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EFFECTS OF HIGH FREQUENCY ELECTROMUSCULAR STIMULATION ON ISOKINETIC STRENGTH OF THE QUADRICEPS MUSCLE GROUP IN ACTIVE, YOUNG ADULTS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Monte Shane Wright

December 1985

DEDICATION

To my family:

Dad, a brilliant, loving man
with a wise heart;
Mom, a fiercely caring mother
with the horizon in her eyes;
Steve, a creative spark of life,
he is My big brother.

You have made me feel capable and so loved. You have kindled a striving to give my best to those around me. You have let me know my own importance within gentle humility.

And to my Creator God who knows my every motive and intention and loves me anyway through Christ Jesus.

ACKNOWLEDGMENTS

Appreciation and gratitude are due several individuals who have contributed to the successful completion of this thesis.

Without the encouragement, guidance, and patience of my major professor, Dr. Edward T. Howley, this project would have been more struggle than education. Not only has his role as classroom teacher been exceptional but also his role as advisor and friend has indicated genuine concern for his students as people and as knowledge seekers.

The constructive criticism and encouragement provided by my other committee members--Dr. B. Don Franks and Dr. Craig A. Wrisberg--enabled me to complete, with little wasted time, a thesis of which the University and I could be proud.

A debt of gratitude is also owed to Gary Buck, Bo Snodgrass, and the staff at the Sports Treatment and Rehabilitation Clinic (S.T.A.R.) at the Fort Sanders Regional Medical Center. Their technical guidance and assistance as well as their enthusiastic support were invaluable.

Of course without the time, willingness, and dedication of my subjects, none of this would have been possible.

Thank you all.

ABSTRACT

The purpose of this study was to investigate the effects of electrical stimulation on isokinetic strength in the quadriceps muscle group of non-competitive but active individuals. Twelve volunteers, six males and six females, participated in this study. From these subjects three groups of four were formed, each consisting of two males and two females. The control group, Group C, received no electromuscular stimulation (EMS) treatment. Groups A and B comprised the EMS treatment groups. All of the subjects were instructed not to participate in any strength training programs during the 4-week study period. Each treatment group received 10 electromuscular stimulations of the quadriceps muscle group 5 days per week for 4 weeks. Group A received all 10 stimulations with the knee maintained at 65 degrees of flexion. Group B received five stimulations at 65 and five at 35 degrees of knee flexion. Isokinetic strength testing, pre and post treatment, was conducted on a Cybex II Dynamometer. Tests consisted of maximal knee extensions through a 90 degree range of motion at both 30 and 60 degrees per second. Maximal torque force was recorded on a Cybex Dual Channel Recorder in foot-pounds and converted to Newton-meters per kilogram of body weight.

Using pre-test strength levels as the covariate, an ANCOVA indicated a trend ($p < 0.081$) for stimulation at two angles of flexion to increase isokinetic strength. However, the results did

not establish support for EMS as an effective means of increasing isokinetic strength in the quadriceps muscle group at the 0.05 level. A power analysis was done using subject scores which indicated a need for 22 subjects at the 0.05 level or 15 subjects at the 0.10 level.

When scores from this study were combined with those of Pyka (1984) who utilized the same protocol on collegiate football players, an ANCOVA indicated significant isokinetic strength gains with EMS at $p < 0.001$. A post-hoc Newman-Keuls indicated significance between each group (B > A > C). This significance was indicated at both test speeds, 30 and 60 degrees per second.

Given the results of the analysis of data from the two studies combined and the trends within this present study, it is reasonable to suggest that an isokinetic strength training effect does occur with EMS, especially with a two angle stimulation protocol.

PREFACE

When to the moon man did race
His weight floated out into space
And when he splashed down
                his legs weren't quite sound
So that he scooted along on his face.

Hence they started to study and test
To get rid of the muscular pest.
A graduate student
                seemed the most prudent,
But the solution too soon was professed,

"To fight atrophy in a rocket
Plug a spaceman into a socket
And give him a jolt
                of a hundred or so volts
'Til he spins fast 'round on his sprocket."

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CHAPTER I

INTRODUCTION

Rehabilitation of muscle damaged as a result of sport, accident, or disease has commonly involved the use of drugs, diets, and/or exercises. One of the newest treatments is electromuscular stimulation. Physicians and therapists have increasingly utilized forms of electrical stimulation of muscle as an adjunctive treatment for muscular disorders or diseases. The use of electromuscular stimulation (EMS) has been prevalent in the field of physical therapy. Electromuscular stimulation has often been employed and evaluated in patients following knee surgery. Evidence has indicated that EMS is beneficial in providing pain relief (18,22), improved range of motion (18,22), prevention of loss of strength, and an actual improvement in quadriceps strength (1,8,12,13,18,22,25,31,33,35).

Similarly, studies (5,12,18,19,20,25) involving cast immobilized, bedrest and para- or quadripalegic patients have shown significant isometric strength gains following EMS. In fact, there is little question or disagreement as to the effectiveness of EMS in maintaining and developing isometric strength. However, at present, evidence for the effectiveness of EMS in developing isokinetic strength is inconclusive. While some studies (13,31,33) have indicated significant isokinetic strength gains, others (7,22,23,35) have shown only significant isometric strength increases. In addition to its rehabilitative and therapeutic applications (i.e., post-operative knee surgery, pain modification, treatment for Multiple Sclerosis patients and para/quadripalegics), the advent of the Space Shuttle program and possible permanent space stations in the future has raised interest in the use of EMS as a training/conditioning mode (5,20,27,36). In the weightlessness of space, traditional isokinetic and isometric training programs have proven ineffective and inefficient in maintaining muscular strength, especially of the lower extremities. Thus, consideration has been given to the effectiveness of EMS as a training modality in a weightless environment.

The purpose of this study then was to evaluate the effectiveness of high frequency electromuscular stimulation on isokinetic strength of the quadriceps muscle group in active, young adults.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

This review of literature consists of three main subdivisions. In the first section a brief description and explanation of various modes of electrical stimulation is given. Secondly, the results of studies indicating biochemical and structural changes in muscle tissue following electrical stimulation are presented. In the final section a review of studies dealing specifically with the use of EMS for the development or maintenance of strength is presented.

MODALITIES OF ELECTROMUSCULAR STIMULATION

Various modalities of electrical stimulation of muscle have been utilized depending upon the treatment objectives. Stimulators are differentiated by parameters of their produced waveform characteristics (1,26). In differentiating these characteristics, several aspects must be considered. One aspect is the direction of current flow. With EMS a pulsatile current is most commonly employed. This consists of either direct or alternating current producing monophasic or biphasic waveforms, respectively. Pulse duration is another aspect of waveforms to consider. This refers to the time in a single waveform during which current is allowed to flow. With some stimulators the term "period" is used rather than "pulse duration." Period refers to the time from the beginning of one waveform to the beginning of the next waveform. This time period includes the interval between pulses when no current is flowing.

Another important aspect of waveform parameters is the intensity or amplitude of the current flow. Simply stated the amplitude refers to the magnitude or amount of current flow produced. This not only varies from one stimulator to another, some having constant current outputs and other providing variable current flow, but also varies from one waveform to another.

Additional aspects of the waveform are frequency and rate of rise. The rate of rise refers to the time required for the current flow to reach its maximum intensity. Stimulators such as high voltage pulsed galvanic stimulators (HVPGS) reach maximum intensity levels almost instantaneously, exhibiting an extremely rapid rate of rise. However, stimulators which produce more sloped waveforms exhibit much slower rates of rise. The number of specific waveforms produced within a certain unit of time is defined by the term "frequency." Basic units normally considered are cycles per second (cps), pulses per second (pps), and Hertz (Hz). Again, the frequency depends upon the type of stimulator used, with some providing a fixed frequency and others allowing variable frequencies.

In classifying electrical stimulators used for muscular treatment, four major types are commonly considered. Traditional low voltage (TLV) stimulators, utilized for treatment of denervated or partially denervated muscle, incorporate variable frequencies with pulse durations greater than 1 millisecond. Transcutaneous electrical nerve stimulators (TENS/TNS) used in rehabilitation, especially for pain modification/relief, exhibit frequencies ranging from 1 to 140 Hz and fixed-pulse durations of less than 1 millisecond. Typically, pulse duration ranges from 20 to 600 microseconds.

For maintenance of muscle integrity and re-education of the intact/innervated muscle, high voltage pulsed galvanic stimulators (HVPGS) and neuromuscular stimulators (NMS) have been utilized most often. Both units incorporate fixed pulse durations of up to 200 microseconds (for HVPGS) and 600 microseconds (for NMS). Pulses of the HVPGS exhibit twin peak monophasic waveforms. Voltage for these units is greater than 100 volts and is maintained at a constant level. Frequency for HVPGS ranges from 1 to around 140 Hz. Pulses of NMS may be either monophasic or biphasic in waveform with either fixed or variable frequencies depending upon the equipment used. Frequencies range from approximately 3 to 200 Hz with some models employing a "carrier" frequency of 2,500 Hz. This "carrier" frequency consists of a series of pulses which provides an effective frequency of around 50 Hz. Neuromuscular stimulators incorporate either constant voltage or constant current. Newer units have been designed which provide the therapist/controller more manual control over the various waveform parameters (1).

In a study by Bouhman and Shaffer (3), frequencies over 1000 cycles per second more generally found to provide the best response in regard to muscular contraction with the least amount of pain. As subject comfort is an important consideration, frequencies of this level appear to be the most appropriate for use in electrical stimulation of innervated muscle.

ELECTROMUSCULAR STIMULATION

Biochemical and Structural Changes

In a study by Heilmann and Pette (17), left hind leg muscles of adult male rabbits were subjected to long term electrical stimulation. With external electrodes located near the popliteal nerve, the muscles were stimulated 24 hours per day. The stimulation consisted of 0.15 microsecond impulses at a range of 2 to 8 volts with a frequency of 10 Hz. Control measurements were made from the contralateral/right hind limb which received no stimulation. Treatments lasted from 2 to 130 days. After treatment, measurements of contractile properties such as time-to-peak tension during an isometric twitch and half relaxation time were made for both limbs. The animals were then sacrificed and the muscles removed from each limb. Several biochemical measurements were then made.

Results indicated a shift from fast-twitch muscle characteristics observed in the non-stimulated limb to characteristics of slow-twitch muscles in the stimulated limb. Biochemical changes such as a decrease in calcium dependent ATPase activity, a decrease in calcium uptake, and structural shifts in polypeptide electrophoretic analyses correlated with physiological measurements. The rapid increase in the time-to-peak contraction and the increase in half relaxation time in the stimulated limb were similar to those found in slow-twitch muscles. These biochemical and physiological changes seen in long-term stimulation suggested that stimulation may alter the ultrastructure of the sarcoplasmic reticulum of a fast-twitch muscle to one more nearly like that of a slow-twitch muscle. In this instance, stimulation was induced in predominantly fast-twitch muscles using a frequency approximating that of slow-twitch motor neurons.

These results support those obtained in an earlier study by Salmons and Sreter (34) who found that EMS was associated with decreases in calcium dependent ATPase activity, increases in time-to-peak tension and in time from peak-to-half relaxation during an isometric twitch, as well as a decrease in maximum tetanic tension.

In a later study by Heilmann, Muller, and Pette (16), electrophoretic analyses and electronmicroscopy revealed that similar biochemical changes (i.e., decreases in calcium ATPase activity, decreases in calcium uptake, and polypeptide shifts) coincided with ultrastructural alterations. These alterations were indicated by changes in the density of several intramembranous protein particles.

Using the same experimental methods previously employed with chronic stimulation of hind limb muscles in rabbits, Eisenberg and Salmons (11) also noted structural alterations. Their results indicated a decrease in the number of triade (junctures of the sarcoplasmic reticulum, T-tubules, and terminal cisternae) per unit area of muscle fiber.

In a recent study by Greathouse, Nitz, Martulionis, and Currier (14) the effects of short-term, moderate frequency, electrical stimulation on the ultrastructure of rat hind limb muscles were investigated. After treatment, muscle tissues were examined under electron microscopes for possible morphological changes. Results indicated no alteration of A-bands, I-bands, Z-disc, or myosin and actin filaments in either stimulated or non-stimulated/control groups. However, treatment groups showed a significant increase in mitochondrial number and volume density. Concomitantly, a decrease in T-tubule systems was noted in the muscles of the treatment groups. These results provided additional supportive evidence of an ultrastructural alteration in muscle fiber under appropriate electromuscular stimulation.

Fewer studies have been conducted in humans with regard to biochemical and structural changes in muscle following electrical stimulation. The difficulty in obtaining volunteers for muscle biopsies has probably been a contributing factor in the lack of detailed information. Yet, several studies do indicate various structural changes (5,12,21,37).

Stanish, Valiant, Bonen, and Belcastro (37) used electrical stimulation of the quadriceps muscle group in immobilized patients following major knee surgery to evaluate effects on muscle glycogen and myofibrillar ATPase. Six subjects/patients were subjected to electromuscular stimulation 10 days after surgery. A control group of three subjects received no electrical stimulation. Treatments were given 5 days per week for a total of 8 to 10 weeks of stimulation being discontinued 4 weeks after cast removal. A high frequency, 2500 Hz, stimulator was used which produced a sinusoidal waveform. Each treatment session consisted of 10 contractions in which the current surged on for 5 seconds, remained constant for 10 seconds, then cut off for a 45-second rest period. Muscle biopsies were taken just prior to surgery, 10 to 15 days after surgery, 6 weeks after surgery, and finally 6 weeks after the cast was removed. These biopsies were evaluated for changes in glycogen content and myofibrillar ATPase activity. Results indicated no alteration in glycogen levels. However, the study showed that electrical stimulation prevented the decrease in myofibrillar ATPase normally associated with immobilization.

A similar study by Eriksson and Haggmark (12) investigated the effects of EMS on the levels of the enzyme, succinic dehydrogenase (SDH), in immobilized patients. In this 4 week study two groups were compared; one received isometric exercises, the other received EMS. Treatment sessions were conducted 5 days per week. Stimulation lasted for 1 hour with repetitions of 5 seconds of current flow followed by 5 seconds of rest. After 4 weeks, muscle biopsies were taken. Results indicated that the isometric exercise group exhibited a significant decrease in SDH levels while the EMS group exhibited a significant increase in SDH levels.

A Soviet study by Kots (21), utilizing a high frequency stimulator, 2500 Hz, revealed ultrastructural alterations following

EMS. Results indicated an increase in myofibril density and a decrease in sarcoplasm within the muscles. Kots suggested that these two factors contributed to the increase in contraction strength that was also noted.

An additional Soviet study (5) indicated that EMS inhibited muscle atrophy during 7 weeks of bedrest in an antiorthostatic position (head-down tilt, -6 degrees). In this study the use of EMS resulted in an improvement of or stabilization of muscle fiber size and leg circumference. This supported the results of an earlier study (20) showing that electrical stimulation of the muscles of the spine, abdomen, and lower extremities was effective in reducing muscle atrophy in bedrest patients placed in an antiorthostatic position.

Strength Gains

Although there is conflicting evidence as to the effectiveness of electromuscular stimulation on strength gains (7,13,22,23), several studies indicate a direct correlation of EMS to strength maintenance and increase (5,13,18,20,22,31,33). A recent study (25) utilizing electrical stimulation during immobilization following knee surgery evaluated the effects of EMS on muscular atrophy (thigh circumference) and isometric strength. A control group and a group receiving EMS participated. Thigh circumference and isometric strength of the quadriceps muscle group were measured 6, 9, and 12 weeks after surgery and cast immobilization. Results indicated no significant differences in thigh circumference changes (atrophy); but, a significant reduction was noted for the EMS group in the rate of decrease in isometric strength.

Using healthy subjects, Selkowitz (35) evaluated the effects of EMS on isometric strength in the quadriceps muscle group. Selkowitz found significant increases in isometric strength in the EMS group over the control, non-stimulated group.

Recently, Laughman (22) investigated the effects of EMS on the quadriceps muscle group as a possible conditioning/training mode. In the study 58 healthy subjects, 28 males and 30 females, ranging from 21 to 39 years of age, were randomly divided into three groups. Nineteen subjects were used as controls in the 5-week study and received no treatment. Twenty subjects received daily stimulation of the quadriceps femoris muscle, 10 times per day, 5 days per week. The stimulation consisted of cycles of 15 seconds of stimulation followed by 50 seconds of rest repeated 10 times. Laughman pointed out that the first 5 seconds of stimulation were used to gradually bring the intensity level up to the selected current intensity level; and, therefore, the subjects effectively received only 10 seconds of the selected stimulation. The final group of 19 subjects received daily isometric strengthening exercises of the quadriceps femoris muscle. This exercise consisted of cycles of 10 seconds of maximal contraction followed by 50 seconds of rest repeated 10 times, 5 days per week. Laughman's study indicated a significant increase in isometric strength with both isometric exercise and EMS when compared with the control group. The results specifically indicated an average control group strength gain of 2 percent, whereas the EMS and isometric exercise groups showed an average strength gain of 22 and 18 percent, respectively.

Laughman's findings supported and extended those of Currier, Lehman, and Lightfoot (7). In this study the effects of isometric exercise, and isometric exercise in combination with EMS, on the quadriceps femoris muscle were compared to those of a control group of non-treated/trained healthy males. While results indicated no significant difference between trained groups after completion of the study, the groups exhibited increases of 19 percent (isometric exercise group) and 21 percent (isometric exercise and EMS group) in isometric strength.

In a more recent study, Currier and Mann (8) investigated the effects of EMS on isometric and isokinetic strength development in healthy individuals. Thirty-four subjects were treated/trained for 5 weeks, 3 days per week. One group trained using only maximal voluntary isometric contractions (Group E). Another group received EMS only (Group S). Group ES received a combination of EMS and isometric exercise. A control group (Group C) received no treatment/training. Stimulation was provided by the Electrostim 180 which incorporates 2500 Hz modulated at 50 pps. Each group performed 10 contractions during each session. Isometric and isokinetic strength levels were measured at rates of 0 degrees/second, 100 degrees/second, 200 degrees/second, and 300 degrees/second using a Cybex II Dynamometer. Pre-training and post-training strength levels were measured. Results indicated significant isometric strength gains in all three trained groups but no significant isokinetic strength gains.

Recently several studies (13,18,31,33) have indicated improvements in isokinetic/dynamic strength following electrical stimulation of muscles. Using transcutaneous electrical nerve stimulation (TNS) Jensen, Conn, Hazelrigg, and Hewett (18) evaluated the effectiveness of EMS on isokinetic strength and leg volume following arthroscopic knee surgery. Three groups, a control/non-stimulated group, a group using a "placebo" unit, and a group using a "live" unit participated. Isokinetic strength and leg circumference measurements were taken 1, 3, and 7 weeks postoperatively. Results indicated the "live" TNS unit group regained pre-operative values in leg volume, isokinetic power in flexion and extension, and range of motion 1 month sooner than either of the other groups.

Romero, Sanford, Schroeder, and Fahey (33) evaluated the effects of EMS on both static/isometric and dynamic/isokinetic strength. Stimulation was provided by a low voltage stimulator with a constant current of 2000 Hz. Treatment/training sessions were conducted for 5 weeks and lasted 15 minutes per session. Both legs of the subjects were stimulated. Strength testing employed the use of a Cybex II Dynamometer with isometric testing at 65 degrees of knee flexion and isokinetic testing at both 30 and 60 degrees per second. Results indicated isometric strength gains in both the weaker and stronger legs, 31 and 21 percent, respectively.

Of the weaker and stronger legs, only the weaker leg exhibited any isokinetic strength gain, 13 percent, and this was found only at 30 degrees per second. Other isokinetic testing did not indicate significant strength gains.

In a study by Fahey, Harvey, Schroeder, and Ferguson (13) EMS was shown to increase strength isometrically and isokinetically. Fifty-five subjects participated, 27 females and 28 males. Subjects were divided into three groups, a control group which received no stimulation and two groups having the quadriceps muscle group stimulated, one at 65 degrees of kene flexion and the other with the knee fully extended. Treatment/training sessions were conducted three times per week for 6 weeks with each stimulation session lasting 15 minutes. The stimulator incorporated 25 volts at 50 Hz producing a pulsatile current of an asymmetrical bi-phasic square wave. Current amperage was based on maximum tolerance levels of the subjects with a current flow cycle of 10 seconds on then 5 seconds off with a 2 second time to peak stimulus surge. Pre and post strength testing was done on a Cybex II at 30, 60, 90, and 120 degrees per second.

Results indicated both isometric and isokinetic strength gains at all angular velocities for both males and females stimulated at 65 degrees of knee flexion. Subjects stimulated at full extension exhibited various responses to the EMS. Several subjects showed strength gains at some angular test velocities while others exhibited little or no strength gains after treatment. Of note was the finding of no significant gender differences in response to EMS. The study also concluded that while EMS can increase isometric and isokinetic strength in healthy individuals, isokinetic strength might be increased more if the knee was flexed during stimulation treatments.

Pyka (31) investigated the effects of high frequency EMS on the quadriceps muscle group of 12 college football players actively involved in a training program. Utilizing a high frequency stimulator, the Electrostim 180, subjects were stimulated 5 days per week for 4 weeks. Subjects were randomly assigned to three groups, a control group (Group C) and two groups receiving stimulation. Using a unique protocol, one group (Group B) received treatments at two angles of knee flexion, 65 and 35 degrees. Group A received treatments at 65 degrees of knee flexion only. Each training group received 10 stimulations per session, either five at 65 degrees and five at 35 degrees of knee flexion (Group B) or all 10 at 65 degrees of knee flexion (Group A). The control group received no EMS treatments. Pre and post isokinetic strength tests of the weaker leg were conducted on a Cybex II Dynamometer at 30 and 60 degrees per second. Results indicated that EMS training at two angles of knee flexion increased isokinetic strength of the quadriceps muscle group in healthy individuals at angular velocities of 30 and 60 degrees per second. There were no significant differences between the control group and Group A, stimulated at only one angle of knee flexion.

SUMMARY

The electrical stimulation of muscle has often been incorporated within physical therapy settings for the treatment and rehabilitation of injuries. Many of the early investigations concerning electromuscular stimulation in humans involved bedrest patients or cast immobilization subjects (5,12,19,20,37). Various aspects and effects of electrical stimulation on muscles were considered and evaluated in these early studies, including biochemical and structural changes of muscle (5,12,37) and prevention of denervation atrophy (5,19,20). With improved technology there has been increased interest in EMS as a strength training modality.

In pursuing research in this area, various protocols and equipment modes have been utilized. This, of course, may have been partially responsible for the varying and sometimes contradictory results. Studies have consisted of sessions of from 3 to 6 weeks and from 3 to 5 days per week. Treatments have incorporated low and high frequency stimulation; some with a brief (8 seconds) rest between contractions and others with a longer (50 seconds) rest between contractions. Some stimulators have utilized pulsed square waves (monophasic) while others have utilized biphasic sine wave patterns. With the advent of the Electrostim 180 and equipment similar in function, studies have exhibited more consistent treatment parameters.

Studies done by Russian scientists have indicated strength gains through an electromuscular stimulation protocol (5,20,21).

Other studies have shown contradictory results (7,23). Though many studies have shown significant increases in isometric strength with EMS, the evidence has been inconclusive for changes in isokinetic strength. A study by Currier in 1983 (8) showed significant isometric strength gains but no isokinetic strength gains. However, research by Romero (1982), Pyka (1984), and Fahey (1985) has indicated significant isokinetic strength gains following an EMS training/ treatment protocol.

As dynamic/isokinetic strength is more important for most physical activities/performances than static/isometric strength, a means of developing dynamic strength through EMS would be a valuable treatment/training tool. To date, only inconclusive evidence has been presented for the use of EMS in developing isokinetic strength.

Fahey et al. (13) found that stimulation with the knee in a flexed position provided a more substantial isokinetic training effect than with the knee extended. The study by Pyka (31) indicated a tendency for stimulation at two angles of knee flexion to develop greater strength increases than stimulation at one angle. Utilizing these concepts and protocols, the purpose of this study was to evaluate the training effects of EMS on isokinetic strength of the quadriceps muscle group in non-strength trained but active individuals being stimulated at one and two angles of knee flexion.

CHAPTER III

METHODOLOGY

SUBJECTS

Twelve young adult volunteers, 21 to 29 years of age, were used in this study. Six males and six females participated. A study by Fahey et al. (13) indicated no significant gender difference in response to EMS treatments, thus supporting the use of both genders. Physical descriptions of the subjects are outlined in Table 1. All subjects were instructed not to begin any lower extremity strength training programs during the study.

STRENGTH TESTING

Each subject was given an isokinetic strength test of both quadriceps the week prior to the initial treatment session. A post-test isokinetic strength evaluation was made on the weaker or non-dominant leg, which was used in the training sessions, the week following stimulation treatments. Tests were conducted on a Cybex II Dynamometer which has been demonstrated to be a valid means of measuring dynamic/isokinetic strength (24,38). Measurements were made of four maximal knee extensions at 30 degrees per second and 60 degrees per second to determine isokinetic strength levels of the quadriceps muscle group. Movement was from 90 degrees through 180 degrees of extension for each test.

Table 1. Group Physical Characteristics Mean ($\bar{x}$) ± Standard Error of the Mean (SEM).

Characteristics	Group A	Group B	Group C
Height (cm)	173.4 ± 6.2	173.4 ± 4.4	172.0 ± 4.3
Weight (Kg)	58.8 ± 4.7	67.1 ± 4.7	65.0 ± 4.1
Age (years)	24.5 ± 1.6	24.3 ± 1.2	25.0 ± 1.7

Placed in a seated position with their backs supported at a 70 degree angle from horizontal, the subjects were secured with Velcro strapping across the chest, hips, and over the thigh involved in testing to prevent extraneous movement. This position has been shown to enable maximal knee extensor force (6,32). The lever arm of the Cybex II was positioned so that its axis of rotation was aligned with that of the knee joint. The lever arm was also adjusted to the length of each subject's leg. A padded Velcro strap was used to secure the leg to the distal end of the lever arm. This was positioned just proximally to the medial malleolus of the tibia. Position/height of the axis and length of the lever arm were recorded for use during the post-testing period.

For each subject both legs were tested at 30 and 60 degrees per second with a 3 to 5 minute rest period between each set of maximal contractions. Subjects were verbally encouraged to perform maximally during each test. Before every test the subject was allowed to warm-up at a higher speed, 120 degrees per second, and then allowed to practice at the test-speed using 50 to 75 percent of maximal effort. Recordings were made of each contraction on the Cybex II Dual-Channel Recorder with measurements in foot-pounds. These were then converted to Newton-meters. This torque force value was then divided by the individual's weight in kilograms to account for the size differences between subjects. The maximal value was determined for each leg and test-speed in order to determine which leg was weaker. In subjects who exhibited no difference in strength levels or who exhibited one leg stronger at 30 and the other leg at 60 degrees per second, the non-dominant leg was used for further study and/or treatment. The weaker/non-dominant leg was used since research (13,33) has indicated that EMS produces greater strength increases in the non-dominant leg.

EXPERIMENTAL PROTOCOL

Three experimental groups were formed with four in each group, two males and two females; one was a control group (Group C) which did not receive EMS and two were groups which received EMS (Groups A and B). Four subjects who were unable to participate 5 days per week were assigned to the control group. The remaining eight subjects were randomly assigned to the groups with equal gender distribution.

Treatment sessions were 5 days per week for 4 weeks. Each session lasted 15 to 20 minutes incorporating 10 maximal involuntary contractions per session. The quadriceps muscle group of the weaker or non-dominant leg of each subject, determined by a Cybex II Dynamometer, was stimulated. Group A received all 10 involuntary contractions with the knee maintained at 65 degrees of flexion while Group B received five contractions at 65 degrees and five contractions at 35 degrees of flexion. Group C received no stimulation treatments.

In order to maintain the subject in the proper position, each subject was placed in a supine position on a flat board with the knee of the treated leg over/across a quadricep board. The hips were then secured with a Velcro strap. The ankle of the treated leg was also secured with a Velcro strap as well as additional ankle weights necessary to prevent movement of the leg during maximal involuntary contractions. These precautions were taken to prevent alteration of the angle of flexion during the treatment sessions. Angles were measured with a goniometer and were rechecked during the treatments to assure constant treatment angles.

Treatment/training sessions were conducted at the Sports Treatment and Rehabilitation Clinic (STAR) at the Fort Sanders Regional Medical Center in Knoxville, Tennessee. The Electrostim 180-2 (Electrostim 180, USA, 333 North Hammes Ave., Joliet, IL 60435) was utilized for the electrical stimulations. This stimulator produces a sinusoidal waveform with a constant pulse width at a frequency of 2500 Hz and a variable current output. Current intensity was determined by maximal individual tolerance level. Current levels were increased when possible according to the subject's accommodative ability. It should be noted that electrical stimulation with frequencies of 2500 Hz has the additional effect of being an afferent pain blocker. This greatly reduces the subject's discomfort.

Daily current levels for each subject and each contraction were recorded. Average current accommodation for each session at each treatment angle was determined and recorded. Current was applied via two transcutaneous electrodes placed: a) 5 to 7 inches proximally to the inferior border of the patella and b) 13 to 15 inches proximally to the inferior border of the patella (approximately 3 inches distal to the inguinal fold) over the vastus medialis and rectus femorus muscles. These electrodes were placed on moist sponges, 4 inches by 6 inches, which were then secured by Velcro straps that covered the entire sponge.

STATISTICAL ANALYSIS

Post-test strength values were analyzed for significant differences with a two-factor ANCOVA (4,10) using group and test-speed as the two factors. The pre-test strength level was used as the covariate. Statistical significance for the analysis was set at $p < 0.05$.

CHAPTER IV

RESULTS

CURRENT ACCOMMODATION

Current intensity was increased during stimulation treatments according to the subject's tolerance level. Though tolerance levels did not necessarily increase from day to day, weekly trends exhibited a gradual increase. Average daily current intensities for Groups A and B are shown in Figures 1 and 2, respectively. Average weekly accommodation for each subject is presented in Table 2. All subjects exhibited an adjustment period of 7 to 10 days during which little change was noted in tolerance levels. With one exception, subject B-3 (Group B), subjects exhibited a marked increse in tolerance levels after 7 to 10 days of treatments.

All subjects indicated an initial apprehension towards the stimulation treatment for the first 2 to 3 days of the treatment/ training sessions, along with a mild discomfort from the muscle contractions. For the most part the only subsequent discomfort was attributed to muscle soreness. This was primarily noted during the first 48 hours after the initial stimulation session. Also, several subjects noted a slight "burning" and/or "tingling" sensation under the electrode sites during later stimulation sessions at the higher intensities. Only one subject, B-3 (Group B), stated

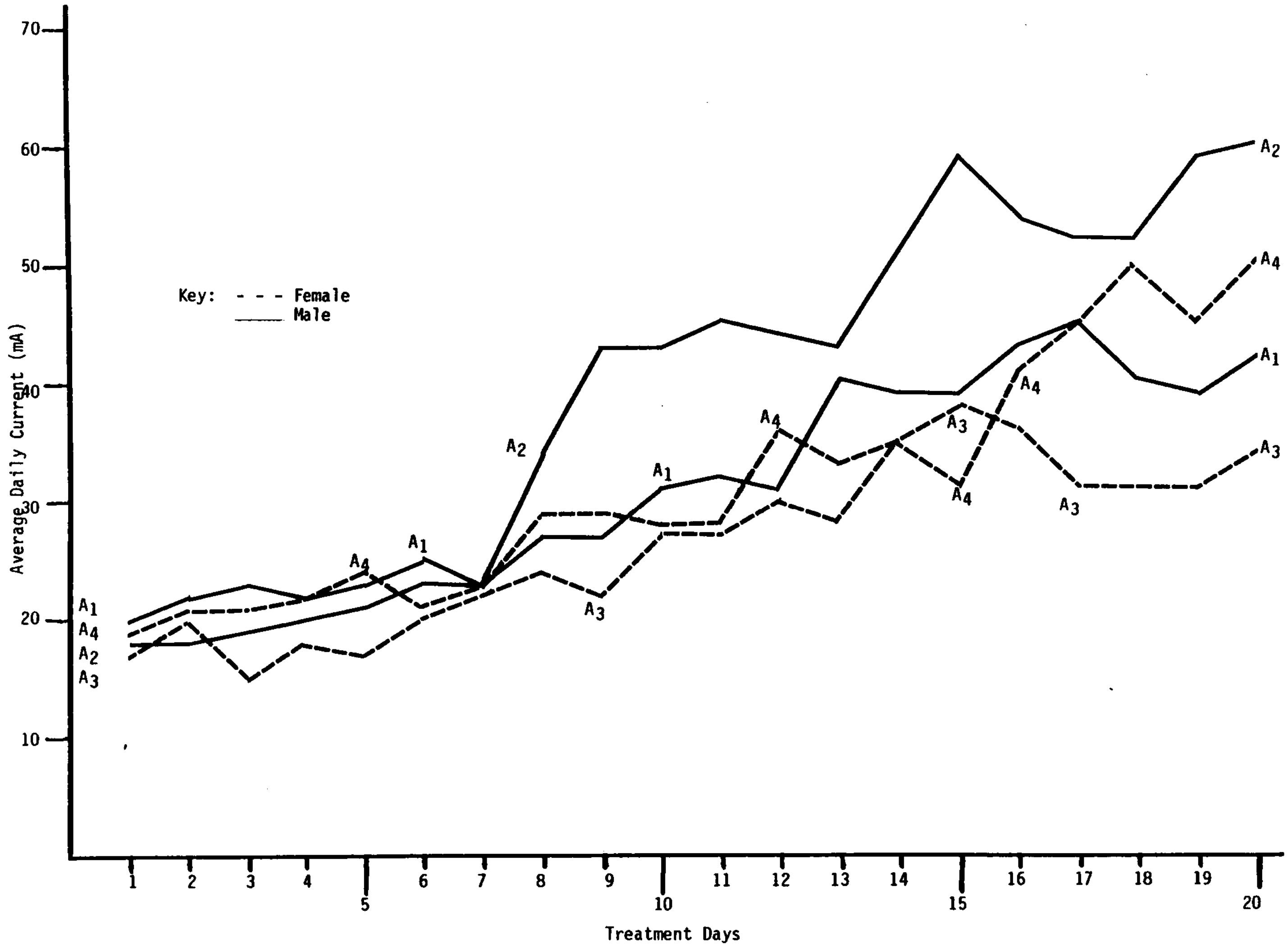

Figure 1. Current Accommodation (Daily Subject Mean--Group A).

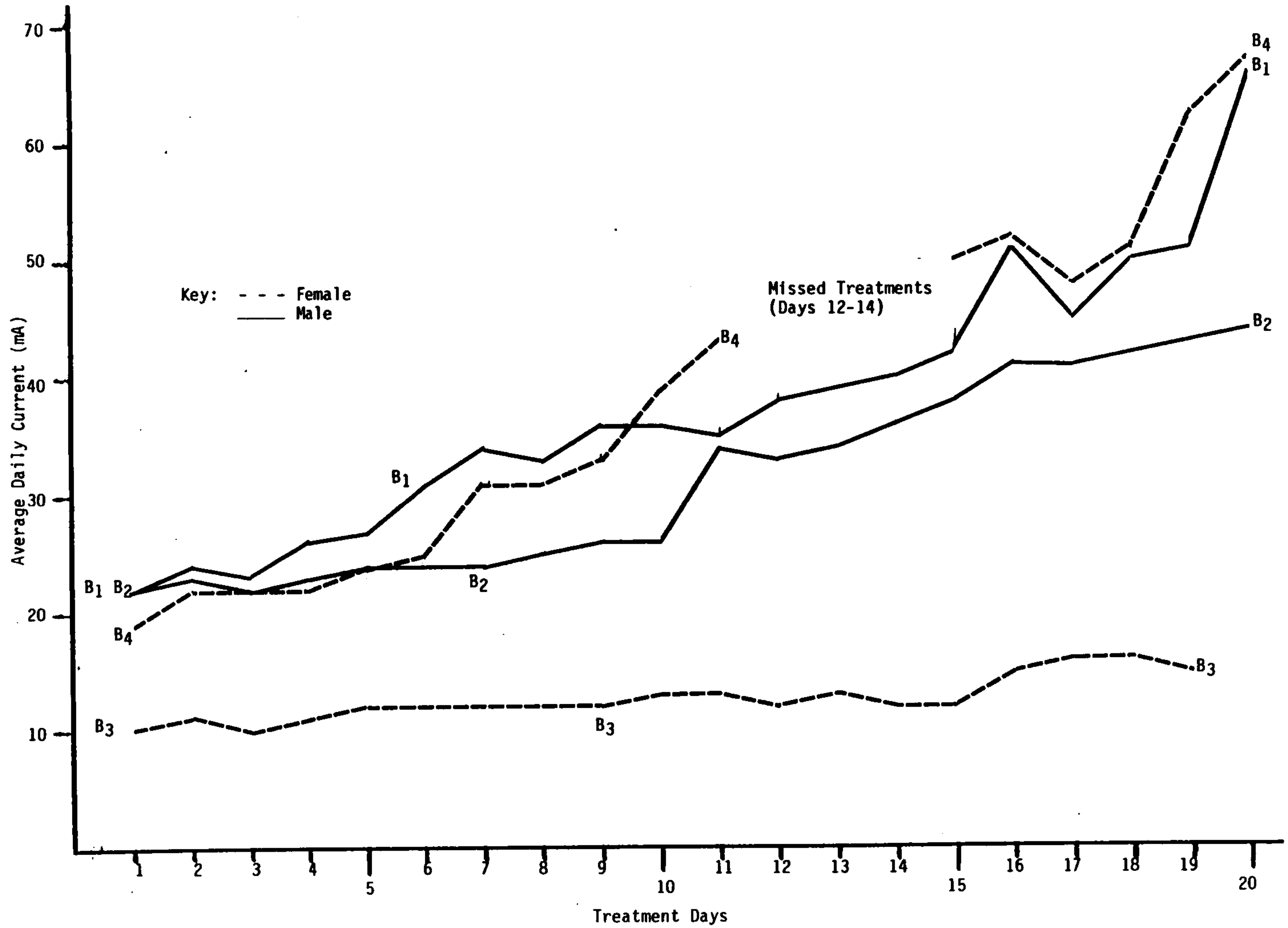

Figure 2. Current Accommodation (Daily Subject Mean--Group B).

Table 2. Average Weekly Current Accommodation (mA).

Subject	Week 1	Week 2	Week 3	Week 4
		Group A		
A-1	22	27	36	42
A-2	19	33	48	55
A-3	17	23	32	33
A-4	21	26	33	46
		Group B		
B-1	24	33	39	52
B-2	23	25	34	42
B-3	11	12	12	15
B-4	21	31	46	55

that the stimulation treatments were hard to tolerate. As was noted earlier (see Figure 2 and Table 2), this subject was able to accommodate only a small increase in current intensity.

Of note was the finding of a wide range of tolerance levels. During the final week, which provided the greatest accommodation levels in all subjects, average current intensities ranged from 15 mA to 59 mA. Though male subjects tolerated more current as a group ($\overline{X}$ = 48 mA) than females ($\overline{X}$ = 40 mA), gender was not a major factor in current accommodation. The first and fourth highest levels of tolerance were recorded by female subjects. Body weight (kg) was also indicated as a non-determinant for tolerance levels. The lightest male and female subjects exhibited the first and second, respectively, highest tolerance levels for their genders, while the heaviest male and female subjects exhibited the second and first, respectively, highest tolerance levels.

Current tolerance levels were unrelated to changes in strength levels in this study. The subject with the lowest tolerance level, B-3 (Group B), exhibited the second largest increase in strength of the experimental subjects. Subject A-3 (Group A), though tolerating the second highest current level, exhibited only moderate strength increases at 30 degrees/second and a decrease in strength levels at 60 degrees/second.

STRENGTH CHANGES

As a whole, all groups exhibited isokinetic strength increases from pre- to post-testing levels. Group A (stimulated at one angle, 65 degrees, of knee flexion) exhibited the least increase at both test speeds, 30 and 60 degrees/second. Group B (stimulated at two angles of flexion, 65 and 35 degrees) exhibited the greatest increase in strength at both test speeds (Tables 3 and 4). Group C (control, non-stimulated) exhibited moderate strength gains at both test speeds. The majority of the control group's increase was attributed to one subject, C-3, who exhibited significant strength increases at 30 (27.6%) and 60 (18.8%) degrees/second, respectively.

Individually, subjects from both Group A and Group C exhibited a mixture of decreases and increases in strength levels at both 30 and 60 degrees/second (Tables 5 and 6). Although two subjects from Group B missed stimulation sessions due to unforeseen schedule conflicts (one missed three sessions while another missed one), every subject in this group exhibited increases in isokinetic strength at both test speeds. Trends in the means suggested a training effect (isokinetic strength gain) with stimulation at two angles (Group B) of knee flexion (see adjusted means, Tables 7 and 8) but not with stimulation at only one angle (Group A). However, a two-factor ANCOVA (group X torque/test speed) indicated that no group exhibited significant isokinetic strength gains at either test speed (Tables 7 and 8).

Table 3. Mean Percent change in Strength/Body Weight Pre-Post Treatment.

Test Speed	Group A	Group B	Group C
At 30 degrees/second	+ 3.1	+ 8.9	+ 4.6
At 60 degrees/second	+ 1.1	+11.0	+ 4.1

Table 4. Group Strength/Body Weight (N-m/Kg) Levels Pre and Post Treatment.*

Group / Speed	Pre $\bar{X}$	Pre ± SEM	Post $\bar{X}$	Post ± SEM
A - 30 degrees/second	2.80	± 0.14	2.89	± 0.10
A - 60 degrees/second	2.75	± 0.11	2.78	± 0.10
B - 30 degrees/second	2.56	± 0.14	2.81	± 0.16
B - 60 degrees/second	2.43	± 0.15	2.73	± 0.17
C - 30 degrees/second	2.29	± 0.15	2.40	± 0.08
C - 60 degrees/second	2.10	± 0.12	2.19	± 0.08

*Mean ($\bar{X}$) and Standard Error of the Mean (SEM).

Table 5. Pre and Post: Strength/Body Weight (N-m/Kg) at 30 Degrees/Second.

Group	Pre	Post
A		
1	3.30	3.28
2	3.32	3.09
3	2.19	2.39
4	2.39	2.78
B		
1	2.99	3.09
2	3.10	3.55
3	1.89	2.11
4	2.27	2.49
C		
1	2.70	2.77
2	2.40	2.43
3	1.47	2.03
4	2.60	2.35

Table 6. Pre and Post: Strength/Body Weight (N-m/Kg) at 60 Degrees/Second.

Group	Pre	Post
A		
1	3.18	3.32
2	3.00	2.88
3	2.53	2.39
4	2.27	2.51
B		
1	2.99	3.34
2	2.90	3.27
3	1.74	1.96
4	2.09	2.33
C		
1	2.58	2.54
2	2.23	2.29
3	1.47	1.81
4	2.10	2.10

Table 7. EMS ANCOVA.

Source	SS	DF	MS	F	P
Group	.221	2	.110	2.895	.081
Test Speed	.005	1	.005	.132	
Group x Speed	.009	2	.004	.105	
Error	.651	17	.038		
Total	.886	22			

Homogeneity of Regression

SS Between Regression = .351

SS Within Regression = .300

F(5,12) = 2.813   P = .065

Within-Groups Correlation: R = .919

Table 8. Adjusted Force Output Means (Single Study).

Group	Test Speed (Degrees/Second) 30	60	Total
A	2.63	2.57	2.60
B	2.75	2.77	2.76
C	2.55	2.50	2.53
Total	2.64	2.61	

CHAPTER V

DISCUSSION

The primary intent of this study was to evaluate the training effect of EMS on a typically active, young adult population. Young adults who participated in this study were active but not involved in any concurrent strength training program. Additionally, an evaluation of the relative effectiveness of stimulation at one or two angles of knee flexion in developing isokinetic strength was considered.

Current intensity has been considered an indication of percent of maximal contraction (2,28) with higher intensities related to greater percentages of maximal contraction. This study indicates a wide range of current tolerance levels (15 mA to 59 mA during the last week) and accommodation rates (Figures 1 and 2, pages 25 and 26, respectively, and Table 2, page 27). Yet, average weekly current accommodation for males (48 mA) and females (40 mA) compare favorably with those noted by Fahey et al. (1985).

Generally, during the first week of the study, current tolerance levels were one-half or less than the maximum tolerance levels achieved before completion of the 4 week treatment protocol. The increase in tolerance between the seventh and tenth days, noted in all but one subject, agrees with results from a study by Owens and Malone (28). Additional increases were noted during the third and fourth weeks of treatments. Pyka (1984) indicated similar progressions in current accommodation though his subjects tolerated much more current. The difference in maximal current tolerance between subjects in Pyka's (31) study and those in this study was probably due to the difference in subject populations. Subjects used in this study were typically active, young adults while Pyka's subjects were drawn from a collegiate football team. Pyka's subjects were 45 to 80 kilograms heavier than subjects in this study and were involved in weight training programs. The initial adjustment period for subjects in the present study suggests that the actual training period in which contractions were greater than 60 percent of maximal voluntary contraction levels was closer to 3 weeks than to 4. Owens and Malone (28) state that for a training/conditioning effect to occur, one must produce contractions greater than 60 percent of a maximum contraction.

The discomfort noted by subjects during EMS varied from subject to subject and from day to day. Responses ranged from concerns about when the increase in current intensity would "stop" during each stimulation's surge to laughter at the "tingling numbness" at higher intensities. These responses were similar to subject sensations described by Pyka (1984) and Currier (1984). In both of these studies primary subject complaints were of muscle soreness and of a "burning" or "tingling" sensation under the electrodes. No apparent reason was indicated for the unusual discomfort of subject B-3 in the present study, who was unable to tolerate current intensities similar to those tolerated by the other subjects. However, the fact that this subject had the lowest initial strength levels of the stimulated subjects may have influenced her accommodative ability.

Noting that no group exhibited significant increases in isokinetic strength at the $p < 0.05$ level, the hypothesis that high frequency EMS would significantly increase isokinetic strength of the quadriceps muscle group in active (but non-strength trained) young adults was not supported. The second hypothesis, that EMS at two angles of flexion would be more effective in producing dynamic strength increases in the quadriceps muscle group than EMS at one angle of flexion, was also not supported at the $p < 0.05$ level. However, the adjusted means from the ANCOVA (Table 8) indicated a trend for an EMS training effect (isokinetic strength gain) most notably in Group B, stimulated at two angles of knee flexion. The trends in the present results indicating that stimulation at two angles of flexion (65 and 35 degrees) may be more effective in developing isokinetic strength than stimulation at one (65 degrees) angle of flexion are consistent with those reported by Pyka (1984). Pyka's findings of significance with the same EMS protocol as used in the present study could be attributable to the higher current intensity tolerated by his subjects, providing a contraction involving a greater number of muscle fibers (2,15,26). Additionally, the fact that Pyka's control group exhibited a large decrease (-7.7 to -9.7 percent) in strength most likely contributed to his findings of significance.

That a significant difference was not found between either of the treatment groups or between the treatment and control groups in the present study may be due in part to the adjustment period the treatment subjects initially experienced for the first week of sessions. The limited number of subjects involved (12 with eight being stimulated) also contributed to the statistical outcome. Obviously, with such a limited subject population, significant group differences were less likely. Additionally, the fact that two subjects in Group B missed treatment sessions (especially subject B-4, who missed three sessions in a row and showed only slight to moderate strength gains) may have influenced the results by lowering post-strength values for that group.

Utilizing the scores obtained from this study, a power analysis was done to determine an appropriate sample size necessary to show significance at the 0.05 level. With the Beta level set at 0.25 and the alpha level at 0.05 the power analysis indicated a need for 22 subjects. With Beta set at 0.50 and alpha at 0.05 the power analysis indicated a need for 11 subjects. However, using a significance level of alpha at 0.10 only 15 subjects were required with Beta at 0.25 and just 7 subjects with Beta at 0.50. Evidently a larger sample size was needed to obtain reliable statistical results.

With this need for a larger sample in mind and noting the fact that Pyka utilized both the same testing and treatment protocol employed in the present study, subject scores from both studies were combined for additional analysis. The subject differences from study to study (football players vs. typically active, young adults) were minimized by using a strength per kilogram of body weight ratio. Force values per kilogram of body weight were similar for both study groups.

A 3 X 2 ANCOVA was then performed on the combined data using pre-test strength values as the covariate and post-test strength values as the dependent variable (Tables 9 and 10). The results indicated a significant isokinetic strength increase, $p < 0.001$, for both test speeds, 30 and 60 degrees per second. A post-hoc Newman-Keuls test indicated a significant difference, $p < 0.01$, between the scores of Group A (stimulated at one angle of knee flexion) and Group C (non-stimulated), Group B (stimulated at two angles of knee flexion) and Group C, and Group A and Group B (Group B > Group A > Group C). These differences were exhibited at both test speeds.

One interesting result was the virtually equal adjusted mean values at 30 and 60 degrees per second for each group (Tables 7-10). This was indicated in both analyses, the combined study ANCOVA and the ANCOVA for the present study. Apparently, the use of one or the other test speeds would have been adequate for the results obtained by these studies.

Table 9. Combined EMS Studies.

Source	SS	DF	MS	F	P
Group	.620	2	.310	10.333	<.001
Test Speed	.003	1	.003	.100	
Group x Speed	.003	2	.002	.067	
Error	1.217	41	.030		
Total	1.844	46			

Homogeneity of Regression

SS Between Regression = .553

SS Within Regression = .664

F(5,36) = 6.001 P = <.001

Within-Groups Correlation: R = .929

Table 10. Adjusted Force Output Means (Combined Wright and Pyka Studies).

Group	Test Speed (Degrees/Second) 30	60	Total
A	2.81	2.82	2.81
B	2.99	2.95	2.97
C	2.70	2.69	2.69
Total	2.83	2.82	

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDY

The purpose of this study was to investigate the effects of electromuscular stimulation on isokinetic strength in the quadriceps muscle group of active, young adults. Subjects were divided into three groups, a control group which did not receive electrical stimulation and two groups receiving electrical stimulation treatments. One treatment group was stimulated with the knee positioned at 65 degrees of flexion; the other treatment group was stimulated with the knee positioned at a combination of 65 and 35 degrees of flexion. Pre- and post-test strength values were analyzed for significant differences.

Though each treatment group exhibited mean isokinetic strength gains from pre to post testing, no group exhibited significant increases at the 0.05 level. Neither was there any significant difference in the effectiveness of stimulation at two versus one angle of knee flexion. Despite nominal strength gains, a training effect of EMS on typically active, young adults was not statistically supported. However, when the data of the present study were combined with those of Pyka (1984), a significant EMS training effect on isokinetic strength resulted. Of particular note was the superior effect of the two angle stimulation protocol.

The results of this study raise several questions which should be explored in subsequent studies.

1. Obviously, with a subject population limited to 12, four per group, any significance is difficult to establish. The power analysis done from this study indicated a need for 22 subjects at the 0.05 significance level. Further research, therefore, would be enhanced by a larger subject population.

2. Additionally, a study involving a longer training period would be advantageous in light of the subjects' initial adjustment to current flow during the first week. A longer treatment/training protocol, 5 to 6 weeks in length, would allow for the initial adjustment period and still provide adequate time for a training effect to occur.

3. Use of the contralateral leg as an additional control along with a non-stimulated group would enhance the reliability of any possible training effect on pre-post strength values.

4. Since the adjusted means from the present study and the combined study analysis indicated virtually no difference in torque-force per kilogram of body weight at 30 and 60 degrees per second, future studies should use only one of these test-speeds. The additional testing at higher rates (i.e., 120 and/or 240 degrees per second) would be more advantageous.

5. Finally, a study monitoring current intensity and percent of maximal isometric contraction concurrently during stimulation would be beneficial in establishing and maintaining intensity levels

high enough for each subject to produce a training effect. This information could be obtained by using a Cybex II Dynamometer to secure the subject in proper position while enabling constant monitoring of torque force output on the Dual-Channel Recorder. As greater muscular tension is produced with increasing stimulation by involving a larger number of motor units (2,15,26), it would be important to reach and maintain the highest level of current intensity tolerable. By utilizing a concurrent gauge of the percent of maximal isometric contraction and current intensity, a ratio of muscular tension to current intensity would be available.

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VITA

Monte Shane Wright was born in Odessa, Texas, on January 31, 1959. Widely traveled and educated he attended elementary and secondary schools in North Carolina, Tennessee, New Jersey, and Alabama. In June 1977 he graduated from high school as Salutatorian. Also actively involved in athletics, he was honored by selection as an All-State linebacker his senior year. The following August he entered Samford University from which he received a Bachelor of Science degree in Biology in May 1982.

For two years after graduation he worked on a cardio-vascular surgery unit at the University of Alabama, Birmingham as a nursing assistant. There he learned about and participated in critical care, post-operative rehabilitation, and cardiac transplantation.

In September 1984 he entered The Graduate School of The University of Tennessee, Knoxville to begin studies in Exercise Physiology. He received the Master of Science degree with a major in Physical Education, emphasizing Exercise Physiology in December 1985.

The author is a member of the American College of Sports Medicine. Mr. Wright has applied to several medical schools for the fall of 1986.