# The Effects of Electrical Stimulation, Isokinetic Exercise and Concurrent Isokinetic Exercise with Electrical Stimulation on Acquisition and Retention of Strength, Endurance and Bilateral Transfer in Females

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Abstract

| | |
|---|---|
| Title of Thesis: | The Effects of Electrical Stimulation, Isokinetic Exercise and Concurrent Isokinetic Exercise with Electrical Stimulation on Acquisition and Retention of Strength, Endurance and Bilateral Transfer |
| Jim Donald Redfearn: | Master of Science in the Theory of Coaching, 1985 |
| Thesis Advisor: | Dr. T. M. K. Song<br>Professor<br>School of Physcial Education and Outdoor Recreation<br>Lakehead University |

The purpose of this study was to examine the effects of four different training methods (isokinetic exercise, electrical muscle stimulation, concurrent electrical muscle stimulation with isokinetic exercise, and no training) on the acquisition and retention of strength, endurance and bilateral transfer in females. Subjects consisted of 30 female volunteers aged 17-25. Subjects were randomly assigned to one of the four treatment groups. Those subjects performing exercise trained only their right leg. Following an explanation as to the premise of the study, subjects were pretested on the four dependent variables of static extension (0°/sec), dynamic extension (60°/sec), dynamic extension (180°/sec), and dynamic muscular endurance (180°/sec). Groups were trained Monday, Wednesday and Friday each week for a six week

duration. Every training session required subjects to warm up with 6-8 repetitions followed by a training phase consisting of 3 sets of 10 repetitions. Subjects trained isokinetically were exercised at a speed of 60°/sec. Electrical stimulation was delivered by way of a 10 second contraction, followed by a 20 second recovery phase. Maximum current was delivered at 50 pulses/sec with a corresponding wave width of 200 microseconds. The protocol utilized for the concurrent treatment was identical to the other two methods. Surge and rest times, however, were altered to allow for a two second contraction followed by a one second recovery phase. Subjects were assessed for strength and endurance at the beginning of the 6 week training program, at the conclusion of training and after a 4 week detraining period. Data were analyzed with a MANOVA in a 4 x 2 x 3 design. Percentage differences between tests and among groups on variables were presented.

An alpha level of .05 was accepted for all statistical procedures. Results showed: (a) the strength training methods employed did not significantly improve either static or dynamic strength; (b) no significant increase in endurance was noted with any of the training procedures; (c) there was a wide variation of training responses among all the subjects; (d) none of the training groups were found to be superior for improving strength and endurance; (e) none of the training procedures resulted in a significant transfer of strength; and (f) following 4 weeks detraining, none of the training procedures resulted in a significant loss of strength.

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# Chapter 1

## Introduction

### Purpose of the Study

The purpose of the study is to compare the effects of four training techniques: 1) isokinetic exercise, 2) electrical stimulation, 3) concurrent isokinetic exericse and electrical stimulation, and 4) no training: on acquisition, retention and bilateral transfer of leg strength and endurance in females.

### Significance

The idea of improving an individual's strength in order to improve his/her performance, as well as reduce the likelihood of injury is not new. Until a couple of decades ago, trainers, coaches and athletes had been exposed primarily to two training modalities. These included isometric and isotonic (e.g., free weights) exercise. With a resurgence of interest to improve athletic performance, reduce injuries, and lessen rehabilitation time, coupled with an accelerated technology, science has generated the development of more sophisticated means to improve strength.

The use of isokinetic (accommodating resistance) exercise appears to be well documented in terms of developing strength. In comparison to either isometric or isotonic exercise, this technique allows the individual to exercise in a dynamic manner with maximal resistance throughout the range of motion. Furthermore, with the added advantage of preselecting the exercise speed, the individual can reduce the effects of acceleration while exercising at speeds approximating those incurred in sport. Although the use of electrical stimulation as a rehabilitative technique has been well established, only within recent years has it re-emerged as a training method for healthy muscle. Unlike volitional exercise, electrical stimulation overrides the central nervous system and thereby induces a muscle contraction. The development of new stimulators and different treatment protocols have resulted in conflicting reports as to the effectiveness of this training method for augmenting strength. Upon closer examination of the literature on strength training many studies have utilized strictly male test populations. Thus, the initial justification for this study is the clarification of evidence to the effectiveness of both isokinetic exercise and electrical stimulation for the improvement of strength in females.

The dissimilarity between these two training techniques makes it possible to combine one with the other in an attempt to maximize the advantages of each. To this point, very few studies exist on combining electrical stimulation with isokinetic exercise and therefore justifies further research in this area. With the close association noted between muscular endurance and strength, the investigation as to which of these training methods is the most effective for improving endurance also seems pertinent. Because of the relative recency of these training methods, very little research exists on the retention of newly acquired strength following the cessation of exercise. Furthermore, the question as to which of these techniques is the most effective for promoting transfer of strength to the contralateral limb warrants investigation.

It is the intention of this study to determine the most effective means for acquiring and retaining strength, endurance and bilateral transfer in females. With the varying amounts of research on these and other training methods, it is hoped that the results from this study will contribute to the existing literature on muscle training techniques.

Limitations

1. All three training techniques are highly dependent on the motivation of the subjects in terms of pain tolerance, and the ability to elicit maximal contractions.

2. It is assumed that all subjects understand the directions and will exert maximal effort during all testing sessions.

3. It is assumed that subjects understand and comply with respect to the extracurricular activities.

4. The use of volunteers from a select group limits this study in terms of generalizing the results to other populations.

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

## Delimitations

1. The subjects will consist of female physical education students aged 17-25 years from Lakehead University.

2. The duration of the training period will not exceed six weeks.

## Definitions

1. Bipolar: method of stimulation where both electrodes are placed over the belly of the muscle.

2. Bilateral transfer: a phenomenon in which following the exercise of one limb, a transfer of a training effect is noted in the unexercised limb.

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

4. Fatigue Index (FI): the mean decline in peak muscular force after 50 contractions and expressed as a percentage (Thorstensson and Karlsson, 1976).

5. Ipsilateral: the muscle group which performs the exercise.

# Chapter 2

# Review of Literature

## Strength: An Overview

The degree to which individuals possess or may develop strength is limited both genetically and biomechanically. As reported by Thorstensson, Grimby and Karlsson (1976a), and Gregor, Perrine, Campion and DeBus (1979), a strong correlation exists between the ability to produce muscular force at high velocities and fast twitch motor units (distribution as well as number) contained within the muscle. Furthermore, the inherent elastic component of both the muscle and corresponding connective tissue has also been shown to contribute to force generation (Thorstensson et al., 1976a; Gregor et al., 1979). The basic ability to exert a force is due to the arrangements of the muscles, bones and joints in the body which form a variety of lever systems (Luciano, Vander & Sherman, 1978). The existence of such mechanisms implies certain biomechanical limitations. The maximum tension which any muscle fibre can develop depends upon the relative length of the fibres at the time of contraction as well as the relative physical placement (e.g. origin and insertion) of the muscle within the body (Astrand & Rodahl, 1977; Perrine, 1968; Thistle, Hislop, Moffroid & Lowman, 1967). Astrand and Rodahl (1977) suggest this maximum tension is attained at a relative length of 1.2:1. The maximal tension can therefore usually be exerted when the muscle is maximally stretched. These variables aside, individuals following a variety of training techniques have been able to improve their existing strength to superior levels.

Regardless of the training method employed, the organism must be subjected to an overloading stress in order for adaptation to occur (Astrand & Rodahl, 1977; Klafs & Arnheim, 1981; Perrine, 1968; Pipes, 1977a). As noted by Perrine (1968), muscles adapt in response to regular mechanically demanding useage. The adaptability of the human body, however, precludes that routine daily activities pose a sufficient overload (Klafs & Arnheim, 1981; Müller, 1970). Perrine (1968) suggests the problem lies in the diagnoses and definition of critical muscular output potential required for some physical activity and to impose these demands in regular training in order to evoke continued high level adaptation. Notwithstanding of the training method used, researchers (Barney & Bangerter, 1961; Berger, 1962a; Coleman, 1972; Fox, 1979; Meadors, Crews & Adeyanju, 1983; Pipes, 1977a) in the field of strength development concur that increasing strength is directly related to the intensity of the stimulus. Therefore individuals who are able to train at maximum contraction levels will realize greater increases in strength development.

From the vast amount of information available on the subject of "strength", it appears that the exact etiology(s) responsible for increasing strength are still in question. The consistency of certain findings in the literature, however, strongly suggests a number of primary causes. The age, sex and weight of an individual are attributed as having a strong correlation to the ability to generate force (Rankin & Thompson, 1983; Thomas, 1984; Wyatt & Edwards, 1981). Christensen (1975) hypothesized that while absolute strength differences between males and females were obvious, if body weight were factored out the relative strength levels may in fact be similar. Rankin and Thompson (1983) investigated this premise and found it not to be valid. Tests performed at all speeds on the Cybex II system showed significant differences between males and females in terms of both Quadraceps/Body Weight (Q/BW) and Hamstring/Body Weight (H/BW) ratios. Studies done by Wyatt and Edwards (1981) and Miyashita and Kanehisa (1979) demonstrated that males can produce greater torque values than females with the latter also reporting similar trends for boys and girls. A number of studies (Alexander & Molnar, 1979; Molnar & Alexander, 1973; Murray, Gardner, Hollinger & Sepic, 1980; Scudder, 1969; Thomas 1984) report that the ability to generate force was found to be less in children than in adults. Molnar and Alexander (1973) found that torque output increased with age in 7-15 year olds and was similarly found to increase by Miyashita and Kanehisa (1979) in 13-17 year old boys and in 13-14 year old girls. Murray et al. (1980) investigated knee muscle torque output in the age groups 20-35, 50-65, 70-86 years and concluded that the 20-35 year old group could generate significantly greater torque than either of the older groups. These findings are in agreement with Goslin and Charteris (1979) who noted a degenerative effect of aging on the ability to develop muscular tension. This decrement was estimated to be 20% between the ages of 20-65 years with the highest portion of the loss occurring from 45 years. In a more recent study Thomas (1984) isokinetically tested nonathletic women aged 20-61 years and concluded that age had a greater effect on torque production than did either height or weight regardless of the speed of movement. As age increased torque values declined whereas the reverse trend was noted with an increase in either height or weight.

A factor more commonly associated with strength is the size or girth of the muscle. Coyle, Feiring, Rotkis, Cote III, Roby, Lee and Wilmore (1981) concluded that the power generating capacity of muscle could be improved through hypertrophy of single muscle fibres or by hyperplasia. Thus the larger the individual muscle fibres or the greater the amount of fibres, the more force can be generated. Research done in this area using a variety of training methods reveal conflicting results. In a comparative study of the Delorme-Watkins method, a traditional bulk program and a traditional power strength program, Barney and Bangerter (1961) found all three methods to improve strength significantly with only the Delorme-Watkins method inducing significant circumferential gain. MacDougall, Ward, Sale and Sutton (1977) reported that

Progressive Resistance Exercise (PRE) training resulted in an 11% increase in arm circumference with a corresponding 28% improvement in maximal elbow extension strength. In instances where increased muscle girth was found not to improve strength, Berger (1972) and Klafs and Arnheim (1981) contend that the greater size is a result of more adipose tissue or activated blood vessels in and around the musculature which has no positive effect on the contractability of the muscle. Whereby increased muscle girth was felt to be a major contributor to improved strength, a number of researchers (Barney & Bangerter, 1961; Berger, 1972; Coyle et al., 1981; Klafs & Arnheim, 1981; Laird & Rozier, 1979; Lesmes, Costill, Coyle & Fink, 1978) have noted significant increases in strength with no apparent morphological changes.

Neuromuscular Adaptation

A high degree of specificty of training noted by Astrand and Rodahl (1977), Berger (1962b), Berger (1963), Clarke and Henry (1961), Coyle et al. (1981), Meadors et al. (1983), Pipes (1977b), Rasch and Morehouse (1957), Sale and MacDougall (1981), Watkins and Harris (1983), Wyatt and Edwards (1981), along with the inability to detect morphological changes suggests another internal mechanism contributing significantly to the augmented torque. Astrand and Rodahl (1977), Osternig, Bates and James (1977), Perrine (1968), Sale and MacDougall (1981), and Thorstensson, Karlsson, Viitasalo, Lutanen and Komi (1976c) support the theory that neuromuscular adaptation is a major proponent to the increased force output by the muscle. This neuromuscular adaptation as suggested by Rasch and Morehouse (1957) is analagous to the nervous system learning specific responses to a particular type of stress and is facilitated in four major areas. With an increasing load, recruitment of more motor units is important until the load becomes heavy; then an increase in the firing rate of these motor units becomes the primary mechanism for developing force. Astrand and Rodahl (1977) cite overwhelming evidence demonstrating that maximal voluntary contractions (MVC) in most unconditioned athletes do not engage all motor units of the muscle at tetanus frequency. Therefore, gains in strength following a training program are partly due to the ability to recruit more motor units as well as increasing the rate of firing (Astrand and Rodahl, 1977; Coyle et al., 1981; Lesmes et al., 1978; Perrine, 1968; Thorstensson, Hulten, Doblen and Karlsson (1976b). Coyle et al. (1981) and Lesmes et al. (1978) further postulated that a higher force output may also be due to more economical useage of motor units recruited, resulting in a more efficient summation, although electromyographs (EMG) in a study by Thorstensson et al. (1976c) elicited no conclusive evidence in this direction. As suggested by Astrand and Rodahl (1977) and Coyle et al. (1981), neuromuscular adaptation may also be facilitated by the removal of inhibitors on various motor neurons that might otherwise limit performance. Coleman (1972) contends that an increase in musculature strength to be more rapid in weak musculature than strong musculature indicating that untrained musculature may be initially more responsive to these types of adaptation.

Training for Strength in Sport

The existence of neuromuscular adaptation as described above implies specific relevance to the relationship between the development of strength in relation to sport performance. It has been suggested in the literature that two ideologies exist on this topic, (Sale and MacDougall, 1981). Training the appropriate muscle group and by practicing the skills of the sport separately, the strength gained in non-specific muscle training may be harnessed for use in performance. Clarke and Henry (1961) investigated the question as to whether improving strength by training the muscles which cause the movement without practicing the movement itself would have any effect on reaction time. In a 10 week isotonic program, strength was found to increase 17.4% with no improvement in reaction time. The second theory proposes that strength training should simulate sport movement patterns, velocity and contraction type and is in agreement with the majority of existing literature. Studies by Fox (1979), Pipes (1977a) and Sale and MacDougall (1981) concluded that a definite specificity movement pattern exists in training and that this response is specific to the joint angle(s) at which training occurs. Osternig et al. (1977) and Sale and MacDougall (1981) contend that the demonstration of specificity of movement patterns in relation to relatively simple movements has even greater relevance to more complex movement patterns in many sports.

Wyatt and Edwards (1981) indicate the growing support in the literature for exercising muscles in a dynamic manner with the velocity of the work approaching that achieved in actual performance. In the original report on specificity of velocity, Moffroid and Whipple (1970) found that training by a low power (low speed, high load) method increased muscular force only when tested at slow speeds whereas high power (high speed, low load) training produced increases in muscular force at or below the training speed. As reported by Sale and MacDougall (1981) mixed training (high and low velocity) produced intermediate results. Fox (1979) investigated the effect of fast (108°/sec) and slow (36°/sec) isokinetic training on two groups and found similar results as those reported by Moffroid and Whipple (1970). Similarly, Coyle et al. (1981) and Elliott (1978) concluded that fast velocity training was able to increase torque output at speeds equal to or below the training speed.

Reaffirmation that the physiological basis for this specificity of velocity is neuromuscular rather than simply adaptations within the musculature come from studies on selective recruitment. Counsilmann (1976a, 1976b) suggested that fast or slow velocity training would result in the selective recruitment of fast or slow motor units respectively. It has been demonstrated by powerlifters and body builders that training causes enlargement of both fibre types (MacDougall, Sale, Sutton and Moroz, 1980a). Furthermore, it has been shown that conventional slow velocity weight training and slow isokinetic training have elicited hypertrophy in both types of fibres with the fast twitch fibres exhibiting the greater increase (MacDougall, Elder, Sale, Moroz and Sutton, 1980b). EMG studies (where the activity of a single motor unit is recorded) as reported by Sale and MacDougall (1981) indicates that provided the degree of voluntary effort is maximal, the motor unit activation is similar regardless of the speed of contraction.

The existence of specificity of contraction type is evidenced in studies by Berger (1962b) and Thorstensson et al. (1976b). These studies revealed that the most significant improvements in strength were noted when the testing device duplicated the type of contraction employed in training.

To review, the degree to which an individual possesses or may develop strength is limited by their genetic endowment. This corresponds to percentage of fibre types, the relative placement of the muscles and tendons on the joint and the contractile dynamics of the existing muscles and connective tissues. The age, sex and weight of an individual have all shown a strong correlation to strength. Males in the majority of instances have been shown to produce greater force output (both absolute and relative) than females at all ages. The ability to produce torque increases in both males and females until approximately 20 years, at which point a degenerative relationship between age and strength has been documented. An increase in muscle girth does not always accompany an improvement in strength. Thus, the mechanism of neuromuscular adaptation is viewed as being a major proponent to augmented force generation. This adaptation suggests the nervous system learning specific responses to a particular stress and is facilitated in four major areas. With sufficient training the nervous system is able to: recruit more fibres, increase the rate of firing, bring about a more synchronous or efficient firing of motor units, remove existing psychological inhibitors. The existence of such an adaptive mechanism implies specific relevance to strength training methods employed in sport. Therefore the most efficacious mode of training is one which simulates sport in terms of movement patterns, velocity and contraction type.

<u>Isometrics</u>

Isometric contractions involve muscular contractions whereby tension is developed in the muscle but no shortening of muscle fibres occur. The resistance therefore must be in direct ratio to the force being applied. While the ability of isometrics to improve strength is well documented, its relevance to sport in general is questionable. Fox (1979) and Klafs and Arnheim (1981) concluded that isometric strength was best developed using 5 second maximum contractions for 5-10 repetitions, 5 days a week, however, significant increases in strength were also noted by Klafs and Arnheim (1981) with a singular contraction of 50% intensity, performed 5 days a week for an unspecified amount of time. In a 12 week comparison between isometric and isotonic training programs, Berger (1963) concluded that training statically, 3 times a week for 6-8 repetitions at 2 different positions was more effective for improving muscular strength than training dynamically with a 2 repetition maximum (RM) for 2 sets, but not as effective as a program of 6 RM performed for 3 sets. The primary advantage of static training as concluded by Berger (1963) is that a greater number of exercises could be performed 5-6 days a week for extended periods of time without fatigue. Thus isometric training may result in greater increases in strength not because of greater effectiveness, but rather the greater number of training sessions it allows. In a similar study Coleman (1972) found that performing two, 20 second isometric contractions, 3 times a week for 12 weeks was as effective as 2 sets of a 5 RM isotonic exercise performed for an equal duration. As previously noted, strength increases documented are directly related to the specific joint angle at which training is effected as well as the type of contraction the muscle performs. The major implication is that specifically strengthening a part in the range of motion (ROM) will not strengthen the skeletal lever throughout the total ROM (Pipes, 1977a; Klafs and Arnheim , 1981). Thus the static nature of this training mode does not coincide with the typical dynamic nature of sports. Pipes (1977a) further contends that by strengthening a limb where no movement is taking place, there is also a reduction in the muscle's ability to contract maximally at higher speeds which are common to athletic performance.

<u>Isotonics</u>

Unlike isometric contractions, an isotonic contraction is dynamic in nature and involves the movement of a constant resistance through a full range of motion at a variable speed. This resistance, however, is not proportional to the muscles' dynamic force curve and as a result is limited to the largest load which can be moved at the weakest point in the ROM (Hislop and Perrine, 1967; Pipe, 1977b; Thistle et al., 1967). It would appear that the tension demand placed on the muscle is maximal only during a small portion of the ROM. Thus as noted by Halling and Dooley (1979) the total amount of work done is significantly less than maximal.

Moffroid, Whipple, Hofkosh, Lowman and Thistle (1969) noted that the speed of exercise with this method is subject to considerable acceleration. This coupled with the length-tension relationship of the muscle further negates the probability of imposing maximum tension demands on the muscle throughout the ROM. As noted by Pipes (1977a) and Fox (1979), researchers agree that by comparison training isotonically is superior to isometrics for the improvement of strength, however, due to the inherent weaknesses described above, isotonic training may still not maximize total strength development. With regards to the improvement of sport performance, Pipes (1977a) reports conflicting results in this area.

Isokinetics

In comparison to isometric and isotonic training, isokinetics is a relatively new training technique. The isokinetic contraction is a further refinement of the controlled motion concept and therefore attempts to utilize the advantages and eliminate the deficiencies of isometric and isotonic training (Fox, 1979; Gleim, Nicholas and Webb, 1978; Pipes and Wilmore, 1975; Thistle et al., 1967). Here the contraction is dynamic with the resistance accommodating to the specific demands imposed by the user and the speed being maintained at a preselected setting. According to Pipes (1977a) isokinetics is predicated on the theory that by controlling the speed at which the muscle contracts, maximum resistance may be imposed on the contracting musculature. Thus greater muscular output is transformed by the internal mechanism of the device into increased resistance rather than acceleration which normally occurs with isotonic contractions (Moffroid et al., 1969). The relative limb speed during an isotonic contraction rarely exceeds 60°/sec, whereas most functional movements in sport achieve speeds well in excess of 90°/sec (Halling and Dooley, 1979; Pipes and Wilmore, 1975). With the added capability of varying speeds from 0°-360°/sec the athlete's training can be somewhat adapted to simulate contraction speeds employed in athletic performance (Halling and Dooley, 1979; Watkins and Harris, 1983). Perrine

(1968) proposed that by defining an appropriate speed and thereby fixing the shortening speed at which the muscle will be loaded, it is possible for the muscle to develop: maximum peak torque, most work per repetitions, highest power output, submaximal average power output per repetition for a maximum time duration. This manipulation of velocity allows for the speed of exercising to be increased above initially slow rates in accordance with neuromuscular adaptation (Halling and Dooley, 1979). As reported in numerous studies on isokinetic exercise, the ability to produce torque by both males and females decreased with increasing speed (Ivy, Withers, Brose, Maxwell and Costill, 1981; Thomas, 1984; Wyatt and Edwards, 1981). Therefore, in performing isokinetic exercise to improve strength, the individual must concentrate on generating the same movement of force that was produced at slower speeds (Halling and Dooley, 1979).

The inherent biomechanical limitations of the other two methods which prevent maximum tension from being sustained throughout the ROM is overcome via accommodating resistance. The existence of the length-tension relationship as previously mentioned demonstrates that muscular force generated throughout the arc of motion is not constant. By accommodating the resistance to the muscle's tension developing capacity, maximum strength has proven to be developed through the ROM provided the contractions are maximal (Elliott, 1978; Gleim et al., 1978; Laird and Rozier, 1979; Moffroid et al., 1969).

By virtue of controlling for the speed and resistance during a contraction, the superiority of isokinetics to improve strength and athletic performance is revealed in a number of studies (Coyle et al., 1981; Moffroid and Whipple, 1969; Pipes and Wilmore, 1975; Pipes, 1977a; Thistle et al., 1967). Following a review of literature Fox (1979) recommends training isokinetically 3 times a week, for 3 sets with 8-15 repetitions per set for optimal strength gains. Lesmes et al. (1978) compared strength gains when subjects trained their right and left legs for 6 and 30 second work bouts respectively. Both programs elicited similar gains in muscular strength at velocities equal to or slower than training velocities. Since increases in peak torque in the range of 5-25% were noted with maximal short duration (6 second) isokinetic training, it was suggested that large volumes of training using isokinetics to improve strength may not be necessary.

While the superiority of this training method over isometrics and isotonics appears obvious, isokinetics is not without problems. As noted by Watkins and Harris (1983) isokinetic exercise is still an artificial condition. Normal motion occurs at variable velocities and in multiple planes. Secondly, with accommodating resistance, the motivation of the individual has a direct relationship to the resistance experienced (KIN-COM, 1985). If the user is motivated, he exerts sufficient force to meet the velocity and experiences accommodating resistance. If the user is undermotivated, he can continue to move through the full ROM at less than the preselected speed and experience no resistance. In an early report on isokinetics, Perrine (1968) indicated that the desired speed always occurs immediately with the advent of maximal force. More recent studies (Gransberg and Knutson, 1983; Osternig, 1975) indicate that during the initial phases of high velocity isokinetic movement, the exercising limb passes through a range of free acceleration. Gransberg and Knutson (1983) suggest that when the freely accelerating limb is abruptly inhibited from further acceleration due to impact with the resistance arm, large oscillations in the torque record are noted until the speed of angular rotation becomes constant. The amount of this acceleration is completely attributed to several factors: the energy built up during the preceeding acceleration, the oscillation in angular velocity, gravitational force, submaximal tension in the muscle (Gransberg and Knutson, 1983; Osternig, 1975; Watkins and Harris, 1983).

In summary, both isometric and isotonic methods of training have been shown to significantly improve strength. The inherent weakness of both these methods is that neither is able to develop maximum strength throughout the ROM. The static nature of isometrics does not coincide with the typical dynamic nature of sports. While isotonic training is dynamic, the person using this method is unable to train at velocities as those attained in sport performance. The technique of isokinetics was established so that the speed of contraction could be varied (0°-360°/sec) and the resistance would accommodate to the demands of the user such that maximum resistance would be maintained through the arc of motion. The literature documents that training should be performed at speeds equal to or greater than those incurred in sport, and that the strength gained by training at a higher speed has a greater carry over effect at lower speeds. As with isometrics and isotonics, the isokinetic system of training is not without its problems. Maximal increases in strength will only occur when the degree of contraction is also at a maximum. Therefore the motivation of the individual has strong relevance to the amount of strength gained. At high velocities, the preselected speed in isokinetics is not reached immediately due to an area of free acceleration at the beginning of the movement. This acceleration results in oscillations in the initial torque readouts and is attributed to: the energy built up in the preceeding acceleration, the oscillation in angular velocity, gravitational force, submaximal tension in the muscle.

## Electrical Stimulation

The idea of using electricity as a therapeutic aid dates back as early as 400 B.C. when the electrical energy of torpedoe fish was used to treat headaches, arthritis and asthma (Benton, Baker, Bowman & Walters, 1981). Almekinders (1984) notes that the first in vitro experiments with electrical stimulation in muscle and nerves were carried out by Galvani in 1791. Galvani observed that with the introduction of two dissimilar metals to a frog's muscle, a muscular contraction was induced. In 1822 Magendie experimented with electropuncture, in which electric current was applied to needles inserted into muscles and nerves. A muscle contraction was elicited, but the apparent lack of any therapeutic benefit and the associated pain resulted in this method's decline (Light, 1971). Duchenne continued to explore the uses of electropuncture throughout the 1830's and eventually discovered a method of "localized electrization" over specific areas of muscle (Benton et al., 1981). These areas were later determined by Remak to be the motor points of the muscle (Benton et al., 1981). In 1831 Faraday built the first electric generator capable of producing a faradic current. With the development of surface electrodes in 1855, Duchenne demonstrated a method of specific faradization of human muscle (Benton et al., 1981). Technological advancements in the ensuing years made it possible to alter the wave form and current type (Schriber, 1975). The interest in electrotherapy increased due to the rise in peripheral nerve injuries sustained in World War II. Thus the use of electric current for diagnoses, stimulation and maintenance of denervated muscle became a common treatment (Benton et al., 1981).

The use of electrical stimulation in clinical rehabilitation has since been well established. Numerous researchers and therapists cite the benefits of utilizing electrical stimulation to prevent denervated atrophy, decrease muscular spasm and pain, reduce contractures and re-educate musculature to specific movement patterns (Eriksson & Haggmark, 1979; Johnson, Thurston & Ashcroft, 1977; Knight, 1980; Kramer & Mendryk, 1982; Lagasse, Boucher, Samson & Jacques, 1979; Wise, 1979). A resurgence of interest in using electrical muscle stimulation (EMS) as a training modality was established following the 1972 Olympics, where it was rumoured that Russian athletes had employed this training technique. At a 1977 symposium at Concordia University, the Russian physician Kots substantiated these rumours and gave further insight in the utilization of EMS to train healthy muscle.

As reported by Halbach and Straus (1980) and Malmberg (1981), the basic theory behind EMS is that if all motor units were innervated, the muscle would respond with a maximal contraction. Astrand and Rodahl (1977), Halbach and Straus (1980), McMiken, Todd-Smith and Thompson (1983) and Belanger and McComas (1981) concur that with any voluntary contraction, there is a resultant force deficit with values usually between 60% - 70%. Belanger and McComas (1981) suggested two possible mechanisms for this occurrence. In the first instance, it is possible that not all motor units have been recruited. This is in agreement with McMiken et al. (1983) who note the non-simultaneous sequence of recruitment whereby the slow twitch (Type 1) fibres are recruited first, followed by the fast twitch (Type 11A and B) fibers when more tension is required. Secondly, the motor units may be discharging at a suboptimal frequency. Malmberg (1981) and McMiken et al. (1983) further suggest that the motivation of the individual also has a direct effect on this force deficit. Belanger and McComas (1983), Kots (1977) and McMiken et al. (1983) proposed that cutaneous EMS is able to override any or all of these conditions and thereby reduce this force deficit to as low as 10%. As explained by Kots (1977) the ability to improve strength occurs via two mechanisms. With electric stimulations, input from the central nervous system (CNS) has been removed. Thus strength increases with voluntary contractions reflect adaptation occurring within the peripheral CNS. In an attempt to evaluate the recruitment of the CNS peripheral nerve control, Kots (1977) found no crossover in strength gain in the non-stimulated limb. Therefore Kots (1977) concluded that stimulation produced the effect on the peripheral nervous system (PNS) and not the CNS. Kots (1977) also proposed that myofibril hypertrophy (e.g., fibre splitting and/or hyperplasia) and a change in the contractile complex (e.g., increase in myofibril density and a decrease in the sarcoplasm) also contributes to the augmented strength. Since strength increases remain in the stimulated tissue even after cross-sectional hypertrophy diminishes, Kots (1977) attributes recruitment of the peripheral nerves to be the primary mechanism behind the stimulated strength gains.

Following the protocol established by Kots (1977), claims of increases in strength from 15-40% and significant improvements in athletic performance have been noted (Malmberg, 1981; Wise, 1979). Moreover, Kots (1977) claims that the current format and application techniques have demonstrated a high degree of specificity with respect to strength, contraction velocity and local muscular endurance. To achieve these improvements Kots (1977) specifies several important parameters in terms of current type and treatment procedures which must be adhered to. In the first instance, the current must promote a strong contraction. The contraction must be equal to or greater than 65% of a maximum isometric contraction being required for maximum strength improvements (Owens & Malone, 1983). Kots reports EMS to have produced contractions 10-30% greater than could be generated with a maximal voluntary contraction. In contrast other researchers have reported that a stimulated contraction generates less tension than in a MVC (Murray et al., 1980; Williams and Stutzman, 1959). Secondly, the current must be tolerable to the individual with respect to pain in order to reach sufficient intensity for a maximum contraction. Cummings (1980), Houston (1983) and Garnhammer (1983) state that the intensity of the contraction is directly related to the intensity and frequency of the stimulation as well as the pulse duration and wave form. Garnhammer (1983) submitted that the intensity of the stimulation is of primary importance. Thus, the higher the current, the greater the resulting contraction. Garnhammer (1983) further notes that too much current is associated with discomfort or injury to the stimulated tissue. This discomfort may be reduced by variation of the frequency and wave form (Cummings, 1980; Garnhammer, 1983).

Cummings (1980) purports when current rapidly changes, it is more effective for stimulation as it does not give sufficient time for the nerve to adapt. The slower the rate of change, the more intensity is required to elicit a strong contraction. In this respect, the rapid rate of change associated with the sinusoidal wave allows for a strong contraction at a reduced intensity and therefore makes it superior to either the rectangular or triangular wave forms (Cummings, 1980). Garnhammer (1983) notes that high frequencies of 2,000-50,000 cycles/second have been experimentally supported as being the best for EMS since maximal contractions may be achieved with little or no discomfort. According to Kramer and Mendryk (1982) Kots is suspected of using a medium frequency current (2,500 cycles/second) for the optimal improvement of strength. Researchers (Cummings, 1980; Houston, 1983; Frey, 1974; Kots, 1977; Malmberg, 1981) further specify that a pulsed rather than a continuous current contributes to a greater and more pain free contraction with an optimal duration of 10 milliseconds (ms) on and 10 ms off being recommended.

The use of EMS alone involves securing the limb such that the contraction is isometric in nature (Benton et al., 1981; Kots, 1977; Malmberg, 1981). Placement of the electrodes on the limb involves placing both perpendicular to the longitudinal directon of the muscle fibres so as to recruit the maximum number of motor units (Benton et al., 1981; Medelco Ltd., 1981). Further refinement of electrode placement suggests using either Monopolar

(Direct) Stimulation or Bipolar (Indirect) Stimulation (Benton et al., 1981; Kots, 1977; Medelco Ltd., 1981). Kots (1977) notes that when the bipolar method is used, it is only the superficial muscles or groups which receive the stimulation.

Kots (1977) proposes the optimum treatment format for improving strength to be 10 contractions with a 10 second contraction phase followed by a 50 second recovery period (e.g., 10/10/50). Kramer and Mendryk (1982) suggest that this protocol represents the maximum workload that muscles can tolerate in a single workout. As noted by Malmberg (1981) when EMS is applied for 15-20 seconds at a maximal contraction, fatigue becomes the limiting factor. Physiologists have stipulated 10 seconds to be the maximum time limit for single maximal contraction (Malmberg, 1981). The establishment of the 50 second recovery period was a result of experimentation by Kots (1977) who demonstrated that without sufficient rest between contractions, the muscle could not sustain a maximum contraction for 10 seconds. Kots (1977) proposed that treatments be given five consecutive days a week with the number of sessions being determined by the purpose. Further investigation by Kots (1977) revealed that identical results could be achieved if treatments were given on alternate days, providing the number of sessions remained the same. Kots (1977) claims that 10, 15 and 20 stimulating sessions will improve strength by 15-20%, 20-30%, and 30-40%, respectively.

Recent investigations attempting to replicate Kots' results have thus far been unable to substantiate these claims. The past inability of the North American stimulators to duplicate the current parameters mentioned by Kots (1977) have caused many researchers to alter both current format and/or treatment procedures (Kramer and Mendryk, 1982). The majority of these researchers have noted significant increases in strength when comparing EMS to control groups, but no significant differences from voluntary isometric or isotonic training modes have been noted (Eriksson, Haggmark, Kiessling & Karlsson, 1981; Garret, Laughman & Youdas, 1980; Halbach & Straus, 1980; Massey, Nelson, Sharkey & Comden, 1965; McMiken et al., 1983). Romero, Sanford, Schroeder and Fahey (1982) investigated whether muscular strength as tested statically and isokinetically would be improved by surging faradic stimulation in untrained young adult females. The results of the 10 contractions study showed EMS to have a marked effect on the isometric knee extension strength, although the treatments became less effective as the velocity of the movement increased. No significant improvements in either leg were observed at a Cybex speed of 60°/second (Romero et al., 1982). The lack of increase in dynamic strength as suggested by Romero et al. (1982) may be a reflection of the recruitment pattern associated with this type of stimulation. Romero et al. (1982) further concluded that the EMS demonstrates little applicability in developing dynamic strength in this test population. In studies utilizing stimulators reputed to permit duplication of the Russian technique, researchers (Garret et al., 1980; Walmsley, Letts & Vooys, 1984) reported similar non-significant results with EMS. Walmsley et al. (1984) further notes that the tension produced by these machines is significantly less than that produced during an MVC.

In summary, the use of electrical stimulation in the rehabilitation of a number of disorders is well documented. The resurgence of interest in using electrical stimulation for the improvement in strength followed claims of significant strength improvements and improved athletic performance. The basic theory behind EMS lies in its ability to override recruitment and motivational deficiencies associated with voluntary contractions and thereby produce greater tension. The treatment protocol recommended by Kots (1977) is 10 repetitions, 10 second contractions interspersed with 50 second recovery phases given five days a week. Kots is suspected of using a medium frequency (2,500 cycles/second), pulsed (10 ms on, 10 ms off) current, such that a maximal contraction could be achieved with little or no discomfort to the individual. Kots (1977) further claims that the current format and application techniques have demonstrated a high degree of specificity with respect to strength, contraction velocity and local muscular endurance. It is suggested that augmented strength due to EMS is primarily a result of adaptation occurring within the peripheral nerve fibres of the stimulated limb, as well as alteration to the contractable elements in the myofibril. The inability of North American researchers to duplicate Kots' results has been attributed to the stimulators being unable to exactly replicate the current put out by the Russian machine. Recent investigations using EMS have shown significant improvements over control groups, but no significant differences when compared to voluntary training methods. A recent study found no significant improvement in dynamic strength when tested isokinetically, and may be a result of the recruitment pattern resulting from this type of stimulation and/or the static nature of this training technique. With the development of stimulators reputed to duplicate the current type of the Russians, investigators have reported no significant differences to that of voluntary training methods. These researchers further claim that the tension developed when using EMS is significantly less than developed during a maximal voluntary contraction.

Concurrent EMS with Maximal Voluntary Exercise

Although no description of the Russian superimposing technique is given, Kots (1977) reported forces of 75-85% of a MVC when combining a maximally tolerated EMS on to a maximal voluntary isometric contraction. According to Kots (1977) the ability of the EMS alone to produce a contraction 10-30% greater than a MVC led to the abandonment of the superimposing technique. Since this time, few studies have been done comparing the effectiveness of a concurrent treatment format to either EMS or voluntary exercise alone. Currier, Lehman and Lightfoot (1979) evaluated the effectiveness of combining EMS with a maximal voluntary isometric contraction and found no significant differences when comparing torque values of EMS alone to the combined group. In a similar study Lainey, Walmsley and Andrew (1983) found that subjects who received concurrent treatment increased only 10% more than those who performed exercise alone. Subjects in this study reported having difficulty "feeling" the voluntary contraction when the stimulus was applied. Lainey et al. (1983) suggested that the sensation from the electric current interferes with the appreciation of proprioceptor information from the muscle. Most subjects were able to overcome this difficulty once they accommodated to this sensation (Lainey et al., 1983). Walmsley et al. (1984) found that when combining EMS with a MVC, the torque values achieved were similar to those produced with a MVC. Several subjects noted a significant decrease in torque output during concurrent treatment. Walmsley et al. (1984) suggest that EMS may cause interference with volitional activity. Pruitt (1982) concluded that faradic electric stimulation superimposed on a maximal isotonic contraction made it possible to produce a complete muscular contraction with each repetition. Pruitt (1982) further noted that when combined with isotonic exercise, the stimulation appeared to be made more tolerable to the athlete. Patterson (1977) tested the effect of a combined EMS and isokinetic training technique on the strength and hypertrophy of the quadriceps muscle. The subjects included college and junior football players who were trained for a 10 week period. The results of this study found the combined treatment to produce the greater increases in dynamic strength than either the isokinetic or the EMS treatments. Furthermore the combined treatment was determined to be as effective as the isokinetic treatment in augmenting static strength. Both the combined treatment and the isokinetic treatment were found to be superior to either EMS treatment or the control in eliciting static or dynamic force production increases (Patterson, 1977).

In summary, the amount of literature dealing with concurrent EMS and maximal voluntary exercise is sparse. Kots (1977) abandoned this technique when he noted superior contraction levels could be attained with EMS alone. Studies comparing a combined treatment of EMS and maximal voluntary isometric exercise found no significant differences to gains achieved solely by maximal voluntary isometric exercise. In some instances subjects noted a significant decrease in torque values when treated concurrently. It was suggested that EMS interferes with volitional activity as well as appreciation of proprioceptor information from the muscle. In a study comparing the effect of combining EMS with isotonic exercise, it was concluded that it is possible to produce complete muscular contractions with every repetition. Subjects combining these two regimes appeared to better tolerate the sensation of the stimulation. The concurrent treatment of EMS and isokinetic exercise was found to be superior in improving dynamic strength over training either isokinetically or with EMS. This treatment was also found to be as effective as isokinetic training in the improvement of static strength.

Retention

Once acquired, improved muscular strength and endurance have been demonstrated to persist for some time before a gradual decrease to pretraining levels (Clarke, 1973). The literature reflects only a sporadic interest as to how long these capacities might be retained following the cessation of training. With the wide range of detraining periods examined, there appear to be conflicting results using both static and dynamic training programs.

Müller and Hettinger (1954) suggested that following maximal isometric training, the average decline in strength is approximately 3% per week. In two subsequent studies Müller (1959) and Hettinger (1961) proposed that the loss of strength by daily contractions is equal to the rate at which it was gained. Hettinger (1961) further suggested that a slower increase in strength by weekly training would result in a more permanent acquisition. Hislop (1963) reported no reduction in strength, 11 months after the termination of isometric exercise. Similarly, Kots (1977) asserted that strength gained by EMS was maintained close to maximum for about 3 months, with 90% being retained after a year.

Clarke, Shay and Mathews (1954) noted that after four weeks of training, only a slight decrease in muscular endurance was observed following a detraining period of equal duration. Waldman and Stull (1969) trained subjects for eight weeks with an endurance training program. Following detraining periods of 8, 10 and 12 weeks, all subjects demonstrated significant losses in endurance. In a similar study, Sysler and Stull (1970) tested periods of inactivity of 1, 3 and 5 weeks on endurance retention. Results of this study indicated that subjects undergoing detraining of 3 and 5 weeks lost more muscular endurance than did the group which remained inactive for one week (Sysler and Stull, 1970). Applegate and Stull (1969) concluded that the closer one comes to his maximum possible endurance attainment, the greater is his absolute loss following the termination of training. Shaver (1973, 1975) suggested this rule was also applicable to strength retention.

Berger (1963, 1965) observed that isotonic strength gained in 12 and 3 week training programs was not reduced after six weeks detraining. In contrast, Shaver (1973, 1975) demonstrated significant losses of strength and endurance occurring between three and five weeks, but no loss after one week of inactivity. Shaver (1973, 1975) concluded that after an initial rapid decrease during weeks three to five, the absolute reduction appears to subside after five to six weeks detraining. McDonald (1978) reported no significant loss of strength in either the concentric or eccentric training groups following four weeks of inactivity.

In summary, improved muscular strength and endurance have been demonstrated to persist for some time before a gradual decrease to pretraining levels. The literature on this topic is sparse with conflicting results reported when using either static or dynamic training methods. It has been suggested that by following a static training program, the decline in strength is 3% per week. More recent studies propose that the loss of strength is at the rate at which it was gained. Thus, the slower the rate of strength increase would result in a more permanent acquisition. Other studies involved with static training report retention of 90-100% of maximum after a year of detraining.

Similar trends for retention were noted for strength and endurance following the cessation of isotonic training. Although one study reports a significant decrease in muscular endurance after eight, 10 and 12 weeks inactivity, further studies note that the most rapid loss of strength and endurance occurs between the third and fifth week. Other researchers concluded that the closer an individual comes to attaining their peak endurance and strength, the greater will be their absolute loss following the termination of training.

## Bilateral Transfer

Since the first report of a cross transfer of strength by Scripture, Smith and Brown (1894), the existence of this phenomenon has been well documented. The term "cross education" as employed by Davis (1899) implies that the training of one limb leads to a complimentary training effect in the contralateral limb. Although the effects of cross transfer have been substantiated for both strength and endurance, there are conflicting reports as to the mechanism responsible for its occurrence as well as the most effective means for promoting transfer.

Scripture et al. (1894) proposed that this transfer may be the result of "indirect learning". Slater-Hammel (1950) postulated that the transfer occurs due to improved fatigue tolerance of the subject. Thus, the psychological and physiological adaptation occurring within the individual would have a positive carry over effect to other musculature. Hellebrandt, Parrish and Houtz (1947) and Rasch and Morehouse (1957) theorized that this cross education may be due to concurrent contractions in the contralateral limb as a result of the individual trying to maintain their balance during the performance of exercise. Still other researchers (Davis, 1899; Wissler and Richardson, 1900; Hellebrandt, 1951; Bowers, 1966; Kroll, 1965) suggest the existence of a central facilitating mechanism within the body. When sufficient stress is imposed, there is a resultant overflow of nerve impulses from this mechanism to the contralateral muscle groups. Panin, Lindenaurer, Weiss and Ebel (1961) and Sills and Olson (1959) refute this theory in that the amplitude and frequencies of these impulses were of insufficient magnitude to elicit a training effect. Hellebrandt (1951) suggested that a transfer of nervous impulses may be less when the dominant limb is exercised and is in agreement with

Wellock (1958) who reported a more favourable direction of transfer. Hellebrandt (1951) proposed that the more highly trained and distinct neural pathways of the dominant limb would permit less of an overflow of impulses.

Regardless of the mechanisms responsible for cross education, researchers concur that the transfer is greatest when the degree of exertion during training is maximal (Hellebrandt et al., 1947; Hellebrandt, Houtz and Krikorian, 1950; Hellebrandt, 1970; Majsak, 1981). Studies by Rose, Radzyminski and Beatty (1957) and Logan and Lockhart (1962) in which subjects trained with maximal knee extensions, noted significant increases in strength in the non-exercised leg. Hellebrandt et al. (1950) and Shaver (1970) demonstrated that with maximal dynamic exercise of the wrist and arm respectively, a significant improvement of both strength and endurance in the contralateral body segment was noted. McDonald (1978), however, failed to elicit any significant improvement in the contralateral arm following 12 weeks of consentric or eccentric training.

By comparison, studies using isometric exercise also reveal conflicting results in terms of transfer. Gardner (1963) and Bowers (1966) report no significant increase in contralateral limb strength following isometric training. Meyers (1967) reported that subjects training with three, 6 second contractions, three times per week for 6 weeks, demonstrated a significant strength increase in the non-exercised limb only when tested at the specific training angle. Darcus and Salter (1955) and Singh and Karpovich (1967) noted a transfer from agonist to antagonistic muscle groups after training isometrically. Using palpation and EMG studies Singh and Karpovich (1967) reported that maximal contractions of the agonist resulted in involuntary contractions of the antagonist.

In comparing the effectiveness of isotonic and isometric exercise for the promotion of transfer, Rasch and Morehouse (1957) noted a significant increase in strength of the contralateral limb following isotonic training, although no such increase was found in the isometric group. Similarly, Lawrence, Meyer and Mathews (1962) repoted that isotonic exercise resulted in a greater transfer of strength than did isometric exercise. Lawrence et al. (1962) further noted that increases in the contralateral limb ranged from 65% - 100% of those achieved in the ipsilateral limb. Coleman (1969a) found that isotonic exercise promoted significant gains in dynamic, but not static strength, while isometric exercise demonstrated the ability to produce both static and dynamic strength increases in the contralateral limb. In another study, Coleman (1969b) attempted to keep the load and duration of the two training programs constant, and found no significant difference with either method in promoting bilateral transfer.

In an attempt to determine the effects of isokinetic exercise on strength, power and EMG activity of the elbow flexors in the contralateral limb, Wagner (1970) trained 18 female physical education students for 5 weeks at six different speeds. Results of the study indicated significant improvement in the contralateral elbow flexors at all test speeds except 20 and 25 revolutions a minute. Wagner (1970) suggested that due to the characteristics of temporal and spacial summation, these speeds did not impose a sufficient level of facilitation.

Other investigations (Smith, 1970; Morris, 1974; Lagasse, 1974; Ashton, 1975) have attempted to evaluate the effectiveness of myotatic strength training in promoting a transfer of strength. Smith (1970) trained subjects using a combination of isometric and myotatic exercises and noted a significant strength improvement in the contralateral limb. Morris (1974) found that when the ipsilateral limb was subjected to training programs involving myotatic stretching, an increase in tension was noted in the contralateral antagonist. In contrast, Lagasse (1974) reported that following myotatic training, subjects exhibited a loss of tension in the contralateral muscle groups.

In summary, the term cross education implies that the training of one limb will lead to a complimentary training effect in the contralateral limb. Although the mechanism responsible for this phenomenon is not clearly understood, it has been suggested that this transfer may be due to: 1) indirect learning, 2) increased tolerance to fatigue, which has a positive carry over effect to other musculature, 3) a concurrent contraction in the contralateral limb as a result of the individual trying to maintain their balance during exercise performance, and 4) the existence of a central facilitating mechanism, that when subjected to sufficient stress permits an overflow of nerve impulses to the contralateral limb.

Regardless of the mechanism responsible for its occurrence, the literature suggests that the transfer is greatest when the degree of exertion during training is maximal. Bilateral transfer is also noted as being direction specific, in that transfer appears to be more favourable from the non-dominant to the dominant limb.

In ascertaining the most effective means of inducing a transfer effect, results of different studies cite conflicting views. Generally, it appears that isotonic exercise derives a more consistent promotion of transfer to the contralateral limb when compared to isometric or myotatic training.

<u>Muscular Endurance</u>

The ability of a muscle to maintain peak toque during a prolonged static contraction or repeated dynamic contractions has come under much investigation. Asmussen, Dobler and Nielson (1948) and Karlsson (1976) proposed that lactate accumulation during heavy muscular work has a direct or indirect effect on muscular function. In an attempt to determine the cause(s) of muscle fatigue, Tesch (1980) used both absolute and relative torque decline following repeated isokinetic knee extensions as the criterion for fatigue. The results of this study demonstrated that following 25 isokinetic contractions, a relationship between the force deficit and FT/ST lactate ratio existed. Tesch (1980) further concluded that the lactate concentration during exercise was related to the percentage of FT fibres within the muscle and is in agreement with findings by Thorstensson (1976) and Thorstensson and Karlsson (1976). Stephens and Taylor (1972) and Astrand and Rodahl (1977) suggest that a blockage at the neuromuscular juction (NMJ) is a major cause of muscle fatigue. Astrand and Rodahl (1977) further propose that NMJ fatigue is the primary contributor during the first minute of exercise, but later contractile element fatigue increases. EMG recordings as reported by Astrand and Rodahl indicate that during this initial phase, there is a decrement of motor units with a high frequency firing rate and a subsequent recruitment of motor units with a lower firing rate. Similarly, Barnes (1981) postulated that the torque produced during high speed contractions is a result of the activation of motor units not participating at slower contraction speeds. Barnes (1981) suggested if isokinetic contractions performed at different velocities involve selective recruitment of functionally different motor units, the fatigue curves associated with the different velocities would reflect the endurance characteristics of the motor units involved. Barnes (1981) tested subjects with 10 maximal knee extensions at speeds of 60°/sec, 120°/sec, 150°/sec and 300°/sec, respectively, and found no evidence of selective recruitment. Barnes (1981) further noted similar results with other investigators, with respect to a linear rate of fatigue during the initial stages of fatigue with the pattern becoming more curvilinear as exhaustion was approached.

Astrand and Rodahl (1977) proposed that the motivation of the individual may also influence endurance capacity.

Watkins and Harris (1983), reported that muscular fatigue or endurance indication tests may be performed isokinetically in several ways:

1. performance of repeated contractions until torque decreases to 50% of the initial level. Here endurance is measured as a function of time.

2. determine the percentage decline after the performance of a predetermined number of repetitions. As noted by Thorstensson and Karlsson (1976), the mean decline in peak muscular force after 50 contractions and expressed as a percentage represents the "Fatigue Index" (FI), and

3. measure the percentage decline in torque within a given time limit.

Shaver (1972) investigated the relationship between maximum isometric strength and relative isotonic endurance of athletes with different levels of strength. Shaver (1972) concluded that individuals demonstrating the highest amount of isometric strength are able to maintain a greater percentage of that strength when using loads of 35%, 40%, and 45%, of the maximum isometric strength values. Start (1964) and McGlynn (1969) noted that stronger subjects fatigued faster than weaker ones. Caldwell (1964) suggested that differences in endurance capacity may be due to motivational factors or the relative level of fitness of the individual. In a separate study, Shaver (1971) attempted to determine the relationship between maximum dynamic strength to absolute and relative dynamic endurance. The results of this study indicated a strong correlation between maximum dynamic strength and absolute dynamic endurance (Shaver, 1971). No such relationships was found to exist between dynamic strength and relative dynamic endurance (Shaver, 1971).

In an attempt to improve muscular endurance Shaver (1971a) trained subjects for 6 weeks with a PRE program and noted a significant increase in work capacity when tested with loads of 20%, 25%, 30% and 35% of maximum strength. Dennison, Howell and Morford (1961) also reported a significant improvement in dynamic endurance when subjects were trained either isometrically or isotonically. Kots (1977) found that using his 10/10/50 protocol for electrical stimulation, muscular endurance was also enhanced. Similarly, Cotton (1967) noted that training isometrically at 100% of maximum was most effective at improving endurance when tested with loads of 25%, 50% and 75%. Fox (1979) reported that training at fast speeds increases muscular endurance at fast speeds more than slow speed training will improve endurance when tested at slow speeds. Lesmes et al. (1981) trained subjects isokinetically at 180°/sec for 6 sec and 30 sec, four times per week for 7 weeks and reported a significant increase in work capacity for both legs.

In summary, the ability of a muscle to maintain peak torque during a prolonged static contraction or repeated dynamic contractions may be limited by any one or a combination of factors. It has been shown that a relationship exists between a force deficit and lactate accumulation following 25 isokinetic contractions. This accumulation of lactate appears to have a direct association with the percentage of fast twitch fibres within the muscle. Other researchers propose that a blockage at the NMJ is a major contributor to fatigue. More specifically, this blockage is responsible during the initial phase of fatigue, after which it is the fatigue within the contractile element which limits muscle fuction. EMG studies have demonstrated that during this early period, there is a decrement of motor units with a high firing rate and a subsequent recruitment of motor units with a slower firing rate. It was postulated that during high speed contractions, selective recruitment was occurring within the motor units, however, evidence from this and other studies failed to support this theory. Following 10 maximal knee extensions at speeds of 60°/sec, 120°/sec, 150°/sec and 300°/sec, respectively, subjects demonstrated a linear rate of fatigue which became more curvilinear as exhaustion was approached. The motivation and fitness level of the individual are also suggested as having an effect on muscular endurance.

The ability to isokinetically determine muscular endurance may be performed in several ways:

1. performance of repeated contractions until torque decreases to 50% of the initial level;

2. determine the percentage decline after a predetermined number of repetitions has been performed. When 50 contractions are used, the mean decline in peak torque expressed as a percentage represents the "Fatigue Index", and

3. measure the percentage decline in torque within a given time limit.

In a study to determine the relationship between maximum isometric strength and relative isotonic endurance in athletes at different strength levels, it was noted that the stronger athletes could maintain a greater percentage of their strength when tested using 35%, 40% and 45% of their maximum. Other researchers refute this result noting that stronger subjects fatigued faster than weaker ones. In another study, a relationship between maximum dynamic strength and absolute dynamic endurance was found to exist. No such relationship was noted between maximum dynamic strength and relative dynamic endurance.

In attempting to improve muscular endurance, significant increases have been noted when training either isometrically or isotonically. Training isometrically at 100% of maximum was most effective at improving muscular endurance when tested with loads of 25%, 50% and 75% of maximum. Another study reported that training at fast speeds increases endurance when tested at fast speeds more than does slow training improving endurance when tested at slow speeds. Finally, a short duration isokinetic program also demonstrated a marked increase in work capacity.

# Chapter 3

# Methodology

## Restatement of Purpose of Investigation

The purpose of the study was to compare the effects of four training techniques: 1) isokinetic exercise, 2) electrical stimulation, 3) concurrent isokinetic exericse and electrical stimulation, and 4) no training on acquisition, retention and bilateral transfer of leg strength and endurance in females.

## Subjects

The subjects in this study consisted of 36 females aged 17 to 25 years with no inhibiting leg injuries. The subjects were full time physical education students at Lakehead University, Thunder Bay, Ontario. Prior to any experimentation, the basic premise of the investigation was explained to all potential subjects. Each volunteer was required to fill out a consent form (see Appendix A) and an information card (see Appendix B).

Subjects were instructed to keep their daily activities as regular as possible in terms of sleep and diet, and to avoid any resistance training, (e.g.,weight training) involved with the quadriceps femoris muscle group. Following pretesting, subjects were randomly assigned to one of four groups. These groups experienced conditions of: 1) control, 2) isokinetic exercise,

3) electrical stimulation, and 4) concurrent electrical stimulation with isokinetic exercise.

## Instrumentation

A pre and two posttests were given to the subjects using a Cybex II Dynamometer (Lumex Inc., Bayshore, N.Y.) in order to ascertain peak torque levels for both legs. All tests were recorded from the Cybex onto a Cybex II Dual Channel Recorder (Lumex Inc., Bayshore, N.Y.). To ensure easy measurements from the Cybex strips, the recorder was turned on before each test and the tracer pen adjusted to baseline zero. Prior to any testing being performed, the Cybex was calibrated, as instructed in the Cybex Instruction Manual (Lumex Inc., Bayshore, N.Y.), using Cybex calibration weights.

## Strength Test

The testing protocol for strength measurement to be used in this experiment was taken directly from the Cybex Instructional Manual (Lumex Inc., Bayshore, N.Y.). In order to compensate for the specificty effect of strength training, each subject was assessed by both static (0°/sec) and dynamic (60°/sec, 180°/sec) tests.

## Endurance Test

To evaluate muscular endurance, the testing protocol devised by Thorestensson and Karlsson (1976) was utilized. This test entails 50 successive maximal contractions in both flexion and extension at a Cybex speed of 180°/sec. The endurance test was given 5 minutes after completion of the strength test.

## Warm Up

To reduce the likelihood of injury and to acquaint subjects with the Cybex, a warm up/familiarization phase of eight repetitions was required prior to the commencement of the test. Three to four additional familiarization repetitions were required with each alteration of the Cybex speed.

## Testing Procedure

The testing procedure for the pretest (T1) was duplicated for the two subsequent posttests (T2 and T3). Posttest one (T2) was carried out in the week immediately following training in order to measure absolute strength changes and posttest two (T3) following four weeks of detraining as an indicator of strength retention.

Each subject was seated in a high back Cybex chair, and the leg pad was secured to the anterior portion of the leg, just superior to the ankle. In the case of shorter subjects, additional pads were inserted behind the back in order to bring the leg into a more testable position. The adjustment height of the leg pad in terms of the hole number was recorded for each subject as was the date and time of testing. To control for any extraneous body movement which might affect torque values, several restraining belts were used. The limb being tested was secured to the table by means of a velcro strap being passed over the quadriceps muscle and fastened on the side from which it originated. A seat belt was placed around the lower portion of the abdomen and pulled taut to reduce lower body movement. A third belt was placed around the back of the chair and fastened in front of the chest to help minimize upper body movement. Subjects were instructed to extend and flex as hard and as fast as possible. Strong verbal encouragement was given during the test. Once the testing schedule had been established, each subject was tested at the same time each testing session.

Data Collection

Following completion of all pretesting, individual Cybex strips were analyzed using a Cybex II Chart Data Card as described in the Cybex Instruction Manual (Lumex Inc., Bayshore, N.Y.). These results were measured in foot-pounds and then converted into Newton-meters. From each specific test, the highest value on the graph was taken as being the peak torque. The results of the endurance test were collected by measuring and recording the torque value of the initial and final repetition of 50 contractions.

Training

Following completion of all pretesting, subjects were trained using their respective methods for a period of six weeks. All subjects were required to train only their right leg. To make training times as convenient as possible, workouts were conducted three days a week (Monday, Wednesday, Friday), between the hours of 8:30 a.m. and 6:00 p.m..

## Electrical Stimulation

Instrumentation. Electrical stimulation of the quadriceps muscle group was done using an Ultra Pulsator Model 4 (Medelco Ltd., Downsview, Ont.). Using the variable setting on the surge program, allowed for the surge and rest times to be set independently. For this training series, both control knobs were set at the maximum (e.g., full clockwise rotation). These settings allowed a 14 sec isometric contraction with an inclusive 4 sec build up and followed by a 20 sec rest period. The pulse control was set on "low" which resulted in a low frequency wavelength, while the wave width was adjusted to the "high" setting. At these settings this machine is able to deliver 50 pulses/sec with a corresponding width of 200 microseconds. Prestudy trials utilizing different combinations of settings indicated that the above choice seemed to promote a more extreme contraction at all current levels.

Training Procedure. Subjects were trained with three sets of 10 repetitions following a warm up/familiarization phase of six repetitions at a setting which induced a sufficient contraction. A rest period of one minute was given between sets.

Subjects were supinated on the table with their leg bent at 120 degrees by means of a roll positioned under the knee. The leg was prevented from straightening by placing sandbags over the ankle. Application of the current was done directly using two 3 x 5 inch rubber/metal electrodes placed diagonally across the quadriceps. The pads were dampened with tap water and were secured to the leg by means of rubberized velcro straps. To achieve more efficient current delivery, the positive (red) lead was inserted into the superior pad (e.g., located across the bulk of the muscle, just below the groin area), and the negative (black) lead was inserted into the inferior pad (e.g., across quadriceps, just superior to the knee). Subjects were encouraged to tolerate any pain caused by the contraction and thereby receive the maximal current in the shortest amount of time.

Isokinetic Exercise

Instrumentation. Subjects were trained on the Orthotron Isolated Joint Exercise System (Lumex Inc., Bayshore, N.Y.). Prior to training the Orthotron was calibrated according to the Orthortron User Service and Parts Handbook (Lumex Inc., Bayshore, N.Y.). The preparation of the Orthotron for training was identical to that of the Cybex for testing without abdominal and upper trunk restraining belts.

Training Procedure. Subjects were instructed to perform a warm-up/familiarization set of eight repetitions, followed by three sets of 10 repetitions. All sets were followed by a one minute recovery period. The Orthotron speed for this training regime was set at 60°/sec for knee extension and 270°/sec during knee flexion. These values correspond to machine settings of 3 and 10 respectively, and were maintained throughout the six-week training period. Strong verbal encouragement was given throughout exercise.

## Concurrent Electrical Stimulation with Isokinetic Exercise

Instrumentation. Subjects utilizing this mode of training followed similar protocols to the two methods previously described. Subject position and Orthotron setting were identical to those mentioned under isokinetic training. Current application was again delivered directly. Pulse rate and wave width were both identical to those previously mentioned. Surge and rest times were adjusted to allow for a two-second contraction phase and a one-second relaxation.

Training Procedure. Subjects were given a warm-up/ familiarization period to consist of 6 repetitions prior to beginning the training bout. Following the warm-up, subjects were required to perform three sets of 10 repetitions. A one minute recovery period was again given between all sets. Subjects were instructed to be synchronous with the current indicator lights on the stimulator. Thus, when the lights turn on, subjects extended the leg and continued the contraction until the current was discontinued, (e.g., lights turn off). At this time, subjects returned their leg to 90° flextion in readiness for the next repetition. Subjects were again encouraged to tolerate any pain caused by the contraction.

## Analysis of Data

All parameters were analyzed using a multivariate analysis of variance (MANOVA) in 4 x 2 x 3 design using the SPSS statistical package. When a significant MANOVA F-ratio was calculated, differences between means were tested for significance using Scheffe's critical difference test. The level of significance was set at $p < .05$.

# Chapter 4

## Results

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

### Initial Comparison of Groups

Using the initial scores, the training groups were analyzed for differences which might exist prior to the training program. The range of the F-ratios for between legs, among groups, and among tests for all variables was .03 - 2.40, however, none of the F-ratios were significant ($p < .05$). The result sections are therefore presented in terms of group mean changes.

### Strength

Static Extension (0°/sec). On a percentage basis, mean improvements at 0°/sec were noted as being 9.7%, 12.2% and 9.3% for the isokinetic, EMS and combined training groups, respectively (Table 5). Individual data for static strength changes are given in Appendix C, Tables 6, 7 and 8.

Dynamic Extension (60°/sec, 180°/sec). Mean improvements at the test speed of 60°/sec were noted as being 9.1%, 7.6% and 2.6% for the isokinetic, EMS and combined training groups, respecitvely.

Table 1

Characteristics of Subjects

| Group | Age (yr) | Height (cm) | Weight (kg) |
|---|---|---|---|
| Control N=5 | 20.6±2.9 | 167.3± 7.6 | 61.3±5.4 |
| Isokinetic N=7 | 21.0+1.7 | 168.4±12.4 | 65.2±8.4 |
| Electrical Stimulation N=9 | 20.6±1.9 | 164.8± 7.5 | 60.5±6.0 |
| Combined N=9 | 19.6±0.9 | 166.7± 5.7 | 63.6±6.0 |

Values presented are means ± standard deviations.

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

Table 2

Means and Standard Deviations of Torque of the Quadriceps at 0°/sec for Four Groups

| | Control (N=5) | | Isokinetic Exercise (N=7) | | Electrical Stimulation (N=9) | | Combined Exercise (N-9) | |
|---|---|---|---|---|---|---|---|---|
| Test | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg |
| T1 | 151.6 ±14.9 | 154.2 ±20.6 | 158.0 ±31.8 | 142.6 ±35.3 | 163.1 ±28.9 | 154.2 ±29.4 | 155.5 ±27.5 | 151.1 ±29.6 |
| T2 | 157.4 ±13.5 | 152.2 ±18.0 | 173.4 ±36.1 | 163.5 ±37.9 | 182.8 ±37.9 | 171.9 ±43.5 | 170.8 ±48.6 | 156.3 ±29.7 |
| T3 | 156.2 ±34.3 | 157.2 ±31.1 | 160.7 ±48.8 | 158.0 ±48.5 | 165.7 ±43.5 | 160.6 ±41.3 | 161.9 ±41.3 | 150.6 ±40.6 |

Values presented in Newton-meters.

T1: Pretest; T2: Posttest; T3: Retention Test.

Table 3

Means and Standard Deviations of Torque
of the Quadriceps at 60°/sec for Four Groups

| Test | Control (N=5) | | Isokinetic Exercise (N=7) | | Electrical Stimulation (N=9) | | Combined Exercise (N-9) | |
|---|---|---|---|---|---|---|---|---|
| | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg |
| T1 | 139.6 ±15.6 | 143.4 ±23.4 | 140.9 ±28.4 | 130.1 ±30.2 | 142.6 ±27.5 | 133.2 ±26.3 | 141.9 ±25.2 | 133.3 ±26.3 |
| T2 | 142.2 ±14.7 | 137.2 ±15.6 | 153.1 ±30.1 | 136.1 ±27.9 | 154.0 ±37.3 | 143.0 ±29.2 | 144.8 ±32.3 | 135.6 ±28.6 |
| T3 | 143.4 ±22.8 | 138.2 ±25.2 | 140.6 ±37.0 | 126.3 ±31.1 | 147.7 ±36.3 | 128.4 ±28.2 | 144.5 ±30.3 | 135.2 ±26.6 |

Values presented in Newton-meters.

T1: Pretest; T2: Posttest; T3: Retention Test.

Table 4

Means and Standard Deviations of Torque
of the Quadriceps at 180°/sec for Four Groups

| | Control (N=5) | | Isokinetic Exercise (N=7) | | Electrical Stimulation (N=9) | | Combined Exercise (N-9) | |
|---|---|---|---|---|---|---|---|---|
| Test | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg | Right Leg | Left Leg |
| T1 | 96.4 $\pm$10.1 | 96.4 $\pm$14.1 | 99.1 $\pm$22.3 | 90.7 $\pm$19.5 | 95.3 $\pm$20.8 | 90.4 $\pm$18.0 | 93.8 $\pm$13.8 | 91.3 $\pm$18.0 |
| T2 | 95.4 $\pm$ 7.8 | 93.2 $\pm$14.3 | 108.0 $\pm$22.4 | 100.0 $\pm$18.0 | 102.8 $\pm$22.1 | 99.7 $\pm$20.7 | 101.6 $\pm$16.2 | 96.9 $\pm$19.0 |
| T3 | 98.4 $\pm$13.4 | 98.6 $\pm$14.5 | 100.7 $\pm$23.9 | 94.4 $\pm$20.6 | 101.6 $\pm$19.8 | 98.4 $\pm$21.2 | 103.5 $\pm$21.5 | 94.9 $\pm$19.6 |

Values presented in Newton-meters.

T1: Pretest; T2: Posttest; T3: Retention Test.

Table 5

Mean Percentage Strength Changes Between
T1 and T2 of 0°/sec, 60°/sec and 180°/sec for the
Isokinetic, Electrical Stimulation and Combined Training Groups

| Training Group | Mean Percentage Strength Change | |
|---|---|---|
| | Trained Leg | Non-Trained Leg |
| | 0°/sec | |
| Isokinetic Exercise | 9.7 ± 7.6 | 15.3 ± 12.1 |
| Electrical Stimulation | 12.2 ± 12.1 | 12.3 ± 21.1 |
| Combined Exercise | 9.3 ± 18.9 | 3.7 ± 15.1 |
| | 60°/sec | |
| Isokinetic Exercise | 9.1 ± 9.7 | 5.2 ± 8.3 |
| Electrical Stimulation | 7.6 ± 12.2 | 7.7 ± 10.0 |
| Combined Exercise | 2.6 ± 14.2 | 1.9 ± 10.8 |
| | 180°/sec | |
| Isokinetic Exercise | 9.6 ± 8.8 | 11.3 ± 12.8 |
| Electrical Stimulation | 8.2 ± 7.4 | 10.3 ± 7.9 |
| Combined Exercise | 8.4 ± 8.3 | 6.3 ± 7.6 |

Values presented are means ± standard deviations.

Similarly, these respective training methods demonstrated mean increases of 4.6%, 8.2% and 8.4% at a test speed of 180°/sec (Table 5). Individual data for the respective training groups at each dynamic test speed are summarized in Appendix C, Tables 6, 7 and 8.

Bilateral Transfer

There was no significant ($p > .05$) strength gain in the contralateral limb at any of the three test speeds. The isokinetic group exhibited improvements of 15.3%, 5.2% and 11.3% at the test speeds of 0°/sec, 60°/sec and 180°/sec (Table 5). At identical speeds, mean improvements of 12.3%, 7.7% and 10.3% versus 3.7%, 1.9% and 6.3% were noted for the EMS and combined groups respectively (Table 5). Individual data are summarized in Appendix C, Tables 6, 7 and 8.

Muscular Endurance

Group means for the respective training groups failed to demonstrate any significant ($p < .05$) improvements of muscular endurance in accordance with Thorstensson and Karlsson's (1976) Fatigue Index. A comparison of the three training methods tested revealed mean improvements in muscular endurance of 6.8% for the combined group versus 1.8% and 1.9% increase for the isokinetic group respectively (Table 6). Individual data of Fatigue Indices are shown in Appendix C, Tables 13, 14 and 15.

Table 6

Means of Fatigue Indices for
the Isokinetic, Electrical Stimulation
and Combined Exercise Groups

| Test | Isokinetic Exercise (N=7) | Electrical Stimulation (N=9) | Combined Exercise (N=9) |
|---|---|---|---|
| T1 | 62.2<br>±5.4 | 60.4<br>±4.3 | 60.2<br>±6.6 |
| T2 | 60.4<br>±6.9 | 58.5<br>±8.2 | 53.4<br>±16.6 |
| T3 | 58.1<br>±4.5 | 57.3<br>±6.3 | 60.1<br>±9.0 |

Values presented are means ± standard deviations. Unit is percentage.

Fatigue Index measured at 180°/sec.

Retention

Following the 4 week detraining period, no significant ($p > .05$) decrease in strength was demonstrated by any of the training groups. Group means for strength retention (Table 7) reveal a range of retention levels from 90.4 - 103.3%. Individual data for strength retention is presented in Appendix C, Tables 16, 17 and 18. Group means for endurance retention (Table 6) reveal Fatigue Indices which are superior to T2 scores for the isokinetic and EMS groups. Endurance retention for the combined group were shown to decrease following the detraining period. Individual data for the endurance retention response are presented in Appendix C, Tables 13, 14 and 15.

Table 7

Summary of Mean Percentages for
Strength Retention in the Trained Leg of
0°/sec, 60°/sec and 180°/sec
for the Isokinetic, Electrical Stimulation
and Combined Training Groups

| Training Group | Mean Percentage of Strength Retained | | |
| --- | --- | --- | --- |
| | 0°/sec | 60°/sec | 180°/sec |
| Isokinetic Exercise | 91.6 ±15.7 | 91.0 ±10.4 | 93.5 ±7.7 |
| Electrical Stimulation | 90.4 ±12.3 | 96.6 ± 8.5 | 99.6 ±6.8 |
| Combined Exercise | 95.9 ±10.3 | 100.1 ± 7.9 | 103.1 ±5.4 |

Values presented are means ± standard deviations.

# Chapter 5

## Discussion

Like most previous studies, the subjects of the present investigation were volunteers and therefore would limit extrapolations to the total population. Few studies reported in the literature employed a sample from this specific segment of the population and consequently this must be considered when discussing the results. To facilitate interpretation, the discussion is presented under the following sections: Strength, (a) Isokinetic Training, (b) Electrical Muscle Stimulation Training, (c) Concurrent Electrical Muscle Stimulation with Isokinetic Exercise; Bilateral Transfer; Retention; Endurance.

### Strength

*Isokinetic Training*. By virtue of controlling for the speed of exercise and by maximizing the resistance throughout the ROM, isokinetics have demonstrated to be a proven method for strength development (Gleim et al., 1978; Laird and Rozier, 1979). Although subjects trained solely with isokinetic exercise demonstrated increases in torque production at all test speeds, group mean improvements were noted as being non-significant ($p > .05$) when compared to the control. Mean increases of 9.7%, 9.1%, 9.6% were noted at test speeds of 0°/sec, 60°/sec and 180°/sec, respectively.

Individual analysis of increases, however, reveal both significant ($p < .05$) and non-significant results which may be attributed to the motivation of the individual during training and/or all testing periods. The major limiting factor of this training method is the motivation of the individual during training (KIN-COM, 1985). Where the individual is under-motivated, the exercise may continue with less than maximum resistance which is translated into smaller improvements in torque production.

Past research has demonstrated that an improvement in torque production occurs at test speeds equal to or below the training speed (Moffroid and Whipple, 1970; Sale and MacDougall, 1981). Contrary to these reports, the present study notes almost equal improvements in torque output at, below and above the training speed. Researchers concur that this specificity of strength improvement is partially the result of neuromuscular adaptation which improves the ability to recruit more motor units; increase their firing rate; and remove neural inhibitors (Astrand and Rodahl, 1977; Osternig et al., 1977; Coyle et al., 1981). Thus, when the individual is subjected to exercise speeds of equal or inferior magnitude, this response is transformed into greater force output. The contrary findings of the study support the contention that neuromuscular adaptation is not the sole mechanism for strength improvement. Therefore, other physiological or morphological adaptations may be occurring which initially override this mechanism.

In comparison to the other training methods examined in this study, isokinetics was found to be superior or as effective in the improvement of both static and dynamic strength (Table 5). None of these improvements, however, were demonstrated to be significantly ($p < .05$) superior than was achieved with either EMS or combined training. In contrast, Patterson (1977) reported that isokinetic exercise was significantly better for the improvement of static (0°/sec) strength than was EMS. The use of a longer duration training period (10 week) as well as an all male test population may account for the significant differences in results. Previous research has shown that males at all ages are able to generate force output (Wyatt and Edwards, 1981; Miyashita and Kanehisa, 1979). Therefore males, when similarly trained, may have a greater potential for improving strength above pretraining levels.

Electrical Muscle Stimulation Training. The non-significance of these results are contrary to other studies which indicate significant strength improvements following an EMS training program (Erikson et al., 1981; McMiken et al., 1983). Using the 10/10/50 protocol with an undisclosed current format, Kots (1977) reported improvements in strength of 30-40% following 20 sessions of EMS. The results of the present study using a modified protocol showed a maximal mean improvement of only 12.2% (0°/sec) with 18 training sessions. This smaller improvement in strength may be attributed to the modified protocol as well as the non-replication of the current format eluded to by Kots (1977). In so doing, the resultant contraction force deficit may be greater than was achieved by Kots and therefore resulted in a smaller strength increase. Similar findings are reported by Erikson et al. (1981) and Garret et al. (1980) in which modification of the current and/or treatment parameters resulted in significant although substantially lower increases than reported by Kots (1977). Other studies using stimulators (e.g., Medelco Pulsator, Model 4) reported to duplicate Kot's technique produced muscular tension that was significantly less than was produced during an MVC (Walmsleg, et al., 1984). The resultant lower tension produced would definitely account for smaller increases in the augmented torque.

While group analyses demonstrated non-signifcant ($\underline{p} > .05$) results, substantial individual differences in response to the exercise regime were noted (Appendix C, Table 7). Percentage strength increases at 0°/sec demonsterated a range between -5.6% - 28.3%. Such variations may be attributed to the individual response to training. Trainer observation during the study noted that subjects appeared to have day to day variation of pain tolerance associated with increasing current intensities. Therefore, it was not always possible to maximize the contraction throughout a particular training session.

The results of the present study support the findings of Romero et al. (1982) and Patterson (1977) who previously reported that EMS was unable to produce significant increases in dynamic strength. Romero et al. (1982) suggested that this non-significant improvement of dynamic strength may be a reflection of the recruitment patterns associated with this type of stimulation.

Concurrent Electrical Muscle Stimulation with Isokinetic Exercise. By comparison, the concurrent treatment was found to be as effective at improving static (0°/sec) strength as either the EMS or isokinetic groups with an increase of 9.3% being noted. Similar findings in both magnitude and non-significance were reported by Currier et al. (1979) and Lainey et al. (1978) who superimposed EMS onto maximal isometric contractions. Contrary to the findings in the present study, Patterson (1977) demonstrated that superimposing EMS onto isokinetic contractions significantly improved static strength when compared to the group trained with EMS alone. Patterson (1977) failed to find any significant difference for the improvement of static strength between the combined group and the group solely isokinetically.

As previously noted, the improvement in torque output is found to occur at or below the training speed (Sale and MacDougall, 1981). Patterson (1977) demonstrated that a combined treatment was more effective in improving dynamic strength than groups trained only with EMS or isokinetic exercise. Contrary to previous research, the results of the present study found the combined group to be not as effective in improving torque when tested at the training speed (60°/sec). Combined treatment was found to produce only a 2.6% mean increase when tested at 60°/sec. Individual analysis of percentage increases (Appendix C, Table 8) indicates a number of strength declines during $T_2$ which would inherently lower the mean. The motivation of the individual at the time of the test may also have been a major factor in these strength reductions.

With the maximal degree of contractions proposed by Pruitt (1982), these decreases in torque production may also be a reflection of overtraining. An examination of the $T_3$ results following a one month detraining period reveals values which are higher than pretest scores for some subjects. Therefore, the premise that declines in torque may be due to overtraining is feasible although appears to be individual specific.

Although Patterson (1977) reports significant differences between training groups, other research has failed to substantiate that a combined treatment format is any more effective in augmenting strength than an individual training regime. The recent re-introduction of this technique has not allowed for replication studies to be performed. Therefore, the contrasting results reported by Patterson (1977) and the present study may have a direct relationship to the current/treatment protocols. Similarly, the 10 week versus the 6 week duration of training may also have affected the level of the training effect. Pruitt (1982) concluded that a combined treatment resulted in a maximal contraction with every repetition. Other researchers (Walmsley et al., 1984) have reported that torque values achieved were similar or lower than produced with an MVC. Walmsley et al. (1984) suggested that the superimposition of EMS may interfere with volitional activity. Whereby contraction levels are found not to be superior than achieved with other training methods, significant differences in results would not be expected.

Bilateral Transfer

Previous research has demonstrated conflicting results as to a significant transfer of strength to the contralateral limb (Coleman, 1969a; Shaver, 1970; McDonald, 1978). Similarly, the reason(s) for these occurrences/non-occurrences are only speculative and cannot be determined due to the limitations of experimental design. The lack of information on how the training methods employed in the present study affects this phenomenon makes interstudy comparisons impossible. Within the limitations of this study, the statistical evidence has failed to indicate any significant function that may be called bilateral transfer and therefore the phenomenon is non-tenable.

Although no significant results in the present study were noted, possible explanations for the mean improvements seem pertinent. Visual observation during training periods noted that with both of the dynamic training methods, there tended to be resulting tension in the contralateral limb. As suggested by Rasch and Morehouse (1957), these concurrent contractions may result in a relative strength increase in the non-trained limb. Whereby the static nature of the EMS training was shown to evoke similar increases as the isokinetic group at all test speeds suggests other mechanism(s) may also be involved in augmenting torque in the non-exercised leg. By comparison, the combined treatment was found to produce smaller increases than either the EMS or isokinetic groups at all test speeds. The superimposition of EMS onto a dynamic exercise may in fact interfere with the mechanism(s) responsible for increasing strength in the contralateral limb. Individual analysis of percentage strength increases in the contralateral limb (Appendix C, Table 8) reveal a wide range of values. As suggested by Slater-Hamel (1950) and McDonald (1978) a 6.0% increase in strength following 6 weeks training is within the limitations of motivation and the ability to exert a maximal force during subsequent test periods.

Muscular Endurance

An examination of both group means (Table 6) and individual results (Appendix C, Tables 12, 13 and 14) reveals Fatigue Indices that are in excess of the 50% torque decline prescribed by Thorstesson and Karlsson (1976). The results of the present study therefore suggest that the number of contractions for females be reduced in order to elicit a more equivalent index of fatigue between the sexes.

The non-significant ($p > .05$) results of the present investigation are in direct contrast with other studies, which have reported significant improvements in muscular endurance utilizing a variety of training methods (Kots, 1977; Dennison et al., 1961).

Cotton (1967) and Shaver (1971a) employing both static and dynamic training techniques, reoprted significant improvements when subjects were tested at varying loads up to 75% of maximum strength values. As previously noted, with maximal exertion, the resistance imparted upon the subject with isokinetic exercise is superior to other forms of training (Moffroid et al., 1969). Thus, the maximal testing load may have a direct relationship on the individual's ability to sustain repeated maximum dynamic contractions. Fox (1979) reported that training isokinetically at fast speeds improves muscular endurance at fast speeds more than slow speed training will improve endurance when tested at slow speeds. It is therefore logical to assume that the slow training speeds employed in the present study (e.g., 0°/sec, 60°/sec) would invariably contribute to less than significant improvements in muscular endurance when tested at a much higher contraction velocity (e.g., 180°/sec). The variability between subjects of all training groups, where the Fatigue Index was shown to decline following training, again suggests that the motivation of the individual during testing may affect the results and is in agreement with Caldwell (1964).

<u>Retention</u>

Following the 4 week detraining period, none of the training groups experienced any significant ($p < .05$) loss of strength or endurance. The relative lack of research as to how the training methods employed in this study affect retention, allows for the possibility that a longer detraining period may cause a significant decrease in these newly acquired levels. In a comparative study, Kots (1977) reported that subjects trained with EMS retained 100% of improved strength for up to three months. The results of the present study, however, demonstrated that strength levels of the EMS group declined after only a one month detraining period (Table 7). Discrepancies between the two studies may again be attributed to the differing protocols.

While Muller (1970) proposed that routine daily activity may not augment strength, the possibility that such activity may have a direct relationship on the retention of newly acquired strength must be considered. Previous retention studies no doubt employed highly cooperative subjects familiar with the disciplined conduct necessary for controlled research. It becomes apparent that in order to objectively verify the retention effects of various training methods, the respective limb must be immobilized during the detraining period.

An examination of group means for strength retention in the trained leg (Table 7) reveals a range of 90.4-103.1% for all training groups across all test speeds. Similar trends were also noted in the results of the endurance test (Table 6) whereby certain group means for T3 were found to be superior to those of T2. Individual analysis for both strength and endurance (Appendix C, Tables 3, 4, 5, 13, 14 and 15) demonstrate certain individuals eliciting greater torque outputs following the period of detraining. The individual's level of motivation at the time of testing may again be a decisive factor in affecting individual and therefore group results. As previously noted, individual's response to training may allow for the possibility that these subjects may have been in an overtrained state during T2. Increase torque production as well as an improved Fatigue Index score during T3 may be due to sufficient recovery time being given during the detraining phase.

# Chapter 6

## Summary, Conclusion and Recommendations

### Summary

The present study was designed to determine the effects of isokinetic exercise, electrical stimulation and concurrent electrical stimulation with isokinetic exercise on the acquisition of strength and endurance in the quadriceps muscle of females. Other problems examined were: (a) the retention of both strength and endurance in the trained leg; and (b) the change, if any, in strength of the contralateral limb quadriceps.

Subjects were 30 female volunteers enrolled in the physical education program at Lakehead University, Thunder Bay, Ontario. The subjects were randomly assigned to one of four groups: (1) Control; (2) Isokinetic Exercise; (3) EMS; and (4) Concurrent EMS with Isokinetic Exercise groups. Subjects assigned to the isokinetic exericse, EMS, or combined treatment trained only their right leg.

The premise of the experiment was explained to all subjects and each was required to fill out a consent form. The test procedure consisted of a pretest and two subsequent posttests interrupted by a one month detraining period. Specific tests consisted of static (0°/sec) and dynamic (60°/sec, 180°/sec) extension as well as an endurance run of 50 successive maximal extensions at a test speed of 180°/sec. The aforementioned tests were identically duplicated for each testing session. The changes for each variable were represented by the scores between two trials.

Subjects trained Monday, Wednesday and Friday during the six week training period. The retention period was the four weeks following the initial posttest. The isokinetic training group were exercised with 3 sets of 10 repetitions at a speed of 60°/sec. Electrical Muscle Stimulation was delivered with a 10 second contraction phase, followed by a 20 second relaxation phase. Subjects in this group were also trained with 3 sets of 10 repetitions. The concurrent training group was exercised by employing a combination of the above methods. The frequency and wave width for the stimulation remained the same while the surge and rest contractions were adjusted to allow for a 2 second contraction and a one second relaxation phase. The exercise speed was set at 60°/sec and the combined group was again trained for 3 sets of 10 repetitions. All subjects were required to perform a warm up set of 6-8 repetitions before initiating any training procedures.

Data were analyzed using a MANOVA in a 4 x 2 x 3 design. F-ratios in which an alpha level of .05 was accepted for statistical significance. Percentage changes of means and individual results was presented in table form to provide further clarification of the data.

## Conclusion

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

1. The training methods utilized failed to elicit any significant improvement of either strength or endurance following 6 weeks of training.

2. Mean percentage improvements of both strength and endurance were noted for all training groups at all tests speeds.

3. No significant difference for the improvement of strength and endurance was found between the training groups.

4. There was a wide variation in the subjects' response to training.

5. None of the training procedures resulted in a significant transfer of strength to the contralateral limb.

6. Following four weeks of detraining, neither of the three training groups experienced any significant loss of strength or endurance.

## Recommendations

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

1. Subjects should be tested weekly in order to ascertain a more comprehensive picture of strength improvement as well as to monitor for incidence of overtraining.

2. In order to gain a significant training effect by the utilization of these training methods, a longer duration of training may be warranted.

3. The inability of the EMS protocol to develop significant results suggests further modification to both current and treatment parameters.

4. In order to negate the timing aspect and thereby ensure a more precise co-contraction for the combined treatment group, it is suggested that a triggering device for the EMS be installed in the leg pad, such that when the subject begins the constraction, so is the EMS more accurately superimposed.

5. EMG studies be performed on concurrent treatment program in order to help define necessary EMS current/treatment parameters required to produce maximal contractions.

6. Continued research in the area of bilateral transfer is warranted, implementing EMG techniques and the immobilization of the non-trained limb.

7. Similar retention studies employing these training procedures be performed with longer detraining periods.

8. Subject's limbs should be immobilized in order to objectively verify retention effects.

9. As a more equitable index of fatigue between the sexes, the number of repetitions performed by females should be reduced from 50.

10. In order to account for the variability in trainability among subjects, fibre type classification may provide an additional reference for equating groups.

11. In recognizing the importance of motivation and the desire to excel as major factors for the augmenting of strength suggests continued exploration involving psychological preparation and endocronological responses and their effects on strength gain.

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# APPENDIX "A"

## CONSENT FORM

I, ___________________________, authorize Lakehead University to perform a series of procedures which constitute the following training methods:

1. Isokinetic Exercise
2. Electrical Muscle Stimulation
3. Concurrent Isokinetic Exercise with Electrical Muscle Stimulation

In agreeing to these procedures, I accept all responsibility and waive my legal recourse against Lakehead University, and members of their staff from any and all claims resulting from personal injuries sustained from these procedures. I have read and understand the above.

Date: ___________________________

Signature: ___________________________

Witness: ___________________________

APPENDIX "B"

SUBJECT INFORMATION SHEET

1. NAME ______________________________

2. BIRTHDATE ______________________________

3. HEIGHT (cm) ______________________________

4. WEIGHT (kg) ______________________________

5. List any physical activities (outside of course practicals) that you are currently involved in, as well as how often you participate:

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

6. List any physical activities (outside of course practicals) that you will be involved in during the course of this study and their respective frequencies:

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

# APPENDIX "C"

## RAW DATA

### Table 1

### Characteristics of Subjects

| Subject | Age (yr) | Height (cm) | Weight (kg) |
|---|---|---|---|
| Control Group | | | |
| JA | 17 | 160.0 | 62.5 |
| BC | 25 | 165.0 | 57.7 |
| MW | 20 | 164.0 | 54.1 |
| LB | 20 | 180.0 | 64.8 |
| GG | 21 | 167.6 | 67.4 |
| Mean | 20.6 | 167.3 | 61.3 |
| S.D. | ±2.9 | ± 7.6 | ±5.4 |
| Isokinetic Group | | | |
| MB | 23 | 151.0 | 54.1 |
| KB | 21 | 180.0 | 69.5 |
| MC | 18 | 166.5 | 63.6 |
| LE | 21 | 187.5 | 79.5 |
| LG | 20 | 158.5 | 69.5 |
| TP | 23 | 165.0 | 59.1 |
| LW | 21 | 170.2 | 61.4 |
| Mean | 21.0 | 168.4 | 65.2 |
| S.D. | ±1.7 | ±12.4 | ±8.4 |

(cont'd.)

Table 1 (cont'd.)

| Subject | Age (yr) | Height (cm) | Weight (kg) |
|---|---|---|---|
| EMS Group | | | |
| SB | 25 | 150.0 | 47.7 |
| NG | 19 | 172.5 | 69.1 |
| KH | 20 | 160.5 | 60.2 |
| SH | 20 | 172.7 | 60.0 |
| KK | 20 | 170.2 | 60.0 |
| JK | 20 | 159.0 | 59.1 |
| CM | 19 | 169.0 | 61.6 |
| IS | 22 | 162.6 | 59.1 |
| TS | 20 | 167.0 | 67.3 |
| Mean | 20.6 | 164.8 | 60.5 |
| S.D. | ±1.9 | ± 7.5 | ±6.0 |
| Combined Group | | | |
| DB | 19 | 174.5 | 71.8 |
| SC | 19 | 167.5 | 62.7 |
| CD | 19 | 168.0 | 63.6 |
| DH | 20 | 174.0 | 74.1 |
| KH | 18 | 169.0 | 57.0 |
| SK | 20 | 160.0 | 58.6 |
| BM | 21 | 162.6 | 59.9 |
| TM | 20 | 158.0 | 59.1 |
| JR | 20 | 167.0 | 65.2 |
| Mean | 19.6 | 166.7 | 63.6 |
| S.D. | ±0.9 | ± 5.7 | ±6.0 |

Table 2

Knee Extension (Control Group)

| Leg & Subject / Cybex Speed & Test Period | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Trained Leg | | | | | | | | | |
| JA | 169 | 165 | 202 | 149 | 148 | 159 | 98 | 89 | 110 |
| BC | 153 | 171 | 168 | 141 | 151 | 159 | 106 | 100 | 108 |
| MW | 136 | 151 | 111 | 115 | 119 | 106 | 85 | 95 | 81 |
| LB | 163 | 163 | 163 | 156 | 156 | 156 | 106 | 106 | 106 |
| GG | 137 | 137 | 137 | 137 | 137 | 137 | 87 | 87 | 87 |
| Mean | 151.6 | 157.4 | 156.2 | 139.6 | 142.2 | 143.4 | 96.4 | 95.4 | 98.4 |
| S.D. | ±14.9 | ±13.5 | ±34.3 | ±15.6 | ±14.7 | ±22.8 | ±10.1 | ± 7.8 | ±13.4 |
| Non-Trained Leg | | | | | | | | | |
| JA | 184 | 175 | 198 | 176 | 145 | 167 | 107 | 85 | 106 |
| BC | 149 | 155 | 175 | 134 | 136 | 138 | 94 | 89 | 106 |
| MW | 151 | 144 | 126 | 129 | 127 | 108 | 91 | 102 | 91 |
| LB | 160 | 160 | 160 | 159 | 159 | 159 | 113 | 113 | 113 |
| GG | 127 | 127 | 127 | 119 | 119 | 119 | 77 | 77 | 77 |
| Mean | 154.2 | 152.2 | 157.2 | 143.4 | 137.2 | 138.2 | 96.4 | 93.2 | 98.6 |
| S.D. | ±20.6 | ±18.0 | ±31.1 | ±23.4 | ±15.6 | ±25.2 | ±14.1 | ±14.3 | ±14.5 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

Table 3

Knee Extension (Isokinetic Group)

| Cybex Speed & Test Period / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Trained Leg | | | | | | | | | |
| MB | 113 | 113 | 81 | 94 | 98 | 77 | 61 | 65 | 65 |
| KB | 157 | 172 | 184 | 144 | 146 | 160 | 111 | 117 | 114 |
| MC | 146 | 167 | 172 | 130 | 167 | 152 | 106 | 110 | 103 |
| LE | 218 | 236 | 236 | 188 | 199 | 199 | 129 | 138 | 138 |
| LG | 144 | 172 | 125 | 132 | 149 | 127 | 81 | 99 | 77 |
| TP | 167 | 167 | 175 | 156 | 156 | 136 | 110 | 110 | 104 |
| LW | 161 | 187 | 152 | 142 | 157 | 133 | 96 | 117 | 104 |
| Mean | 116.6 | 173.4 | 160.7 | 140.9 | 153.1 | 140.6 | 99.1 | 108.0 | 100.7 |
| S.D. | ±31.8 | ±36.1 | ±48.8 | ±28.4 | ±30.1 | ±37.0 | ±22.3 | ±22.4 | ±23.9 |
| Non-Trained Leg | | | | | | | | | |
| MB | 118 | 122 | 95 | 104 | 106 | 92 | 68 | 73 | 69 |
| KB | 138 | 182 | 183 | 138 | 157 | 140 | 89 | 118 | 114 |
| MC | 136 | 142 | 160 | 126 | 127 | 118 | 98 | 99 | 85 |
| LE | 220 | 239 | 239 | 194 | 188 | 188 | 129 | 127 | 127 |
| LG | 141 | 157 | 111 | 123 | 127 | 107 | 76 | 94 | 76 |
| TP | 119 | 157 | 178 | 115 | 115 | 126 | 87 | 89 | 92 |
| LW | 126 | 146 | 140 | 111 | 133 | 113 | 88 | 100 | 98 |
| Mean | 142.6 | 163.5 | 157.2 | 130.1 | 136.1 | 126.3 | 90.7 | 100.0 | 94.4 |
| S.D. | ±35.3 | ±37.9 | ±31.1 | ±30.2 | ±27.9 | ±31.1 | ±19.5 | ±18.0 | ±20.6 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

Table 4

Knee Extension (Electrical Stimulation Group)

| Cybex Speed & Test Period / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Trained Leg | | | | | | | | | |
| SB | 134 | 144 | 133 | 103 | 107 | 117 | 62 | 75 | 83 |
| NG | 210 | 252 | 222 | 207 | 233 | 221 | 137 | 148 | 142 |
| KH | 144 | 172 | 123 | 138 | 133 | 123 | 87 | 85 | 85 |
| SH | 195 | 184 | 168 | 141 | 157 | 142 | 95 | 102 | 100 |
| KK | 152 | 151 | 125 | 136 | 136 | 127 | 89 | 94 | 89 |
| JK | 144 | 180 | 140 | 144 | 152 | 130 | 87 | 103 | 92 |
| CM | 176 | 178 | 168 | 148 | 155 | 138 | 100 | 104 | 99 |
| IS | 129 | 148 | 163 | 129 | 126 | 133 | 87 | 89 | 98 |
| TS | 184 | 236 | 248 | 137 | 187 | 198 | 114 | 125 | 126 |
| Mean | 163.1 | 182.8 | 165.7 | 142.6 | 154.0 | 147.7 | 95.3 | 102.8 | 101.6 |
| S.D. | ±28.9 | ±37.9 | ±43.5 | ±27.5 | ±37.3 | ±36.3 | ±20.8 | ±22.1 | ±19.8 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

(cont'd.)

Table 4 (cont'd.)

| Leg & Subject \ Cybex Speed & Test Period | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Non-Trained Leg | | | | | | | | | |
| SB | 127 | 129 | 123 | 94 | 98 | 94 | 65 | 72 | 68 |
| NG | 195 | 271 | 217 | 186 | 207 | 180 | 127 | 144 | 134 |
| KH | 155 | 156 | 119 | 132 | 132 | 108 | 85 | 89 | 81 |
| SH | 183 | 178 | 163 | 136 | 151 | 136 | 91 | 99 | 100 |
| KK | 165 | 165 | 155 | 144 | 142 | 118 | 91 | 92 | 94 |
| JK | 165 | 184 | 142 | 138 | 145 | 132 | 83 | 107 | 95 |
| CM | 167 | 144 | 153 | 141 | 133 | 108 | 95 | 103 | 98 |
| IS | 104 | 129 | 134 | 103 | 126 | 115 | 73 | 81 | 87 |
| TS | 127 | 191 | 239 | 125 | 153 | 165 | 104 | 110 | 129 |
| Mean | 154.2 | 171.9 | 160.6 | 133.2 | 143.0 | 128.4 | 90.4 | 99.7 | 98.4 |
| S.D. | ±29.4 | ±43.5 | ±41.3 | ±26.3 | ±29.2 | ±28.2 | ±18.0 | ±20.7 | ±21.2 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

Table 5

Knee Extension (Combined Group)

| Cybex Speed & Test Period / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Trained Leg | | | | | | | | | |
| DB | 122 | 130 | 134 | 117 | 129 | 132 | 95 | 100 | 103 |
| SC | 184 | 202 | 214 | 184 | 160 | 187 | 114 | 119 | 134 |
| CD | 165 | 160 | 157 | 146 | 152 | 152 | 94 | 100 | 107 |
| DH | 199 | 285 | 239 | 179 | 221 | 199 | 119 | 134 | 142 |
| KH | 171 | 168 | 133 | 140 | 125 | 130 | 84 | 77 | 77 |
| SK | 133 | 175 | 182 | 126 | 151 | 144 | 85 | 96 | 96 |
| BM | 121 | 142 | 148 | 121 | 123 | 117 | 84 | 94 | 91 |
| TM | 160 | 134 | 127 | 146 | 125 | 129 | 89 | 96 | 92 |
| JR | 142 | 141 | 123 | 118 | 118 | 111 | 80 | 98 | 89 |
| Mean | 155.5 | 170.8 | 161.9 | 141.9 | 144.8 | 144.5 | 93.8 | 101.6 | 103.4 |
| S.D. | ±27.5 | ±48.6 | ±41.3 | ±25.2 | ±32.3 | ±30.3 | ±13.8 | ±16.2 | ±21.5 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

(cont'd.)

Table 5 (cont'd.)

| Leg & Subject \ Cybex Speed & Test Period | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| Non-Trained Leg | | | | | | | | | |
| DB | 122 | 132 | 122 | 118 | 119 | 122 | 87 | 94 | 99 |
| SC | 184 | 191 | 195 | 171 | 174 | 178 | 121 | 133 | 130 |
| CD | 141 | 148 | 144 | 122 | 148 | 144 | 98 | 98 | 96 |
| DH | 209 | 209 | 239 | 186 | 188 | 180 | 119 | 121 | 122 |
| KH | 156 | 164 | 134 | 122 | 111 | 113 | 73 | 72 | 71 |
| SK | 118 | 160 | 149 | 115 | 132 | 130 | 79 | 95 | 85 |
| BM | 137 | 145 | 132 | 130 | 122 | 117 | 87 | 85 | 83 |
| TM | 138 | 110 | 115 | 122 | 107 | 115 | 73 | 83 | 79 |
| JR | 164 | 148 | 125 | 114 | 119 | 118 | 85 | 91 | 89 |
| Mean | 151.1 | 156.3 | 150.6 | 133.3 | 135.6 | 135.2 | 91.3 | 96.9 | 94.9 |
| S.D. | ±29.6 | ±29.7 | ±40.6 | ±26.3 | ±28.6 | ±26.6 | ±18.0 | ±19.0 | ±19.6 |

T1: Pretest; T2: Posttest; T3: Retention Test (values presented in Newton-meters)

Table 6

Strength of Individual and Mean Pre-, Post-tests and Percentage Strength Changes of 0°/sec, 60°/sec and 180°/sec on Isokinetic Training Group

| Test Period & Percentage Strength Changes / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | % Change | T1 | T2 | % Change | T1 | T2 | % Change |
| Trained Leg | | | | | | | | | |
| MB | 113 | 113 | 0.0 | 94 | 98 | 4.3 | 61 | 65 | 6.6 |
| KB | 157 | 172 | 9.6 | 144 | 146 | 1.4 | 111 | 117 | 5.4 |
| MC | 146 | 167 | 14.4 | 130 | 167 | 28.5 | 106 | 110 | 3.8 |
| LE | 218 | 236 | 8.3 | 188 | 199 | 5.9 | 129 | 138 | 7.0 |
| LG | 144 | 172 | 19.4 | 132 | 149 | 12.9 | 81 | 99 | 22.2 |
| TP | 167 | 167 | 0.0 | 156 | 156 | 0.0 | 110 | 110 | 0.0 |
| LW | 161 | 187 | 16.2 | 142 | 157 | 10.6 | 96 | 117 | 21.9 |
| Mean | 158.0 | 173.4 | 9.7 | 140.9 | 153.1 | 9.1 | 99.1 | 108.0 | 9.6 |
| S.D. | ±31.8 | ±36.1 | ± 7.6 | ±28.4 | ±30.1 | ± 9.7 | ±22.3 | ±22.4 | ± 8.8 |
| Non-Trained Leg | | | | | | | | | |
| MB | 118 | 122 | 3.4 | 104 | 106 | 1.9 | 68 | 73 | 7.4 |
| KB | 138 | 182 | 31.9 | 138 | 157 | 13.8 | 89 | 118 | 32.6 |
| MC | 136 | 142 | 4.4 | 126 | 127 | 0.8 | 98 | 99 | 1.0 |
| LE | 220 | 239 | 8.6 | 194 | 188 | -3.1 | 129 | 127 | -1.6 |
| LG | 141 | 157 | 11.3 | 123 | 127 | 3.3 | 76 | 94 | 23.7 |
| TP | 119 | 157 | 31.9 | 115 | 115 | 0.0 | 87 | 89 | 2.3 |
| LW | 126 | 146 | 15.9 | 111 | 133 | 19.8 | 88 | 100 | 13.6 |
| Mean | 142.6 | 163.5 | 15.3 | 130.1 | 136.1 | 5.2 | 90.7 | 100.0 | 11.3 |
| S.D. | ±35.3 | ±37.9 | ±12.1 | ±30.2 | ±27.9 | ± 8.3 | ±19.5 | ±18.0 | ±12.8 |

T1: Pretest; T2: Posttest (T1, T2 presented in Newton-metres) (-ve denotes percentage strength decrease)

Table 7

Strength of Individual and Mean Pre-, Post-tests and Percentage Strength Changes of 0°/sec, 60°/sec and 180°/sec on Electrical Muscle Stimulation Group

| Test Period & Percentage Strength Changes / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | % Change | T1 | T2 | % Change | T1 | T2 | % Change |
| Trained Leg | | | | | | | | | |
| SB | 134 | 144 | 7.5 | 103 | 107 | 3.9 | 62 | 75 | 21.0 |
| NG | 210 | 252 | 20.0 | 207 | 233 | 12.6 | 137 | 148 | 8.0 |
| KH | 144 | 172 | 19.4 | 138 | 133 | -3.6 | 87 | 85 | -2.3 |
| SH | 195 | 184 | -5.6 | 141 | 157 | 11.3 | 95 | 102 | 7.4 |
| KK | 152 | 151 | -0.7 | 136 | 136 | 0.0 | 89 | 94 | 5.6 |
| JK | 144 | 180 | 25.0 | 144 | 152 | 5.6 | 87 | 103 | 18.4 |
| CM | 176 | 178 | 1.1 | 148 | 155 | 4.7 | 100 | 104 | 4.0 |
| IS | 129 | 148 | 14.7 | 129 | 126 | -2.3 | 87 | 89 | 2.3 |
| TS | 184 | 236 | 28.3 | 137 | 187 | 36.6 | 114 | 125 | 9.6 |
| Mean | 163.1 | 182.8 | 12.2 | 142.6 | 154.0 | 7.6 | 95.3 | 102.8 | 8.2 |
| S.D. | ±28.9 | ±37.9 | ±12.1 | ±27.5 | ±37.3 | ±12.2 | ±20.8 | ±22.1 | ± 7.4 |

T1: Pretest; T2: Posttest (T1, T2 presented in Newton-metres) (-ve denotes percentage strength decrease)

Table 7 (cont'd.)

| Leg & Subject / Test Period & Percentage Strength Changes | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | % Change | T1 | T2 | % Change | T1 | T2 | % Change |
| Non-Trained Leg | | | | | | | | | |
| SB | 127 | 129 | 1.6 | 94 | 98 | 4.3 | 65 | 72 | 10.8 |
| NG | 195 | 271 | 39.0 | 186 | 207 | 11.3 | 127 | 144 | 13.4 |
| KH | 155 | 156 | 0.7 | 132 | 132 | 0.0 | 85 | 89 | 4.7 |
| SH | 183 | 178 | -2.7 | 136 | 151 | 11.0 | 91 | 99 | 8.8 |
| KK | 165 | 165 | 0.0 | 144 | 142 | -1.4 | 91 | 92 | 1.1 |
| JK | 165 | 184 | 11.5 | 138 | 145 | 5.1 | 83 | 107 | 28.9 |
| CM | 167 | 144 | -13.7 | 141 | 133 | -5.7 | 95 | 103 | 8.4 |
| IS | 104 | 129 | 24.0 | 103 | 126 | 22.3 | 73 | 89 | 11.0 |
| TS | 127 | 191 | 50.4 | 125 | 153 | 22.4 | 104 | 110 | 5.8 |
| Mean | 154.2 | 171.9 | 12.3 | 133.2 | 143.0 | 7.7 | 90.4 | 99.7 | 10.3 |
| S.D. | ±29.4 | ±43.5 | ±21.2 | ±26.3 | ±29.2 | ±10.0 | ±18.0 | ±20.7 | ± 7.9 |

T1: Pretest; T2: Posttest (T1, T2 presented in Newton-metres) (-ve denotes percentage strength decrease)

Table 8

Strength of Individual and Mean Pre-, Post-tests and Percentage Strength Changes of 0°/sec, 60°/sec and 180°/sec on Concurrent Training Group

| Test Period & Percentage Strength Changes / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | % Change | T1 | T2 | % Change | T1 | T2 | % Change |
| Trained Leg | | | | | | | | | |
| DB | 122 | 130 | 6.6 | 117 | 129 | 10.3 | 95 | 100 | 5.3 |
| SC | 184 | 202 | 9.8 | 184 | 160 | -13.0 | 114 | 119 | 4.4 |
| CD | 165 | 160 | -3.0 | 146 | 152 | 4.1 | 94 | 100 | 6.4 |
| DH | 199 | 285 | 43.2 | 179 | 221 | 25.8 | 119 | 134 | 12.6 |
| KH | 171 | 168 | -5.1 | 140 | 125 | -10.7 | 84 | 77 | -8.3 |
| SK | 133 | 175 | 31.6 | 126 | 151 | 19.8 | 85 | 96 | 12.9 |
| BM | 121 | 142 | 17.4 | 121 | 123 | 1.7 | 84 | 94 | 11.9 |
| TM | 160 | 134 | -16.5 | 146 | 125 | -14.4 | 89 | 96 | 7.9 |
| JR | 142 | 141 | -.07 | 118 | 118 | 0.0 | 80 | 98 | 22.5 |
| Mean | 155.5 | 170.8 | 9.3 | 141.9 | 144.8 | 2.6 | 93.8 | 101.6 | 8.4 |
| S.D. | ±27.5 | ±48.6 | ±18.9 | ±25.2 | ±32.3 | ±14.2 | ±13.8 | ±16.2 | ± 8.3 |

T1: Pretest; T2: Posttest (T1, T2 presented in Newton-metres) (-ve denotes percentage strength decrease)

(cont'd.)

Table 8 (cont'd.)

| Test Period & Percentage Strength Changes / Leg & Subject | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | % Change | T1 | T2 | % Change | T1 | T2 | % Change |
| Non-Trained Leg | | | | | | | | | |
| DB | 122 | 132 | 8.2 | 118 | 119 | 0.9 | 87 | 94 | 8.0 |
| SC | 184 | 191 | 3.8 | 171 | 174 | 1.8 | 121 | 133 | 9.9 |
| CD | 141 | 148 | 5.0 | 122 | 148 | 21.3 | 98 | 98 | 0.0 |
| DH | 209 | 209 | 0.0 | 186 | 188 | 1.1 | 119 | 121 | 1.7 |
| KH | 156 | 164 | 5.1 | 122 | 111 | -9.0 | 73 | 72 | -1.4 |
| SK | 118 | 160 | 35.6 | 115 | 132 | 14.8 | 79 | 95 | 20.3 |
| BM | 137 | 145 | 5.8 | 130 | 122 | -6.2 | 87 | 85 | -2.4 |
| TM | 138 | 110 | -20.3 | 122 | 107 | -12.3 | 73 | 83 | 13.7 |
| JR | 164 | 148 | -9.8 | 114 | 119 | 4.4 | 85 | 91 | 7.1 |
| Mean | 151.1 | 156.3 | 3.7 | 133.3 | 135.6 | 1.9 | 91.3 | 96.9 | 6.3 |
| S.D. | ±29.6 | ±29.7 | ±15.1 | ±26.3 | ±28.6 | ±10.8 | ±18.0 | ±19.0 | ± 7.6 |

T1: Pretest; T2: Posttest (T1, T2 presented in Newton-metres) (-ve denotes percentage strength decrease)

Table 9

Knee Extension Endurance (Control Group)

| Leg & Subject \ Test Period | T1 | | | T2 | | | T3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | % Retained | Initial | Final | % Retained | Initial | Final | % Retained |
| Trained Leg | | | | | | | | | |
| JA | 88 | 20 | 23.1 | 83 | 24 | 29.5 | 108 | 38 | 35.2 |
| BC | 106 | 34 | 32.1 | 100 | 39 | 39.2 | 108 | 39 | 36.1 |
| MW | 84 | 47 | 56.5 | 95 | 38 | 40.0 | 76 | 33 | 43.4 |
| LB | 106 | 38 | 35.9 | 106 | 38 | 35.9 | 106 | 38 | 35.9 |
| GG | 87 | 34 | 39.1 | 87 | 34 | 39.1 | 87 | 34 | 39.1 |
| Mean | 94.2 | 34.7 | 37.8 | 94.2 | 34.7 | 36.8 | 97.0 | 36.4 | 37.9 |
| S.D. | ±10.9 | ± 9.8 | ±12.1 | ± 9.4 | ± 6.2 | ± 5.5 | ±14.7 | ± 2.7 | ± 3.4 |
| Non-Trained Leg | | | | | | | | | |
| JA | 107 | 24 | 22.8 | 85 | 33 | 38.1 | 106 | 41 | 38.7 |
| BC | 89 | 37 | 41.0 | 89 | 38 | 42.4 | 106 | 38 | 35.9 |
| MW | 91 | 43 | 47.8 | 98 | 37 | 37.5 | 91 | 38 | 41.8 |
| LB | 113 | 35 | 31.3 | 113 | 35 | 31.3 | 113 | 35 | 31.3 |
| GG | 77 | 27 | 35.1 | 77 | 27 | 35.1 | 77 | 27 | 35.1 |
| Mean | 95.4 | 33.2 | 35.1 | 92.4 | 34.0 | 36.9 | 98.6 | 35.8 | 36.6 |
| S.D. | ±14.5 | ± 7.4 | ± 9.5 | ±13.8 | ± 4.4 | ± 4.1 | ±14.5 | ± 5.4 | ± 4.0 |

T1: Pretest; T2: Posttest; T3: Retention Test (Initial and Final Values presented in Newton-meters)

Table 10

Knee Extension Endurance (Isokinetic Group)

| Test Period / Torque & % Strength Retained / Leg & Subject | T1 | | | T2 | | | T3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | % Retained | Initial | Final | % Retained | Initial | Final | % Retained |
| Trained Leg | | | | | | | | | |
| MB | 61 | 23 | 38.0 | 65 | 33 | 50.0 | 65 | 22 | 33.3 |
| KB | 111 | 43 | 39.0 | 117 | 41 | 35.0 | 114 | 54 | 48.0 |
| MC | 106 | 30 | 28.2 | 110 | 38 | 35.0 | 102 | 42 | 41.3 |
| LE | 129 | 49 | 38.0 | 138 | 60 | 43.1 | 138 | 57 | 41.2 |
| LG | 83 | 33 | 39.3 | 95 | 45 | 41.3 | 104 | 48 | 40.4 |
| TP | 108 | 39 | 36.3 | 108 | 45 | 41.3 | 104 | 48 | 44.2 |
| LW | 96 | 45 | 47.0 | 107 | 49 | 46.0 | 102 | 48 | 45.3 |
| Mean | 99.1 | 37.4 | 38.0 | 105.9 | 42.0 | 40.1 | 100.3 | 43.1 | 42.0 |
| S.D. | ±21.9 | ± 9.2 | ± 5.5 | ±22.2 | ±10.6 | ± 7.3 | ±23.9 | ±12.6 | ± 4.7 |
| Non-Trained Leg | | | | | | | | | |
| MB | 68 | 19 | 28.0 | 73 | 23 | 32.0 | 69 | 31 | 45.1 |
| KB | 89 | 34 | 38.0 | 118 | 47 | 40.2 | 114 | 41 | 36.0 |
| MC | 95 | 27 | 29.0 | 99 | 35 | 36.0 | 85 | 30 | 35.0 |
| LE | 127 | 52 | 40.4 | 127 | 47 | 37.2 | 127 | 47 | 37.2 |
| LG | 76 | 41 | 54.0 | 89 | 45 | 50.0 | 76 | 34 | 45.0 |
| TP | 87 | 33 | 37.5 | 85 | 37 | 43.0 | 88 | 43 | 49.2 |
| LW | 88 | 42 | 48.0 | 100 | 49 | 49.0 | 98 | 42 | 43.1 |
| Mean | 90.0 | 35.4 | 39.3 | 98.7 | 40.4 | 41.1 | 93.9 | 38.3 | 41.5 |
| S.D. | ±18.7 | ±10.8 | ± 9.4 | ±18.8 | ± 9.4 | ± 6.7 | ±20.7 | ± 6.6 | ± 5.5 |

T1: Pretest; T2: Posttest; T3: Retention Test (Initial and Final Values presented in Newton-meters)

Table 11

Knee Extension Endurance (Electrical Stimulation Group)

| Test Period / Torque & % Strength Retained — Leg & Subject | T1 Initial | T1 Final | T1 % Retained | T2 Initial | T2 Final | T2 % Retained | T3 Initial | T3 Final | T3 % Retained |
|---|---|---|---|---|---|---|---|---|---|
| Trained Leg | | | | | | | | | |
| SB | 58 | 22 | 37.2 | 75 | 22 | 29.1 | 83 | 28 | 34.4 |
| NG | 132 | 46 | 35.1 | 148 | 58 | 39.4 | 140 | 56 | 40.0 |
| KH | 85 | 35 | 41.3 | 85 | 30 | 35.0 | 85 | 35 | 41.3 |
| SH | 89 | 33 | 36.4 | 102 | 53 | 52.0 | 100 | 46 | 46.0 |
| KK | 89 | 33 | 36.4 | 91 | 33 | 36.0 | 89 | 49 | 55.0 |
| JK | 85 | 34 | 40.0 | 103 | 38 | 37.0 | 92 | 35 | 38.2 |
| CM | 100 | 43 | 43.2 | 99 | 50 | 51.0 | 92 | 46 | 50.0 |
| IS | 84 | 33 | 39.0 | 89 | 45 | 50.0 | 92 | 38 | 41.2 |
| TS | 119 | 52 | 43.2 | 114 | 52 | 45.2 | 126 | 49 | 39.0 |
| Mean | 93.4 | 36.7 | 39.4 | 100.6 | 42.3 | 41.6 | 100.0 | 42.4 | 42.7 |
| S.D. | ±21.5 | ± 8.9 | ± 3.0 | ±21.1 | ±12.2 | ± 8.2 | ±19.7 | ± 8.9 | ± 6.4 |
| Non-Trained Leg | | | | | | | | | |
| SB | 61 | 22 | 36.0 | 62 | 24 | 39.1 | 62 | 27 | 44.0 |
| NG | 127 | 37 | 29.0 | 144 | 49 | 34.0 | 134 | 41 | 30.3 |
| KH | 85 | 31 | 37.0 | 89 | 34 | 38.0 | 89 | 28 | 35.0 |
| SH | 88 | 33 | 37.0 | 99 | 49 | 49.3 | 95 | 41 | 43.0 |
| KK | 91 | 35 | 39.0 | 92 | 43 | 47.1 | 88 | 45 | 51.0 |
| JK | 83 | 33 | 39.3 | 107 | 30 | 28.0 | 95 | 38 | 40.0 |
| CM | 95 | 34 | 36.0 | 98 | 45 | 46.0 | 98 | 56 | 57.0 |
| IS | 69 | 35 | 51.0 | 79 | 35 | 45.0 | 84 | 34 | 40.3 |
| TS | 98 | 49 | 50.0 | 104 | 47 | 46.0 | 111 | 53 | 48.0 |
| Mean | 88.6 | 34.3 | 39.4 | 97.1 | 39.6 | 41.4 | 95.1 | 40.3 | 43.2 |
| S.D. | ±18.7 | ± 7.0 | ± 7.0 | ±22.4 | ± 9.1 | ± 7.1 | ±19.6 | ±10.0 | ± 8.1 |

T1: Pretest; T2: Posttest; T3: Retention Test (Initial and Final Values presented in Newton-meters)

Table 12

Knee Extension Endurance (Combined Group)

| Test Period / Torque & % Strength Retained — Leg & Subject | T1 Initial | T1 Final | T1 % Retained | T2 Initial | T2 Final | T2 % Retained | T3 Initial | T3 Final | T3 % Retained |
|---|---|---|---|---|---|---|---|---|---|
| Trained Leg | | | | | | | | | |
| DB | 89 | 35 | 39.4 | 100 | 49 | 49.0 | 103 | 43 | 42.1 |
| SC | 111 | 38 | 34.2 | 119 | 52 | 43.2 | 134 | 45 | 33.3 |
| CD | 92 | 27 | 29.4 | 103 | 35 | 34.2 | 107 | 24 | 23.0 |
| DH | 111 | 52 | 46.3 | 129 | 54 | 42.1 | 132 | 53 | 40.2 |
| KH | 81 | 41 | 50.0 | 77 | 33 | 42.1 | 77 | 34 | 44.0 |
| SK | 85 | 35 | 41.3 | 95 | 41 | 43.0 | 94 | 49 | 52.2 |
| BM | 84 | 28 | 34.0 | 85 | 38 | 44.4 | 91 | 46 | 51.2 |
| TM | 84 | 28 | 34.0 | 85 | 38 | 44.4 | 91 | 46 | 51.0 |
| JR | 76 | 34 | 45.0 | 98 | 33 | 33.3 | 89 | 31 | 35.0 |
| Mean | 90.9 | 36.2 | 40.0 | 100.2 | 40.7 | 40.4 | 102.0 | 40.6 | 40.0 |
| S.D. | ±12.3 | ± 7.4 | ± 6.6 | ±15.9 | ± 8.9 | ± 5.7 | ±19.5 | ± 9.6 | ± 9.0 |
| Non-Trained Leg | | | | | | | | | |
| DB | 87 | 39 | 45.3 | 91 | 42 | 46.3 | 99 | 42 | 43.0 |
| SC | 121 | 41 | 34.0 | 130 | 56 | 43.0 | 130 | 45 | 34.4 |
| CD | 98 | 22 | 22.2 | 98 | 23 | 23.6 | 96 | 39 | 41.0 |
| DH | 119 | 41 | 34.1 | 114 | 43 | 38.1 | 122 | 49 | 40.0 |
| KH | 73 | 34 | 46.3 | 72 | 35 | 49.1 | 71 | 38 | 54.0 |
| SK | 73 | 27 | 37.0 | 95 | 42 | 44.3 | 85 | 28 | 33.3 |
| BM | 87 | 30 | 34.4 | 85 | 35 | 41.3 | 83 | 41 | 49.2 |
| TM | 73 | 38 | 52.0 | 83 | 27 | 33.0 | 79 | 35 | 45.0 |
| JR | 85 | 41 | 48.0 | 91 | 35 | 39.0 | 89 | 38 | 42.4 |
| Mean | 90.7 | 34.7 | 39.3 | 95.4 | 37.6 | 39.7 | 94.4 | 39.4 | 43.0 |
| S.D. | ±18.6 | ± 7.0 | ± 9.4 | ±17.3 | ± 9.7 | ± 7.5 | ±19.6 | ± 6.0 | ± 6.5 |

T1: Pretest; T2: Posttest; T3: Retention Test (Initial and Final Values presented in Newton-meters)

Table 13

Individual and Mean Endurance Results
for the Trained Leg of the Isokinetic Group

| Subject | T1 Start | T1 Finish | T1 Fatigue Index % | T2 Start | T2 Finish | T2 Fatigue Index % | T3 Start | T3 Finish | T3 Fatigue Index % |
|---|---|---|---|---|---|---|---|---|---|
| MB | 61 | 23 | 62.2 | 65 | 34 | 50.0 | 65 | 22 | 66.3 |
| KB | 111 | 43 | 61.0 | 117 | 41 | 65.1 | 114 | 54 | 52.4 |
| MC | 106 | 30 | 71.8 | 110 | 38 | 65.4 | 102 | 42 | 58.7 |
| LE | 129 | 49 | 62.1 | 138 | 57 | 58.8 | 136 | 57 | 58.8 |
| LG | 83 | 33 | 60.7 | 95 | 28 | 70.0 | 77 | 31 | 59.7 |
| TP | 108 | 39 | 63.8 | 108 | 45 | 58.8 | 104 | 46 | 55.8 |
| LW | 96 | 45 | 53.5 | 107 | 49 | 54.4 | 102 | 46 | 54.7 |
| Mean | 99.1 | 37.4 | 62.2 | 105.7 | 41.7 | 60.4 | 100.0 | 42.6 | 58.1 |
| S.D. | ±21.9 | ± 9.2 | ± 5.4 | ±22.2 | ± 9.7 | ± 6.9 | ±23.3 | ±12.4 | ± 4.5 |

T1: Pretest; T2: Posttest; T3: Retention Test (Start and Finish values presented in Newton-meters).

Table 14

Individual and Mean Endurance Results
for the Trained Leg of the Electrical Stimulation Group

| Subject | T1 Start | T1 Finish | T1 Fatigue Index % | T2 Start | T2 Finish | T2 Fatigue Index % | T3 Start | T3 Finish | T3 Fatigue Index % |
|---|---|---|---|---|---|---|---|---|---|
| SB | 58 | 22 | 62.8 | 75 | 22 | 70.9 | 83 | 28 | 65.9 |
| NG | 132 | 46 | 65.0 | 148 | 58 | 60.6 | 140 | 56 | 60.2 |
| KH | 85 | 35 | 58.7 | 85 | 30 | 65.1 | 85 | 35 | 58.7 |
| SH | 89 | 33 | 63.6 | 102 | 53 | 48.0 | 100 | 46 | 54.1 |
| KK | 89 | 33 | 63.6 | 91 | 33 | 64.2 | 89 | 49 | 45.5 |
| JK | 85 | 34 | 60.3 | 103 | 38 | 65.2 | 92 | 35 | 61.8 |
| CM | 100 | 43 | 56.8 | 99 | 50 | 49.3 | 92 | 46 | 50.0 |
| IS | 84 | 33 | 61.3 | 89 | 45 | 50.0 | 92 | 38 | 58.8 |
| TS | 106 | 52 | 51.3 | 114 | 52 | 54.8 | 126 | 49 | 61.3 |
| Mean | 92.0 | 36.8 | 60.4 | 100.7 | 42.3 | 58.5 | 99.9 | 42.4 | 57.3 |
| S.D. | ±20.0 | ± 8.9 | ± 4.3 | ±21.1 | ±12.2 | ± 8.2 | ±19.7 | ± 8.9 | ± 6.3 |

T1: Pretest; T2: Posttest; T3: Retention Test (Start and Finish values presented in Newton-meters).

Table 15

Individual and Mean Endurance Results
for the Trained Leg of the Combined Group

| Subject | T1 Start | T1 Finish | T1 Fatigue Index % | T2 Start | T2 Finish | T2 Fatigue Index % | T3 Start | T3 Finish | T3 Fatigue Index % |
|---|---|---|---|---|---|---|---|---|---|
| DB | 89 | 35 | 60.6 | 100 | 49 | 51.4 | 103 | 43 | 57.9 |
| SC | 111 | 38 | 65.9 | 119 | 52 | 56.8 | 134 | 45 | 66.7 |
| CD | 92 | 27 | 70.6 | 100 | 35 | 64.9 | 107 | 24 | 77.2 |
| DH | 111 | 52 | 53.7 | 129 | 54 | 57.9 | 132 | 53 | 59.8 |
| KH | 81 | 41 | 50.0 | 77 | 33 | 57.9 | 77 | 34 | 56.1 |
| SK | 85 | 35 | 58.7 | 95 | 41 | 57.1 | 94 | 49 | 47.8 |
| BM | 84 | 28 | 66.1 | 85 | 38 | 55.6 | 91 | 48 | 49.3 |
| TM | 89 | 35 | 60.6 | 96 | 31 | 67.6 | 91 | 35 | 61.2 |
| JR | 76 | 34 | 55.4 | 37 | 33 | 11.1 | 89 | 31 | 65.2 |
| Mean | 66.7 | 36.1 | 60.2 | 93.1 | 40.7 | 53.4 | 102.0 | 40.2 | 60.1 |
| S.D. | $\pm 27.0$ | $\pm 7.4$ | $\pm 6.6$ | $\pm 26.3$ | $\pm 8.9$ | $\pm 16.6$ | $\pm 19.5$ | $\pm 9.7$ | $\pm 9.0$ |

T1: Pretest; T2: Posttest; T3: Retention Test (Start and Finish values presented in Newton-meters).

Table 16

Individual and Mean Retention Scores
for the Trained Leg of the Isokinetic Group

| Test Period & Percentage of Strength Retained / Subject & Training Group | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T2 | T3 | % Retained | T2 | T3 | % Retained | T2 | T3 | % Retained |
| Isokinetic | | | | | | | | | |
| MB | 113 | 81 | 72.3 | 98 | 77 | 79.2 | 65 | 65 | 100.0 |
| KB | 172 | 184 | 107.1 | 146 | 160 | 109.3 | 117 | 114 | 97.7 |
| MC | 167 | 172 | 103.3 | 167 | 152 | 91.3 | 110 | 103 | 93.8 |
| LE | 236 | 236 | 100.0 | 199 | 199 | 100.0 | 138 | 138 | 100.0 |
| LG | 172 | 125 | 72.4 | 149 | 127 | 85.6 | 99 | 77 | 78.1 |
| TP | 167 | 175 | 104.9 | 156 | 136 | 87.0 | 110 | 104 | 95.1 |
| LW | 187 | 152 | 81.2 | 157 | 133 | 84.5 | 117 | 104 | 89.5 |
| Mean | 173.4 | 160.7 | 91.6 | 162.3 | 140.6 | 91.0 | 108.0 | 100.7 | 93.5 |
| S.D. | ±36.1 | ±48.7 | ±15.7 | ±19.4 | ±37.0 | ±10.4 | ±22.4 | ±23.9 | ± 7.7 |

T2: Posttest; T3: Retention Test (T2 and T3 values presented are in Newton-metres).

Table 17

Individual and Mean Retention Scores
for the Trained Leg of the Electrical Stimulation Group

| Test Period & Percentage of Strength Retained / Subject & Training Group | 0°/sec T2 | 0°/sec T3 | 0°/sec % Retained | 60°/sec T2 | 60°/sec T3 | 60°/sec % Retained | 180°/sec T2 | 180°/sec T3 | 180°/sec % Retained |
|---|---|---|---|---|---|---|---|---|---|
| Electrical Stimulation | | | | | | | | | |
| SB | 144 | 133 | 92.5 | 107 | 117 | 108.9 | 75 | 83 | 110.9 |
| NG | 252 | 222 | 88.2 | 233 | 221 | 94.8 | 148 | 142 | 96.3 |
| KH | 172 | 123 | 71.7 | 133 | 123 | 92.9 | 85 | 85 | 100.0 |
| SH | 184 | 168 | 91.2 | 157 | 142 | 90.5 | 102 | 100 | 98.7 |
| KK | 151 | 98 | 82.9 | 136 | 127 | 94.0 | 94 | 89 | 95.7 |
| JK | 180 | 140 | 77.4 | 152 | 130 | 85.7 | 103 | 92 | 89.5 |
| CM | 178 | 168 | 94.7 | 155 | 138 | 89.5 | 104 | 99 | 94.8 |
| IS | 148 | 163 | 110.1 | 126 | 133 | 105.4 | 89 | 98 | 109.1 |
| TS | 236 | 248 | 105.2 | 184 | 198 | 107.4 | 125 | 126 | 101.1 |
| Mean | 182.8 | 162.6 | 90.4 | 153.7 | 147.7 | 96.6 | 102.8 | 101.6 | 99.6 |
| S.D. | ±37.9 | ±47.4 | ±12.3 | ±36.9 | ±36.3 | ± 8.5 | ±22.1 | ±19.8 | ± 6.8 |

T2: Posttest; T3: Retention Test (T2 and T3 values presented are in Newton-metres).

Table 18

Individual and Mean Retention Scores
for the Trained Leg of the Combined Group

| Test Period & Percentage of Strength Retained / Subject & Training Group | 0°/sec | | | 60°/sec | | | 180°/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | T2 | T3 | % Retained | T2 | T3 | % Retained | T2 | T3 | % Retained |
| Combined | | | | | | | | | |
| DB | 130 | 134 | 106.1 | 129 | 132 | 102.1 | 100 | 103 | 102.7 |
| SC | 202 | 214 | 106.0 | 160 | 187 | 117.0 | 119 | 134 | 112.5 |
| CD | 160 | 157 | 98.3 | 152 | 152 | 100.0 | 100 | 107 | 106.8 |
| DH | 285 | 239 | 83.8 | 221 | 199 | 90.2 | 134 | 142 | 106.1 |
| KH | 168 | 133 | 79.0 | 125 | 130 | 104.4 | 77 | 77 | 100.0 |
| SK | 175 | 182 | 103.9 | 151 | 144 | 95.5 | 96 | 96 | 100.0 |
| BM | 142 | 148 | 103.8 | 123 | 117 | 94.5 | 94 | 91 | 97.1 |
| TM | 134 | 127 | 95.0 | 125 | 129 | 103.3 | 96 | 92 | 95.8 |
| JR | 141 | 123 | 87.5 | 118 | 111 | 94.3 | 84 | 89 | 106.5 |
| Mean | 170.8 | 161.9 | 95.9 | 144.9 | 144.6 | 100.1 | 100.0 | 103.4 | 103.1 |
| S.D. | ±48.6 | ±41.3 | ±10.3 | ±32.3 | ±30.2 | ± 7.9 | ±17.2 | ±21.5 | ± 5.4 |

T2: Posttest; T3: Retention Test (T2 and T3 values presented are in Newton-metres).