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Cross Exercise: A Comparison of Electromyographic Recordings During Maximal Static Performance of the Vastus Lateralis Muscle

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CROSS EXERCISE: A COMPARISON OF ELECTROMYOGRAPHIC RECORDINGS DURING MAXIMAL STATIC PERFORMANCE OF THE VASTUS LATERALIS MUSCLE

by
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This Thesis submitted by Jeffrey S. Monroe in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Date April 26, 1974

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ABSTRACT

The purpose of this study was to investigate the transient response of cross exercise during maximum static performance by electromyography. Thirty male athletes performed maximum static exercise at 115 degrees extension of the knee. Action potentials generated in this dominant exercising and nondominant, nonexercising vastus lateralis muscles were compared to determine whether or not the nonexercising muscle was affected during exercise.

Surface electrodes were attached to both vastus lateralis muscles. The muscular impulses were recorded on a Grass Five Polygraph. The amplitude of the EMG tracings were then measured to determine the relative quantity of stimulus that each muscle received during exercise. A comparison of the exercising vastus lateralis muscle's mean EMG amplitudes to that of the nonexercising vastus lateralis muscle provided the basis for analyzing cross exercise. The comparison indicated the nonexercising musculature's mean EMG amplitude was eleven percent of the exercising musculature's mean EMG amplitude. The eleven percent cross exercise response was shown to be significant to the .01 level of confidence when compared to the resting EMG amplitude.

CHAPTER I

INTRODUCTION

The phenomenon of cross exercise may be explained as the transient production of muscle tone in unexercised musculature as a result of exercise of the contralateral musculature. For example, if a volitional movement is made using the elbow flexors of the right arm, an increase in muscle tone would be demonstrated in the left elbow flexors. Thus, if a systematic training program involves one limb only, the contralateral response in the opposite limb would cause the transient phenomenon of cross exercise to become persistent. The persistent effect of such an exercise program would be demonstrated by strength increases in the nonexercising limb.

The phenomenon of cross exercise has been explained by examining the neurological pathways of the motor neurons. The upper motor neurons of the pyramidal tract originate in the precentral gyrus of the brain. Impulses originating here pass over projection fibers through the corona radiata to descend as the pyramidal tract passing through the internal capsule. Upper motor neurons destined for motor nuclei of cranial nerves, form the corticobulbar tract in the genu of the internal capsule, while the remaining upper motor neurons form the corticospinal tract in the posterior limb of the internal capsule. The corticobulbar tract containing the upper motor neurons of the cranial nerves will for the most part cross over to the opposite side of the brain stem after passing through the internal capsule.

Upon reaching the base of the brain stem ninety percent of the corticospinal upper motor neurons will cross over to the opposite side at the area of decussation of the pyramids. The crossed neurons descend within the spinal cord via the lateral corticospinal tract, while the uncrossed ten percent continue descent within the ventral corticospinal tract. At exit root level, the upper motor neurons of the corticospinal tract terminate on ventral horn motor neurons and the processes of these lower motor neurons exit the spinal cord to innervate the muscles.

The remaining ten percent of upper motor neurons continue descent until the designated root level is reached. At this point five percent more neurons will cross over to the ventral horn to exit via the lower motor neuron. The remaining five percent, of the upper motor neurons, innervate muscles on the same side of the body as the origin in the brain. It is this five percent that does not cross over which provides the pathway for cross exercise.

The myoneural interaction is also important in the discussion of cross exercise. Upon leaving the spinal cord, the lower motor axon enters the muscle where it divides into several branches. Each nerve fiber terminates at the motor endplate of the muscle. The impulse is transmitted across the endplate by the release of acetylcholine which initiates the muscle action potential to result in muscle contraction. Because the action potential is electrochemical in nature, it is possible to monitor it as a transient response with electromyography.

Electromyographic recordings of muscle contractions have been used to demonstrate and evaluate the transient response of muscle to exercise. Since electrical activity is propogated in both exercising and nonexercising muscles, it is reasonable to assume that the EMG technique would demonstrate the five percent of electrical activity in the nonexercising contralateral muscle.

Nature of the Study

The preceding examination of cross exercise would be in vain if the importance of cross exercise were to go unmentioned. Cross exercise has many uses in physical medicine and rehabilitation. A major use would be in preventing atrophy of musculature through cross exercise of the contralateral limb. Since it is reasonable to assume that the afflicted musculature would be stronger, the recovery time from surgeries, strokes, injuries, etc., would be decreased. Athletic medicine would also involve the use of the phenomenon for injuries. If the recovery time for an injured knee is less because the opposite knee was performing on a cross exercise program, then the exercise program is welcomed.

Cross exercise certainly cannot be overlooked as a method to use in physical rehabilitation. However, some disagreement regarding the phenomenon appears in the literature. Evidence appears to support the existence of positive results from cross exercise training. These studies generally employ training programs which demonstrate persistent effects of cross exercise. For example, Slater-Hammel (1) studied the elbow flexors of twenty subjects exercising for three weeks. At the end of the training period, a significant increase of strength was noted in the nonexercising elbow flexors. F. A. Hellebrandt (2) conducted a study of cross exercise with subjects performing finger dexterity tests. This form of cross exercise is called cross education, and was demonstrated to occur in the contralateral noninvolved hand after six weeks of training.

However, not all studies on cross exercise have demonstrated the phenomenon. Kruse and Mathews (3) instructed 120 subjects to exercise at various levels of exercise on the left elbow flexors. At the end of six weeks a nonsignificant increase of strength was noted in nonexercising right elbow flexors. Electromyography was used by Panin et al. (4) to illustrate the phenomenon during minimal exercises. No EMG responses were recorded from any of the musculature that were of acceptable level.

Purpose of Study

A controversy has existed in the literature over cross exercise since the initial research of the phenomenon. Most previous studies have used systematic training programs to evaluate the persistent effects of cross exercise. Several studies have used EMG to examine the transient responses of the phenomenon, but only one employed static exercise. It was the purpose of this research paper to examine the transient response of maximal static performance to cross exercise with the use of EMG.

Review of Related Literature

The ability of the body to increase in bilateral strength through unilateral exercise has been the interest of researchers since 1894. Scripture et al. (5) who described the phenomenon as "cross education," did his early work in the Yale Psychological Laboràtory. Davis (6), who also worked at Yale in 1898, reported that systematic exercise with a dynometer, dumbells, and ergograph on one body part, influenced the muscular activity in other parts of the body. He noticed the increase was greatest in symmetrical and related parts.

Two other early investigators, Wissler and Richards (7), reported that exercise with a dynometer on the flexors of one arm, increased muscular performance in the extensors of that arm and in the flexors of the opposite arm.

F. R. Walshe (8), who was chief neurologist in London's Queen Hospital in 1923, did a classic paper concerning hemiplegia patients and associated movements they exhibited during forced volitional movements. Walshe concludes that these associated movements are actually "tonic postural reflexes arising in and acting on the limbs." He went on to say that they are aroused only if voluntary contractions are forceful enought to demand synergic fixation of the musculature. Walshe's observations gave indirect support to the theory of cross education, by explaining the phenomenon of associated movement, which is,

> ...dependent upon reflex mechanisms situated in the brain

> stem which unite the musculature of the extremities into a labile, adaptive postural substrate, upon which cortically controlled movements may be superimposed.

As cited earlier, F. A. Hellebrandt (2) from Richmond, Virginia, did an important study concerning "cross education." Cross education refers to the training of motor skills of one appendage and the transfer of skills to contralateral extremity. Finger dexterity exercises were performed on the dominant hand by fifty-one subjects for eight weeks. The end of testing found: "The unpracticed contralateral extremity improves significantly in mechanical ability."

Also cited earlier, Slater-Hammel (1), published in 1950 the following results of his investigation of cross exercise:

> Twenty male college students were employed in a study to test bilateral effects of systematic exercise. Ten students received three weeks of exercise in flexion and extension of the right arm. Ten control students received no special exercise. At the end of the exercise period, the experimental group showed a significant gain in strength over the control group in flexion and extension of the left arm.

reference of block alignment

A physical therapist, Etta C. Walters (9), relized the clinical importance of cross exercise in the treatment of immobilized and non-functioning innervated muscles. Walters administered the "turn and place" and "displace tests" of the Minnesota Rate and Manipulation Test, to thirteen women. She concluded that: 1) the greatest transfer effects are attainable by practice in overload, and 2) as much can be gained by indirect practice in overload as by direct training in under-load.

Partridge (10), who used electromyographic techniques on subjects afflicted with poliomyelitis, arrived at the following conclusion:

> Systematic application of repetitive resistive exercise to the good musculature remaining in a partially disabled extremity, produces reflex activity of functional value in weak or paralyzed muscles.

The phenomenon of contralateral motor irradiation was discussed by F. Podivinsky (11) in 1963. Through the use of EMG techniques he was able to demonstrate the need for the use of overload. Podivinsky said, "motor contralateral irradiation can occur only if the motor irradiation in the active extremity reaches a certain threshold value." In other words, the heavier the resistance, the more motor units activated, and when overload is reached, cross exercise will occur. Podivinsky also indicated that more transfer will occur from the dominant limb to the nondominant limb. Important contribution of Podivinsky's study were the physiological factors involved in the transfer of motor irradiation to the contralateral side. These factors were: 1) motor dominance of the hemispheres, 2) number of activated motor units in the active extremity in a given unit of time, i.e., voluntary effort at overload, 3) facilitating effect of the repeated movements, and 4) the constitution of the individual.

The interplay of cerebral dominance and its effect on contralateral motor irradiation was also indicated by J. Cernacek (12).

Electromyography was also used by Gregg et al. (13). They exercised the dominant biceps brachii at different levels of stress. The following conclusions were based on the evidence collected: 1) overflow to the nonexercised contralateral muscles did not occur during, simple nonresistive exercise or static contraction of the biceps brachii, 2) as the stress of dynamic exercise increased overflow was indicated.

Two well researched studies that were cited earlier have not indicated the phenomenon of cross exercise. Kruse and Mathews (3) exercised the left elbow flexors of 120 subjects. Sixty were divided into four different exercise groups of fifteen each. A control group of equivalent size was matched for each group. The results indicated significant strength increases in the exercising left arm, but no significant strength increases were noted in the nonexercised arm.

Panin et al. (4) used EMG to monitor the activity of eight groups of musculature during exercise. Since no acceptable responses were noted in the demonstration of cross exercise, the investigators felt the phenomenon did not occur in any of the eight muscle groups monitored.

Summary of Review of Literature

From the preceding review of literature, the following conclusions may be assumed to be present in the demonstration of cross exercise:

1. symmetrical body parts must be involved,

2. the use of overload must be present in exercise, and

3. transfer occurs best from the dominant limb to the nondominant limb.

CHAPTER II

METHODOLOGY

A nonprobability sample of thirty male athletes were selected from the University of North Dakota athletic teams. The subjects were asked to report to the psychomotor performance laboratory at the University of North Dakota fieldhouse.

Each subject performed a fifteen to twenty minute test which consisted of maximal static contractions of the dominant vastus lateralis muscle. The exercise produced muscle action potentials in the left and right vastus lateralis which were recorded by electromyography. The data were compiled and statistically analyzed for the maximum static contraction in pounds, and the amplitude of the action potentials for the exercising and nonexercising vastus lateralis muscles in microvolts.

Test Procedure

Upon arrival at the laboratory, the subjects were instructed to sit on a formica covered bench with their knees on the padded edge. A Burdick forty-three hundred muscle stimulator was used in finding the exact location of the vastus lateralis motor points. Location of these points consisted of placing the negative electrode over the area superior to the inquinal ligament. Positioning of the positive electrode was made by referring to a motor point chart, this however, did not always indicate the exact location. The final placement of the electrode was made after the greatest amount of contraction was observed in the vastus lateralis. It was this final position that was assumed to be the location of the vastus lateralis motor point. The position was marked on the subject's skin with indelible ink.

Preparation of the motor point area was accomplished by shaving an area three inches in diameter and rubbing the skin with an acetone soaked gauze pad until a redness appeared. This procedure was performed over the motor point area of the left and right vastus lateralis muscle.

After preparation of the skin, three gold cup electrodes, one centimeter in diameter, were filled with Grass Electrode Paste and applied to both motor points (see Figure 1, page 11). The ground electrode was first to be applied, it was placed six to seven centimeters from the motor point. The two active electrodes were then placed equidistant from the motor point and within two to three centimeters of each other.

The electrodes were connected by extension cables to a Grass Five Polygraph Recorder. The polygraph amplified the action potentials received by the surface electrodes and recorded them on two channel curvilinear paper that was calibrated in millimeters. Upon connection of the polygraph and surface electrodes the electromyographic recording was tested for response. All subjects were asked to extend and lock both knees; if a recording was produced, proper functioning was then

Fig. 1. Placement of electrodes.

Fig. 2. Proper positioning of sling and tensiometer.

assumed.

After attaching the electrodes, the subject was asked to slip a cotton sling over the ankle of the dominant leg. The sling was attached to a ten inch section of one-eighth inch cable that fastened to three feet of adjustable chain. The chain then encircled the water pipe to which it was anchored. With the sling over the ankle, the subject extended the leg until the slack was removed from the cable and chain. A goniometer, manufactured by Orthopedic Incorporated, was used to adjust the angle of extension to 115 degrees. One-hundred and fifteen degrees extension of the knee was chosen because Clarke (14) has shown this to be the strongest position in knee extension during static exercise.

The subject was instructed to give maximal effort for the test duration. The subject was also instructed to begin and end the maximal static contraction on the tester's command, and that thirty seconds rest would be given between trials.

A cable tensiometer, with a range from zero to 240 pounds, was used in determining maximal static strength. With the tensiometer attached to the ten inch section of cable, the subject was instructed to begin maximal static contraction (see Figure 2, page 11). At the peak of maximal performance the tensiometer measured and recorded the tension in the cable. When two consecutive efforts within five pounds were recorded, maximal static performance was determined. The two consecutive static contractions did not include the first trial.

Every action potential response in both vastus lateralis muscles were recorded. However, the amplitude of these action potentials were those action potentials which were recorded when the maximal static performance test was performed. The amplitudes of the action potentials were measured in millimeters and converted to microvolts (see Appendix A, page 26).

Limitations

J. V. Basmajian (15) has listed four limitations encountered when using surface electrodes on the skin: 1) the type of metal used; human skin has characteristic responses to each metal used in an electrode, 2) the temperature and humidity of the electrode environment can also change the impedance of the skin metal interface, 3) the size of the electrode determines the current density across the skin-electrode interface, and consequently, the amplitude of the signal received, and 4) the subject's inherent resistance.

Another limitation concerning electrical equipment was each subject's attitude toward performing with electrodes attached.

Experimental Design

A single group design with nonprobability sampling was employed in this study. Descriptive statistics were used to show the resulting scores of the test and to analyze the data.

Three scores were recorded on both the test and retest of maximal static exercise. The scores were maximal static performance, in pounds, the amplitudes of the action potentials for the exercising vastus lateralis muscle in microvolts and the amplitude of the nonexercising vastus lateralis muscles, in microvolts.

Maximum static performance was determined after a minimum of three trials. The test was terminated after two consecutive trials occurred within five pounds.

The maximum static performance was compared with the amplitude of the action potentials in the exercising thigh to determine the validity of the EMG recording.

Reliability was established by comparing the test values to the retest values. Maximal static performance for test one was compared with test two. The amplitude of the action potentials for the exercising vastus lateralis of test one and test two were correlated. Action potential amplitudes of the nonexercising vastus lateralis for test one were correlated with test two. The significance of the reliability coefficients was determined at .01 level. This was assured by consulting a reliability significance table by Fisher and Yates (16).

To evaluate the cross exercise effect of maximal static contractions of the dominant exercising thigh to the nondominant, nonexercising thigh, a comparison of action potential amplitudes for both thighs was done.

A "t" test was applied to the data of the unexercised musculature, to determine the significance of action potentials present during exercise of the dominant vastus lateralis. Significance was tested at the

.01 level.

The following hypotheses were established:

H_0 During exercise of the dominant vastus lateralis muscle, there were nonsignificant action potentials recorded in the non-exercising, nondominant vastus lateralis.

H_1 During exercise of the dominant vastus lateralis muscle, there were significant action potentials recorded in the nonexercising, nondominant vastus lateralis.

CHAPTER III

ANALYSIS OF THE DATA

At the completion of the test the data were collated and analyzed by the IBM 370 Computer at the University of North Dakota. The program used was the MSDCC program, which includes computation of the mean, standard deviation, and the Pearson Product Moment coefficient.

Reliability

The correlation coefficient for the maximal static performance in pounds was 1.00. A .99 was correlated for the amplitude of the action potentials in the exercising vastus lateralis muscle. The correlation coefficient for the amplitude of the action potentials for the non-exercising vastus lateralis muscle was .59. Table 1, page 17, indicates the scores of reliability for all three variables.

The significance of these correlation coefficients was determined by a test of significance. If a correlation coefficient was equal to or greater than .45, for n = 30, it was significant at the .01 level. All three correlations were greater than .45, thus, the null hypothesis was rejected and the alternate hypothesis accepted. This is illustrated in Table 1.

TABLE 1

MEAN, STANDARD DEVIATION, RELIABILITY COEFFICIENT, AND SIGNIFICANCE LEVELS FOR MAXIMAL STATIC PERFORMANCE, AMPLITUDE OF ACTION POTENTIALS FOR EXERCISING VASTUS LATERALIS, AND AMPLITUDE OF ACTION POTENTIALS FOR NONEXERCISING VASTUS LATERALIS

	Variables					
Computations	Maximal Static Performance		Amplitude of Action Potentials in Exercising Vastus Lateralis		Amplitude of Action Potentials in Non-exercising Vastus Lateralis	
N = 30	Test	Retest	Test	Retest	Test	Retest
Mean	139.23 lbs	139.40 lbs	16.21 uv	15.73 uv	1.91 uv	1.73 uv
Standard Deviation	27.23 lbs	26.97 lbs	6.50 uv	6.49 uv	1.21 uv	.75 uv
Reliability Coefficient	1.00		.99		.59	
Significance levels for Reliability Coefficient	.01		.01		.01	

Validity

The validity of the maximal static performance test was established by correlating the amplitude of the action potentials in the exercising vastus lateralis muscle to the maximal static performance in pounds. The rational for this estimate was based on the assumption that higher action potential amplitudes will be present during greater effort of maximal static performance. The correlation coefficient of these two variables was -.07. This was not an acceptable value for reliability.

Results

A single group "t" test was used to compare the zero resting action potential amplitude to the amplitude of action potentials in the non-exercising vastus lateralis. A critical "t" ratio of 2.75 for twenty-nine degrees of freedom, was needed to be significant. Analysis of the data indicated a "t" ratio of 12.56. Since this computed "t" ratio was larger than the critical value, the null hypothesis was rejected and the alternate hypothesis accepted (see Appendix B, page 27 and Table 2).

Comparison of the action potential amplitudes for the exercising and nonexercising vastus lateralis muscles, indicated the cross exercise effect of maximal static exercise. The mean exercising value was 15.73 microvolts and the mean nonexercising value was 1.73 microvolts. This comparison indicated the nonexercising action potential amplitude was eleven percent of the exercising action potential amplitude.

TABLE 2

SINGLE GROUP SIGNIFICANCE COMPUTATIONS

Mean for Amplitude of Action Potentials in Nonexercising Vastus Lateralis	Resting Action Potential	$t_{.01}$	Level of Confidence
1.73 uv	.00 uv	12.56	.01*

*Test was significant

CHAPTER IV

DISCUSSION

The electrochemical activity recorded for the nonexercising vastus lateralis muscle was eleven percent by amplitude of the electrochemical activity recorded for the exercising vastus lateralis muscle. This eleven percent activity, in the nonexercising muscle, was the transient response to cross exercise. Two reasons may be cited for this cross exercise phenomenon. Podivinsky's (11) discussion of "motor dominance of the hemispheres," was one reason. This was further explained to indicate that cross irradiation occurred more readily from the dominant exercising musculature to the nondominant, nonexercising musculature. The second reason for cross exercise was explained by Walters who noted, "the greatest transfer occurs during overload." In the present study, overload was involved because the test was performed to maximum.

The eleven percent cross exercise response to static exercise was a conservative estimate. This phenomenon may be explained by skin resistance to the real electrochemical activity of the muscle. For example, the contrasting scores of two subjects in this study clearly illustrates the limitation of inherent skin resistance. Subject A was a heavy set football player and subject B was a lean distance runner.

Subject A exerted 190 pounds of force during maximum static performance and recorded an amplitude of 18.5 microvolts for the action potentials in the exercising muscles. Subject B exerted only 125 pounds, but recorded an amplitude of 42.5 microvolts for the exercising muscle's action potentials. Assuming, a direct and valid relation between maximum static performance and electrochemical activity, for the exercising musculature, subject A should have a higher amplitude. This was not the case and it appears, that skin resistance would be a logical reason for the inverted results.

Therapeutic uses of cross exercise would benefit from eleven percent of cross transfer. If an injury caused immobilization to a body part, the eleven percent cross exercise would be of greater benefit than no exercise at all. To achieve an eleven percent persistent effect of cross exercise a systematic training program would be needed. The training program would cause the inactive musculature to respond to the cross exercise stimulus. Supporting research on normal subjects has indicated that the unexercised musculature would either maintain or increase in strength. For example, Partridge (10) demonstrated the effects of systematic application of repetitive resistance exercise to the good musculature of poliomyelitis victims. As a result of the exercise, Partridge observed increases of strength in the subjects' afflicted musculature. Karl Klein (17), who selected subjects with post-surgical injuries, was another example. He noted that it took four to six weeks of progressive resistance exercise by the contralateral uninjured knee to achieve a bilateral balance in strength.

In his explanation of associated movements in hemiphegia patients, Walshe (8) concludes that they are actually "tonic postural reflexes arising in and acting on the limb." Hellebrandt and Waterland (18), who worked with motor patterning in stress, observed that, "progressively increasing exercise stress evokes an orderly expansion of motor response in normal individuals." Hellebrandt and Waterland also noticed that during maximal volitional exercise of one limb, "copying movements" were observed to occur in the contralateral resting limb. These copying movements were also observed to have a tonic postural component. During maximal exercise of one limb all four extremeties participated in postural tonic copying movements.

Because of the nature of maximal exercise, it was assumed these tonic contractions were present during the maximal static performance test. The writer feels that this overflow of irradiation of impulses could be partially responsible for the phenomenon of cross exercise.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

A maximal static exercise test of the dominant vastus lateralis muscle was performed by thirty varsity athletes from the University of North Dakota. The action potentials of both the exercising and non-exercising vastus lateralis muscles were monitored with electromyography. The amplitude of the action potentials were compared to determine the cross exercise of maximal static exercise on the exercising dominant vastus lateralis to the nondominant, nonexercising vastus lateralis. The comparison demonstrated the neuromuscular activity in the non-exercising musculature to be eleven percent of the activity in the exercising musculature.

Conclusion

Based on the findings and in consideration for the assumptions and limitations, this study appears to support the following conclusion: the amplitude of action potentials for the nonexercising vastus lateralis muscle increased significantly above the resting action potential.

Recommendations

As a result of this study the following recommendations were made:

1. It is recommended that needle electrodes be employed to reduce inherent body resistance.

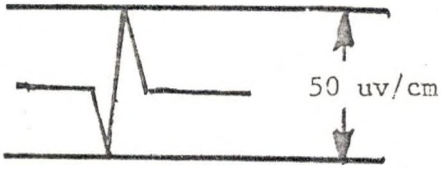
2. A random sample of a larger population is recommended for use in further studies.

3. An investigation should be made to determine the effects a four to six week training program on the transient responses of cross exercise.

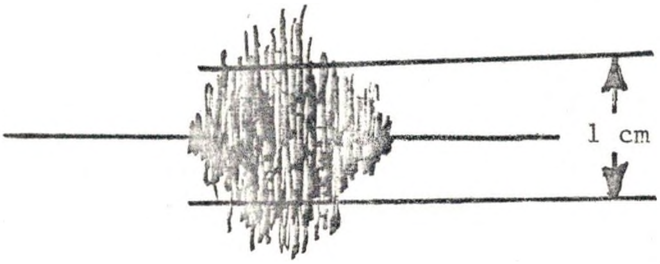
APPENDIXES

Appendix A

Conversion of EMG Tracings to Microvolts



Calibration of Polygraph



Amplitude of Action Potential Recording in Centimeters

Since there are 50 microvolts per centimeter, then 1 cm of displacement is equal to 50 microvolts.

Appendix B

The Analysis of the Action Potential Amplitude in the Nonexercising Vastus Lateralis Muscle

<u>"t" Test of Significance for One Mean to a Known Value</u>

$N = 30$

$\bar{X} = 1.73$

$S = .754$

$K = .00$

$"t"_{.01} = 2.756$

$$t_{x.01} = \frac{\sqrt{N}\ (\bar{X}-K)}{S}$$

$$= \frac{\sqrt{30}\ (1.73-.00)}{.754}$$

$$= \frac{(5.49)\ (1.73)}{.754}$$

$$t_{x.01} = 12.56$$

test was significant

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