK TENSION PARAMETER**

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>BETWEEN GROUPS PROBABILITY (p &lt;)</th>
<th>BETWEEN TESTS PROB.</th>
<th>INTERACTION T X G PROBABILITY</th>
<th>BETWEEN SPEEDS PROB.</th>
<th>INTERACTION S X G PROBABILITY</th>
<th>INTERACTION T X S PROBABILITY</th>
<th>INTERACTION T X S X G PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME TO PEAK TENSION</td>
<td>0.5885</td>
<td>0.1470</td>
<td>0.2648</td>
<td>0.0000</td>
<td>0.9738</td>
<td>0.0593</td>
<td>0.0101</td>
</tr>
<tr>
<td>UNIVARIATE F VALUE</td>
<td>0.54</td>
<td>2.00</td>
<td>1.35</td>
<td>160.27</td>
<td>0.21</td>
<td>2.08</td>
<td>2.31</td>
</tr>
</tbody>
</table>

**TUKEY'S POST HOC ANALYSIS:**

0.01

NO SIG.
TABLE V

COMPARISON OF THIGH GIRTHS BETWEEN
ELECTRICAL STIMULATION AND ISOKINETIC EXERCISE (ES + IE), ISOKINETIC EXERCISE (IE)
AND ELECTRICAL STIMULATION (ES) GROUPS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ES + IE GROUP</th>
<th>IE GROUP</th>
<th>ES GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE</td>
<td>MID</td>
<td>POST</td>
</tr>
<tr>
<td>THIGH GIRTH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PATELLAR</td>
<td>50.44*</td>
<td>46.97</td>
<td>50.42</td>
</tr>
<tr>
<td></td>
<td>± 2.45</td>
<td>±10.76</td>
<td>± 2.60</td>
</tr>
<tr>
<td>GLUTEAL</td>
<td>53.79</td>
<td>54.19</td>
<td>53.80</td>
</tr>
<tr>
<td></td>
<td>± 2.28</td>
<td>± 2.94</td>
<td>± 2.64</td>
</tr>
</tbody>
</table>

* centimeters
### TABLE VI

**MULTIVARIATE ANALYSIS OF VARIANCE FOR THIGH GIRTH PARAMETER**

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>BETWEEN GROUPS PROBABILITY ($p &lt;$)</th>
<th>BETWEEN TESTS PROBABILITY</th>
<th>INTERACTION T X G PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATELLAR THIGH GIRTH</td>
<td>0.0238</td>
<td>0.3244</td>
<td>0.4096</td>
</tr>
<tr>
<td>UNIVARIATE F VALUE</td>
<td>4.39</td>
<td>1.15</td>
<td>1.01</td>
</tr>
<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
<td>NO SIG.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLUTEAL THIGH GIRTH</td>
<td>0.0052</td>
<td>0.1120</td>
<td>0.6519</td>
</tr>
<tr>
<td>UNIVARIATE F VALUE</td>
<td>6.59</td>
<td>2.29</td>
<td>0.62</td>
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<tr>
<td>TUKEY'S POST HOC ANALYSIS:</td>
<td>.05 ES+IE-ES</td>
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</tbody>
</table>
APPENDIX B

(Figures)
Figure 1

Time to peak tension for ES + IE, IE and ES groups at 30°, 100°, 180° and 0° x s⁻¹ speeds during pre, mid and post tests.
FIGURE II

PATELLAR THIGH Girth for ES + IE, IE and ES Groups

During Pre, Mid and Post Tests

Pre
Mid
Post

PATELLAR THIGH Girth (cm)

ES + IE •
IE ○
ES △
FIGURE III

GLUTEAL THIGH GIRTH FOR ES + IE, IE AND ES GROUPS
DURING PRE, MID AND POST TESTS

GLUTEAL THIGH GIRTH (cm)

ES + IE ●
IE ○
ES △

PRE       MID       POST
TESTS
FIGURE IV

COMPARISON OF MEAN FARADIC CURRENTS THAT COULD BE TOLERATED WITH ELECTRICAL STIMULATION IN THE ES + IE GROUP AND ES GROUP

Faradic Current (mAmp)

TRAINING SESSIONS
FIGURE V

PRE AND POST COMPARISON OF DOMINANT LEG POWER

BETWEEN ES + IE, IE AND ES GROUPS

POWER (N·m·s⁻¹)

PRE POST

TESTS

ES + IE ●
IE ○
ES △
APPENDIX C

(Sample Calculation)
Sample Calculation for Newton-meters per Second

Power = force \times distance \times time^{-1} \quad \text{or} \quad Power = \text{Work} \times time^{-1}

Power = \text{Newton-meters} \times \text{second}^{-1} = \text{torque} \times \frac{1.356^*}{\text{radian}} \times \text{speed}

torque = \text{foot-pounds}

\text{radian} = \frac{180^\circ}{\pi} \quad \pi = \frac{22}{7}

speed = \text{velocity of lever arm (degrees per second}^{-1})

* foot-pounds of torque may be converted to Newton-meters of torque by multiplying by 1.356

Example:

N-m \times s^{-1} = 60 \text{ ft-lb} \times \frac{1.356}{57.30} \text{ radian} \times (30^\circ \times s^{-1})

= 60 \times 0.024 \times 30

= 43.2

\therefore \quad \text{Power} = \text{N-m} \times s^{-1} = 43.2