CHANGES IN MOTOR NEURON EXCITABILITY ASSESSED BY THE HOFFMANN REFLEX FOLLOWING EXERCISE AT LOW AND HIGH INTENSITIES

by

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Dedicated to my Mother and Father.

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CHAPTER 1

Introduction

Tension reduction or relaxation following exercise can be measured in various ways. One way is to measure the amount of central nervous system excitability associated with the amount of relaxation. A method used to assess central nervous system excitability is the Hoffmann or H-reflex. The H-reflex occurs as a result of artificial stimulation to the tibial nerve as it passes through the popliteal fossa. A single shock to the nerve produces two distinct soleus muscle action potentials, the M- and H-waves. The M-wave is the result of direct stimulation of the motor fibers innervating the soleus muscle. The H-wave is the result of a reflex response in which signals travel in afferent nerve fibers from the muscle and back again in efferent nerve fibers of the same muscle (Magladery and McDougal, 1950; Magladery, Porter, Park, and Teasdall, 1951). Recordings of these two waves can provide a measure of motor neuron excitability (Angel and Hofmann, 1963). The usual convention is to calculate a ratio by dividing the largest obtainable H-reflex response by the largest M response.

Previous investigators have used the H-reflex to study various neural dysfunctions (Mayer and Maudsley, 1965; Angel and Hofmann, 1963; Magladery and McDougal, 1950; Magladery et al., 1951) and normal reflex phenomena (Angel and Hofmann, 1963; Hagbarth, 1962; Landau, Weaver, and Hornbein, 1960). One group of investigators has used the reflex to observe the amount of change in the ratio following low level exercise (de Vries, Wiswell, Bulbulian, and Moritani, 1981). The study by de Vries, et al., used 8 young subjects, age 20 to 34, and 2 elderly subjects, ages 80 and 66, who exhibited symptoms of high anxiety. H/M ratios were measured before and after 20 minutes of exercise on a bicycle ergometer at 40% of heartrate range. They found a highly significant reduction in the ratio following and concluded that the exercise had a tranquilizing effect.

The aforementioned study by de Vries et al. (1981), used low level exercise and found a significant reduction in motor neuron excitability following exercise. With an increase in exercise intensity one would expect to observe a greater lactic acid production with an accompanying decrease in pH, a small increase in core temperature, and changes in plasma hormone levels. All of these changes could possibly alter motor neuron excitability.

Statement of the Problem

The purpose of this study was to examine the effect of low and high intensity exercise on motor neuron excitability. Specifically, the H/M ratio was recorded before and after treadmill running at intensities equivalent to 40 and 75 percent of maximum oxygen consumption.

Significance of the Study

Most individuals report a feeling of being relaxed following a period of physical activity. The intensity of this exercise bout may have an effect on the degree of relaxation produced. Psychological studies using subjective questionnaires have determined that high intensity exercise lowers anxiety levels. Physiological studies have found low intensity exercise to reduce tension levels and motor neuron excitability; however, high intensity exercise has not been adequately investigated. An objective measure used in physiological studies is the Hoffmann reflex which measures motor neuron excitability. This study will try to determine whether exercise intensity has an effect on motor neuron excitability.

Hypotheses

This study proposes the following hypotheses:

1. Low intensity exercise will produce a reduction in the H/M ratio or motor neuron excitability.
2. High intensity exercise will produce a reduction in the H/M ratio equal to or greater than the reduction following low intensity exercise.
3. Sitting quietly will produce no change in the H/M ratio.

Delimitations

The boundaries of this study were restricted by the following:

1. The subjects of this study were five male and five female volunteers, aged 20 to 34 years.
2. All subjects were recreational or competitive runners who could run on the treadmill for 20 minutes at intensities equivalent to 40 and 75 percent of their maximal oxygen consumption.

Limitations

Certain elements which may have limited this study warrant attention:

1. Subjects were volunteers and thus not randomly selected.
2. The subjects may have experienced a familiarization effect of the artificial stimulation.
3. The level of consciousness may have varied due to the subjects daily routines changing, and this may have effected the H/M ratio response.

Definition of Terms

Electromyography (EMG): The summated electrical potentials within a muscle measured between two electrodes.

H/M Ratio: The largest H wave divided by the largest M wave.

Hoffmann Reflex (H-Reflex): A reflex produced by artificial electrical stimulation of the mixed nerve in man.

H Wave: The result of a reflex response in which signals travel in afferent nerve fibers from the muscle and back again in efferent nerve fibers of the same muscle.

Maximal Oxygen Consumption (maxVO_2): Represents the body's capacity for the aerobic resynthesis of energy.

Muscle Action Potential (MAP): The initiation of contraction in skeletal muscle begins with action potentials in the muscle fibers.

M Wave: The result of direct stimulation of the motor fibers of a particular muscle.

CHAPTER 2

Literature Review

Literature concerning exercise and anxiety level, resting electromyography level, and H/M ratio will be reviewed. Also, literature pertaining to the Hoffmann reflex and physiological mechanisms of motor neuron excitability reduction will be discussed.

Anxiety Level and Exercise

Psychological studies have used questionnaires before and after an acute bout of exercise to observe any change in anxiety. Most often anxiety is characterized by subjective feelings of tension (Bahrke, 1979). Therefore, a reduction in anxiety level demonstrates the body is less tense or more relaxed. Bahrke and Morgan (1978) evaluated state anxiety, which is the individual's present level of anxiety given the present circumstances, using the State Trait Anxiety Inventory (STAI) on 75 adult males before and after 20 minutes of one of the following treatments: 1) treadmill exercise at 70 percent of maximum oxygen consumption, 2) meditation using Benson's relaxation response, and 3) distraction, which involved sitting quietly in a sound-filtered room. All three groups demonstrated a significant reduction in STAI scores within one minute following the treatment. In a similar study Morgan and Horstman (1976) used both males and females, and surveyed state anxiety before and after exercise at 80 percent of maximum oxygen consumption to exhaustion. They found that anxiety was significantly decreased immediately following exercise and went below baseline level after ten minutes of recovery. Thus, both of these psychological studies demonstrated significant reductions in anxiety following exercise. The principal interest here is that while exercise and meditation seemingly represent opposing ends of the arousal continuum, both result in anxiety reduction (Bahrke, 1979). However, different results were obtained in a third study. Sime (1977), used 48 students who reported symptoms of test anxiety and randomly assigned them to one of 3 treatment procedures: 1) treadmill exercise at a heartrate of 100-110 beats/minute for 10 minutes with 5 minutes of recovery, 2) meditation via Benson's relaxation response, and 3) an innocuous pill claimed to be either a tranquilizer or placebo. The results showed no significant decreases in state anxiety when response before and after treatment were compared. By examining the exercise treatments in these three studies one can see that the difference in results may be due to the intensity level of the exercise. The first two studies used high intensity exercise (70 and 80 percent of maximum oxygen consumption), whereas, the third study used a low intensity exercise (100-110 beats/minute). Also it has been reported in a preliminary investigation by Raglin and Morgan that the observed anxiety decrement lasts longer following exercise as compared to distraction (sitting quietly). Thus, a survey of psychological studies that examined exercise and anxiety levels demonstrates that in both males and females high intensity exercise reduces anxiety levels with its associated relaxation.

Resting Electromyography Level and Exercise

To reduce the concerns associated with the use of subjective questionnaires typically employed in psychological studies, physiological studies have used more objective measures such as electromyography (EMG), which is a record of the electrical activity of a particular muscle, to observe changes in resting muscle activity following exercise. The resting EMG measured from one muscle is then used as a reflection of the tension level of the whole body. The body is said to be more relaxed when a reduction in the EMG level is found following the treatment condition, such as after exercise. Several studies have used EMG of the frontalis muscle to assess the effects of exercise on relaxing the body (Balog, 1983; Farmer, Olevine, Cower, Edwards, Coleman, and Hames, 1978; and Sime, 1977) and contradictory findings were reported. Sime found that frontalis muscle activity decreased in subjects who were assessed as being trait anxious following 10 minutes of treadmill exercise at a low intensity level (heartrate 100-110 beats/minute). On the other hand, Farmer et al., (1978) and Balog (1983) found bicycle exercise at both low and high intensities to have no significant effect on frontalis muscle activity. The contradictory results, however, are not surprising because of the findings from a factor-analytic study done by Nidever (1959) on the "generality of resting muscle tension". Nidever reported that out of 23 muscles tested the frontalis muscle was 1 of only 4 muscles that did not appear on the "common tension factor at rest," which indicates the frontalis muscle is not the best muscle used to assess the level of activity of other muscles. Consequently, de Vries (de Vries, 1968; and de Vries and Adams, 1972) in two separate studies measured the EMG from the right biceps brachii muscle, which scored the highest on the common tension factor at rest. The EMG from the right biceps brachii was measured before and after bench stepping and bicycling at 100 and 120 beats/minute. Significantly lower EMG levels were observed following both the bench stepping and bicycling at 100 beats/minute with the differences at 120 beats/minute approaching but not reaching significance. Thus, EMG studies using the frontalis muscle have been contradictory, whereas studies using the biceps brachii muscle have demonstrated that low intensity exercise results in lower muscle activity and thus relaxation.

Hoffmann Reflex

Another physiological measure that has been used to assess the effects of exercise on relaxation is the Hoffmann reflex. The Hoffmann reflex or H-reflex is a reflex that is elicited by artificial stimulation to the tibial nerve at the level of the popliteal fossa. The stimulation results in two muscle action potentials from the soleus muscle, the M- and H-wave. The first wave, the M-wave, is the response to direct stimulation of efferent nerve fibers to the soleus muscle. The second muscle action potential, the H-wave, is the reflex response which is mediated by afferent nerve fibers from the soleus muscle to the spinal cord and back again via efferent nerve fibers of the same muscle.

Traditionally, the H-reflex has been cited as a monosynaptic reflex because no internuncial neurons were thought to be involved (Angel and Hofmann, 1963; de Vries, Wiswell, Bulbulian, and Moritani, 1981; Garcia, Fisher, and Gilai, 1979; and Mayer and Maudsley, 1965). However a recent study by Burke, Guadevia, and McKeon (1983) suggested that the H-reflex cannot be considered a purely monosynaptic reflex. They made direct recordings of muscle afferent activity using micro-electrodes inserted into the tibial nerve in the popliteal fossa on ten healthy volunteers. Their conclusion from these recordings were the afferent volley responsible for the H-reflex is contaminated by activity from other afferents, such as from mechanoreceptors in triceps surae, in skin, and in other muscles. Therefore, the afferent activity from the other sources may affect the reflex discharge, consequently making the H-reflex the response to the activity of several afferent sources. Thus, it would appear from this new evidence that the H-reflex may not be accurately described as a monosynaptic reflex. In spite of this complexity, the H-reflex has been found to be highly reproducible (Crayton and King, 1981; Garcia et al., 1979). Two separate investigations, one by Crayton and King looking at inter-individual variability of the H-reflex and the other by Garcia et al., looking at the H-reflex in flexor and extensor muscles, found that under constant measurement conditions the H-reflex is a highly stable characteristic of an individual in its latency, amplitude, and configuration. Crayton and King suggested that, because the H-reflex is highly reproducible, it would be a good measure of change in neuromuscular functioning. Therefore, the necessity to determine whether the H-reflex is a monosynaptic reflex may be less important when one is observing a change in central nervous system functioning as a result of some treatment condition. In light of the observations of Crayton and King, it is appropriate to use the H-reflex when measured under constant measurement conditions to assess changes in neuromuscular functioning or motor neuron excitability under a variety of experimental conditions.

Additional studies have shown that the H/M ratio, which is the largest obtainable H-wave divided by the largest obtainable M-wave, may be more useful than the H-reflex alone (Angel and Hofmann, 1963). Angel and Hofmann (1963) recorded M- and H-waves on 7 normal, 14 spastic, and 7 rigid subjects. They found that 1) absolute values of the H-wave were affected by electrode placement and thickness of the skin, and 2) relative size of the M- and H-waves at one stimulus intensity was misleading since the ratio varies widely as shock intensity was changed. They concluded that a more valid indication is obtained by the H/M ratio with a stimulus intensity that produced the greatest H and M waves. The ratio can be taken to indicate the number of motor neurons that can be excited reflexly and provided an estimate of the fraction of the motor neuron pool. Therefore, rather than looking at changes in the H-reflex, it is more useful to look at changes in the H/M ratio as a consequence of the treatment condition.

H/M Ratio and Exercise

A study done by de Vries et al., (1981) used the H/M ratio measurement for evaluation of motor neuron excitability before and after exercise. Ten subjects were tested, eight aged 20 to 34 years and 2 aged 66 and 80. The subjects possessed anxiety symptoms which were assessed by whether they exhibited one or more symptoms from a list of items and possessed greater than 2 uV resting level EMG. Each individual was tested 3 times before and after a 20-minute bicycle exercise at 40 percent of heartrate range and before and after 20-minutes of sitting quietly (the control situation). The results were expressed as the mean change of the H/M ratio before and after treatment. The ratio decreased from 6 to 44 percent after exercise, with a mean drop of 18.7 percent which was highly significant as compared to the 1.2 percent rise for the control treatment. The investigators concluded that the reduction of the H/M ratio provided strong support for the "tranquilizer effect" of exercise performed at appropriate levels of intensity and duration. In this case exercise of low intensity and 20 minutes duration produced relaxation.

Physiological Mechanisms of Motor Neuron Excitability Reduction

In the above mentioned study conducted by de Vries et al., (1981), no physiological mechanisms to explain the reduction observed in the H/M ratio were discussed. However, in a review article on the tranquilizer effect of exercise written by de Vries (1981) after the H/M ratio study was performed, two hypotheses were offered to explain why exercise could cause relaxation. One hypothesis was that exercise produces a small temperature rise in the brain stem or the whole body. That rise in temperature could result in decreased muscle spindle activity and synchronized electrical activity in the cortex of the brain, both of which are typical of a more relaxed state. Experimental work on cats has demonstrated that with a small rise in temperature, decreased electrical activity in the cortex of the brain does occur (Von Euler and Soderberg, 1956; Von Euler and Soderberg, 1957). However, de Vries pointed out that the temperature rise explanation would only be sufficient for an acute effect of exercise. To explain a chronic tranquilizer effect, the work of Haugen, Dixon, and Dickel (1960) was cited. This work demonstrated that random, intermittent, and changing proprioceptive stimuli allowed for normal cortical activity, but a persistent bombardment of excessively strong stimuli from all muscles resulted in over activity of the arousal area in the cortex. Thus, low intensity exercise would provide the stimuli to produce normal cortical activity, and a subsequently more relaxed state. Whether or not high intensity exercise will provide a persistent bombardment or an intermittent stimuli is uncertain.

Thus far, the physiological research done has demonstrated that low intensity exercise produces relaxation, although the causal mechanisms are not understood. However, the relationship between high intensity exercise and relaxation has not been adequately researched in the past using physiological measures to permit one to state or conclude whether or not it too can produce the tranquilizer effect. High intensity exercise produces a temperature rise and intermittent stimuli that have been suggested as possible explanations for the effect of low intensity exercise on relaxation. However, other changes observed with high intensity exercise, such as, differences in lactate production, endorphins, and neurotransmitters may also be important.

The rate of lactate production and removal are different for low and high intensity exercise, and thus may be important in the effect of exercise on relaxation. Lactate production is known to be greater during high intensity exercise. Also, it has been demonstrated that the optimal level of exercise for an active recovery of lactate that has been produced by heavy exercise is approximately 35 percent of maximal oxygen consumption (Belcastro and Bonen, 1975; Boileau, Misner, Dykstra, and Spitzer, 1983; and Stamford, Weltman, Moffatt, and Sady, 1981), whereas the slowest recovery occurs during an intensity of 60-80 percent (Boileau et al., 1983). Therefore, there would be a greater amount of lactate present during high intensity exercise, since more would be produced and the rate of removal would be slower. And yet, does the amount of circulating lactate determine whether or not relaxation occurs following exercise? Pitts and McClure (1967), gave to patients known to possess anxiety neurosis a 20-minute venous infusion of dl-sodium lactate. The lactate infusion resulted in anxiety attacks in these patients. They concluded that similar lactate levels occur with exercise and that vigorous exercise could cause some anxiety symptoms in others. Support for the conclusion that increased lactate levels caused anxiety was provided by Fink, Taylor, and Volarka (1969) who found that with high lactate doses, changes in the electroencephalogram (EEG) were observed which are usually seen in anxiety states. In the review article by de Vries (1981) on the tranquilizer effect of exercise, several reasons are given as to why the results showing that increased lactate levels produce increased anxiety levels do not apply to real situations. The reasons included: 1) The effect of dl-sodium lactate is different from that of endogenous lactate, in that, dl-sodium lactate results in alkalosis, whereas, endogenous lactate produces a drop in pH. The metabolic pathways for the two responses differ. 2) High lactate levels are not found at rest even in severely anxious neurotic individuals. 3) Excess lactate has not been consistently shown to cause anxiety attacks in anxiety neurotic patients. The conclusion drawn by de Vries in this review states that it is not necessary to conclude that moderate to vigorous exercise cannot produce a significant tranquilizer effect simply because it may also increase lactate production. Thus, it appears that the relationship between high intensity exercise and relaxation warrant more investigation to determine whether high lactate levels are or are not associated with relaxation.

Other changes that occur with exercise involve the level of brain neurotransmitters, such as norepinephrine (NE), serotonin, and endorphins. Brown and Van Huss (1973) and Brown, Payne, Kim, Moore, Krebs, and Martin (1979) in two similar studies found chronic exercise in rats significantly increased NE and serotonin in the brain when compared to sedentary control animals. Also, Barchus and Freedman (1962) found that an acute bout of swimming significantly altered NE and serotonin levels in rats' brains. Thus, exercise in lab animals produced increased levels of brain neurotransmitters. Whether or not this increase is associated with relaxation has not been established. Other substances the brain produces are the endorphins, which act like morphine and reduce sensations of pain and produce a state of euphoria (Morgan, 1985). Pert and Bowie (1979) demonstrated in rats that exercise was associated with an increase in opiate receptor occupancy, and they concluded that this was due to an increased release of endorphins or a decreased dissociation rate from receptors. Once again whether the change in brain endorphins are causally linked with exercise to produce relaxation has not been addressed.

Summary

The present review of the literature has shown that relaxation occurs following exercise. To measure relaxation, several different determinations have been used. Psychological studies have employed questionnaires to survey anxiety levels. The physiological studies have used both EMG and H-reflex changes to measure muscle activity levels and motor neuron excitability, respectively. However, the results of these studies leave uncertain the relationship between the intensity of exercise and relaxation. The psychological studies found that high intensity exercise significantly reduces anxiety levels, whereas, EMG studies have found low intensity exercise significantly reduces resting muscle activity levels. Thus far, the one study that measured motor neuron excitability with H/M ratio only looked at low intensity exercise. In addition, during low versus high intensity exercise there are physiological similarities - such as increased temperature and intermittent proprioceptive stimuli - and differences - increased lactate, neurotransmitter, and endorphin production - that exist. Therefore, further investigation is necessary to determine whether or not high intensity exercise does produce as much or more relaxation.

CHAPTER 3

Methods

The subjects, the experimental design, the maximal oxygen consumption and H-reflex measurements, and the statistical analysis will be outlined in this section.

Subjects

The subjects in the study were ten students or faculty members at Kansas State University, five males and five females, aged 20-45 years with a mean age of 28.7 years. All subjects were required to be experienced recreational or competitive runners. They were healthy and had no known neurological dysfunction, and they were not taking any medication at the time of testing. Each subject was fully informed of the testing procedures and signed an informed consent statement.

Experimental Design

The experimental design consisted of two exercise and one control treatments. The two exercise treatments were 20 minutes of running on a treadmill elevated to a 4 percent grade.

Exercise intensity was held at two levels, determined by monitoring heartrate every minute by electrocardiogram. Heartrate was correlated with oxygen consumption before the treatments began. Each subject was given a graded maximal oxygen consumption (VO_{2max}) test with simultaneous recording of heartrate prior to any of the treatment conditions to determine a linear regression of oxygen consumption and heartrate. Then from this linear regression, predicted heartrates were determined corresponding to 40 and 75 percent values of maximum oxygen consumption. The 20 minutes of exercise started when the subject reached the predetermined heartrate for each treatment level. The speed was adjusted every minute to maintain a steady state heartrate. The control treatment was 20 minutes of sitting quietly and reading. After each condition, ten minutes of rest was allowed to return the subject's heartrate to within +15 beats of resting heartrate. The treatments were given at the same time of day with at least one day in between testing, and with each subject performing each treatment condition once. The experimental and control treatments were administered to all subjects in an order that would counterbalance each treatment.

Before and after each treatment H- and M-waves were measured to calculate H/M ratios. In this manner, with pre- and post-treatment H/M ratios measured for all three treatments, each subject acted as his/her own control.

Measurement of Maximal Oxygen Consumption and H-Reflex

Maximum oxygen consumption (VO_{2max}) was measured while subjects ran on a Quinton treadmill. The protocol used consisted of two-minute stages at a 4 percent grade, which remained constant throughout. Treadmill speed started at 3 miles per hour and increased by 0.5 mph until the subject's VO_{2max} was obtained. During the second minute of each stage, expired air was analyzed for oxygen and carbon dioxide content with Beckman OM-11 and LB-2 analyzers, respectively. The volume of expired air was also measured the second minute of each stage using an Alpha Technologies Ventilation Meter. Heartrate was recorded the last ten seconds of each stage on a HP1500B electrocardiogram machine. The data collected were used to calculate minute oxygen consumption (VO_{2max} in L/min).

The H-reflex was measured as follows using the method of de Vries et al. (1981). The tibial nerve was stimulated by an indifferent lead and a stimulating electrode on the leg (Figure 1). The indifferent lead was an ECG plate electrode located 15 centimeters above the popliteal fold on the posterior thigh. The stimulating electrode was a small disc electrode in the popliteal fossa. Before securing the stimulating electrode in place, a probe electrode was used to find the location that produced the greatest M-wave (most intense electrical focus) at a given stimulus intensity. Single square wave impulses of 0.5 msec. duration were delivered using an electric stimulator (Grass S 44) via a stimulation isolation unit (Grass SIU5). The interval between stimuli was never less than 20-30 seconds. Stimulation voltage was first selected by choosing a threshold value that produced an M-wave. Thereafter the voltage was increased in 5 volt increments until a plateau M value was reached. The plateau M-wave value was accepted when 3 consecutive stimulation impulses of increasing nominal value (5 volt increments) produced no further increase in M-wave amplitude. The stimulation voltage necessary for all subjects ranged from 10-110 volts with maximal M-wave amplitudes reached in the 70-110 volt range. The H-wave amplitude was initially identified during determination of the M-wave amplitude, and then re-examined more accurately by adjusting the stimulus in 1.0 volt increments and increasing the oscilloscope sensitivity to better observe the event throughout the 10-15 volt range where the peak H-wave had previously been recorded. The peak H-wave amplitude was usually identified in the 30-45 volt range. Thus re-examination at 1.0 volt stimulus increments provided assurance that the greatest H-wave amplitude was not missed between the wider 5.0 volt increments initially used to identify the H-wave location and M-wave amplitude.

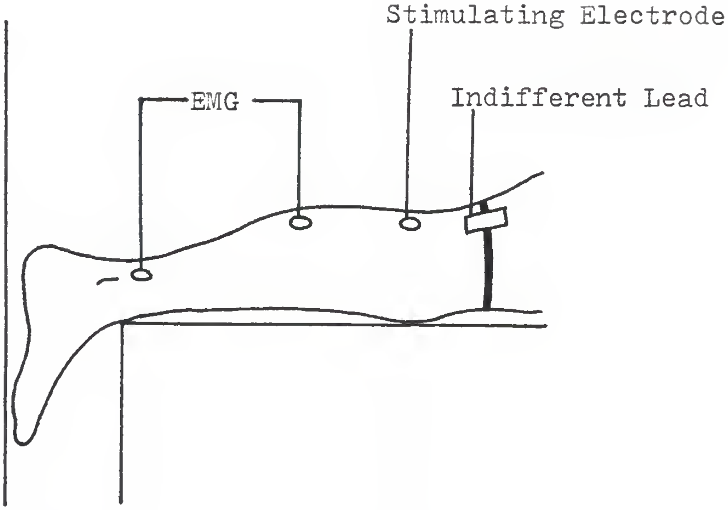

Figure 1 - Schematic Diagram of Stimulation and Electromyography Electrode Placements.

The muscle action potentials were recorded by using two small disc electrodes in a bipolar arrangement (Figure 1). The active electrode was placed on the midline of the calf over the belly of the gastrocnemius; the reference electrode was placed proximal to the medial malleolus. The ground electrode was located proximal to the lateral malleolus. The electrode sites were abraded to produce interelectrode resistances no greater than 5000 ohms. Muscle potentials were amplified (Narco Bio-Systems) with a gain of 100 displayed, and stored on a storage oscilloscope (Tektronix (T912)) from which the M- and H-wave amplitudes were measured. Appropriate adjustment of the oscilloscope sensitivity allowed for larger tracings of the muscle potentials for best measurement resolution.

Following each pre-test H-reflex determination, it became necessary to remove the stimulating and indifferent electrodes from the popliteal fossa and posterior thigh during exercise. However, before removing both of the electrodes, the locations were well marked to allow accurate replacement of the electrodes for the post-treatment H-reflex measurement.

Possible sources of error included electrode movement and placement. To minimize electrode movement the EMG electrodes were secured in place with elastic bands and the stimulating electrodes were sufficiently marked to allow accurate replacement. The M-wave plateau responses were observed before and after each treatment condition and their reproducibility was noted. Furthermore, using the H/M ratio rather than the absolute voltages of each wave minimized the error that might be introduced if electrical resistance changed during or after exercise. To reduce the error due to differences in electrode placement from one test day to the next, measurements and descriptions of electrode locations were recorded. In addition, day-to-day variability was assessed by using the six M plateau values (post hoc) from the three pre- and post-treatment measurements, the differences were small and insignificant ($p < .05$). Therefore, any changes observed in the H/M ratios were due to changes in the H-wave plateau value or motor neuron excitability change, and not the M-wave value changes.

Another consideration to eliminate measurement errors involved duplicating the body position of the subject from test to test. The individual maintained a supine position with the head and arms located similarly during all of the testing. Also, the subject was encouraged to remain still and alert while being tested since changes in conscious states can alter spinal cord excitability levels (unpublished data).

Statistical Analysis

The data was analyzed through a general linear model procedure involving a least square mean analysis.

CHAPTER 4

Results and Discussion

The physical characteristics will be summarized and a typical H- and M-wave response will be illustrated. The raw data are given and the results pertaining to the percent change, and comparisons between and of the percent change in the H/M ratio are presented. A discussion of the change in H/M ratio after exercise follows.

Physical Characteristics

The physical characteristics of the ten subjects are summarized in Table 1. The average age, weight, and height of the individuals utilized in this study was 28.7 years, 64.5 kg, and 168 cm, respectively. The mean maximal oxygen consumption was 55.8 ml/kg/min.

Table 1

Physical Characteristics of the Subjects

Subject	Sex	Age (Yrs)	Weight (kg)	Height (cm)	VO_{2max} (ml/kg min)
RG	M	45	76.4	173	51.8
JA	F	21	61.4	162	48.6
MB	M	20	61.6	165	68.6
KW	F	33	53.9	165	54.4
SN	F	21	59.4	173	56.4
DS	F	31	62.6	162	54.6
RB	M	36	72.4	165	61.8
DG	M	33	49.6	160	51.4
MM	M	23	67.9	165	53.6
DC	F	24	79.7	191	56.6
Mean		28.7	64.5	168	55.8
±SE		± 2.60	± 3.03	± 2.88	± 1.81

H- and M-wave Response

A typical H-wave and M-wave response is illustrated in Figure 2. The H-wave increases, plateaus, and decreases in value before the maximum M-wave response has occurred. The H/M ratio is the result of the maximum H response divided by the maximum M response.

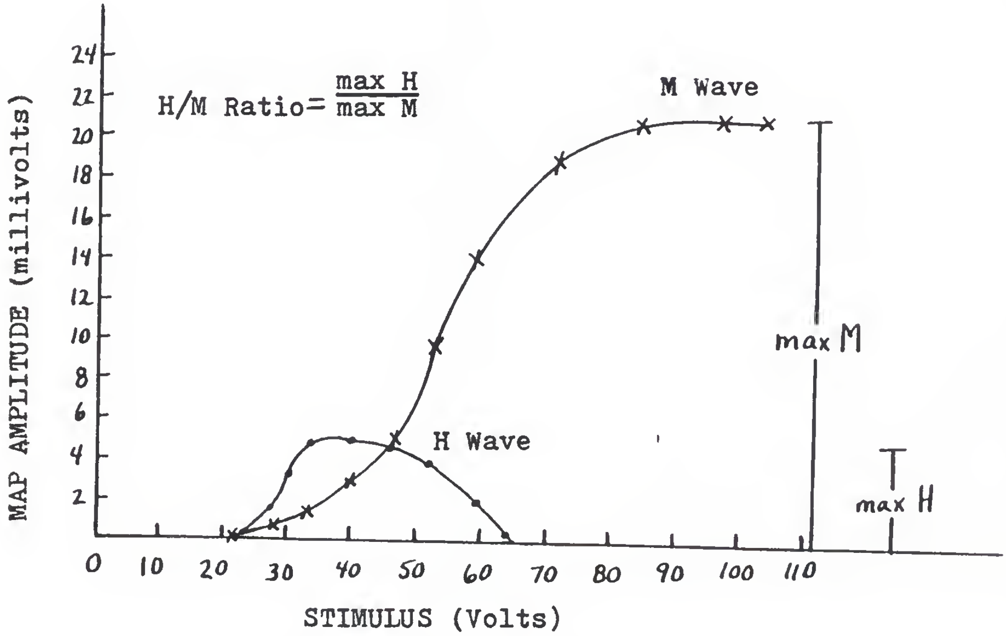

Figure 2 - Plot of the Stimulus-Response for Both H and M Waves. Stimulus is in volts; and response is in millivolts. Illustration for Determination of H/M Ratio.

Raw Data

In Table 2, data were collected for three treatments: 0, 40, and 75 percent exercise intensity. The H-wave and M-wave maximal amplitudes (mV), H/M ratio, and percent change are tabulated for each subject. Also, the mean (±SE) of each of these results is given. The data were analyzed with respect to the mean percent change (pre- and post-

Table 2

Values for H- and M-Waves, H/M Ratio, and Percent Change in the H/M Ratio (PC) Are Provided for Each Subject and for the Mean of All Ten Subjects

	Control - Pre			Control - Post				40% - Pre			40% - Post				75% - Pre			75% - Post			
Subject	H	M	H/M	H	M	H/M	PC	H	M	H/M	H	M	H/M	PC	H	M	H/M	H	M	H/M	PC
RG	4.0	15.5	25.8	4.8	16.5	29.1	12.7	4.6	20.0	23.0	4.0	19.2	20.8	- 9.4	4.5	18.0	25.0	3.8	18.5	20.5	-17.8
JA	7.0	25.0	28.0	7.0	24.5	28.6	2.0	5.1	24.5	20.8	4.3	25.5	16.9	-19.0	7.2	27.0	26.7	4.7	24.5	19.2	-28.1
MB	5.9	20.0	29.5	6.2	22.5	27.6	- 6.6	5.2	22.5	23.1	5.2	22.2	23.4	1.4	5.2	22.5	23.1	4.3	23.0	18.7	-19.1
KW	5.2	20.0	26.0	5.6	20.0	28.0	7.7	3.9	17.5	22.2	2.8	17.5	16.0	-28.2	4.6	20.0	23.0	4.1	20.0	20.5	-10.9
SN	8.2	17.0	48.2	7.2	14.5	49.7	2.9	7.5	17.0	44.1	6.9	16.2	42.6	- 3.5	5.9	16.2	36.4	6.5	16.2	40.1	10.2
DS	5.2	14.5	35.9	5.2	15.0	34.7	- 3.3	4.9	14.0	35.0	4.6	14.5	31.7	- 9.4	5.0	15.0	33.3	4.0	15.5	25.8	-22.6
RB	3.5	20.6	17.0	3.8	20.6	18.4	8.6	2.4	20.0	12.0	1.9	21.0	9.0	-24.6	3.0	19.2	15.6	2.2	20.8	10.6	-32.3
DG	2.2	18.2	12.1	2.3	19.0	12.1	0.1	2.5	20.0	12.5	2.5	21.5	11.6	- 7.0	3.0	18.0	16.7	2.0	18.2	11.0	-34.1
MM	0.8	19.2	4.2	0.8	19.7	4.1	- 2.5	0.6	19.0	3.1	0.5	20.0	2.5	-20.8	0.7	18.2	3.8	0.5	18.0	2.8	-27.8
DC	13.5	28.8	46.9	12.5	26.8	46.6	- 0.5	10.0	24.0	41.7	9.2	24.0	38.3	- 8.0	11.2	25.0	44.8	7.5	25.0	30.0	-33.0
(n=10) Mean	5.6	19.9	27.3	5.5	19.9	27.9	2.1	4.7	19.8	23.8	4.2	20.2	21.3	-12.8	5.0	19.9	24.8	4.0	20.0	19.9	-21.5
SE±	1.12	1.36	4.44	1.00	1.25	4.44	1.90	0.84	1.02	4.17	0.80	1.08	4.08	3.07	0.89	1.21	3.66	0.65	1.05	3.35	4.25

treatment) of the H/M ratio between the control and each of the 2 experimental treatments.

Nine of the ten subjects showed a fall in the H/M ratio after 40 percent and 75 percent exercise intensity. For all subjects, the range for 40 percent exercise intensity was +1.4 to -28.2 percent with a mean of -12.85 percent. The range for 75 percent exercise intensity was +10.2 to -34.1 percent with a mean of -21.55 percent. The mean percent change for the control days was +2.11 percent.

Percent Change in H/M Ratio

Figure 3 illustrates the percent change in the H/M ratio for each individual under a control and 2 experimental conditions. The data demonstrate a general trend toward tranquilization with high intensity exercise compared to low intensity exercises.

Comparisons Between and of the Percent Change in the H/M Ratio

The mean changes in spinal cord activation as measured by changes in the H/M ratio in ten subjects for the control, 40 percent exercise intensity, and 75 percent exercise intensity treatment are shown in Table 3. Comparisons are also provided for the same data with one unresponsive subject's data (SN) withdrawn.

Comparison of the percent change between the 3 treatments are shown in Figure 4. The general linear models procedure involving least squares was used to analyze the data.

In observing the significance, the differences between the mean percent change for control and 40 percent intensity and also between the control and 75 percent intensity treatment conditions were highly significant ($p < .01$ and $p < .001$). The differences between mean percent

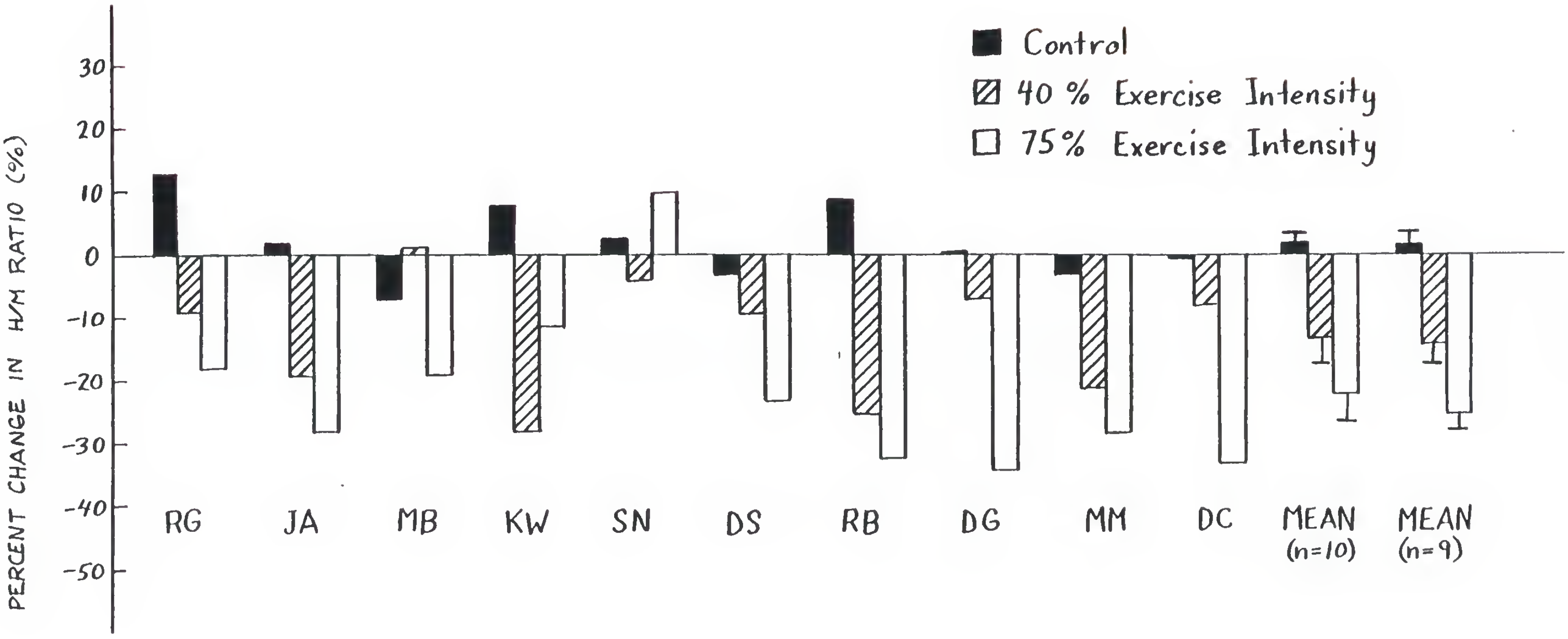

Figure 3 - Change in the H/M Ratio Before and After Control Treatment Compared With the Change Before and After Exercise at 40 and 75 Percent of Maximal Oxygen Consumption. Percent Change in the H/M Ratio is Provided for Each Subject, and for the Mean of 10 Subjects and 9 Subjects (Excluding SN's Data).

Table 3

Comparisons Between the H/M Ratios Are Given for the Three Treatment Conditions for All Ten Subjects and Nine Subjects (Excluding SN's Data). H/M Ratios Are Referred to as Follows: Pre = Pre-Treatment, Post = Post-Treatment, and PC = Percent Change.

Values Compared			Calculated P-Value	
Pre	vs	Pre	10s	9s
Control		40	.0055*	.0010*
Control		75	.0408*	.1134
40		75	.3541	.0325*
Post	vs	Post		
Control		40	.0001*	.0004*
Control		75	.0001*	.0001*
40		75	.3098	.4045
Pre	vs	Post		
Control		Control	.6635	.7149
40		40	.0459*	.0325*
75		75	.0002*	.0001*
Control		40	.0001*	.0001*
Control		75	.0001*	.0001*
40		75	.0026*	.0021*
PC	vs	PC		
Control		40	.0034*	.0013*
Control		75	.0001*	.0001*
40		75	.0655	.0148*

*p < .05

change for the 40 and 75 percent intensity treatment conditions approached but did not reach significance (p = .066). However, removing subject SN's data which demonstrated unstable baseline data and subsequently a notable rise in the H/M ratio following exercise at 75 percent intensity as compared to the remaining subjects' responses resulting in the mean percent change between the 40 and 75 percent treatment conditions achieving statistical significance (p = .015). Additionally, this removal of SN's data resulted in the mean percent change for the 40 percent and 75 percent treatments becoming -13.89 percent and -25.07 percent, respectively. Also, examination of the H/M ratio between the control and 75 percent exercise intensity showed a large decrease in percent change in eight out of ten subjects (see Table 2).

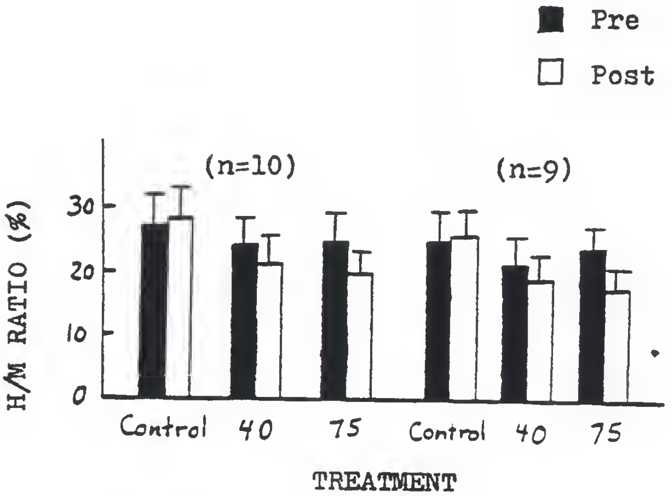

Figure 4 - Effects of a Control Treatment (Sitting Quietly) and Two Exercise Treatments (40 and 75 Percent of Maximal Oxygen Consumption) on H/M Ratio Response Pretreatment (Pre) and Posttreatment (Post).

Discussion

The present study demonstrated that an acute bout of exercise at intensities equivalent to 40 and 75 percent of maximum oxygen consumption for 20 minutes resulted in a significant reduction in the H/M ratio as compared to a control treatment of sitting quietly. Thus, the results suggest that exercise brought about a reduction in motor neuron excitability and relaxation.

The results also indicated that the difference between 40 and 75 percent exercise intensity approached but did not reach significance, possibly due to one subject's (SN) abnormal response to the testing procedures. Removing the SN's data from the analysis renders the two treatment effects significantly different ($p < .02$). Deleting this one subject's data from the analysis can be supported on several grounds. First, the subject was extremely stressed in dealing with serious professional and personal problems. Second, the subject's values for H/M ratio were as high as 15 times the value for the lowest H/M ratio in the sample. Third, out of the 20 experimental trials, subject SN's 75 percent H/M ratio was the only one to change significantly (10%) in the upward direction. Only one other subject had a small one percent rise. Fourth, SN was one of two subjects out of 20 trials to show an opposite (75 percent less effective than 40 percent) response in the 10 subjects. In conclusion it may be stated that the additional suppression in the spinal cord activation after 75 percent intensity exercise compared to 40 percent intensity exercise appears to be real if only of borderline significance. Thus, it would seem that exercise may result in relaxation only for those individuals who are not under the influence of particular types of stressful situations. Further research is necessary to establish such a contention.

The findings also show the pre-treatment H/M ratios varied greatly. At first these differences in pre-treatment ratios may seem to be a problem. To explain these pre-treatment differences, one must observe how the H-wave values and M-wave values varied. The M-wave values, which are the responses of the soleus muscle to the stimulation, remained relatively constant pre-test to post-test and among trials. Whereas, the H-wave values, which are the reflex responses from the soleus muscle, varied greatly. Thus, H-wave changes accompanied by a constant or nearly constant M-wave is interpreted as a change in motor neuron excitability (de Vries et al., 1981). Therefore, this variability observed in the H-wave in the present study could be a result of the various levels of tension or anxiety the subjects possessed upon arrival to laboratory. Consequently, an upward or downward shift in the H/M ratio in a pre- and post-treatment measure indicates changes in motor neuron excitability and reflects the treatment effect no matter what the initial level of excitability.

The finding of the present investigation is in general agreement with the result of de Vries et al. (1981), who demonstrated 40 percent exercise intensity for 20 minutes produced a reduction in the H/M ratio. The magnitude of the reduction observed was slightly different, in that de Vries reported an 18 percent decrease as compared to a 12.8 percent decrease found in the present study. This difference in magnitude may be due to two subjects in the present study who displayed noticeable dissimilar responses to the 40 percent intensity treatment. A possible reason as to why the magnitude of the reduction was not as great is that treadmill running was used in the present study as compared to ergometer bicycling in de Vries's work. Haugen et al. (1960), has demonstrated that random, intermittent, and changing proprioceptive stimuli allowed for normal cortical activity, but a persistent bombardment of excessively strong stimuli from all muscles resulted in over activity of the arousal area in the cortex. Therefore, bicycling at low intensity may provide more of an intermittent stimuli, which allowed for more normal cortical activity than running on a treadmill. The 40 percent exercise intensity for the subjects represented a level that was between a fast walk and a slow run. All subjects chose to run and not walk. Thus, the awkwardness involved for the subjects when running slowly may have resulted in an excessively strong stimuli, which produced over activity of the arousal area in the cortex. Possibly the over arousal being a result of increased nervous input from the brain, muscles, and joints. This over arousal would then result in less of a reduction in motor neuron excitability and H/M ratio. In general, the results of both studies have shown that low level exercise of a 20-minute duration produced a reduction in the H/M ratio. de Vries et al. (1981), referred to the observed reduction in the H/M ratio following low intensity exercise as support for a tranquilizer effect of exercise.

High intensity exercise (75 percent of maximal oxygen consumption) produced an even greater reduction in the H/M ratio. The difference was statistically marginal when comparison was made with the reduction following low intensity exercise. The reduction after high intensity exercise was found to be 21.5 percent compared to 12.8 percent for 40 percent intensity exercise.

One possibility as to why high intensity exercise resulted in a greater reduction in the H/M ratio is in the amount of lactate present. Lactate production is known to be greater during high intensity exercise and high levels of circulating lactate have been associated with anxiety symptoms. Pitts and McClure (1967) have suggested that a high level of lactate similar to the level that occurs with vigorous exercise would result in anxiety symptoms in anyone. The present study provided evidence against this suggestion, in that high intensity exercise did not increase motor neuron excitability or central nervous system excitability. Also, it has been demonstrated that high intensity exercise resulted in lowering state anxiety or tension (Bahrke and Morgan, 1978; Morgan and Horstman, 1976). Thus, the results of the present study support the interpretation of the latter authors that showed high intensity exercise reduced tension.

Another possibility as to why high intensity exercise resulted in a greater reduction in the H/M ratio is in the type of stimuli provided. High intensity exercise may provide random and intermittent proprioceptive stimuli which allows for normal cortical activity (Haugen et al., 1960). This normal cortical activity produced by high intensity exercise may result in the observed reduction in the H/M ratio as compared to persistent bombardment stimuli, such as constant nervous input from the body, which results in over arousal in the cortex.

Other possible changes that occur with exercise involve the level of brain neurotransmitters, such as norepinephrine (NE), serotonin, and endorphins. It has been demonstrated that in lab animals, exercise produced increased levels of NE and serotonin (Brown and Van Huss, 1973; Brown et al., 1979; and Barchus and Freedman, 1962). This increase in the levels of brain neurotransmitters may be even greater in high intensity exercise, and thus result in less motor neuron excitability and in a reduction of the H/M ratio. Other substances the brain produces are the endorphins, which act like morphine and reduce sensations of pain and produce a state of euphoria (Morgan, 1985). Pert and Bowie (1979) found that exercise in rats was associated with an increase in receptor occupancy, and they concluded that this was due to an increased release of endorphins or a decreased dissociation rate from receptors. This increase in brain endorphins may also be responsible for reducing the motor neuron excitability and H/M ratio. Thus, several changes that occur with exercise, such as increased lactate, neurotransmitter, and endorphin production and a change in cortical activity may be even more pronounced during high intensity exercise versus low intensity exercise. The above mentioned changes following high intensity exercise may result in a greater amount of relaxation.

CHAPTER 5

Summary, Conclusions, and Recommendations for Future Research

A summary of this study will be given and conclusions will be drawn. Recommendations for future research follow.

Summary

Various techniques are used today to relax the body, such as meditation, relaxation methods, drugs, and exercise. High intensity exercise has been shown to lower state anxiety (Bahrke and Morgan, 1978; Morgan and Horstman, 1976) and low intensity has been shown to lower resting muscle activity (Sime, 1977; de Vries, 1972; de Vries and Adams, 1968) and reduce motor neuron excitability (de Vries, et al., 1981). However, high intensity exercise using a motor neuron excitability measurement has not been investigated.

A way to measure motor neuron excitability is the Hoffmann or H-reflex. The H-reflex is a result of artificial stimulation of the tibial nerve that results in two muscle action potentials (MAPs) in the soleus muscle. The two MAPs are referred to as the M- and H-waves. The M-wave is the direct stimulation to the motor fibers and the H-wave is the reflex response which travels from the muscle and back again to the same muscle. The usual convention is to calculate an H/M ratio, which is the largest H wave divided by the largest M wave. A change in the H/M ratio is an indication of a change in motor neuron excitability.

The purpose of the present study was to observe the changes in motor neuron excitability following low and high intensity exercise. To accomplish this purpose, the H/M ratio was measured before and after exercise intensities equivalent to 40 and 75 percent of maximal oxygen consumption.

Ten recreational or competitive runners, aged 20 to 45 years, volunteered to be tested under three different experimental conditions. The experimental conditions lasted for 20 minutes and consisted of a control treatment, which was sitting quietly, 40 percent exercise intensity treatment, and 75 percent exercise intensity treatment. The H/M ratio was measured pre- and post-treatment.

The data were analyzed using a general linear procedure model to observe the percent change in the H/M ratio from pre- to post-treatment. The percent changes in the H/M ratio for the 40 and 75 percent treatments compared to the control treatment were highly significant ($p < .01$ and $p < .001$). The percent change in the H/M ratio for the 40 percent treatment compared to the 75 percent treatment approached but did not reach significance ($p = .066$). Removing one subject's data, who was unresponsive to either exercise treatments, resulted in the comparison between the 40 and 75 percent treatments to reach significance ($p = .015$). Therefore, both low and high intensity exercise resulted in a reduction in motor neuron excitability. High intensity exercise produced a greater effect when an analysis was done without one subject's data included.

Conclusions

Two assumptions are made in the present study about the H-reflex measurement. The first assumption was that one can generalize the motor neuron excitability at one spinal level, assessed by the H-reflex, to the whole body's state of excitability. Support for this generalization has been shown by an earlier EMG study that showed a decrease in resting muscle activity in arm muscles as the result of leg exercise (de Vries, 1968). The second assumption was that changes in motor neuron excitability demonstrated changes in the whole body's level of relaxation. Evidence has been provided by de Vries et al. (1981), who reported that a reduction in motor neuron excitability following exercise demonstrated the exercise had a tranquilizer effect. That is the exercise acted similar to tranquilizers which relax the whole body. Thus, when using the interpretations made in the present study, one must keep in mind these two assumptions just mentioned.

In conclusion, the results show exercise results in a reduction in motor neuron excitability, assessed by the H-reflex. If one can assume the reduction in motor neuron excitability is an indication of a more relaxed state, both low and high intensity exercise for 20 minutes duration resulted in relaxation.

Recommendations for Future Research

Since stress is encountered by most individuals daily and aerobic exercise has been shown to reduce tension levels, further research investigating extremely stressed individuals and relaxation effects following exercise is needed. Also, information needs to be gathered on how long the relaxation effect after exercise lasts. The possibility of either an optimal intensity or duration exercise to produce the most relaxation should also be investigated.

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APPENDIX A

Informed Consent H-Reflex Study

I ______________________ voluntarily consent to participate in this study examining the effects of exercise intensity on stress. Stress will be measured by placement of a muscle stimulation surface electrode on the back of the knee, and another set of surface electrodes on the calf to measure the response of the muscles. This measurement will involve electrical shock ranging from zero to the maximum voltage needed to cause a strong muscle twitch. The electrical stimulation will produce at most a muscle cramp. The stress test will be given before and after the two exercise conditions. The exercise conditions will consist of running at less then maximal efforts on the treadmill for twenty minutes.

To determine the two exercise conditions, I will administer a graded exercise test which measures maximum exercise capacity; and consists of steadily increasing levels of work performed on a treadmill. The workload starts very light and progresses to fatigue. I am free to terminate the effort at any time. The possible discomforts include breathlessness and muscle soreness.

I hereby authorize Barb Darabos and Dr. Bulbulian and/or such assistants as may be selected by them to conduct the procedures explained to me. Questions concerning these procedures have been answered and I understand the following:

1. The inherent risks and attendant discomforts to be expected.
2. The benefit of participation will include knowledge of results regarding my physical fitness, and the possibility of learning whether exercise is causing a relaxing effect on one's body.
3. I understand that in the event of physical injury resulting from the research procedures involved in this experiment, no financial compensation will be available since the regulations of the state prohibit Kansas State University from carrying insurance for such purposes.
4. I understand that if I have any questions regarding my participation in this study, or about the nature of this study, I may contact the project director, Barb Darabos (532-6765).
5. I am free to withdraw my consent and participation in the study at any time without prejudice to me.
6. All results will be kept confidential and will be made available to me upon request at the conclusion of the study.

Signature ______________________

Date ______________________

CHANGES IN MOTOR NEURON EXCITABILITY ASSESSED BY THE HOFFMANN REFLEX FOLLOWING EXERCISE AT LOW AND HIGH INTENSITIES

by

BARBARA LYNNE DARABOS

B.S., Kansas State University, 1983

AN ABSTRACT OF A MASTER'S THESIS

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Manhattan, Kansas

1985

ABSTRACT

The objective of this study was to observe changes in motor neuron excitability following low and high intensity exercise. Changes in motor neuron excitability were assessed with the Hoffmann reflex as the objective measure. The Hoffmann or H-reflex occurs as a result of artificial stimulation to the tibial nerve. A single shock to the nerve produces two muscle action potentials, M- and H-waves. The H- and M-waves are used to calculate a ratio, the H/M ratio, which is equal to the largest H-wave divided by the largest M-wave. A previous study using the H-reflex demonstrated that relaxation occurred after low level exercise (40 percent of maximal oxygen consumption). Relaxation following high intensity exercise has not been investigated using this objective measure. Ten recreational or competitive runners were run on a treadmill for 20 minutes at heartrates equivalent to 40 and 75 percent of their maximal oxygen uptake. H/M ratios were measured before and after the two exercise treatments and before and after the control treatment, which involved sitting quietly for 20 minutes. Comparisons of pre-treatment and post-treatment results showed that 40 percent exercise intensity reduced the H/M ratio by 12.85 percent, 75 percent exercise intensity reduced to 21.55 percent, and the control treatment resulted in an increase in the ratio by 2.1 percent. The data were analyzed using a repeated measures general linear model. The analysis showed that the reductions in the H/M ratio produced by exercise were significantly different from the control value. The high intensity exercise produced a slightly greater reduction in the H/M ratio; however, the difference between the effects of low and high intensity exercise was not statistically significant. Thus, if motor neuron excitability is taken as a measure of relaxation, exercise at either low or high intensity results

in relaxation, with high intensity exercise providing a slightly greater effect.