The Effects of Isometric Exercise versus Electrical Muscle Stimulation on Serum Enzymes, Plasma Lactate and Peak Torque Levels in Males

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ABSTRACT

Title of Thesis: The Effects of Isometric Exercise versus Electrical Stimulation on Serum Enzymes, Plasma Lactate and Peak Torque in Males

J. Ross Hodgkinson: Master of Science in the Theory of Coaching, 1990

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The purpose of the study was to examine the effects of electrical muscle stimulation (EMS) and isometric exercise (IE) on peak torque, plasma lactate and serum enzymes. The subjects were 14 male volunteers aged 22-41. The subjects were randomly assigned to either the EMS group (Stayodyn EMS/plus stimulator; bipolar technique of the quadriceps; 50 pulse/sec; pulse width of 200 μsec; 2 sec ramp and 8 sec maximum /10 sec rest for 45 trials) and the IE group (Kin-Com); 10 sec maximal voluntary contraction /10 sec rest for 45 trials). The subjects performed both tests on two alternate weekends. The peak torque value was measured for each contraction for both tests. Blood samples were taken from the antecubital vein prior to testing and at 5 minute, 1 hour and 24 hours post exercise to determine plasma lactate concentrations (HLA), serum creatine kinase (CPK), serum aspartate aminotransferase (AST), and serum lactate dehydrogenase (LDH) activities. The enzymes and HLA were analyzed using an Abbott VP Bichromatic Analyzer.

The results indicated that: (a) peak torque produced by IE was significantly greater ($P<0.05$) than that produced by the EMS/plus stimulator; (b) both exercise modes produced significant

increases ($P<0.05$) in HLA concentrations 5 minutes post exercise, with the increase in HLA concentration of the IE group being significantly greater ($P<0.05$) than that of the EMS group; (c) both exercise modes resulted in significant increases ($P<0.05$) in serum CPK activity 24 hours post exercise, with the increase in serum CPK activity of the IE group being significantly greater ($P<0.05$) than that of the EMS group; (d) both exercise modes resulted in significant increases ($P<0.05$) in serum AST activity 24 hours post exercise, with the increase in serum AST activity of the IE group being significantly greater ($P<0.05$) than that of the EMS group; (e) neither IE nor EMS resulted in a significant increase ($P>0.05$) in serum LDH activity.

It was concluded that both IE and EMS can produce an acute exercise response. The significant difference ($P<0.05$) in peak torque, HLA, serum CPK and AST between the two groups would suggest that the exercise stress of the IE group was greater and therefore, the intensity of the exercise was greater than that of the EMS. The significantly lower ($P<0.05$) torque values in the EMS group may have been due to: (a) "failed force outputs", due to the inability to activate all of the motor axons of a large muscle group; (b) "accommodation" to the electrical stimulator output; (c) motivational factors, which may include the inability to tolerate the electrical current, by some subjects.

Whether the increased acute exercise response demonstrated by the IE group would result in significant improvements in strength or endurance over the EMS group, would require a comparison over an extended training program.

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CHAPTER I

Introduction

Purpose of the Study

The purpose of the study was to compare the effects of isometric (static) exercise versus electrical muscle stimulation (EMS) on serum enzymes, plasma lactate, and peak torque levels in males.

Significance

Physical strength to some extent is essential to perform any athletic event. The benefit of exercising and strength training is also well established in the areas of rehabilitation and the prevention of injury (Booher & Thibodeau, 1985; Ericksson, 1976; Klafs & Arnheim, 1981). Therefore, it is important in athletics, rehabilitation and injury prevention to understand more about methods to increase bodily strength.

In recent years, there has been a development in exercise equipment, exercise programs and training protocols. One piece of equipment which has experienced increased use both in the area of rehabilitation and in the area of strength training is the electrical muscle stimulator (EMS). Although, electrical stimulation dates back to the early 1800's, much of the research and development has taken place within the

last 20 years. This work, both in rehabilitation and in athletics has dealt primarily with the chronic training effects of electrical muscle stimulation (Boutelle, Smith & Malone, 1985; Currier & Mann, 1983; McMiken, Todd-Smith & Thompson, 1983).

There has been little research done comparing the acute responses of the body to both isometric exercise and electrical muscle stimulation. Yoshimine-Gries (1986) has suggested that the changes produced after electrically induced muscular contractions maybe similar to those changes following voluntary muscle contractions. He has also suggested that electrical muscle stimulation may therefore, provide benefits similar to those achieved through traditional strengthening and exercise programs.

By measuring the tension generating capacities of electrical muscle stimulation as it compares to voluntary isometric exercise we may better determine the best application of this modality. Secondly, by comparing the acute metabolic and enzyme responses of the body to the two modes of exercise, the possible benefits of electrical muscle stimulation as it relates to isometric exercise may be determined. These results will clarify the efficacy and potential of electrical stimulation for the athletic trainer, sports therapist and physiotherapist.

The purpose of the present study was two fold. Firstly,

to determine the differences in peak torque values between voluntary isometric muscular contraction and involuntary electrically induced muscular contraction, and to compare the acute metabolic and enzyme responses of the body to the two types of muscular contractions.

Limitations

1. The two training techniques were highly dependent on the motivation of the subject. This may have limited the subjects' ability to tolerate a maximal level of electrical current.

2. It was assumed that the subjects understood the directions and complied with the instructions with respect to restricting extracurricular activities, diet, and exercise.

3. The subjects were able to determine their dominant leg, unless precluded by injury, either present or past.

4. It was assumed that the subjects attempted a maximal effort on each voluntary contraction.

5. The use of volunteers from a select group limited this study in terms of generalization to other populations.

6. An alpha level of .05 was established as the level of significance for statistical tests.

Delimitations

1. The subjects consisted of 14 male volunteers aged 22 to 41 years.

2. The study was limited to the maximum output of the Staodyn EMS/plus stimulator (Staodynamics Inc., Longmont, Colorado).

3. The data was collected at Intercity Orthopedic and Sports Medicine Clinic, Thunder Bay, Ontario.

Definitions

1. actuator - a lever arm aligned with a body segment to transmit force to a measuring device.

2. anticubital vein - a superficial vein of the anterior (antecubital) fossa of the proximal forearm.

3. aspartate aminotransferase (AST) - a group of enzymes which transfer amino groups from amino acid to alpha keto acids. They are found in both mitochondria and cytoplasm. Serum AST is derived mainly from cytoplasm. Isoenzymes of AST are not well defined.

4. biphasic - the flow of electrons alternating in both directions from the isoelectric point.

5. bipolar - the placement of surface electrodes on the distal and proximal attachments of a muscle/muscle groups.

6. creatine kinase (CPK) - a group of enzymes which catalyse the phosphorylation of creatine by adenosine triphosphate. They are most abundant in muscle. There are three isoenzymes of CPK.

7. electrical muscle stimulator (EMS) - an electro-therapeutic generator designed to electrically induce a muscle contraction.

8. enzyme - an organic substance working as a catalyst in a chemical reaction.

9. goniometer - protractor for measuring joint angles.

10. intensity - the amplitude, magnitude of current flow or amperage.

11. isoelectric - the point where no electrons are flowing.

12. lactate - or lactic acid is produced in the absence of oxygen by the reaction of pyruvic acid and hydrogen ions, diffusing into the blood during vigorous exercise.

13. lactate dehydrogenase (LDH) - a group of enzymes which catalyse the oxidation of lactate to pyruvate. They are found in most tissues. There are five isoenzymes of LDH.

14. maximum voluntary contraction (MVC) - greatest force generated from a willed muscle contraction.

15. monophasic - the flow of electrons in one direction from the isoelectric point.

16. on ramp - the gradual rise in the electrical stinulator amplitude to a pre-determined level.

17. peak torque - the maximum force generated about an axis, usually measured in foot/pounds or Newton/metres.

18. pulse width - the length of time of current flow for one waveform. Pulse duration may also be used.

19. repetition maximum (RM) - the total mass or percentage thereof that can be lifted a specific number of times.

20. waveform - a graphic representation of the pattern of electron flow generated by an electrotherapeutic device.

CHAPTER 2

Review of Literature

Strength

Strength, as defined by Wilmore (1977) is, "the ability to apply or resist force" (p. 21). Although strength can be enhanced by increasing the load or stress applied to a muscle through a variety of forms of exercise, certain inherent genetic factors may also limit our ability to increase strength. The most obvious of these differences are sex and somatotype, or body build. In the case of sex and skeletal configuration, there is little that can be done to modify their influences on strength training. Other traits, such as aerobic capacity and muscle fibre type although genetically determined, are subject to a certain degree of adaptability or trainability (Edington & Edgerton, 1976). In spite of these inherent limitations, there are good reasons to maintain a level of physical conditioning regardless of the level of athletic competition. Roy and Irvin (1983) have suggested that a conditioning program that is well designed, supervised, and scientifically sound can benefit in at least four ways: a) enhanced athletic performance, b) decreased risk of injury, c) decreased severity of injury, d) accelerated rehabilitation and return to activity after an injury (p. 28).

Conditioning and strength improvements occur as a result of the principle of specific adaptation to imposed demands (Arnheim, 1985). Whether it be isometric, isotonic or isokinetic exercise, it is necessary for the organism to be subjected to an overloading stress for this adaptation to occur (Astrand & Rodahl, 1986; Klafs & Arnheim, 1981; Perrine, 1968; Pipes, 1977). Any corresponding increase in strength due to this overloading is directly related to the intensity of the stimulus being applied (Berger, 1962a; Pipes, 1977). Similarly then, strength improvements are dependent upon the muscle tension generated. Therefore, the contractile stimulus that causes the greatest tension, whether it be voluntarily or electrically induced should theoretically result in the greatest improvement (Williams, Morrissey & Brewster, 1986). This is contrary to the findings of McMiken et al. (1983), who stated that changes in strength were not dependent upon the magnitude of the electrical stimulator voltage, nor on the muscular tension induced by the current.

The exact mechanism by which strength adaptations are caused are unclear. Increases in muscular strength have been attributed to cellular adaptations and to neuromuscular adaptations. The most widely accepted cellular adaptation is that of muscular hypertrophy.

Muscular hypertrophy due to strength training is the result of enlargement of the cross-sectional area of the myofibrils (Lesmes, Costill, Coyle & Fink, 1978). Edington and Edgerton (1976) have also stated that this increase in myofibril size may also be accompanied by the addition of myofibrils within the membrane boundary. Coyle, Feiring, Rotkis, Cote, Roby, Lee and Wilmore (1981) concluded that the force generating ability of a muscle could be increased through the hypertrophy of a single muscle fibre, or through hyperplasia, the splitting of individual muscle fibres. MacDougall, Ward, Sale and Sutton (1977) measured hypertrophic changes and found that progressive resistance training produced a 28% increase in elbow extension strength with a corresponding 11% increase in arm circumference. Using chronic electrical stimulation as the training stimulus, Curwin, Stanish and Valiant (1980) also reported both increases in hypertrophy, or muscle girth as well as increases in strength. In contrast, a number of researchers have demonstrated increases in strength without corresponding increases in hypertrophy (Berger, 1972; Coyle et al., 1981; Klafs & Arnheim, 1981). Currier and Mann (1983), and Taylor, Kots and Lavoie (1978) found significant increases in strength without corresponding changes in muscle girth in

a study comparing electrical stimulation, isometric exercise and a combined stimulation-isometric exercise group. It has been suggested that some of the hypertrophic increases measured as girth changes may be the result of some of the immediate responses to an acute strength training workout rather than the chronic adaptations to training. These acute responses may include increased blood flow to an exercised limb (Berger, 1962; Klafs & Arnheim, 1981). In addition, the reduction of adipose tissue as a chronic adaptation to training combined with the greater capacity to compress other soft tissue components of a limb may also contribute to inaccurate girth measurements.

Strength improvements have also been attributed to neuromuscular adaptations (Sale & MacDougall, 1981; Rasch & Morehouse, 1957). These neurological controls of muscular force include the variation of the number of motor units recruited, as well as the timing of the recruitment of the motor units and the rate at which each motor unit is triggered (Edington & Edgerton, 1976). This neuromuscular variability has been said to be analogous to the learning of specific responses to a particular type of applied load or stress (Astrand & Rodahl, 1986; Kots, 1977; Ostering, Bates & James, 1977). Gordon, Kowalski and Fritts (1967) have suggested that a facilitory reflex

resulting in a greater willed recruitment of motor units occurs in the central nervous system in response to specific daily training. This neurological control of muscular strength has been described by Lamb (1978) as an adaptation in the neurotransmitters or the chemical signals sent to the neurons. These neurotransmitters regulate both excitatory stimuli as well as inhibitory stimuli to the muscles. He suggests that through strength training we learn to reduce the inhibitory output of the brain and thereby increase the muscular response. However, this inhibitory response from the central nervous system means that even with maximum effort, neither all the motor units nor their maximal frequencies of discharge are mobilized (Ishiko, 1974; Mortani & DeVries, 1979).

On the basis of the above review, it is likely that some combination of the various physiological effects, in concert with genetic and biomechanical factors results in the variability in strength improvements from program to program and individual to individual (Booher & Thibodeau, 1985).

Isometric Exercise

Gordon et al. (1967) define maximum isometric exercise as "a deliberate exercise of the intact muscle working against an immovable resistance" (p. 139). They also stated

that it is proper to speak of static work rather than isometric work. Although the ability of isometric exercise to improve strength is well documented, the magnitude of muscular contraction necessary for a training stimulus is not well established (Mohr, Danzl, Akers & Landry, 1986). Klafs and Arnheim (1981) concluded that isometric strength was best developed exercising 5 days a week, with 5 to 10 repetitions of a maximal contraction held for 5 seconds. Coleman (1972) found that two, 20 second repetitions performed 3 times a week for 12 weeks as effective as two sets of 5 repetition maximum (RM) performed over an equal duration. In another study, Berger (1963) demonstrated that isometric exercise, three times a week, of 6 to 8 repetitions performed at two different joint angles was more effective than 2 RM sets, but not as effective as 6 RM sets. He concluded that the advantage of isometric exercise was that it enabled the athlete to perform a greater number of exercises in a shorter period of time. However, one of the major limitations to isometric exercise is that strength gains are specific to the joint angle exercised and to the type of contraction (Klafs & Arnheim, 1981; Pipes, 1977). The optimum angle for maximum isometric tension of the quadriceps has been found to be 60 degrees (Parker, Berhold, Brown, Hunter, Smith & Runhling, 1986; Selkowitz, 1985).

As stated previously, there is no agreement to the necessary contraction intensity needed to elicit isometric strength gains. Klafs and Arnheim (1981) demonstrated strength improvement with a program using a single contraction of 50% intensity performed daily for 5 weeks. Mohr et al. (1986) have reported values of 40% as well as intensity levels of 35% in work done by Muller (1957). Others have indicated that contraction levels of 65% are necessary to achieve strength gains (Owens & Malone, 1987; Stamford, 1987).

Due to the dynamic nature of sports, the relevance of isometric exercise to athletic performance is somewhat questionable. However, isometric exercise may have a limited place in sports like gymnastics, wrestling, football and downhill skiing where limited range isometric contractions are common place.

The greatest application of isometric exercise is likely in the area of rehabilitation. In cases where immobilization of injured limbs or limited movement of affected joints occurs, isometric exercise becomes a practical and effective method of reducing or preventing muscle atrophy (Selkowitz, 1985; Amuza & Obajuluwa, 1986). By preventing or minimizing muscle atrophy or muscle wasting, rehabilitation time can be reduced and the

return to athletic competition hastened.

Electrical Stimulation

While the application of electrical current as a treatment modality has increased in popularity in recent years, it is certainly not a new concept in the medical community. The use of electrical energy from the torpedo fish to treat a variety of ailments dates back to 400 B.C. (Benton, Baker, Bowman & Walters, 1981). In Germany, in 1744, Kratzenstein (cited in Benton et al., 1981) claimed he cured paralyzed fingers in 15 minutes utilizing an electrostatic generator (Almekinders, 1984). In 1922, Magendine (cited in Benton et al., 1981) applied an electrical current to needles inserted into muscle and nerves. Although he elicited a muscular contraction, the resultant pain and apparent lack of a therapeutic application led to the decline in use of the method (Licht, 1971). With the development of an electrical generator capable of producing a faradic current, work in the area continued into the 1830's. Further work by Duchenne led to the discovery of a method of "localized electrization" over specific areas of muscle. These areas were later determined, by Remak, to be the motor points of the muscle (cited in Benton et al., 1981). With the invention of the surface electrodes by Duchenne, and the

future application of faradic current, a specific method of faradization of human muscle was developed (Benton et al., 1981; Moreno-Aranda & Seirg, 1981). Electrical stimulation regained its popularity during the Second World War when it was used extensively for the diagnosis and maintenance of denervated muscle due to peripheral nerve injuries (Benton et al., 1981; Kramer & Mendryk, 1982). There was a further resurgence in the area of electrical muscle stimulation following the 1972 Olympics. It had been speculated that the Soviets were using electrical stimulation as a supplemental pre Olympic strength training technique (Campbell, 1979). This interest was largely due to the work of a Soviet physician, Kots. Kots (1977) reported that electrically induced muscle contractions could be produced that were 10 to 30% greater than the torque produced by a voluntary contraction. He also reported strength increases ranging from 15 to 40% following a treatment regime that involved 10 contractions of 15 seconds followed by a 50 second rest, repeated 5 times a week for 2 to 4 weeks (Kots, 1977).

The basic theory behind the use of electrical muscle stimulation is that if all the motor units of a muscle are stimulated or innervated simultaneously,

a muscle will respond with a maximal contraction (Halbach & Strauss, 1980; Malmberg, 1981). However, a muscle that is undergoing a voluntary contraction does so with a resultant force deficit. Values can be 60 to 70% of a maximal contraction (Astrand & Rodahl, 1986; Halbach & Strauss, 1980; McMiken et al., 1983). This resultant force deficit may be caused by two factors. In a voluntary contraction not all the motor units are recruited at the same time (Belanger & McComas, 1981; Kramer, Lindsay, Magee, Mendryk & Wall, 1984). Initially, the Type I slow twitch fibres are recruited, followed by the Type II A and B fast twitch fibres when more tension is required (McMiken et al., 1983). In addition, a force deficit may result from the discharging of motor units at a suboptimal frequency (Belanger & McComas, 1981).

There are conflicting positions on both the theoretical potential of electrical stimulation and its practical benefits in strength training. Jones, Bigland-Ritchie and Edwards (1979) have stated that "skeletal muscle can be maximally activated equally by voluntary effort and by electrical stimulation" (p. 402). This theory of equal or superior training stimulus using electrical stimulation is also supported by Ishiko (1974). Massey, Nelson, Sharkey and Comden, (1965) and Ward and

Grabnier (1982) have also stated that both the immediate and long term changes in metabolism, capillarization, blood flow, glycogen, the enlargement of fibres and the ability to exert force produced through electrical stimulation are similar to those changes associated with a normal voluntary contraction. In contrast, a number of researchers have failed to produce force outputs similar to those of a voluntary contraction (Houston, 1983; Walmsley, Letts & Vooys, 1984; Williams & Stutzman, 1959). It was suggested that this is due to an inability to activate muscle fibres in all portions of large muscle. The depolarizing current necessary to produce a maximal contraction must be capable of penetrating the skin as well as the superficial adipose tissue. The result has been the incomplete activation of all of the motor axons of a muscle (Houston, 1983).

The precise mechanism by which electrically induced strength gains are manifested is unclear. As stated previously, voluntary muscular training results in both central nervous system and cellular adaptations. McMiken et al. (1983) and Lamb (1978) have suggested that electrical stimulation bypasses or overrides the central nervous system with the resultant strength gains achieved by cellular adaptations alone. However, Kots (1977) has

demonstrated both cellular adaptations (manifested as cellular hypertrophy) as well as peripheral nervous system alterations through electrical stimulation. He found that strength increases achieved through stimulation remained even after the fibre cross-sectional hypertrophy had diminished. Kots (1977) concluded the recruitment of the peripheral nerves was, therefore, the primary mechanism behind electrically stimulated strength gains.

A number of studies have reported both sensory discomfort and a deep muscular "cramping" sensation associated with the use of electrical muscle stimulation (Cummings, 1980; Currier & Mann, 1984; Mohr et al., 1986). There has been extensive work carried out to eliminate this sensory discomfort and improve the quality of electrical muscle stimulators. One of the most popular stimulator formats utilizes a sinusoidal wave with a frequency between 50-100 cycles per second and a pulse duration modulated in a range of 1 to 10 milliseconds (Boutelle et al., 1985; Curwin et al., 1980; Hultman, Sjholm, Jaderholm & Krynicki, 1983). The most widely used stimulator exercise protocol uses 15 seconds of current followed by a 50 second rest period. This regime was first implemented by Kots (1977).

A number of modifications have been made to the

frequency, current waveform and pulse duration of electrical stimulators. Some stimulators have used a high frequency current as a carrier frequency in the 60-to-500 Hz range in an effort to eliminate associated sensory discomfort by producing an anesthetic effect. This current is applied in addition to a tetanizing current at 50 cycles per second (Parker et al., 1986; Solomonow, Eldred, Lyman & Foster, 1983). It was this concept that became known as the "Russian" stimulator thought to be utilized by Kots (1977) However, Edwards, Young, Hosking and Jones (1977) found that in order to maintain optimum force during a fatiguing contraction, it was necessary to alter the firing frequency to the motor units from the initial 50 Hz to 20 Hz after the first 30-45 seconds of stimulation.

In a study comparing different current waveforms, Kramer et al. (1984) found similar mean torque values between a maximum voluntary contraction and a stimulator producing an asymmetrical biphasic rectangular wave. They also found that stimulators producing a monophasic square wave and an asymmetrical biphasic spike wave produced significantly less torque than a maximum voluntary contraction. When comparing the three waveforms, Kramer et al. (1984) also found that with the asymmetrical biphasic rectangular wave, a symmetrical biphasic spike

and a monophasic square wave that 20, 50 and 100% of the subjects reached the maximum output of the stimulators, respectively.

In studies measuring the peak torque generated, researchers have been unable to duplicate the contractile forces 10 to 30% greater than a MVC reported by Kots (1977) and Walmsley et al. (1984). Kramer and Semple (1983) reported EMS generated torque at 93% of a MVC, while Mohr et al. (1986) reported the highest value to be 85%, with a mean torque value of 47% of the MVC value. In other studies measuring peak torque, Owens and Malone (1987) and Parker et al. (1986) obtained average electrically stimulated values of 60% and 27%, respectively. Although Laughman, Youdas, Garrett and Chao (1983) obtained EMS peak torque values of 33% of a MVC, they reported similar increases in strength when compared to isometric exercise at 78% of a MVC.

A number of researchers have also reported the decline over time of contractile force, in electrically induced muscle contractions. When examining the contractile force in frog muscle, Fitts and Holloszy (1976) reported a 36% decline from the initial torque values following 15 minutes of 30 second stimulation and 30 second rest. When comparing the 15/50 stimulator protocol of Kots (1977) to the 12/8 regime,

Parker et al. (1986) found the torque of the latter to be 50% less. Parker et al. (1986) and Laughman et al. (1983) concluded that even though the stimulated muscle was working at a lower contraction intensity, it was experiencing a chronic training effect similar to that of voluntary exercise. This characteristic loss of force at the later stages of an electrically induced contraction was described by Boutelle et al. (1985) as an accommodation phenomenon. It was postulated that this phenomenon may be due to muscle fatigue, increased apprehension, phosphagen depletion or decreased sensitivity to the contractile stimulus (Boutelle et al., 1985).

As reported earlier, in a voluntary contraction the slow twitch fibres are recruited before the fast twitch motor units. However, in an electrically induced contraction, the fast twitch fibres are activated by the large nerve fibres in the peripheral nerve trunk. These fast twitch motor units are composed of muscle fibres that fatigue quickly but contribute to the strength performance of an individual (Parker et al., 1986; Tesch, Sjodir, Thortensson & Karlsson, 1978).

There is some question as to the role patient motivation plays in the application of EMS. McMiken et al., (1983) have stated that the therapeutic value of EMS lies

in the fact that voluntary exertion by the patient is not required. Therefore, the results of treatment are not bound to motivation or tolerance for exertion. However, Williams et al. (1986) and Murray, Gardner, Mollinger and Sepic (1980) reported that the current must be tolerated to achieve sufficient intensity for an optimal contraction.

A number of researchers concluded that the intensity of an electrically induced contraction was directly related to the intensity and frequency of the stimulator, as well as the pulse duration and waveform (Cummings, 1980; Houston, 1983; Garnhammer, 1983). This was contrary to the work of Selkowitz (1985) and McMiken et al. (1983) who found that there was no consistent relationship between changes in current amplitude and the torque produced. They concluded that this variability may be the result of central nervous system influences comprised of sensory, emotional responses and the perception of anxiety and discomfort. Williams et al. (1986) concluded that the higher the patient's motivation and tolerance to exertion the better they would be suited to withstand increased electrical current.

A number of researchers have noted significant increases in strength when comparing EMS to control groups but no significant differences when compared to voluntary isometric

training protocols (Eriksson, Haggmark, Kessing & Karlsson, 1981; Garrett, Laughman & Youdas, 1980; Halbach & Strauss, 1980; Kubiak, Whitman & Johnston, 1987; Massey et al., 1965; McMiken et al., 1983; Romero, Stanford, Schroder & Fahey, 1982).

The efficacy of electrically stimulated chronic training effects in patient populations is well documented (Eriksson, et al., 1981; Johnson, Thurston & Ashcroft, 1977; Laughman et al., 1983; Selkowitz, 1985). However, the findings of Kots (1977), with regard to contractile forces and strength increases in healthy subjects and athletes have not been replicated (Massey et al., 1965; Mohr et al., 1986; Parker et al., 1986; Walmsley et al., 1984).

Plasma Lactate

The primary function of many chemical reactions in the cell is making energy in foods available to the various physiological systems of the cell (Guyton, 1977). The substance adenosine triphosphate (ATP) is the key element in providing the fuel for physiological systems like that of muscular contraction.

In high-intensity activities of a duration of 10-30 seconds, energy is provided from the breakdown of creatine phosphate that is stored in limited supply in the muscle (Edington & Edgerton, 1976). For activities lasting between

30 seconds and 2 minutes, the primary source of ATP is through the process of anaerobic glycolysis. This process involves the breakdown of muscle glycogen when oxygen is unavailable or insufficient for cellular oxidation of glucose to take place. The end products of this glycolytic reaction are pyruvic acid and hydrogen atoms which are combined with nicotinamide adenine dinucleotide (NAD+) to form reduced nicotinamide adenine dinucleotide (NADH). The accumulation of either or both of these would stop the glycolytic process and prevent the further formation of ATP. When the quantities of pyruvic acid and hydrogen atoms become excessive they react with each other to form lactic acid (Guyton, 1977). Under anaerobic conditions, the major proportion of the pyruvic acid is converted into lactic acid which readily diffuses out of the muscle and into the blood (Hermansen, 1971; McGrail, Bonen & Belcastro, 1977). Thus, the formation of lactate signifies that the nonoxidative or anaerobic phase of glycolysis is taking place (Edington & Edgerton, 1976). The normal range of serum lactate is 0.6 to 1.8 mmol/L., at rest.

The peak blood levels of lactate vary depending on the intensity and duration of the exercise and may not become evident until 1 to 10 minutes following the completion of the activity (McGrail et al., 1977). Hermansen (1971)

concluded that blood lactate concentrations were dependent upon the rate of production of lactate by the muscle, the rate of diffusion of lactate from the cell to the blood, and the rate of removal. It was concluded by Karlsson (1970) that there was good agreement between blood lactate concentrations and corresponding muscle lactate concentrations. In contrast, Tesch (1980) found that after 50 maximum contractions of one leg that the muscle lactate values were eight times greater than the blood lactate values. This finding, and the lag time noted above for the appearance of lactate in the blood after completion of exercise, would suggest that lactate diffusion from the muscle is the rate limiting step in the reaction.

A number of studies have been done to determine the effects of intermittent exercise on lactate levels. Edwards, Melcher, Hesser and Wigertz (1970) found no increase in lactate concentrations with intermittent exercise at 10 second intervals. When comparing a number of work to rest schedules, Saltin and Essen (1970) reported that lactate levels were elevated with 30 seconds of exercise followed by 60 seconds of rest, and 60 seconds of exercise followed by 120 seconds of rest. They also found no significant increases in lactate with 10 seconds of exercise to 20 seconds rest and 20 seconds of exercise to 40 seconds rest.

A number of researchers have also reported significant increases in blood lactate following electrically induced muscle contractions (Fitts & Holloszy, 1976; Gollnick, Karlsson, Piehl & Saltin, 1978; Hermansen, 1971; Houston, Farrance & Wright, 1982). Hermansen (1971) also compared lactate concentrations in the blood to those in the muscle and found them to be approximately equal following EMS.

Serum Enzymes

The concentration of intracellular enzymes normally found in the serum is an index of the constant replacement of cells which occurs in the body (Stokke, 1982). This steady state of enzymes will be altered by a change in cell permeability (Ball, Kirby & Bogen, 1965; Brown, 1973). There is also some question as to what degree the leakage of enzymes from the cells may be the result of cell necrosis. Stokke (1982) has attributed the efflux of enzymes to three possible causes: 1) due to a significant "normal-physiological" rise in the permeability of the cell; 2) due to a "pathological" reversible rise in the permeability; 3) due to more permanent cell damage associated with pathological processes that are followed by the customary repair processes.

Research has shown that exercise of sufficient intensity will result in an elevation of the serum level of

these intracellular enzymes. These include creatine phosphokinase (CPK), lactate dehydrogenase (LDH), and aspartate aminotransferase (AST) (Hunter & Critz, 1971). Other exercise variables that will effect cell permeability include the type of exercise, the duration and the fitness level of the individual (Ahlborg & Brohult, 1967; Berg & Haralambie, 1978; Schwane, Johnson, Vandenakker & Armstrong, 1983; Stokke, 1982).

Serum Creatine Phosphokinase

Creatine phosphokinase (CPK) is present in high concentrations in skeletal and cardiac muscle and is the catalyst for the reversible phosphorylation of creatine by ATP (Szasz, Gruber & Bernt, 1976). It is of clinical significance because increases in serum CPK almost exclusively reflect disease or trauma in skeletal or cardiac muscle (Szasz et al., 1976). The normal range for serum CPK is between 10-100 IU/L (Brown, 1973; Canatorow & Trunper, 1975; Noakes & Carter, 1976; Shumate, Brooke, Carroll & Davies, 1979). Studies examining the effects of endurance exercise on serum CPK levels have demonstrated significant post exercise increases (Magazanik, Shapiro, Meytes & Meytes, 1974: Sanders & Bloor, 1975; Schnorr, Grande & Christiansen, 1980).

Research examining the effects of intermittent exercise

has been less conclusive. Graves, Clarkson, Kirwin and Litchfield (1984) found no significant increase in serum CPK following 40 repetitions of isometric exercise utilizing a work to rest ratio of 10:20 seconds.

In a study examining the effects of 3 sets of 8 repetitions at 70% of one repetition maximum of an isotonic exercise, Otto and Smith (1984) also found no significant increases in serum CPK. In contrast, Clarkson, Litchfield, Graves, Kirwin and Byers (1985) found isometric exercise of 10 seconds work to 10 seconds rest caused significant increases in serum CPK after 60 repetitions.

In research examining the effects of electrical stimulation on serum CPK levels there have also been conflicting results. Yoshimine-Gries (1986) found that 10 electrically induced contractions of 15 seconds duration, followed by 50 seconds rest raised serum CPK levels significantly. In contrast, Spare (1986) found EMS of the quadriceps muscle had no significant effect on serum CPK values.

The most significant increases in serum CPK values were found to occur at 24 hours post exercise (Newham, Jones & Edwards, 1983; Stokke, 1982; Tiidus & Ianuzzo, 1985).

Serum Lactate Dehydrogenase

In the process of anaerobic glycolysis lactate dehydrogenase (LDH) is the catalyst in the conversion of pyruvic acid to lactic acid (Guyton, 1977).

Although serum LDH is found in a number of body tissues the isoenzymes LDH-5 is predominantly found in skeletal muscle (Dito, 1979; Rose, Lowe, Carrol, Wolfson & Cooper, 1970). Rose et al. (1970) has stated that the release of serum LDH may reflect cellular disruption resulting in the efflux of the enzyme from intracellular to extracellular compartments. This rise in serum LDH levels may be used as an indicator of cellular necrosis and increased cell membrane permeability due to myocardial trauma or skeletel muscle stress (Halonen & Konttinen, 1962; Otto & Smith, 1984; Rose et al., 1970). The changes in serum LDH values were noted within the first 24 hours post-exercise (Cerny & Haralambie, 1975; Clarkson, Kroll, Graves & Record, 1982). Normal resting values in the range of 60 to 250 IU/L have been reported by Brown (1973), while Noakes and Carter (1976) have established resting serum LDH values to be in the range of 60-145 IU/L.

In studying the effects of endurance exercise on serum LDH levels Halonen and Konttinen (1962) and Cerny and Haralambie (1975) found significant increases had occured.

In contrast, Sanders and Bloor (1975) found no change in serum LDH values after endurance exercise.

Short duration, high intensity exercise also had conflicting results. Haralambie, Cerny and Huber (1976), studying the effects of bobsledding and Armstrong, Ogilive and Schwane (1983), studying eccentric leg exercise found significant increases in serum LDH levels. Significant increases were also found by King, Statland and Savoy (1976) and Tiidus and Ianuzzo (1985) following short term exercise, although of the enzymes studied, LDH exhibited the smallest change. A number of researchers found no significant changes in serum LDH levels due to short term exercise (Karlsson, 1970; McGrail et al., 1977; Otto & Smith, 1984).

In examining the effects of an electrically induced muscle contraction on serum LDH levels there is limited research. Yoshimine-Gries (1986), using 10 repetitions of the 15/50 second Kots' protocol found significant increases in serum LDH. Spare (1986) also found significant increases in serum LDH following EMS of the quadriceps muscle.

Serum Aspartate Aminotransferase

Aspartate aminotransferase (AST) was formerly known as glutamine-oxaloacetic transaminase (GOT) (Brown, 1973).

Aspartate aminotransferase provides intermediates in the tricarboxylic acid cycle, converting aspartate and pyruvate into oxalocetate and alanine. It is found in high concentration in cardiac and skeletal muscle (Schlang & Kirkpatrick, 1961). The normal resting range of serum AST is 4-20 IU/L (Brown, 1973; Noakes & Carter, 1976). Research has shown that exercise of sufficient intensity will result in significant increases in serum AST (Hunter & Critz, 1977; Stokke, 1982).

Significant increases in serum AST levels have been reported after a variety of activities including distance running, basketball and swimming (Critz & Cunningham, 1972; Noakes & Carter, 1976; Schnohr et al., 1980). King et al., (1976) as well as Tiidus and Ianuzzo (1985) reported significant increases in serum AST following short term exercise. However, Halonen and Knottinen (1962) found that 2 hours of marching did not result in a significant increase in serum AST values.

Research on the effects of electrical stimulation on serum AST has been limited. Increased serum AST levels were reported by Yoshimine-Gries (1986) and Spare (1986) with electrically stimulated exercise.

CHAPTER 3

Methodology

Restatement of the Purpose of the Investigation

The purpose of the study was to compare the effects of isometric (static) exercise versus electrical muscle stimulation (EMS) on serum enzymes, plasma lactate and peak torque levels in males.

Subjects

The subjects in this study consisted of 14 male adults (characteristics of the subjects are presented in Table 1). The subjects were volunteer recreational athletes. Prior to any experimentation, the basic premise of the study was explained to the subjects.

Procedures

The subjects were instructed to refrain from exercising 48 hours prior to testing on the test day and until after the 24 hour post test blood samples were taken. The subjects received a written copy of these instructions prior to testing (see Appendix A). Each volunteer was required to fill out a consent form (see Appendix B).

The subjects were randomly assigned to either Group 1

Table 1

Characteristics of Subjects

Subject	Age (yr)	Weight (kg)	Height (cm)
1	22	84.5	174.5
2	34	92.0	183.0
3	24	65.0	172.0
4	33	79.0	181.0
5	32	100.0	185.0
6	26	85.0	170.0
7	24	75.0	178.0
8	41	77.0	183.0
9	25	86.0	178.0
10	30	87.0	178.0
11	31	82.0	177.0
12	26	71.0	177.0
13	29	69.0	173.0
14	28	83.0	172.0
Mean	28.9	81.1	177.3
S.D.	5.1	9.3	4.6

(isometric exercise) or Group 2 (electrical muscle stimulation) on the first test date. One week later the subjects in Group 1 performed the electrical stimulation protocol, and those in Group 2 performed the isometric exercise protocol.

Isometric Exercise

The subjects selected their dominant leg. The choice of preferred leg was recorded. The subjects were then seated in in the corresponding side of the Kin-Com (Med-Ex Diagnostics, Vancouver, British Columbia) and the axis of the actuator arm was aligned with the axis of the knee. The shin pad was then aligned with the distal tibia and the radius measurement was recorded. The actuator was adjusted to place the knee in 60 degrees of flexion, with the setting on the Kin-Com verified using a goniometer.

A pre-exercise maximum voluntary contraction (MVC) was performed isometrically for 10 seconds. The maximum peak torque value was measured and recorded.

The subjects were then instructed to perform a series of isometric exercises. They were instructed to push as hard as they could, building to a maximal contraction as the Kin-Com counted to 10 seconds. After 10 seconds they were

instructed to relax the contraction for a 10 second timed rest. The maximum peak torque value was measured and recorded for each of 45 repetitions. The subjects were informed of their results after each repetition. The subjects were instructed to attempt a maximum contraction for each repetition, without attempting to pace themselves.

Electrical Muscle Stimulation

The subjects selected their dominant leg. The choice of preferred leg was recorded. The subjects were connected to the EMS/plus, electrical muscle stimulator (Staodynamics Inc., Longmont, Colorado) using the bipolar technique, as outlined by Benton et al., (1981). The quadriceps was first wiped with an alcohol swab to reduce electrical impedance. Ultrasound gel was used as the conducting medium for the electrodes. Both channels of the stimulator were utilized simultaneously. The two negative electrodes were placed on the proximal end of the belly of the quadriceps. The two positive electrodes were aligned with the appropriate negative electrode at the distal end of the belly of the quadriceps. The electrodes were secured to the leg with an elastic compression bandage.

The subjects were then seated on the corresponding side of the Kin-Com, and the axis of the actuator arm was aligned with the axis of the knee. The shin pad of the

acutuator arm was aligned with the distal tibia and the radius measurement was recorded. The acutuator was the adjusted to place the knee at 60 degrees of flexion. This setting was verified using a goniometer.

A pre-exercise maximum voluntary contraction was performed isometrically for 10 seconds. The maximum peak torque value was measured and recorded.

The EMS/plus stimulator was set to deliver an AC biphasic symmetrical rectangular wave with a pulse frequency of 50 pps, and a pulse duration of 200 microseconds. A 2 second on ramp and an 8 second on time was set and verified with a stopwatch. The rest cycle was set at 10 seconds and verified with a stopwatch. The subjects were instructed not to voluntarily contract their quadriceps when the stimulator current was activated. They were instructed to tolerate as much current output as possible. The two channels of the stimulator were turned on, and the intensity was increased as tolerated.

The Kin-Com program was engaged and the first two repetitions were used to increase the stimulator output, and to synchronize the Kin-Com and the EMS/plus stimulator. On subsequent repetitions the maximum peak torque generated by the involuntary contraction was measured and recorded for each of 45 repetitions. The subjects were informed of the

reading. The subjects were instructed to tolerate as much current output as possible. The stimulator intensity was increased as accommodation to the current occured.

For the second segment of the study, the subjects were scheduled at the same time of day, one week later. Again, subjects were instructed to refrain from strenuous activity or exercise 48 hours prior to testing and until the 24 hour post-exercise blood sample was taken.

Blood Sample

A pre-exercise blood sample was taken from the antecubital vein of each subject.

After the final repetition, a 5 minute interval was timed and a post-exercise blood sample taken. An additional 55 minute interval was timed and a 1 hour post-exercise blood sample taken. The subjects were instructed to return in 24 hours for another post-exercise blood sample. The subjects were again instructed to refrain from strenuous activity or exercise during this time.

The blood samples were centrifuged and the serum was refrigerated. The samples were analyzed within 24 hours of being taken.

Enzyme Determination

The Abbott Laboratories VP Bichromatic Analyser (Abbott

Laboratories (Canada) Ltd., Toronto, Canada) was used for enzyme determination.

Measurement of Serum LDH

Serum LDH (EC 1.1.1.27) was measured by a modification of the method of Armadore (Henry, Cannon & Winkelman, 1974). In this method, lactic acid is converted to pyruvic acid by the action of the LDH in the sample. Nicotinamide adenine dinucleotide (NAD) is required as a coenzyme and is reduced to NADH during the reaction. The activity of LDH is measured by the increase in absorbance of NADH with time, as measured at 340 nm.

Measurement of Serum CPK

Serum CPK (EC 2.7.3.2) was measured by a modification of Rosalki (Henry et al., 1974; Szasz et al., 1976; Szasz, Gerhardt & Gruber, 1977; Szasz, Walsenstrom & Gruber, 1979). In this procedure CPK removes a phosphate group from creatine phosphate and transfers it to adenosine diphosphate (ADP) to form ATP. The reaction is coupled with a second enzyme, hexokinase (HK), which converts glucose to glucose-6-phosphate. The amount of glucose-6-phosphate formed is limited by the ATP produced in the first reaction because ATP is required as a coenzyme for the second reaction. In order that the reaction rate may be measured at 340 nm, a

third enzyme is introduced which uses NAD as a coenzyme. The enzyme is glucose-6-phosphate dehydrogenase (G-6-PD) which converts glucose-6-phosphate to 6-phosphoguconate (6-PG).

Measurement of Serum AST

Serum AST (EC 2.6.1.1) activity was measured by a modification of Karmen's method (Henry et al., 1974). In this method, AST in the sample catalyzes the transfer of theasparate amino group to alpha-ketoglutarate forming oxalacetate and glutamate.

In order for the reaction to be measured at 340 nm, malic dehyrogenase (MD), which requires NADH as a coenzyme, is used. This allows the conversion of oxalic acid to malic acid with concomitant conversion of NADH to NAD. As the second reaction is limited by the amount of oxalic acid formed in the first reaction, the change in absorbance at 340 Nm is a measure of serum AST activity.

Measurement of Plasma Lactate (LA)

Plasma LA was measured enzymatically using a fluro-metric technique described by Sigma Chemical Co. (St. Louis, Missouri; Technical Bulletin No. 826-UV). In this method pyruvic acid is converted to lactic acid by the action of the LDH in the sample. In the presence of excess NADH,

the pyruvic acid is converted to LA. The reduction of absorbance at 340 nm becomes a measure of the amount of pyruvic acid originally present. To measure LA the reaction is carried out in reverse with excess NAD.

Quality Control

Within run and between run quality control, sera were used with all assays. The quality control materials were supplied by Wellcome Diagnostics, Dartford, England. Assay control results not within the acceptable limits were repeated.

Analysis of the Data

The data from both tests were analyzed statistically utilizing a two-way analysis of variance for repeated measures (ANOVA), and a Tukey test was used to identify differences when a significant F-ratio was observed. The significance level was set at 0.05.

Chapter 4

Results

Peak Torque

The means, standard deviations and percent of the MVC pretest for the two treatments are shown in Table 2. The F-ratios indicated that there was a significant difference ($P<0.05$) between the groups, within the trials and within the groups vs trials (Table 3).

The pretest, mean peak torque MVC of the isometric exercise and electrical stimulation groups were 715 Nm and 719 Nm, respectively. The Tukey test indicated that there was no significant difference ($P>0.05$) between the pretest values of the two groups. The pretest MVC values were significantly greater ($P<0.05$) than all other trials in both groups (Table 4). There was a significant difference ($P<0.05$) in all trials except the pretest values between the two groups.

The within trial Tukey test illustrates the rate at which torque production diminished for the groups. In examining the isometric exercise group it was noted that the torque for trials 1-5 (613 Nm, 86% of the MVC) and trials 6-10 (591 Nm, 83% of the MVC) decreased significantly ($P<0.05$), after 15 repetitions to 567 Nm (79% of the MVC) in trials 16-20 and 547 Nm (76% of the MVC) in trials 21-25, respectively. The rate of decline in torque production

Table 2

Means, Standard Deviations, Range and Percent of MVC
for Isometric Exercise and Electrical Stimulation

Group and	Pretest MVC	Trial (1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
Isometric Exercise										
Mean	715	613	591	584	567	547	545	528	522	518
S.D.	97	103	118	110	104	97	90	84	93	89
Range	536 - 865	445 - 792	445 - 792	431 - 768	408 - 731	392 - 685	397 - 673	395 - 634	379 - 677	409 - 696
% of MVC	100	86±7	83 ±9	82 ±10	79 ±11	76 ±11	76 ±10	74 ± 10	73 ±12	72 ±11
Electrical Stimulation										
Mean	719	296	324	311	305	298	271	273	272	275
S.D.	87	100	144	152	144	126	112	143	123	126
Range	552 - 815	152 - 484	126 - 506	130 - 537	115 - 568	123 - 520	136 - 520	125 - 538	118 - 477	99 - 429
% of MVC	100	41 ±16	45±22	43±22	42±22	41±19	38±18	38±18	38±18	38±17

Unit is Nm.

Table 3

Summary of Analysis of Variance for Peak Torque Values

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F-ratio
Between				
Groups (ISO vs ES)	3,699,254.496	1	3,699,254.496	34.822*
Error	2,549,634.769	24	106,234.782	
Within				
Trials	2,136494.419	9	2,377,388.269	86.145*
Groups vs Trials	450,508.85	9	50,056.539	18.165*
Error	595,225.231	216	2,755.672	
Total	9,431,117.765	259	6,235,689.758	

* $p < 0.05$

Table 4
Comparison of Maximum Voluntary Peak Torque to Isometric Exercise Peak Torque and Electrical Stimulation Peak Torque

Group	Trial		Isometric Exercise									
			Pre	(1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
		Peak Torque	715	613	591	584	567	547	545	528	522	518
Isometric	Pre	715	--	102*	124*	131*	148*	168*	170*	187*	193*	197*
	(1-5)	613		--	22	29	46*	66*	68*	85*	91*	95*
	(6-10)	591			--	7	24	44*	46*	63*	69*	73*
	(11-15)	584				--	17	37	39	56*	62*	66*
	(16-20)	567					--	20	22	39	47*	49*
	(21-25)	547						--	2	19	25	29
	(26-30)	545							--	17	23	27
	(31-35)	528								--	6	10
	(36-40)	522									--	4
	(41-45)	518										--
Electrical Stimulation	Pre	719										
	(1-5)	296										
	(6-10)	324										
	(11-15)	311										
	(16-20)	305										
	(21-25)	298										
	(26-30)	271										
	(31-35)	274										
	(36-40)	272										
	(41-45)	275										

*: The Tukey value at $P<0.05$ is 40. Unit is Nm.

Table 4 continued.

Group	Trial		Electrical Stimulation									
			Pre	(1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
		Peak Torque	719	296	324	311	305	298	271	274	272	275
Isometric	Pre	715	4	419*	391*	404*	410*	417*	498*	441*	443*	440*
	(1-5)	613	106*	317*	289*	302*	308*	315*	396*	339*	341*	338*
	(6-10)	591	128*	295*	267*	280*	286*	293*	374*	317*	319*	316*
	(11-15)	584	135*	288*	260*	273*	279*	286*	367*	310*	312*	309*
	(16-20)	567	152*	271*	243*	256*	262*	269*	350*	293*	295*	292*
	(21-25)	547	172*	251*	223*	236*	242*	249*	330*	273*	275*	272*
	(26-30)	545	174*	249*	221*	234*	240*	247*	328*	271*	273*	270*
	(31-35)	528	191*	232 *	204*	230*	236*	243*	324*	267*	269*	264*
	(36-40)	522	197*	226*	198*	224*	230*	237*	318*	261*	263*	258*
	(41-45)	518	201*	222*	194*	220*	226*	231*	312*	255*	257*	252*
Electrical Stimulation	Pre	719	--	423*	395*	408*	414*	421*	448*	445*	447*	444*
	(1-5)	296		--	28	15	9	2	25	22	24	21
	(6-10)	324			--	13	19	26	53*	50*	52*	49*
	(11-15)	311				--	6	13	40*	37	39	36
	(16-20)	305					--	7	34	31	33	30
	(21-25)	298						--	27	24	26	23
	(26-30)	271							--	3	1	4
	(31-35)	274								--	2	1
	(36-40)	272									--	3
	(41-45)	275										--

*: The Tukey value at P<0.05 is 40. Unit is Nm.

continued at a lesser rate for trials 11-15 (584 Nm, 82% of the MVC), and trials 16-20 (567 Nm, 79% of the MVC) decreasing significantly ($P<0.05$), after 20 repetitions to 528 Nm (75% of the MVC) in trials 31-35 and 522 Nm (73% of the MVC) in trials 36-40, respectively. After declining to 547 Nm (76% of the MVC) at trials 21-25 there was no further significant difference ($P>0.05$) in torque production for the isometric exercise group (Table 4).

In examining the electrical stimulation torque values, the greatest mean torque value was 324 Nm (45% of the MVC) during trials 6-10. This value declined significantly ($P<0.05$) to 271 Nm (38% of the MVC) at trials 26-30 and continued to be significantly lower ($P<0.05$) through trials to 41-45. The 311 Nm (43% of the MVC) produced in trials 11-15 was the only other trial that was significantly greater ($p<0.05$) than the torque produced in trials 26-30 (271 Nm (38% of the MVC) (Table 4).

Of note was the fact that 9 of the 14 subjects accommodated to the maximum current output of the EMS/plus stimulator, prior to the completion of the 45 trials. Three of the remaining subjects did not reach the maximum output of the EMS/plus stimulator. One subject failed to register any torque production after the initial 15 trials of electrical stimulation and his values were excluded.

Serum Enzymes

Serum Creatine Kinase

The means and standard deviations of the serum creatine kinase activities are presented in Table 5. The analysis of variance indicated that while there was no significant difference ($P>0.05$) between the two groups, there was a significant difference ($P<0.05$) with time (Table 6).

The Tukey test indicated that the serum CPK activities 24 hours after both isometric exercise and electrical stimulation were significantly greater ($P<0.05$) than the before, 5 minutes, and 1 hour post-exercise levels. The serum CPK activities for the isometric exercise 24 hour post-exercise were also significantly greater ($P<0.05$) than the 24 hour electrical stimulation (Table 7).

Serum Aspartate Aminotransferase

The means and standard deviations of the serum aspartate aminotransferasee activities are presented in Table 8. The F-ratios indicated that there was a significant difference ($P<0.05$) in serum AST activities with time (Table 9). The Tukey test indicated the serum AST activities 24 hours after both isometric exercise and electrical stimulation were significantly greater ($P<0.05$) than the before, and 1 hour post-exercise levels. However, only the 24 hour post-exercise value for the isometric exercise group was significantly greater ($P<0.05$)

Table 5

Serum CPK Activities Before and After
Isometric Exercise and Electrical Stimulation

Group	Before	5 min after	1 h after	24 h after
Isometric Exercise	141.8 ±106.7	144.3 ±110.5	166.9 ±104.0	312.5* ±236.2
Electrical Stimulation	135.3 ±90.1	140.1 ±97.4	151.5 ±101.5	232.2* ±188.2

Values are means ± S.D.. Unit is IU/L .

* : $p < 0.05$ (between Before and 24 h after).

Table 6

Summary of Analysis of Variance for CPK Activities

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F-ratio
Between				
Groups (ISO vs ES)	20,966.516	1	20,966.516	.327
Error	1,667,494.251	26	64,134.394	
Within				
Time	338,672.20	3	112,890.736	26.414*
Groups vs Time	27,388.678	3	9,129.559	2.136
Error	333,368.823	78	4,273.959	
Total	2,387,890.477	111	211,395.164	

* $p < 0.05$

Table 7

Comparisons of CPK Activities Before and
After Isometric Exercise and Electrical Stimulation

		Isometric Exercise				Electrical Stimulation			
		Before (142)	5 min after (144)	1 h after (167)	24 h after (312)	Before (135)	5 min after (148)	1 h after (151)	24 h after (232)
ISO	(142)	--	2	25	170*	7	2	9	90*
	(144)		--	23	168*	9	4	73	88*
	(167)			--	145*	32	27	16	65*
	(312)				--	177*	172*	161*	80*
ES	(135)					--	5	16	97*
	(140)						--	11	92*
	(151)							--	81*
	(232)								--

* $p < 0.05$ Tukey value 65.

Table 8

Serum AST Activities Before and After
Isometric Exercise and Electrical Stimulation

Group	Before	5 min after	1 h after	24 h after
Isometric Exercise	20.7 ± 5.4	22.4 ±5.8	21.0 ±6.8	26.4* ±8.5
Electrical Stimulation	19.8 ±4.2	20.0 ±5.3	19.3 ±4.6	22.8* ±4.3

Values are means + S.D.. Unit is IU/L .

* : $p < 0.05$ (between Before and 24 h after).

Table 9

Summary of Analysis of Variance for Serum AST Activities

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F-ratio
Between				
Groups (ISO vs ES)	102.223	1	102.223	.973
Error	2,730.581	26	105.022	
Within				
Time	351.752	3	117.251	12.61*
Groups vs Time	30.919	3	10.306	1.11
Error	725.264	78	9.298	
Total	3,940.739	111	344.1	

* $p < 0.05$

than the 5 minute post-exercise level. The 24 hour post-exercise serum AST activities for isometric exercise were significantly greater ($P<0.05$) than all the electrical stimulation serum AST activities, including the 24 hour post-exercise level (Table 10).

Serum Lactate Dehydrogenase

The means and standard deviations for serum lactate dehydrogenase activities are presented in Table 11. There was no significant difference ($P>0.05$) in serum LDH activity, either between or within the groups (Table 12).

Plasma Lactate

The means and standard deviations of the plasma lactate concentrations are presented in Table 13. Analysis of variance indicated that the plasma lactate concentrations of the isometric exercise were significantly greater ($P<0.05$) than those of the electrical stimulation. The test also indicated that the plasma lactate concentration increased significantly ($P<0.05$) with time in both groups (Table 14).

The Tukey test revealed that the plasma lactate concentrations at 5 minute post-exercise in both groups were significantly greater ($P<0.05$) than those of before, 1 hour and 24 hour post-exercise, and the plasma lactate concentrations at 5 minute post-exercise of isometric exercise were also significantly greater ($P<0.05$) than those of electrical stimulation (Table 15).

Table 10

Comparisons of AST Activities Before and
After Isometric Exercise and Electrical Stimulation

		Isometric Exercise				Electrical Stimulation			
		Before	5 min after	1 h after	24 h after	Before	5 min after	1 h after	24 h after
		(20.7)	(22.4)	(21.0)	(26.4)	(19.8)	(21.0)	(19.3)	(22.8)
ISO	(20.7)	--	1.7	0.3	5.7*	0.9	0.3	1.4	2.1
	(22.4)		--	1.4	4.0*	2.6	1.4	3.1*	0.4
	(21.0)			--	5.4*	1.2	0.0	1.7	1.8
	(26.4)				--	6.6*	5.4*	7.1*	3.6*
ES	(19.8)					--	1.2	0.5	3.0*
	(21.0)						--	0.7	1.8
	(19.3)							--	3.5*
	(22.8)								--

* $p < 0.05$ Tukey value 3.03.

Table 11

Serum LDH Activities Before and After
Isometric Exercise and Electrical Stimulation

Group	Before	5 min after	1 h after	24 h after
Isometric Exercise	163.1 ±37.8	168.8 ±26.6	154.9 ±24.8	153.9 ±20.5
Electrical Stimulation	158.7 ±23.1	159.4 ±32.6	154.9 ±22.3	158.0 ±20.0

Values are means ± S.D.. Unit is IU/L

Table 12

Summary of Analysis of Variance for Serum LDH Activities

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F-ratio
Between				
Groups (ISO vs ES)	165.143	1	165.143	.081
Error	52,887.821	26	2,034.147	
Within				
Time	1,568.679	3	522.893	1.961
Groups vs Time	696.714	3	232.238	.871
Error	20,797.607	78	266.636	
Total	76,115.964	111	32,221.057	

* $p < 0.05$

Table 13

Plasma Lactate Concentrations Before and After
Isometric Exercise and Electrical Stimulation

Group	Before	5 min after	1 h after	24 h after
Isometric Exercise	1.35 ±0.25	4.99*+ ±2.82	1.76 ±0.46	1.38 ±0.37
Electrical Stimulation	1.28 ±0.24	2.82* ±1.39	1.49 ±0.82	1.09 ±0.34

Values are means + S.D.. Unit is IU/L

* : $p < 0.05$ (between Before and 5 min after).

+ : $p < 0.05$ (between two groups).

Table 14

Summary of Analysis of Variance for Plasma Lactate Concentrations

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F-ratio
Between				
Groups (ISO vs ES)	13.948	1	13.948	8.691*
Error	41.724	26	1.605	
Within				
Time	135.917	3	45.306	33.907 *
Groups vs Time	21.152	3	7.051	5.277*
Error	104.222	78	1.336	
Total	316.963	111	69.246	

* $p < 0.05$

Table 15

Comparisons of Plasma Lactate Concentrations Before and After Isometric Exercise and Electrical Stimulation

		Isometric Exercise				Electrical Stimulation			
		Before (1.35)	5 min after (4.99)	1 h after (1.76)	24 h after (1.38)	Before (1.28)	5 min after (2.82)	1 h after (1.49)	24 h after (1.09)
	(1.35)	--	3.64*	0.41	0.03	0.07	1.47*	0.14	0.26
ISO	(4.99)		--	3.23*	3.61*	3.71*	2.17*	3.50*	3.90*
	(1.76)			--	0.38	0.48	1.06	0.27	0.67
	(1.38)				--	0.10	1.44*	0.11	0.29
	(1.28)					--	1.54*	0.21	0.19
ES	(2.82)						--	1.33*	1.73*
	(1.49)							--	0.40
	(1.09)								--

* $p < 0.05$ Tukey value 1.15.

CHAPTER 5

Discussion

This study used peak torque, metabolic changes in plasma lactate concentrations, and serum enzyme activities as indicators of exercise stress.

External variables which may have influenced the findings were controlled as well as possible by the experimental design. Population variables, muscle testing variables and biochemical assay procedures were rigidly monitored to minimize their effects on the results of the present study. For example, several population variables were controlled by the experimental design. The subjects of the present study were considered to be recreational athletes of comparable fitness levels. The subjects were given specific instructions to restrict exercise and strenuous activity prior to and during the testing. The subjects participated in both exercise protocols to eliminate variation due to using independent populations. It must be recognized, however, that by controlling these population variables this study has limited extrapolation of the date to the general population.

In order to minimize any undesired muscle testing variables, certain precautions were taken. For example, the subject's positioning on the Kin-Com included recording

of the actuator shin pad measurement to insure reproducible placement of the pad for both tests. Optimal knee angle positioning, as determined by Parker et al. (1986) and Selkowitz, (1985), was measured using the internal goniometer of the Kin Com and verified using a hand goniometer. The batteries of the EMS/plus stimulator were replaced after every four tests to insure optimal power output from the stimulator. However subject acccommodation and tolerance for the electrical current was a determining factor. It determined the rate at which the stimulator intensity was increased as well as the stimulator intensity at the conclusion of the test session.

Some limitations must be recognized in the present findings. Firstly, although the subjects were given instructions to refrain from exercise or strenuous activities prior to the testing, they were trusted to comply with these instructions. It was deemed unfeasible to monitor the subjects 24 hours a day to insure compliance.

Serum Enzymes

Serum Aspartate Aminotransferase

The resting serum AST values (4-20 IU/L) found in the present study were similar to the values reported by Brown (1973) and Noakes & Carter (1976). The serum AST activities 24 hours after exercise were significantly greater ($P<0.05$)

than the before, 5 minute and 1 hour after exercise for the isometric exercise test. The 24 hour post-exercise serum AST activities in the isometric exercise test were significantly greater ($P<0.05$) than the corresponding 24 hour level in the electrical stimulation test. Tiidus and Ianzzo (1983) also found significant increases in serum AST activities following short duration, high intensity exercise. Other studies indicated that serum AST activities increased significantly using electrical stimulation (Spare, 1986; Yoshimine-Gries, 1986) and it was confirmed by the results of the present study. The fact that the 24 hour post-exercise serum AST activities were significantly greater ($P<0.05$) in the isometric exercise test may suggest that the intensity of the electrically induced exercise was less than that of the isometric exercise regime.

Serum Lactate Dehydrogenase

The resting serum LDH values were also similar to the values (60-250 IU/L) reported by Brown (1973). There was no significant change ($P>0.05$) in serum LDH activity following either electrical stimulation or isometric exercise. This is consistent with previous observations of serum LDH activity following short duration, high intensity exercise (Karlsson, 1970; McGrail et al., 1977; Otto & Smith, 1984). However, Harlambie et al. (1976) found significant increases in serum

LDH following bobsledding, as did Armstrong et al. (1983) examining one-legged eccentric exercise. Other studies have found significant increases in serum LDH following electrical stimulation (Spare, 1986; Yoshimine-Gries, 1986). Increases in serum LDH have been demonstrated in cases where cell damage has occured, such as myocardial infarction, as well as being an indicator of changes in cell permeability (Stokke, 1982). It is possible, therefore, that the present study lacked the intensity to cause the cellular damage necessary to produce increases in serum LDH activity observed in other studies (Schwane et al., 1983; Tiidus & Ianzzo, 1985).

Serum Creatine Phosphokinase

The mean, resting serum CPK values of 137 IU/L were higher than the resting levels of 10-100 IU/L reported elsewhere (Brown, 1973; Canatrow & Trumper, 1975; Noakes & Carter, 1976; Shumate et al., 1979). The elevated resting serum CPK values would suggest that the "normal" daily activity level of the subjects was greater than that observed in other studies. Serum CPK levels have been demonstrated to remain elevated up to 48 hours after an exercise bout (Tiidus & Ianzzo, 1983). Thus, the two day rest period prior to testing may not have been of sufficient duration to allow serum CPK levels to return to normal values.

Both tests were of sufficent intensity to elicit

significant increases ($P<0.05$) in serum CPK activities at 24 hours post-exercise. However, the 24 hour serum CPK activities for the isometric exercise test were significantly greater ($P<0.05$) than that of the electrical stimulation test. In studying the effects of isometric exercise on serum CPK, Clarkson et al. (1985) also found that 60 repetitions of 10 seconds work to 10 seconds rest resulted in significant increases in serum CPK activity. Graves et al. (1984) failed to produce significant increases in serum CPK activity after 40 repetitions of isometric exercise using a ratio of 10 seconds exercise to 20 seconds rest. In examining the effects of electrical stimulation on serum CPK activities, the present study found, as did Yoshimine-Gries (1986), that electrical stimulation can result in significant increases ($P<0.05$) in serum CPK activity. These findings are contrary to those of Spare (1986), who, using female subjects, failed to demonstrate significant increases in serum CPK activity using electrical stimulation. Based on the serum CPK activity, the findings of the present study would suggest that while both treatments may provide a significant exercise stress to the muscle, isometric exercise may be superior to electrical stimulation, provided by the EMS/plus stimulator.

Plasma Lactate

The resting plasma lactate concentrations were within the .6 to 1.8 MMOL/L range described by Noakes & Carter (1976).

Both test sessions demonstrated a significant increase ($P<0.05$) in plasma lactate concentrations 5 minutes after exercise. The plasma lactate concentrations in the isometric exercise group were significantly higher ($P<0.05$) than those for the electrical stimulation group. Tesch (1978) demonstrated similar increases in lactate concentrations with exercise bouts of 30 seconds, followed by 60 seconds rest, but failed to demonstrate significant increases with exercise bouts of 10 seconds or 20 seconds duration. Edwards et al. (1970) also did not produce significant increases in lactate concentrations with 10 second intermittent exercise intervals, however the exercise may have been of insufficient intensity to produce changes in lactate concentrations. Significant increases in lactate concentrations following electrical stimulation were demonstrated by a number of researchers (Fitts & Holloszy, 1976; Gollnick et al., 1978; Hermansen, 1971; Houston et al., 1982).

Peak plasma lactate concentrations vary depending upon the duration and intensity of the exercise (McGrail et al., 1977). The exercise duration and rest schedules were timed

and remained consistent for both exercise protocols in the present study. However, the exercise intensity varied depending upon the motivational level of the subject, in the case of the isometric exercise test and on their ability to tolerate and "accommodate" to the current, in the electrical stimulation test. The significant increases ($P<0.05$) in plasma lactate concentrations for both groups at 5 minutes post exercise would suggest that both forms of exercise produced some degree of exercise stress to the exercised muscle. However, since the plasma lactate concentrations of the isometric exercise group were significantly higher ($P<0.05$) than that of the electrical stimulation group, this may indicate that the exercise stress of the isometric exercise was greater than that of the electrical stimulation group. Whether this difference in exercise stress, as measured by the plasma lactate concentrations, would translate into a difference in a training effect, would require the examination of the two protocols over a long term training program.

Peak Torque

It is well established that to improve strength it is necessary to apply a load, stress or stimulus to a muscle (Arnheim, 1985; Astrand & Rodahl, 1986; Perrine, 1968; Pipes, 1977). There is, however, little agreement as to the

optimal intensity necessary to maximize strength improvements. The theory that the stimulus causing the greatest muscular tension (whether voluntary or from electrical stimulation) will result in the greatest improvement in strength is widely supported (Berger, 1962a; Pipes, 1977; Williams, et al., 1986).

In the present study, the subjects averaged 78% of the MVC while performing the isometric exercise and 40% of the MVC while performing the electrical stimulation test. Both of these values meet or exceed the 40-65% of the MVC reported by others to be necessary to produce improvements in strength (Klafs & Arnheim, 1981; Mohr et al., 1986; Owens & Malone, 1987). However, the 40% of the MVC produced by the electrical stimulation test was significantly lower ($P<0.05$) than the 78% of the MVC for the isometric exercise test. The value for the electrical stimulation test meets only the minimum requirements necessary to produce strength gains reported by Mohr et al. (1986). If applied to a training program, the EMS/plus stimulator may fail to apply the necessary exercise stress to overload the muscle and produce strength gains as the muscles adapt to the applied load over an extended training program. Others have found that electrical stimulation torque levels of only 33% of the MVC have produced strength gains similar to those produced by an equivalent 78%

of the MVC, isometric exercise protocols (Laughman et al., 1983). Parker et al. (1986) also found that the modification of the traditional 15 seconds stimulation to 50 seconds rest schedule of Kots (1977), to a 12 seconds stimulation to 8 seconds rest schedule resulted in a 50% decrease in torque (to 27% of the MVC). They also found that the diminished torque production of this 8 to 12 seconds work to rest schedule did not result in decreased strength gains when compared to an isometric exercise protocol. It has been postulated that this decrease in torque is the result of the faster fatiguing of the fast twitch fibres that are more rapidly activated in an electrically induced muscular contraction (Parker et al., 1986; Tesch et al., 1978). This might explain the similar reduction in torque values with the 10 seconds stimulation, 10 seconds rest schedule of the present study. However, on the premise that the exercise stimulus producing the greatest muscle tension will result in the greatest improvement in strength, the results of the present study would suggest that isometric exercise produces a greater exercise stress and therefore a greater potential for a training effect than the EMS/plus stimulator.

Based on peak torque values, increases in serum AST and CPK activities and plasma lactate concentrations, the results indicated that voluntary isometric exercise may have

produced a greater exercise stress when compared to the EMS/plus electrical stimulator. We may hypothesize that isometric exercise may provide a greater potential for producing a training effect, if continued over a longer duration training program. This study measured the acute exercise stress produced under a work to rest ratio of 1:1. It is not possible to hypothesize if this exercise stress would translate into strength, endurance or a combination of the two when applied to a training program.

The degree of variation in the electrical stimulation torque values may be the result of a number of factors. One of the limiting factors of this study was the maximum current output of the EMS/plus stimulator. It was found that 64% of the subjects tolerated the maximum current output of the stimulator prior to completing the 45 trials. This is evident in the fact that electrically induced torque values began to decline in the 16-20 and 20-25 trial periods for a number of the subjects. In a study using a similar asymetrical biphasic rectangular wave current, Kramer (1984) found that 20% of the subjects tolerated the maximum current output. However, the study utilized a stimulator powered by a 115 volt current, rather than a 9 volt battery current used in the present study. The ability to adapt to or tolerate electrical current produced by an electrical muscle stimulator has been

termed "accommodation" (Boutelle et al., 1985). In the subjects that did not accommodate the maximal stimulator output, motivation may have caused variations in the EMS torque values. McMiken et al. (1983) stated that since no voluntary exertion was required during electrical stimulation, motivation was not a factor. However, this has been disputed by others. Williams et al. (1986) and Murray et al. (1980) stated that in order to tolerate the current necessary to obtain a maximal contraction during stimulation, subjects must be highly motivated.

A number of researchers have also described diminished torque values in electrical stimulation testing as "failed force outputs" due to the inability to activate all of the motor axons of a large muscle group with an electrical current (Houston, 1983; Walmsley et al., 1984; Williams & Stutzman, 1959). While it was the result of "failed force outputs" or extreme accommodation, it was necessary to exclude one subject's electrical stimulation torque values from the results when he failed to register any torque production after the initial 15 trials.

Both pre-test torque values were significantly greater ($P<0.05$) than the subsequent 45 trials of the two tests. In the case of the EMS test, this may again have been the result of the "failed force outputs" discussed previously. However, the decreased torque production demonstrated in the isometric

exercise test is likely due to motivational factors, or pacing, the saving of effort for subsequent trials. In both pre-test measurements the subjects were instructed to give a singular maximal 10 second effort. The subjects were then instructed to give a maximal effort for the subsequent isometric exercise trials. Although the subjects were not informed of the number of trials, they were informed that the test would take approximately 15 minutes. That may have resulted in them consciously or unconsciously, decreasing their force output from their initial pre-test effort to complete the test.

Summary of the Discussion

Based on the peak torque values, serum AST and CPK activities and plasma lactate concentrations, it appears that both isometric exercise and electrical stimulation may have the potential to produce strength or endurance gains when applied to a training program. The significant differences ($P<0.05$) in the peak torque values, plasma lactate concentrations and serum AST and CPK activities would further suggest that the potential for strength or endurance improvement may be significantly greater utilizing isometric exercise versus the EMS/plus stimulator. When attempting to extrapolate the results of a single training episode to an extended training program, it is necessary to consider a number of factors, such as motivation, current

accommodation, electrical stimulator output and the work to rest schedule. As stated previously, 60% of the subjects tolerated the maximum current output of the EMS/plus stimulator in a single training session. To produce strength improvements it is necessary to subject the exercised muscle to a repeated overloading stress. The present findings would suggest that repeated exposure to the EMS/plus stimulator may result in increased accommodation with decreased torque outputs. As these torque outputs decline, the exercised muscle may not be subjected to an exercise stimuli of sufficient intensity to produce strength improvements. The declining electrical stimulation torque values, due to limited stimulator output combined with subject motivation, resulted in a wide range of peak torque values (18-78% of the MVC). The limited output of the EMS/plus stimulator was evident when one subject averaged 84% of the MVC for the initial 25 trials of the electrical stimulation test. However, the values declined for the remaining trials, lowering the average torque values when the maximum stimulator output was reached. This would suggest that a highly motivated individual, combined with an electrical stimulator with a greater current output, may be able to train at a higher percentage of their MVC, as outlined by Kots (1977). Thus, there may be potential for electrical stimulation as

an adjunct in a training program. This may warrant consideration by both coaches and athletes when designing training programs.

It is, however, important to remember that both isometric exercise and electrical stimulation have produced strength gains specific to the joint angles trained and to the speed of exercise training (Klafs & Arnheim, 1981; Pipes, 1977). This may limit the application of these types of training to a specific segment of the athletic population.

In the area of rehabilitation, strength training within a limited range of motion is often both necessary and desirable. The results of this study would suggest that both isometric exercise and electrical stimulation demonstrate potential for producing training effects where cast immobilization or joint pathology limits the range of motion of exercise. In the early stages of rehabilitation the decreased torque produced by electrical stimulation may be desirable where less joint loading and joint compressive forces are indicated.

In the course of daily rehabilitation programs, both isometric exercise and electrical stimulation are often incorporated as part of a patient's daily exercise routine. The serum CPK and AST activities for both tests may be indicative of significant cellular damage. While this cellular damage may not be of the magnitude experienced by

training athletes, it may warrant consideration when planning rehabilitation programs that allow for suitable recovery time for muscular function and regeneration.

CHAPTER 6

Summary, Conclusions and Recommendations

Summary

The present study was designed to determine the effects of electrical muscle stimulation and isometric exercise on peak torque, plasma lactate concentrations and serum enzyme activities. The subjects were 14 male volunteers between the ages of 22-41 and were considered to be recreational athletes. The subjects were informed of the premise of the experiment along with specific instructions regarding the restriction of strenuous exercise or activity prior to any testing.

All subjects performed both the isometric exercise and electrical stimulation tests on two weekends. Prior to performing the test protocols, a pre-test maximum voluntary contraction of the quadriceps was performed. The electrical stimulation protocol involved 45 x 10 seconds trials of am involuntary contraction of the quadriceps induced by an EMS/plus stimulator (Stayodynamics Inc., Longmont, Colorado; bipolar technique, 50 pulse/sec; pulse width of 200 μsec; 2 sec ramp and 8 sec maximum / 10 sec rest). The isometric exercise protocol required the subject to perform 45 x 10 second maximal isometric contractions of the quadriceps, followed by a 10 second rest (Kin-Com). The peak torque generated by each contraction was measured for both tests. Pre-test,

5 minute, 1 hour and 24 hour post exercise blood samples were taken from the antecubital vein to measure plasma lactate, serum creatine kinase, serum aspartate aminotransferase, and serum lactate dehyrogenase activities of both exercise groups. The plasma lactate and serum enzymes were analyzed using an Abbott VP Biochromatic Analyzer. Data were analyzed using a two-way ANOVA and a Tukey test was used to identify differences when a significant F-ratio was observed.

The results indicated that: (a) peak torque produced by isometric exercise was significantly greater ($P<0.05$) than that produced by the EMS/plus stimulator; (b) both isometric exercise and electrical muscle stimulation produced significant increases ($P<0.05$) in plasma lactate concentrations 5 minutes post exercise, with the increase in the isometric exercise group being significantly greater ($P<0.05$) than that of the electrical stimulation group; (c) both exercise modes resulted in significant increases ($P<0.05$) in serum CPK activity 24 hours post exercise, with the increase in the isometric exercise group being significantly greater ($P<0.05$) than that of the electrical stimulation group; (d) both exercise modes resulted in significant increases ($p<0.05$) in serum AST activity 24 hours post exercise, with the increase in the isometric group being significantly greater ($P<0.05$) than that of the electrical stimulation group; (e) neither exercise mode resulted in a significant increase ($P>0.05$) in serum LDH activity.

Conclusions

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

1. The peak torque produced by isometric exercise was significantly greater ($P<0.05$) than that produced by the EMS/plus stimulator.

2. Both isometric exercise and electrical stimulation produced significant increases ($P<0.05$) in plasma lactate concentrations 5 minutes post exercise, with isometric exercise being significantly greater ($P<0.05$) than electrical stimulation.

3. Both exercise modes produced significant increases ($P<0.05$) in serum creatine kinase activities 24 hours post-exercise, with isometric exercise being significantly greater ($P<0.05$) than electrical stimulation.

4. Both exercise modes produced significant increases ($P<0.05$) in serum aspartate transaminase activities 24 hours post-exercise, with isometric exercise being significantly greater ($P<0.05$) than electrical stimulation.

5. Neither isometric exercise nor electrical stimulation resulted in significant increases ($P>0.05$) in serum lactate dehydrogenase activity.

Recommendations

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

1. A more stringent restriction in pre-test activity, from 48 to 72 hours to insure base line serum enzyme levels.

2. The comparison of a number of electrical muscle stimulators, with greater current output to prevent possible subject compliance ("accommodation") to the maximum stimulator output.

3. The use of audio or visual biofeedback as a possible motivational factor in peak torque production.

4. Shaving of the leg prior to electrode placement to reduce electrical impedance at the electrode site.

5. Use of muscle biopsy to obtain a biochemical measurement of muscle metabolism.

6. A pre-test program of electrical muscle stimulation to allow subjects to become more familar with the application of electrical current to the muscle and the sensation and discomfort of an electrically induced involuntary muscle contraction.

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APPENDIX "A"

SUBJECT INFORMATION LETTER

Dear

I am attempting to recruit subjects for my masters thesis experiment in April. I consider you to be both reliable and well motivated and therefore I would greatly appreciate your assistance.

The study is to compare changes in serum enzymes after both electrical muscle stimulation and isometric exercise of the quadriceps . It would involve 1-1/2 hours of your time on each of two Saturdays in April, and 5 minutes of your time on the following Sunday. The specific dates are Saturday April 11 and 18th as well as Sunday, April 12th and 19th. I realize that April 18th is Easter weekend but scheduling is a problem.

The study would involve you restricting your exercise activity on the Thursday and Friday prior to the Saturday testing. This is extremely important as exercise on these days will alter certain blood enzymes and influence the results. One of the Saturdays will involve you performing a series of competitive exercises of the quadriceps for 15 minutes following which two post-exercise blood samples will be taken. On the other Saturday an electrical muscle stimulator will be connected to your quad to perform the

same series of isometric exercises only utilizing an involuntary contraction of the muscle. On both of the following Sundays you will be required to return to give a 24 hour post-exercise blood sample. This should only take 5 minutes of your time.

The important considerations are the restricting of activity on the Thursday and Friday both weeks and until after the 24 hour blood sample is taken. Another consideration is that you are motivated to perform 15 minutes of isometric exercise and 15 minutes of electrical muscle stimulation.

If you are interested in participating and understand that is necessary for you to participate on both weekends, again for 1-1/2 hours on the Saturday and 5 minutes on the Sundays, I would ask you to do the following:

1. Contact Sharon Kozak at Lakehead University Athletic Department, 345-2121 Ext. 213 and register for a time slot on Sat. April 11th and 18th. The times will be every 1/2 hour starting at 9:00 AM. Again it will take 1-1/2 hours or less with the actual exercise time being 15 minutes.

2. Give Sharon your name and a business and home phone number.

3. Again realize that limiting your activity on Thursday and Friday is <u>important</u>, as is participating both weekends.

4. The activity is 15 minutes of isometric quad exercise with you attempting to do your best. And 15 minutes of electrical muscle stimulation with you attempting to get the best possible involuntary contraction.

5. Again I will emphasis that you have been pre-selected because I consider you to be both reliable and well motivated. Because the subject numbers will be small I can't afford to have either people not show up or drop out once they have started.

6. If you are not interested I would appreciate it if you would phone Sharon so that I can get another subject to take your place. Or if you know of another male between approximately 20 and 35 years of age, please have them call Sharon.

I sincerely appreciate your cooperation and will contact you prior to the start. I look forward to seeing you.

Sincerely,

J. Ross Hodgkinson

APPENDIX "B"

CONSENT FORM

LAKEHEAD UNIVERSITY

HUMAN PERFORMANCE LABORATORY

I, , authorize Lakehead University to perform a series of procedures which constitute the following anthropometry, muscular strength and exercise, and hematological studies:

1. Measurement of height, weight, and thickness of skinfolds.
2. Measurement of muscular strength .
3. Muscular exercise (isometric and electrical stimulation).
4. Collection of a small blood sample from fingertip and/ or a vein in the arm. Complications of such blood sampling rarely arise but may include hematoma (swelling), bruising or thrombosis.

I understand that I have the option to stop the test(s) at any time and/ or omit any part of any test. In agreeing to these tests, 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 tests. I further consent to the use of information obtained from these tests by Lakehead University. I have read and understand the above.

DATE : SIGNATURE:

WITNESS :

Appendix C
Raw Data

Table 1

Peak Torque for Isometric Exercise and Electrical Stimulation

Subject	Treatment	Leg	Radius (mm)	Pre-MVC Torque Test	Trial-Peak Torque							
					1	2	3	4	5	6	7	8
1	ISOM	R	345	671	633	546	602	557	586	562	523	629
	ES			652	269	354	341	227	297	257	291	307
2	ISOM	L	385	616	516	478	489	464	481	441	437	435
	ES			608	248	355	284	397	607	512	500	418
3	ISOM	R	330	637	601	576	548	523	620	614	610	620
	ES			552	172	203	179	283	313	254	159	219
4	ISOM	R	335	865	811	722	777	739	739	771	801	815
	ES			815	362	371	412	514	572	584	581	592
5	ISOM	R	310	810	685	807	740	695	715	703	663	724
	ES			751	320	213	210	393	458	378	307	342
6	ISOM	R	320	820	620	649	769	767	742	717	790	778
	ES			723	109	175	203	159	116	113	89	140
7	ISOM	R	310	758	708	636	615	574	509	536	531	512
	ES			812	224	125	145	303	256	272	230	218
8	ISOM	R	335	721	720	704	712	720	675	667	674	654
	ES			692	163	204	113	105	232	157	103	202
9	ISOM	L	330	672	547	522	550	537	515	503	497	513
	ES			784	252	263	265	305	309	194	294	246
10	ISOM	L	302	805	771	763	742	721	691	710	690	685
	ES			762	297	430	246	250	501	456	527	357
11	ISOM	R	310	536	456	426	430	490	426	449	429	496
	ES			777	210	257	237	167	163	220	265	230
12	ISOM	R	325	635	521	542	523	494	531	520	490	502
	ES			620	530	390	490	476	534	558	470	540
13	ISOM	R	320	754	601	543	493	504	510	471	503	536
	ES			804	336	323	426	245	372	419	426	356

Unit is Nm.

Table 1 continued ....

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
545	530	572	553	628	641	661	663	671	663	641	615	642	672	647	610	598
224	213	264	259	247	205	212	179	202	243	215	217	342	219	249	198	214
439	474	478	480	428	402	447	467	466	414	477	492	472	458	547	491	352
507	489	369	307	269	451	503	483	461	504	239	403	406	257	401	327	310
585	543	602	613	536	604	610	565	571	559	574	615	574	581	534	504	534
207	195	157	160	249	237	289	273	254	203	246	249	211	226	194	273	287
779	795	724	801	806	787	720	726	738	734	742	714	723	704	665	657	675
585	523	585	538	707	581	584	537	528	535	485	501	512	459	516	499	498
721	725	683	703	676	654	586	632	612	614	573	601	536	562	532	536	512
325	342	380	354	331	310	353	356	264	327	320	237	250	196	206	316	193
732	742	762	692	742	697	639	617	634	627	642	670	671	597	564	549	581
93	194	142	148	136	107	226	157	193	213	168	113	113	154	145	145	102
512	526	562	549	542	512	552	476	574	579	552	523	562	534	540	497	503
243	249	218	253	198	257	246	223	203	193	237	257	226	203	232	201	256
702	672	667	640	667	640	671	663	656	693	640	621	646	651	640	642	673
198	207	189	195	125	170	210	136	207	231	267	253	235	242	254	242	187
494	530	528	565	542	523	457	502	439	475	479	503	455	482	503	475	493
183	175	275	193	274	293	202	224	223	209	257	226	304	237	325	247	220
671	645	681	705	683	693	691	672	671	647	700	685	667	694	686	669	650
462	479	357	398	296	298	319	315	234	253	198	289	249	279	256	283	286
451	410	437	395	429	429	463	379	371	402	434	456	374	402	404	380	401
202	115	139	136	137	123	114	125	114	98	125	112	90	134	153	120	119
501	531	493	507	539	551	558	529	530	529	540	537	557	515	523	535	521
420	542	545	510	550	560	520	538	587	580	569	571	550	579	555	439	479
514	436	427	440	505	404	412	449	397	439	402	356	378	402	373	412	446
453	448	446	407	490	472	415	475	456	503	458	551	449	460	492	379	470

Table 1 continued ....

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
578	602	552	583	587	582	581	429	613	602	614	619	595	584	597	597	573
212	225	202	225	202	189	195	209	174	172	168	194	156	165	156	125	157
507	443	460	462	402	404	419	420	460	467	411	378	492	463	446	407	472
301	370	407	389	357	390	297	369	390	403	452	461	402	371	370	383	370
574	494	596	598	594	591	525	520	512	582	543	529	501	537	561	476	495
211	193	162	137	139	152	169	203	157	165	168	161	145	281	205	231	130
665	656	673	742	727	738	721	675	652	602	679	678	652	703	674	672	720
570	498	467	502	563	571	512	522	547	536	426	524	463	472	501	541	492
601	474	567	556	543	516	476	530	459	523	503	520	521	460	512	493	423
163	230	134	156	175	206	131	171	250	264	198	316	193	320	230	198	303
632	654	612	529	672	592	585	502	582	507	502	507	545	513	532	447	475
120	157	165	154	109	98	114	123	135	157	135	124	115	103	113	112	95
480	561	504	618	528	539	518	518	521	538	575	513	502	503	447	478	516
173	218	220	285	246	256	183	274	281	346	295	302	297	274	305	317	303
674	626	612	640	623	621	632	670	635	614	656	657	670	672	679	691	689
237	176	134	190	175	237	159	203	159	197	147	230	203	125	173	263	274
450	494	502	494	505	494	496	456	489	502	510	480	475	456	437	465	457
175	157	284	202	318	271	285	207	220	184	108	208	207	267	290	303	331
654	651	659	633	623	610	586	633	610	592	605	612	546	603	590	563	590
172	343	283	248	249	237	307	240	307	202	256	298	214	287	315	256	279
379	372	410	434	372	417	454	379	414	343	368	421	379	405	391	357	406
133	124	138	165	118	107	144	153	152	129	196	123	103	112	93	111	90
553	542	534	542	572	532	509	540	522	523	508	493	501	506	507	451	476
479	493	432	459	473	464	413	396	457	449	466	445	403	404	427	432	375
417	434	416	373	343	390	417	374	365	428	416	354	393	339	391	401	406
434	423	498	491	408	457	420	462	434	418	473	398	455	432	290	425	420

Table 1 continued ....

43	44	45
575	568	570
138	139	153
478	479	484
253	394	327
560	440	557
197	183	256
701	682	703
543	461	562
501	512	543
270	219	301
449	457	467
94	115	113
479	458	486
279	253	259
691	663	697
194	216	211
450	483	494
272	284	290
569	540	556
271	241	258
403	356	521
103	95	95
504	476	519
421	411	394
371	501	545
434	397	467

Table 2
Means, Standard Deviations, Range and Percent of MVC
for Peak Torque of Isometric Exercise

Subject	Pre Test	Trials (1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
1	671	585 ± 35* 577-633 87	558 ± 43 523-629 83	611 ± 46 553-661 91	651 ± 23 615-671 97	634 ± 29 598-671 94	579 ± 19 552-602 86	561 ± 75 429-613 84	602 ± 14 584-619 90	577 ±12 568-597 86
2	616	486 ± 94 464-516 79	445 ± 16 435-474 72	441 ± 28 402-478 72	463 ± 29 414-492 75	464± 71 352-547 75	455 ± 38 402-507 72	440 ± 28 404-467 71	439 ± 40 378-492 71	464 ± 32 407-484 75
3	637	574 ± 39 523-620 90	594 ± 32 543-620 93	593 ± 32 536-613 93	577 ± 22 559-615 90	545 ± 32 504-581 85	571 ± 44 494-598 90	546 ± 37 512-591 86	534 ± 22 501-561 84	506 ± 52 440-560 78
4	865	758 ± 36 722-811 88	792 ± 18 771-815 92	768 ± 42 724-806 89	731 ± 11 714-738 85	685 ± 28 657-723 79	673 ± 33 656-742 78	678 ± 55 602-738 78	677 ± 18 652-703 78	696 ± 19 672-720 80
5	810	728 ±48 769-620 90	707 ±26 717-790 87	660 ± 45 639-762 81	606 ± 22 617-670 75	536 ± 18 512-562 66	548 ± 47 474-601 68	509 ± 32 476-530 63	503 ± 25 460-521 62	494 ± 44 423-543 61
6	820	709 ± 70 769-620 86	752 ± 31 717-790 92	706 ± 48 639-762 86	638 ± 20 617-670 78	592 ± 47 529-671 72	620 ± 56 529-672 76	554 ± 45 502-592 67	520 ± 18 502-545 63	459 ± 12 447-467 56
7	758	608 ± 74 507-708 80	523 ± 11 512-536 69	542 ± 19 512-562 71	541 ± 42 476-579 71	527 ± 11 497-562 69	538 ± 54 480-618 71	527 ± 11 518-539 69	508 ± 46 447-575 67	483 ± 21 458-516 64

Table 2 continued...

Subject	Pre Test	Trials (1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
8	721	706 ± 19 *	674 ± 18	657 ± 16	655 ± 22	650 ± 13	635 ± 24	634 ± 22	667 ± 10	686 ± 13
		675-720	654-702	640-671	621-693	640-673	612-674	614-670	656-679	663-697
		98	93	91	91	90	88	88	92	95
9	672	554 ± 54	507 ± 15	523 ± 40	480 ± 26	481 ± 19	489 ± 22	487 ± 18	472 ± 27	470 ± 18
		515-550	494-530	457-565	439-503	455-503	450-505	456-502	437-510	450-494
		82	75	78	71	71	73	72	70	70
10	805	738 ± 32	680 ± 24	691 ± 9	675 ± 20	673 ± 17	644 ± 15	606 ± 18	591 ± 26	564 ± 18
		691-771	645-715	681-705	647-700	650-694	623-659	586-635	546-612	540-590
		92	85	86	84	84	80	75	73	70
11	536	445 ± 28	447 ± 32	431 ± 24	408 ± 36	392 ± 14	393 ± 28	401 ± 42	392 ± 21	409 ± 67
		426-490	410-496	395-463	321-456	374-404	373-434	343-454	368-421	357-521
		83	83	80	76	73	73	75	73	76
12	635	552 ± 18	509 ± 16	530 ± 28	533 ± 5	531 ± 16	549 ± 15	525 ± 12	503 ± 6	485 ± 27
		494-542	490-531	493-558	529-540	515-557	534-572	509-540	493-508	451-519
		82	80	83	84	84	86	83	79	76
13	754	530 ± 44	492 ± 39	438 ± 40	409 ± 37	402 ± 29	397 ± 37	395 ± 27	379 ± 31	445 ± 74
		493-601	471-536	404-505	399-499	373-446	343-434	374-428	339-416	371-545
		70	65	58	54	53	53	52	50	59
$\bar{X}$ ± S.D.	751 ± 97	86 ± 7	83 ± 9	82 ± 10	79 ± 11	76 ± 11	76 ± 10	74 ± 10	73 ± 12	72 ± 11

* $\bar{X}$ ± S.D.
Range
% of Maximal Voluntary Contraction (MVC)

Unit is Nm.

Table 3
Means, Standard Deviations, Range and Percent of MVC
for Peak Torque of Electrical Stimulation

Subject	Pre Test	Trials (1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
1	652	298 ± 52* 227-354 46	258 ± 41 213-307 40	237 ± 27 205-264 36	211 ± 21 179-243 32	244 ± 58 198-342 37	213 ± 11 202-225 33	188 ± 15 172-209 29	168 ± 16 156-194 26	142 ± 13 125-157 20
2	608	378 ±141 248-607 62	485 ± 39 418-512 80	380 ± 97 269-503 63	418 ±107 239-504 69	340 ± 63 257-406 56	364 ± 36 301-407 60	370 ± 42 297-403 61	411 ± 43 370-461 68	345 ± 58 253-394 57
3	552	230 ± 64 172-313 42	207 ± 35 159-254 38	218 ±58 157-289 39	245 ± 26 203-273 44	238 ± 40 194-287 43	168 ± 33 137-211 30	169 ± 20 152-203 31	192 ± 52 145-280 35	199 ±48 130-256 36
4	815	446 ± 93 362-572 55	573 ± 28 523-592 70	599 ± 64 538-707 73	517 ± 23 485-537 63	497 ± 23 459-516 61	520 ± 45 467-570 64	538 ± 23 512-571 66	477 ± 37 426-524 59	520 ± 45 461-562 64
5	751	319 ±109 210-458 42	339 ± 26 307-378 45	346 ± 26 310-380 46	301 ±49 237-356 40	232 ± 52 193-250 31	172 ± 36 134-230 23	204 ± 55 131-264 27	251 ± 62 193-320 33	258 ± 48 198-303 34
6	723	152 ± 40 109-203 21	126 ± 43 89-194 17	152 ± 44 107-226 21	169 ± 35 113-213 23	132 ± 23 102-154 18	141 ± 25 109-165 20	125 ± 22 98-157 17	118 ± 12 103-136 16	106 ± 10 94-115 15
7	812	211 ± 75 125-303 26	242 ± 20 218-272 30	234 ± 25 198-257 29	223 ± 26 193-257 27	224 ±23 201-256 28	228 ± 41 173-285 28	268 ± 58 183-346 33	295 ± 12 274-305 36	282 ± 28 253-317 35

Table 3 continued...

Subject	Pre Test	Trials, (1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	(31-35)	(36-40)	(41-45)
8	692	163 ± 55 *	173 ± 44	178 ± 33	219 ± 52	332 ± 26	182 ± 37	191 ± 33	176 ± 42	232 ± 35
		105-232	103-207	125-210	136-267	187-254	134-237	159-237	125-230	194-263
		24	25	26	32	34	26	28	25	34
9	784	279 ± 26	218 ± 51	247 ± 46	228 ± 18	267 ± 45	227 ± 70	233 ± 43	216 ± 71	296 ± 23
		252-309	175-294	193-293	209-257	220-325	157-318	184-285	108-290	272-331
		36	28	32	29	34	29	30	28	38
10	762	345 ± 115	456 ± 62	334 ± 44	263 ± 43	271 ± 17	259 ± 62	259 ± 47	274 ± 40	261 ± 15
		246-501	357-527	296-398	198-315	249-286	172-343	202-307	214-315	241-279
		45	60	44	35	36	33	33	36	34
11	777	207 ± 42	206 ± 56	130 ± 11	115 ± 11	123 ± 23	136 ± 18	137 ± 19	125 ± 41	99 ± 8
		163-257	115-265	114-139	98-125	90-153	118-165	107-153	93-196	90-111
		27	27	17	15	16	18	18	16	13
12	620	484 ± 58	506 ± 59	537 ± 21	568 ± 18	520 ± 59	467 ± 23	436 ± 30	429 ± 27	407 ± 23
		390-534	420-558	510-560	538-581	439-579	432-493	396-464	403-466	375-432
		78	82	87	92	84	75	70	69	66
13	804	340 ± 67	420 ± 39	446 ± 36	489 ± 40	450 ± 43	451 ± 41	438 ± 20	410 ± 72	429 ± 25
		245-426	356-453	407-490	456-551	379-492	408-498	418-462	290-473	397-467
		42	52	55	61	56	56	54	51	53
$\bar{X}$ ± S.D.	719 ± 87	41 ± 16	45 ± 22	43 ± 22	42± 22	41 ± 19	38 ± 19	38 ± 18	38± 18	38 ± 17

* $\bar{X}$ ± S.D.
Range
% of Maximal Voluntary Contraction (MVC)

Unit is Nm.

Table 4

Serum Creatine Kinase Activities Before and After Isometric Exercise

Subject	Before	5 min after	1 h after	24 h after
1	54.3	58.4	64.4	99.1
2	88.0	83.0	93.1	298.8
3	77.0	78.5	132.8	398.4
4	210.3	216.8	235.8	365.2
5	259.1	283.2	288.2	322.3
6	139.8	145.9	225.0	245.0
7	66.4	61.4	121.7	255.5
8	76.4	76.0	84.0	164.0
9	144.7	144.7	189.8	384.8
10	128.3	119.2	130.8	237.4
11	445.7	450.7	433.7	1046.0
12	64.9	66.4	70.9	134.8
13	164.5	168.0	194.4	360.7
14	65.4	67.4	72.4	74.4
Mean	142	144	167	312
S.D.	107	110	104	236

Unit is IU/L.

Table 5

Serum Creatine Kinase Activities Before and After Electrical Stimulation

Subject	Before	5 min after	1 h after	24 h after
1	120.7	122.7	133.2	195.6
2	143.4	142.9	150.4	208.7
3	89.5	94.6	126.8	213.8
4	129.8	131.3	130.3	153.8
5	310.9	345.6	360.9	680.1
6	142.9	144.4	145.9	157.9
7	108.2	101.1	119.2	137.8
8	69.8	76.0	82.0	98.5
9	176.1	176.1	190.0	250.5
10	54.8	60.4	62.4	88.5
11	347.1	362.2	389.0	629.3
12	72.4	73.8	79.4	115.7
13	72.9	73.9	85.1	250.5
14	55.3	55.8	65.9	69.4
Mean	135	140	151	232
S.D.	90.1	97.4	101	188

Unit is IU/L.

Table 6

Serum Aspartate Aminotransferase Activities Before and After Isometric Exercise

Subject	Before	5 min after	1 h after	24 h after
1	20.0	23.9	21.5	22.6
2	19.2	18.0	16.7	23.9
3	18.2	21.0	21.8	40.5
4	16.4	17.2	16.7	17.2
5	26.9	25.1	21.0	38.0
6	23.6	23.1	27.2	24.6
7	17.2	19.0	15.9	20.5
8	12.3	17.2	12.3	17.4
9	26.4	32.3	21.3	23.6
10	25.4	30.3	27.7	28.2
11	29.7	31.3	37.7	42.3
12	18.0	18.0	18.5	23.9
13	24.1	23.6	23.3	30.5
14	12.8	13.9	12.1	16.2
Mean	20.7	22.4	21.0	26.4
S.D.	5.4	5.8	6.8	8.5

Unit is IU/L.

Table 7

Serum Aspartate Aminotransferase Activities Before and After Electrical Stimulation

Subject	Before	5 min after	1 h after	24 h after
1	21.3	21.3	19.5	21.8
2	24.4	25.9	23.1	20.8
3	11.8	14.6	13.6	17.2
4	21.0	23.9	21.0	19.7
5	20.0	21.5	19.2	28.0
6	17.2	23.1	27.2	24.6
7	17.2	15.6	13.1	21.0
8	20.3	20.3	24.6	19.5
9	11.8	13.3	11.5	20.0
10	23.3	25.1	21.0	23.6
11	24.6	27.2	24.6	29.2
12	20.5	19.5	19.0	24.6
13	24.9	31.0	25.9	32.3
14	18.5	20.8	20.0	19.2
Mean	19.8	21.0	19.3	22.8
S.D.	4.2	5.3	4.6	4.3

Unit is IU/L.

Table 8

Serum Lactate Dehydrogenase Activities Before and After Isometric Exercise

Subject	Before	5 min after	1 h after	24 h after
1	157	173	170	166
2	177	156	148	146
3	152	204	198	167
4	207	201	181	179
5	258	184	161	179
6	192	180	162	161
7	150	146	139	146
8	115	142	125	109
9	168	222	141	151
10	145	160	137	147
11	167	168	199	179
12	127	135	142	143
13	153	151	146	158
14	116	141	120	124
Mean	163	169	155	154
S.D.	37.8	26.6	24.8	20.5

Unit is IU/L.

Table 10

Serum Lactate Dehydrogenase Activities Before and After Electrical Stimulation

Subject	Before	5 min after	1 h after	24 h after
1	182	154	165	146
2	189	197	207	179
3	124	137	128	121
4	205	235	187	180
5	165	177	153	162
6	147	140	135	175
7	151	130	141	158
8	137	139	159	163
9	130	134	151	157
10	167	176	144	154
11	169	187	170	187
12	138	114	134	132
13	162	171	160	168
14	156	141	134	130
Mean	159	159	155	158
S.D.	23.1	32.6	22.3	20.0

Unit is IU/L.

Table 11

Plasma Lactate Concentrations Before and After Isometric Exercise

Subject	Before	5 min after	1 h after	24 h after
1	1.305	2.810	1.484	1.151
2	1.251	3.045	1.413	1.299
3	1.433	9.209	2.268	1.299
4	1.332	3.386	1.288	.864
5	1.154	7.251	1.110	1.939
6	1.817	3.345	2.168	1.364
7	.846	9.157	1.907	1.024
8	1.492	5.501	2.697	2.228
9	.970	2.933	1.650	1.198
10	1.563	10.170	1.473	1.776
11	1.292	5.754	1.667	1.186
12	1.480	2.474	2.189	1.292
13	1.357	3.087	1.275	1.205
14	1.554	2.078	1.934	1.550
Mean	1.34	4.99	1.76	1.38
S.D.	.245	2.82	.46	.37

Unit is mM/L.

Table 11

Plasma Lactate Concentrations Before and After Electrical Stimulation

Subject	Before	5 min after	1 h after	24 h after
1	1.201	1.958	1.239	.837
2	1.232	2.938	1.369	1.731
3	1.647	2.297	.887	.821
4	1.331	1.835	1.097	.754
5	1.395	5.527	1.580	1.105
6	1.367	3.310	4.077	1.743
7	1.051	2.330	.940	.725
8	1.351	1.728	1.909	1.142
9	1.185	1.628	1.334	1.140
10	1.557	1.831	.980	.918
11	.936	2.634	1.367	.735
12	.922	1.382	1.972	1.053
13	1.125	5.520	1.086	1.360
14	1.647	4.435	1.070	1.140
Mean	1.28	2.82	1.496	1.09
S.D.	.24	1.39	.82	.34

Unit is mM/L.