THE EFFECTS OF PHYSICAL TRAINING ON STATIC STRENGTH AND DYNAMIC WORK OF THE GASTROCNEMIUS - PLANTARIS MUSCLE GROUP IN MALE ALBINO RATS

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By

Donald D. Lund

AN ABSTRACT OF

A THESIS

Submitted to
Michigan State University
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THE EFFECTS OF PHYSICAL TRAINING ON STATIC STRENGTH AND DYNAMIC WORK OF THE GASTROCNEMIUS-PLANTARIS MUSCLE GROUP IN MALE ALBINO RATS

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An attempt was made to evaluate quantitatively the static-strength and dynamic-work performances of the rat gastrocnemius-plantaris muscle group.

Thirty-six adult male Sprague-Dawley rats were divided randomly into training and control groups. All animals were housed in sedentary cages, but the animals in the training group were removed from their cages twice daily for two periods of forced swimming. Each swimming period lasted two hours. Each animal in the training group was forced to swim with a weight of up to three per cent of its body weight attached to its tail. This training program was conducted five days a week for a period of six weeks.

At the end of the training program, each animal was anesthetized with ether and the gastrochemius-plantaris muscle group was exposed by clipping the achilles tendon. The tendon then was attached to a strain gauge and stimulated continuously for two seconds for an indication of static-strength. The muscle then was attached to a

one-hundred-gram weight while periodic stimulation was applied for a ten-minute period. A linear variable differential transformer recorded the total distance the muscle lifted the weight for an indication of dynamic-work.

It was found that there were no significant mean differences in either static-strength or dynamic-work performances measured in absolute terms. However, when the performances were divided by body weight, it was found that there were statistically significant mean differences between the two groups. The trained animals had greater relative static strengths and higher relative work outputs, from the third through the tenth minutes of dynamic work, than the control animals.

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DEDICATION

This thesis is respectfully dedicated to my parents, John and Lorraine Lund, whose insight and sacrifice made it possible for me to obtain my education.

ACKNOWLEDGMENTS

The author is indebted to Dr. William W. Heusner for his guidance throughout my course of study; D. Edington for his personal help and assistance; Robert L. Wells for his work on the design and construction of the electrical system of the apparatus; and D. Litwhiler, B. Sarnac and R. Bowzer who gave willingly of their time and effort.

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CHAPTER I

INTRODUCTION

Muscular performance has long been a subject of research in physical education as well as in other areas of science. It is a known fact that training produces increases in muscle size, strength, and endurance (19). Although this has become fundamental knowledge, the causes behind these gross changes within the muscle still remain open to detailed research.

In order to discover exactly what changes occur with training, it has become necessary to go to the cellular, subcellular, and enzyme level to perform anatomical and biochemical assays on trained and untrained muscles. Since it is impossible to run these studies on human beings, the research must be modified so as to be applicable to laboratory animals. By using animal studies, general principles may be established relating to actual muscle changes. The principles then may be applied to help understand muscular performance in man.

Need for the Study

In humans it has been found that different types, intensities and durations of physical training have various

effects on the muscular strength and endurance of the subjects. Corresponding changes have been hypothesized, but seldom observed, in animal training studies. With modern techniques requiring extensive use of animals, there is need for investigation to determine the specific effects of various training programs on the muscular strength and endurance of animals. The information gained from this study should aid work which presently is being done on muscle changes produced by training and should provide insight as to the reasons for some of the histochemical, anatomical and biochemical phenomena that have been observed within the trained muscle.

Purpose of the Study

The purpose of this study was to measure the effects of a program of endurance swimming on the rat gastrocnemius-plantaris muscle group, according to its ability to perform two well defined tests of muscular performance. These two tests consisted of: (a) the measurement of static strength and (b) the measurement of dynamic work.

Scope of the Problem

Forty-eight adult male laboratory rats were randomly assigned to one of two groups. The control animals were housed in sedentary cages with no outside activity. The experimental group was housed in sedentary cages and removed from their cages twice daily for two periods of forced

swimming. The training program was conducted five days a week for a period of six weeks.

At the conclusion of the training period, each animal was anesthetized with ether, and the gatrocnemius-plantaris muscle group was exposed by surgically freeing the achilles tendon. The tendon then was attached to a muscle performance analyzer. The muscle was stimulated and measurements of static strength and dynamic work were taken.

Subproblem

Since there was no readily available apparatus for the measurement of static strength and dynamic work in the rat, an instrument was developed for this purpose. That instrument has been called a "Muscle Performance Analyzer" and is described in Chapter III.

Limitations of this Study

1. Method of training: Swimming as a method of training gave no way to quantitatively measure the total work which was being done by each animal during each training session.
2. Size of sample: Due to the laboratory conditions, the number of animals was limited to forty-eight.
3. Span of time: Training the animals for six weeks may not have been a sufficient length of time to establish maximal performance changes in the muscle groups studied.

4. Type of exercise: In the current study, the forced swimming was a different type of exercise in both intensity and duration than either the static-strength or dynamic-work tests. These tests may not have been accurate measurements of the changes that occurred within the training program.

Definition of Terms

1. Static Strength: A maximal contraction of the muscle group against an immovable resistance.
2. Dynamic Work: A muscular contraction in which a given resistance is moved a given distance as the muscle contracts.

CHAPTER II

REVIEW OF RELATED LITERATURE

It is beyond the scope of this paper to report on all of the different studies pertaining to muscular performance. This paper will be limited, therefore, to pertinent works concerning animal research such as the study upon which this thesis is based.

Hypertrophy within muscle fibers, as the result of athletic training, has been an accepted fact for many years. Morpurgo, (12), in his classic anatomical study during 1897, was the first to show the effects of training on hypertrophy of muscles. In his study, the satorious muscle was removed from one leg of a dog. After removal of the muscle, the dog was trained strenuously through running. Upon completion of the training period, Morpurgo removed the satorious muscle from the dog's other leg and compared it to the first muscle. He found an increase in muscle-mass which was due entirely to an increase of sarcoplasm within the individual muscle fibers. There was no change in the number of muscle fibers, the fiber length, the number of nuclei, or the number or size of the muscle fibrillae.

A study similar to Morpurgo's was conducted by Siebert (17) in which the results of Morpurgo's study were

substantiated. Siebert also found further indications relating to the great importance of the type of training used. As part of the study there was stimulation of both legs of a frog for a period of twenty minutes each day. One leg of the frog was found to contract isotonically, while the other was forced to contract isometrically. After fourteen days of this type of training, it was found that the leg contracting isometrically was thirteen per cent heavier than the leg which was trained with isotonic contractions.

Steinhaus (19) cited Siebert as stating that the extent of hypertrophy of a muscle is related to the speed of running rather than to the duration of the running period. By examining the gastrocnemius of running rats, Siebert found that those who had run at a moderate speed had only slight hypertrophy and that this degree of hypertrophy was independent of the distance the animal was forced to run. In order to obtain increased hypertrophy within the muscle, it was necessary to make the animal run at a greater speed. It was concluded that the extent of hypertrophy is a function of the amount of work performed in a given unit of time.

Gordon, Kowalski and Fritts (7) found that changes within the muscle depend upon the type of training that is utilized. A repetitive low-force type of training, such as running, when applied to rats produces a trend toward an increase in the concentration of sarcoplasmic proteins. Following

forceful activities, such as weight-lifting, there tends to be an increase in the concentration of actomyosin within the muscle fibers. This indicates that training does not cause a general change within the muscle. The type of change is dependent upon the type of training.

Until 1961, hypertrophy of the muscle was attributed to an increase in the volume of the muscle fibers. In 1962, Van Linge (21) reported changes on the plantaris muscle caused by heavy training. The triceps surae muscle of the hind limb of a rat was denervated. Then the tendon of the plantaris muscle was implanted onto the tuberosity of the calcaneus. This was done so that the work of the triceps surae would be assumed by the plantaris. The weight of the plantaris is normally only eighteen per cent that of the triceps surae. The animals then were forced to run up a twenty-seven degree incline for nine hours a day. This was done for a period of thirty days.

The changes Van Linge noted were astonishing. It was found that the plantaris could take the place of the triceps surae, a muscle group which is normally over five times its size. The plantaris had almost doubled its weight and had tripled its force of contraction. Along with an increase in sarcoplasmic material, Van Linge also noted indirect evidence of hyperplasia, the formation of new muscle fibers within the experimental muscle.

Increases in muscle strength do not necessarily accompany muscle hypertrophy. Bigland and Jehring (2) injected full grown rats with a growth hormone over a twenty-one day period. Upon completion of the test period, the injected animals were found to be heavier than the controls by twenty per cent. Also, cross sections of the muscles revealed a six to twelve per cent increase in area of the experimental group over the control group. However, isometric records taken of single twitches, summated twitches, tetanus, and fatigue showed that the treated animal's muscles produced less tension per gram of muscle weight than did those of the control group.

An increase in strength does not always cause a noticeable hypertrophy within the muscle. A study carried out by Goldspink (6) showed that muscle weight, and consequently muscle girth, are unreliable indices of hypertrophy. In young mice exercised by weight lifting, Goldspink found no change in the weight of the muscle; but upon examination of the fibers, he found an increase of about thirty per cent in the mean cross-sectional area. He concluded that the muscle fiber growth came about at the expense of the extra-cellular tissue.

Schwarts (18) performed a study in which she measured the gastrocnemius and soleus muscle weight, length, water and nitrogen content, active and passive length-tension curves, and twitch and tetanic-tension responses in

growing male rats between the ages of twenty-four and one-hundred and thirty-one days. She found that the muscle weight was an increasing proportion of the body weight of the animal, whereas the muscle length increased at a declining rate, as the animal aged. Water constituted a decreasing, and nitrogen an increasing, proportion of muscle weight as the animal aged. The length-tension relationship was unchanged over the measured span of time. Contraction strength to wet muscle weight was a constant ratio throughout the age range. However, the ratios of contraction strength to dry weight or to nitrogen content were higher in the younger rats than in the older rats.

Often the mechanical advantage of muscles acting together can make a difference in performance. Thompson (20) investigated how the responses of the separate heads of the rat gastrocnemius muscle were related to the response of the whole muscle. By using isometric twitch-tension contractions he found that the response of the lateral head was forty-six and three-tenths per cent greater than the response of the medial head. Comparing the summation of the responses of these two separate heads to the response of the whole muscle, he found that this summation was within four and six-tenths per cent of the response of the whole muscle. When using isometric tetanus-tension contractions of the medial and

lateral heads there was found to be little if any difference between the heads. However, when these individual tetanus-tension responses were added together, the value was only sixty-eight per cent of the value of the response of the whole muscle. In summary, he showed that the tensions of the two halves of the muscle did not equal the total tension of the whole muscle, for something was lost in the separation. Thompson attributed this loss to a decrease in mechanical advantage brought about by the muscle being separated.

In measuring muscle contractions of animals, it must be remembered that a true isometric or isotonic contraction rarely occurs in the body (1). That is, laboratory tests of animals are highly artificial, and at their best will give only partial information concerning the animals' true capacity for muscular performance.

In 1964 Coutts (4) introduced a method for controlled muscular exercise in anethetized laboratory rats without removing the muscle. This method involves implantation of permanent electrodes around the tibial nerve. The advantage of this method is the ability to take intermittent measurements during exercise-bouts throughout the study, rather than just a single measure of muscle work output upon sacrifice of the animal. At the same time, this method of exercise allows for greater specification of work-output within the experimental

group. In order for this method to be successful, however, the techniques of anethetization and electrode implantation need further investigation and perfection.

The methods of measuring static contractions have varied according to the methods used for muscle stimulation. In studies using a single twitch, the muscle was stimulated by one electrical impulse which caused the muscle to contract. Following contraction, complete relaxation took place (11, 13, 18, 20). A muscle stimulated in this manner forms a bell-shaped tension curve.

In one study, the muscle was stimulated by using a summated twitch, in which a second stimulus was applied before the muscle had time to relax from the first stimulus (2). This caused the muscle to contract again before complete relaxation occurred. Individual responses could be seen in the contraction.

In other studies, the rate of stimulation was increased even more so that the responses became completely fused. When the contraction curve is completely fused it is called a tetanic contraction. This is the method that has been used most often in tests for static contractions (2, 10, 16, 18, 20).

For dynamic-work performance, stimulations have been applied to the muscle so it could move a given resistance a number of times in single twitches. An early attempt of this type was made by Heron, Hales, and

Ingles (8) when they tried to determine the capacity of the rat gastrocnemius muscle group to maintain work output. The tibias of ten rats were exposed, and a one-hundred-gram weight was attached by a linen thread to the freed tendon of each gastrocnemius. The muscle then was stimulated directly at the rate of three times per second. Upon stimulation, the muscle lifted the weight by means of the attached thread which was looped around a pully. The pully was attached to an apparatus which activated a veeder counter and measured the total distance the weight had been moved. From this measurement, the work output could be expressed in kilogram-meters for each twenty-four hour period.

The experimenters found that continuous muscle contractions were in one case carried out over a seventeen-day period, after which the muscle still was contracting at thirty per cent of the initial work rate. It also was noted that work output does not always decrease at a uniform rate. In some cases, the animals were capable of out performing their own activity record from the preceding day.

In 1944 Ingle (9) replaced this original apparatus with a compact one-way clutch within the pully, which was attached directly to the veeder counter. When the muscle contracted, the weighted cord around the pully moved, giving a direct read-out of the work done on the veeder counter.

From these aforementioned studies, it can be seen that most of the problems relating to changes within the muscle are still unanswered or open to controversy. A great deal of extensive research still needs to be done to determine the causes of muscle changes brought about by training. To do this effectively, the researcher must first qualify his measurements so he may identify and objectively define a trained muscle.

CHAPTER III

EXPERIMENTAL METHOD

Experimental Design

One-hundred-five male, weanling (twenty-three day old), Sprague-Dawley rats were brought into the laboratory and housed in individual voluntary activity cages for five days. The cages housing these rats were 18 x 18 x 24 centimeters, with an activity wheel 12.5 centimeters wide, and 35 centimeters in diameter.

The animals were allowed two days of adjustment to their new laboratory environment, after which spontaneous activity records of total revolutions run in the activity wheels were kept for three days. In order to obtain a homogeneous sample, those animals with the highest and lowest activity levels were eliminated from the study.

Forty-eight animals in the central activity range for the three day period, were selected for the study. These then were ranked according to revolutions run during the aforementioned three-day period. After being ranked, the animals were systematically assigned into one of two groups. This assignment consisted of putting the first animal into group A, the second and third animals into group B, the fourth and fifth animals into group A, the

sixth and seventh animals into group B, etc. By using this method, any bias from assigning the animals into groups was eliminated. A flip of a coin was the determining factor deciding which group would receive the experimental procedure.

Once the groups were determined, the animals were transferred into 18 x 18 x 24-centimeter sedentary cages. The activity of the sedentary animals was further curtailed by inserting a piece of sheet metal from the upper left corner of the cage to the lower right corner, which cut the total volume of the cage in half. All forty-eight cages were held on a rack, with twenty-four cages on each side. The rack was divided into four levels housing six animals on each row. The cages for the experimental and control animals were alternated on the rack so there were three animals from each group on every row.

The lighting in the room where the animals were housed was in cycles of twelve hours of light and twelve hours of darkness. The temperature was held at twenty-five degrees centigrade with a variation allowance of plus or minus one degree. All of the animals were fed "Wayne Lab Blox" ad libitum and given free access to water. The body weight of each animal was taken and recorded on Thursday of each week.

Training Routine

The experimental group was removed from their cages twice daily (from three to five P.M. and from nine to

eleven P.M.) Monday through Friday each week, for forced swimming sessions. The animals were then placed into especially constructed individual cylinders, twenty-five centimeters in diameter and one and two-tenths meters deep, so as to eliminate any interference with other animals. Throughout this period the water temperature was maintained at thirty to thirty-two degrees centigrade.

During the first week of training, the experimental animals swam without any extra weight so as to allow for adjustment to swimming in the tanks. During the second week, each animal was made to carry a weight which consisted of two per cent of his body weight. The extra weight was added to the end of the animals tail by means of a plastic clothes pin. For the third and all subsequent weeks, the extra weight was maintained at three per cent of the animals body weight which was determined the Thursday before. These weights were accurate to a plus (or minus) ten milligrams.

Upon termination of each swim, the weights were removed and the animals were individually dried with towels and then returned to their cages.

Sacrifice Schedule

At the completion of the experimental period, eighteen animals from each group were randomly selected by use of a table of random numbers. The order in which the animals were randomly selected served as the sacrifice schedule.

Three animals were sacrificed from each group, each day, for a total of six days. All of the experimental animals went through their daily training schedule until the day before they were sacrificed.

Measurement Procedure

The measurement procedure consisted of anesthetizing the animals by use of an anesthetic chamber containing ether. Once the animal was lightly anesthetized, he was maintained in this state by administration of additional ether through a nose cone.

A sample of blood for a pre-exercise lactic acid analysis was taken from each animal. The femoral vein was exposed and one milliliter of blood was extracted. The data obtained from this analysis is reported in another study (14). The gastrocnemius-plantaris and soleus muscle group of the left hind leg then was freed surgically by clipping the Achilles tendon. The soleus muscle of that leg was removed for histochemical analysis which was part of another study (3). The animal then was placed on his back and attached to the "muscle performance analyzer" (see Figures 1a and 1b). In this position, the proximal end of the muscle group was held in a fixed position by a hemostat which was attached to the apparatus. The distal end (the Achilles tendon) was attached by an alligator clip to a nylon filament which could be attached to either a static or dynamic recording unit.

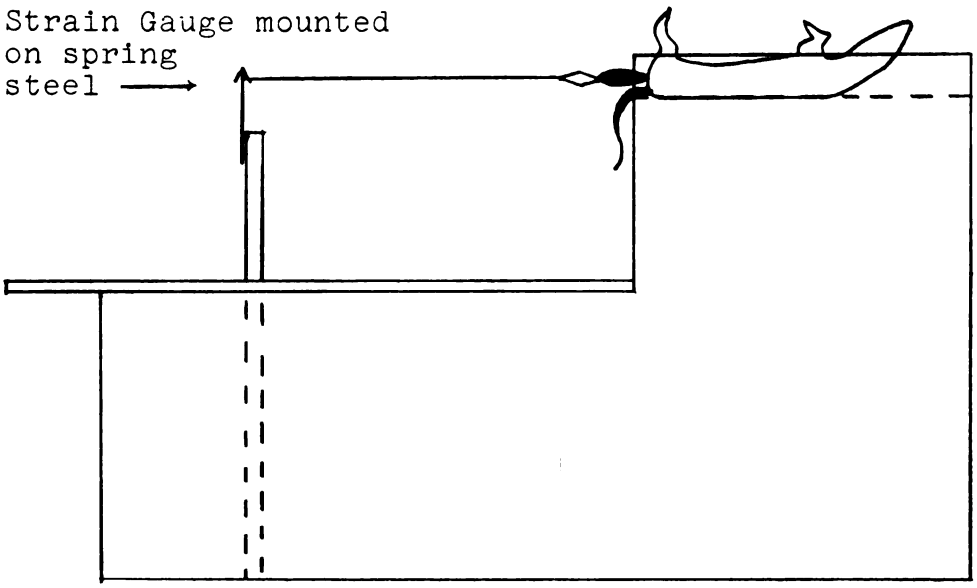

Figure 1a.--Animal hooked up for test of static strength.

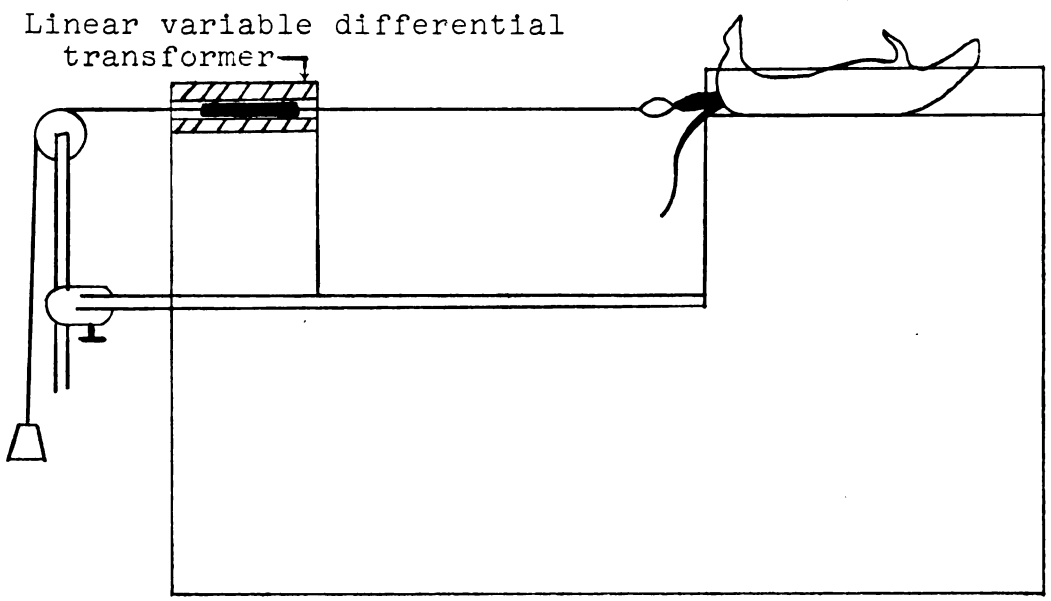

Figure 1b.--Animal hooked up for test of dynamic work.

With the anesthetized animal on the apparatus, the gastrocnemius-plantaris muscles group was stimulated directly. The hemostat holding the leg served as the anode and the clip attached to the Achilles tendon was used for the cathode. To stimulate the muscle, a twenty-volt square wave impulse from a Grass Model S-4 stimulator was used with a ten-thousand ohm resister in the circuit. This made the current across the muscle approximately two milliamperes. By using this large voltage with a high resistance in the circuit, any additional resistance that might occur from the electrodes or the muscle itself would not affect the experiment.

The measurement of static-strength was made by the use of a strain gauge mounted on a piece of spring steel which was attached to the nylon filament from the muscle. The muscle was stimulated for two seconds, and this stimulation was repeated a total of three times. The strain gauge acted as a variable resister, giving a linear output on a Gilson recorder for the static contraction from the muscle. A second strain gauge was used to provide a constant reading for variations in temperature and humidity that might occur in the laboratory during the course of the experiment.

For measurement of the dynamic-work capacity of the muscle, the nylon monofilament was attached to a one-hundred-gram weight. Stimulation was applied to the muscle

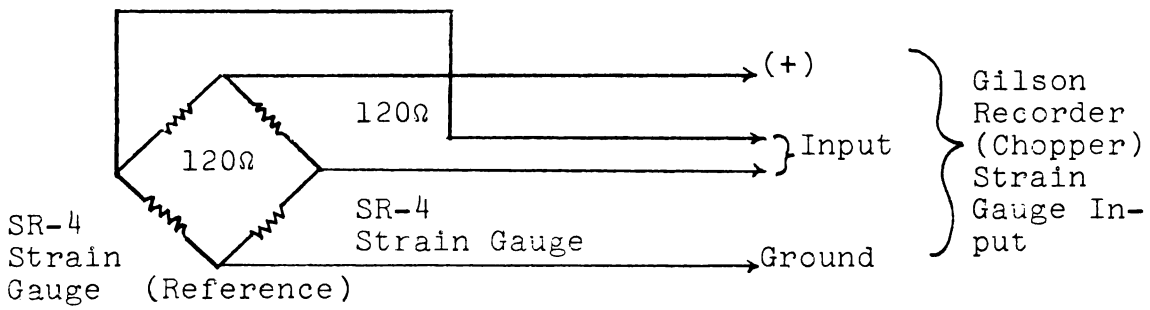

Figure 2.--Strain Gauge hook-up.

twice a second for a total of ten minutes. To find the total distance that the weight was lifted, the filament was attached to a bar which passed through a linear variable differential transformer. The linear variable differential transformer consists primarily of three coils interwound with a sixty cycle A.C. current running through them. As the bar is displaced from the center it causes the current to vary. This current is changed into a D.C. output which can be recorded on a Gilson recorder (see Figure 3).

With the instruments calibrated, measurements of the deflections could be taken with calipers directly from the Gilson paper and then converted to actual values. These values were the actual work done by each animal.

After the exercise routine was completed, a second blood sample was obtained from the femoral vein for a post-exercise lactic acid analysis. This sample was compared to the pre-exercise sample, and the results are

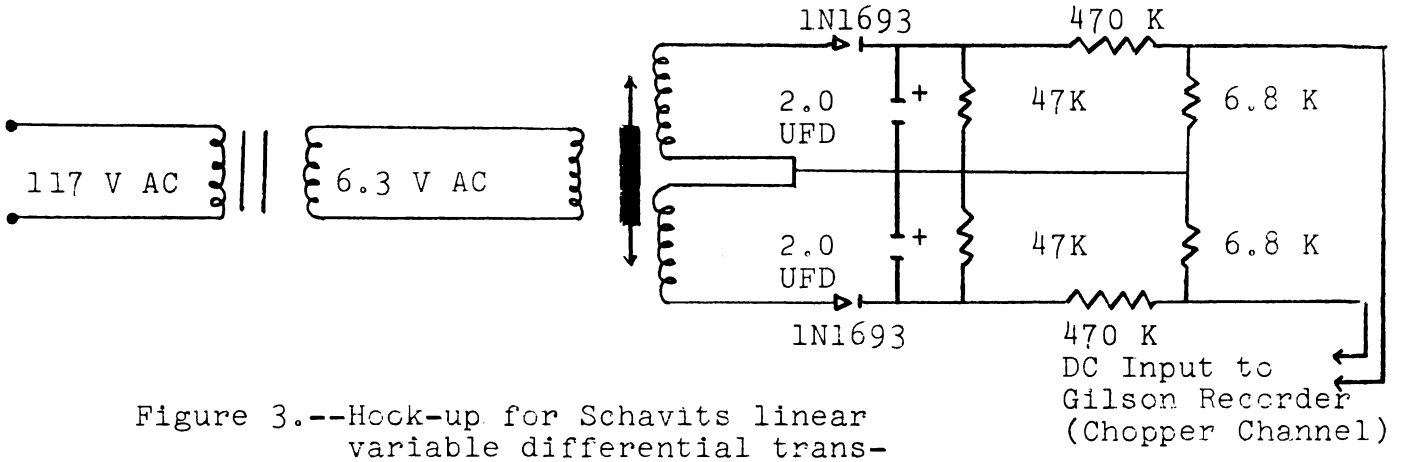

Figure 3.--Hook-up for Schavits linear variable differential transformer.

reported in another study (14). Lastly, the muscle, heart, and the liver of each animal were frozen and used for biochemical assays which are reported in another study (5).

Statistical Procedure

Statistical calculations were done using the UNEQ1 routine for one-way analyses of variance, and the BASTAT routine for the correlation analyses. All work was done using Michigan State University's Control Data 3600 Computer.

The null hypothesis tested was $(M_1 - M_2 \leq 0)$. Alpha was set at 0.05 while bata was set at the .20 level. It was decided that any mean difference between groups as large as or larger than one-half of one standard deviation was biologically important and should be detected as significant. With these specifications, a sample of sixty-three animals per group was necessary and sufficient. Since the groups $n_1 = n_2 = 18$ the following critical regions were established.

$F > 4.12$: Reject H_o at the ninety-five per cent level of confidence.

$F < 1.53$: Accept H_o at the eighty per cent level of confidence.

$4.12 \leq F \leq 1.53$: Reserve judgement.

CHAPTER IV

RESULTS AND DISCUSSION

This experiment was undertaken to determine the effects of a low-intensity high-duration training program on the static-strength and dynamic-work performance of the rat's gastrocnemius-plantaris muscle group. It was hypothesized that the experimental group would out-perform the control group in both static-strength and dynamic-work output. This data will be useful in other studies pertaining to this experiment (3,5,14). The correlations between pyridine nucleotides, blood lactic acid, and performance may be found in Edington (5).

Absolute Static Strength

Statistically, there were no significant differences between the groups in absolute static strength. The results of this analysis are presented in Table 1.

TABLE 1.--Analysis of variance of data for absolute static strength.

Source	Sums of Squares	Degrees of Freedom	Mean Squares	F	Sign.of F Stat.
Among Groups	5775.99	1	577.99	0.77	0.38
Within Groups	252909.22	34	7438.50		
Total	258685.22	35			

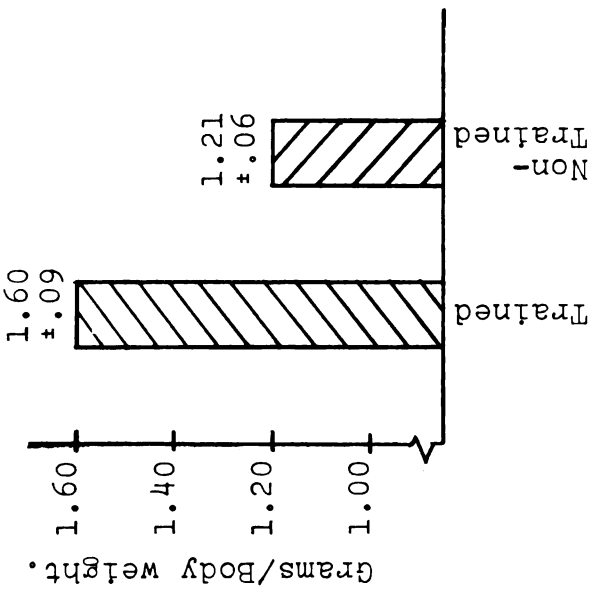

Figure 4b.--Static strength/ body weight.

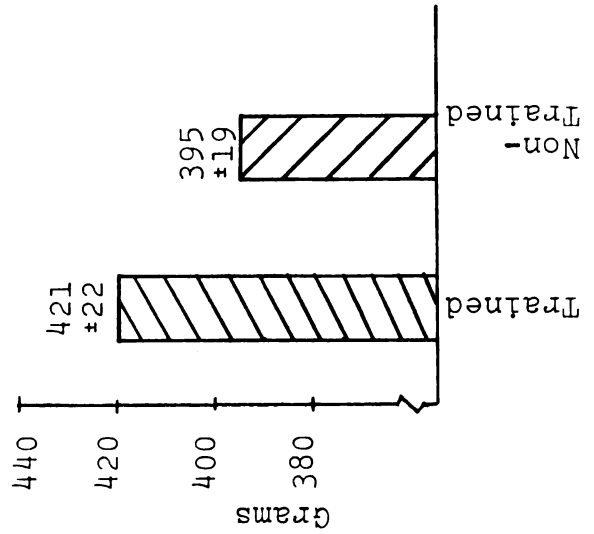

Figure 4a.--Static strength.

The static-strength means and standard deviations for the trained and untrained groups are presented in Figure 4a. The raw data may be found in Appendices A and B.

Absolute Dynamic Work

The analysis of variance did not detect a significant difference in total mean dynamic work between the trained animals (2645.4 ± 142.5 grams-cms.) and the untrained animals (2715.4 ± 145.5 grams-cms.). However, when the total work is broken down into individual minutes it can be seen that the untrained animals performed significantly more work during the first minute than the untrained. These results may be found in Table 2 and in Figure 5. The values and the probability levels are recorded in Appendix C.

Body Weight

The mean difference in final body weight was statistically significant ($p < .0005$). At the end of the study the exercised animals weighed an average of 264 grams per animal, while the controls weighed an average of 328 grams each. These results may be seen in Table 3.

Sarville and Smith (15) found that the weight of the muscle in the hind limb is highly correlated ($r = .96$) with the body weight of the animal. Since this is the case, dividing static-strength or dynamic-work performance

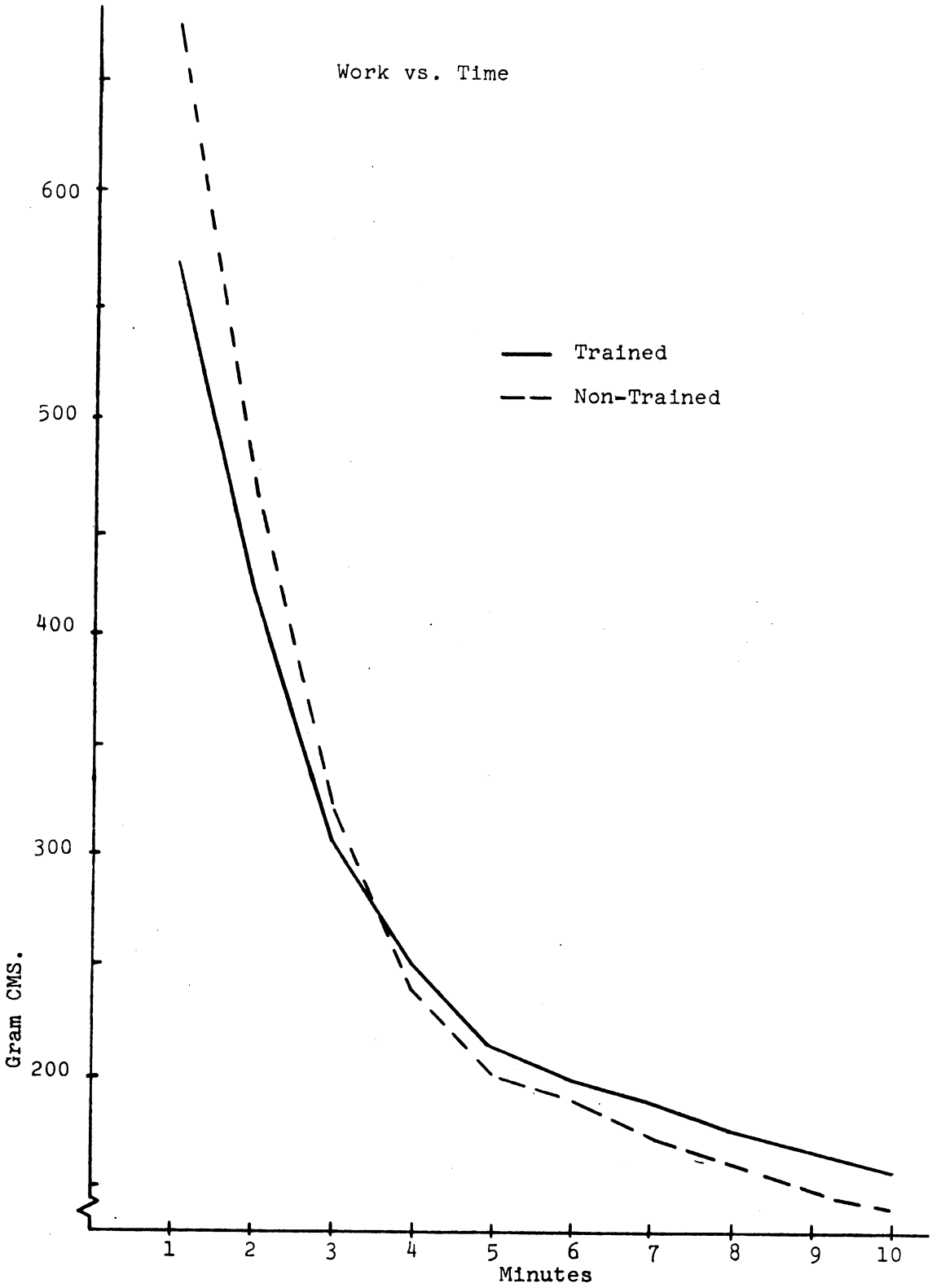

Figure 5.--Dynamic work performance.

TABLE 2.--Dynamic-work performance of the Gastrocnemius-plantaris muscle group in Gram-Centimeters.

Variable	Trained	Non-Trained
One*	570.61 ± 22.76	677.58 ± 15.89
Two	421.71 ± 20.87	467.98 ± 19.40
Three	304.60 ± 19.12	320.62 ± 18.77
Four	250.65 ± 17.42	241.32 ± 17.33
Five	211.98 ± 16.77	200.79 ± 17.51
Six	198.32 ± 13.68	189.35 ± 19.83
Seven	189.35 ± 13.33	171.05 ± 16.23
Eight	175.39 ± 13.67	159.03 ± 16.67
Nine	165.89 ± 13.66	147.30 ± 15.41
Ten	156.89 ± 13.05	140.33 ± 16.00

* $p < .05$

TABLE 3.--Analysis of variance of data on body weight.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	Sign. of F Stat.
Among Groups	36608.44	1	36608.44	52.50	0.0005
Within Groups	23704.44	34	697.18		
Total	60312.88	35			

by body weight would give a good indication of performance per gram of muscle weight of the animal. This method might provide a better indication of the actual performance of the animal than the absolute strength or values.

Static-Strength/Body Weight

When static strength was divided by body weight, it was found that the exercised animals had more relative strength than the sedentary group ($p = 0.001$). The results may be seen in Figure 4b. The analysis of variance may be seen in Table 4.

TABLE 4.--Analysis of variance of data of static-strength divided by body weight.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	Sign. of F Stat.
Among Groups	1.43	1	1.42	12.66	0.001
Within Groups	3.83	34	0.11		
Total	5.26	35			

Dynamic Work/Body Weight

The results of dynamic work divided by body weight have been summarized in Figure 6. In analyzing the data by individual minutes, it was found that there was no significant difference between the groups during the first minute. The value of the F-stastic obtained for the second minute was in the reserve-judgement region. This value may be found in Appendix C. During the third through the tenth minutes, it was found that the trained animals significantly ($p = 0.05$) out-performed the untrained animals in relative dynamic work. The results may be seen in Table 5. The F values and the probability levels may be found in Appendix C.

Discussion

As was reported earlier, the type of training is important when specific changes are sought within the body. In order for training of any type to occur, stress has to be placed upon the body. In this study, the animals were stressed through forced swimming. They swam two periods of two hours each, five days a week. During the swimming exercise, each animal had a weight of up to three per cent of its body weight attached to its tail. This was a low-intensity, high-duration type of training.

In evaluating muscle performance, a static contraction of the muscle was used as one test. This type of test was based upon the total strength of the muscle and

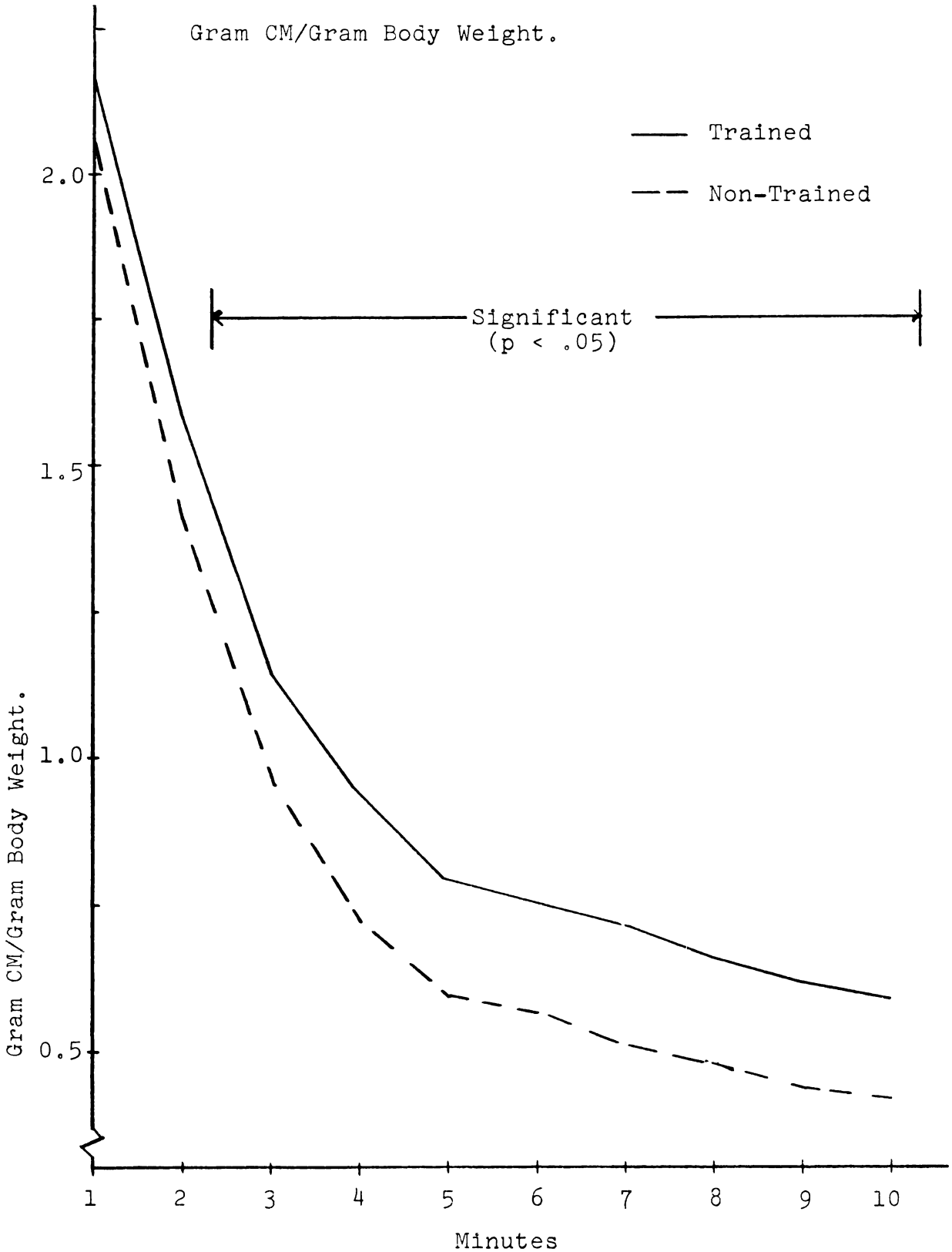

Figure 6.--Dynamic work performance/body weight.

TABLE 5 --Dynamic-work performance of the gastrocnemius-plantaris muscle group in Gram-Centimeters per-gram-body-weight.

Variable	Trained	Non-Trained
One/Wt.	2.15 ± .061	2.06 ± .047
Two/Wt.	1.58 ± .058	1.42 ± .056
Three/Wt.	1.14 ± .063	0.97 ± .053
Four/Wt.	0.94 ± .062	0.73 ± .047
Five/Wt.	0.79 ± .060	0.60 ± .049
Six/Wt.	0.75 ± .052	0.57 ± .059
Seven/Wt.	0.72 ± .052	0.51 ± .047
Eight/Wt.	0.66 ± .053	0.48 ± .049
Nine/Wt.	0.62 ± .051	0.44 ± .046
Ten/Wt.	0.59 ± .046	0.42 ± .049

was not necessarily related to the type of training program employed. Thus, this test would be best suited for evaluating the effects of a high-intensity, low-duration type of training program such as weight lifting. It was not well suited to the forced-swimming training program that was used.

The second test was for dynamic work in which the muscle lifted a one-hundred-gram weight twice a second for ten minutes. Although this test was better suited to the type of training that was used, it still may not have been ideal. The work rate of lifting a one-hundred-gram weight twice a second was relatively high as compared to the forced-swimming program. Also, the period of time may have been too short to give the trained animals a chance to demonstrate the full effects of this type of training. If the testing had been carried out over a period of two hours, such as was used in the training program, the trained animals might have been able to out-perform the sedentary group even more.

Another factor affecting muscle performance could have been the stimulation of the muscle. The muscle was stimulated directly, causing all of the muscle fibers to contract at once. In training, certain patterns are set up in which only specific fibers contract for optimum muscle performance. These patterns are controlled by motor units which fire in a given order. By stimulating

all of the muscle fibers at once, this training effect may have been lost.

Another difficulty encountered was that the stress applied during the training was large enough to produce a significant difference between groups in body weight. This variation of body weights between groups could have made a big difference in the performances of the animals. In sporting events such as wrestling, boxing, judo and weight lifting, the contestants are matched according to body weight. If the muscles in the hind limb of the rat are related to body weight as Sarville and Smith (15) suggested, then the trained group was at a disadvantage in the tests of absolute performance. The tests of relative performance probably were much more valid.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effects of forced-swimming training on the gastrocnemius-plantaris muscle group through static-strength and dynamic-work tests.

Two groups, each consisting of eighteen young male albino (Sprague-Dawley) rats, were randomly assigned to training and control groups. All of the animals were housed in standard 18 x 18 x 24 centimeter sedentary cages. The controls had their activity further curtailed by bisecting the volume of the cages.

The training group was removed from their cages twice daily, once from three to five P.M. and again from nine to eleven P.M. for four hours of forced swimming daily. Each animal swam with a weight of up to three per cent of its body weight attached to its tail. This program was carried on five days a week for a period of six weeks.

At the end of the training period, each animal was anesthetized lightly with ether and the left femoral vein was exposed. One milliliter of blood was removed for a

blood lactic acid analysis. The gastrocnemius-plantaris-soleus muscle group of the left hind leg was surgically freed by clipping the Achilles tendon. The soleus muscle was removed for a parallel histochemical study. The tendon was attached to a nylon monofilament which was attached to a spring steel plate. A strain gauge on the steel plate was used to measure static strength. The muscle was stimulated directly for two seconds using a supermaximal square-wave impulse from a Grass Model S4 stimulator.

The filament from the muscle then was attached to a one-hundred-gram weight and the muscle was stimulated twice a second for a total of ten minutes. The filament attached to the weight passed through a linear variable differential transformer which recorded the total dynamic-work output of the muscle.

At the end of the stimulation phase, one milliliter of blood was extracted from the left femoral vein and used for a post exercise blood lactic acid analysis. Finally, the heart, the liver, and the muscle were quick-frozen for use in biochemical assays of pyridine nucleotides.

The lactic acid and pyridine-nucleotide results are reported in other studies (5, 14).

Conclusions

1. The training routine of forced swimming significantly reduced the body weight of the experimental animals as compared to the controls.

2. There were no significant differences between groups either in absolute static strength or in absolute dynamic work performance.

3. When static strength was divided by body weight, the trained animals were found to have significantly greater relative strength.

4. The trained group significantly out-performed the sedentary control group in dynamic work divided by body weight during the third through the tenth minutes of the dynamic-work test.

Recommendations

1. The experimental procedure should be repeated under conditions designed to equalize the mean body weights of the two groups of animals.

2. In future studies, the muscle weights and the fiber sizes should be established at the conclusion of the study.

3. Training routines other than forced swimming should be studied under the same experimental design.

4. Studies using varying intensities and durations of training programs should be conducted.

5. Similar studies should be conducted using different time intervals to determine the optimum period of training.

6. Attempts should be made to control the temperature of the muscle during the testing of work performance.

7. Several anesthetics including ether, should be studied to determine what effects they may have on work performance.

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APPENDICES

APPENDIX A.--Trained.

Animal Number	Weight	Static Strength	Dynamic Work									
			1	2	3	4	5	6	7	8	9	10
36	258	380	534.80	426.08	341.12	335.52	261.12	225.68	247.12	238.72	241.84	212.56
45	257	290	461.44	373.92	273.92	228.48	194.24	193.76	219.84	184.32	180.16	141.36
32	234	364	539.12	371.76	311.36	281.61	194.16	194.96	192.16	145.84	135.28	127.04
37	229	276	368.64	402.08	341.12	283.80	248.64	246.08	246.40	214.24	192.48	191.04
29	229	416	452.96	324.48	233.12	161.92	123.68	114.40	115.20	118.72	118.88	114.56
20	304	384	589.98	500.80	412.16	353.44	313.44	274.08	253.92	235.68	226.40	203.44
9	296	423	782.40	597.76	426.24	326.88	284.48	254.40	216.80	193.12	185.28	159.60
12	264	423	600.48	408.16	218.72	157.44	165.60	155.20	153.76	134.72	144.64	144.76
16	304	467	693.60	535.04	382.72	343.84	299.52	267.20	264.96	231.84	249.92	273.72
24	304	460	654.88	502.08	376.96	302.08	261.92	219.36	193.28	206.08	210.88	186.36
17	248	438	547.36	303.68	208.16	189.12	168.00	174.08	167.20	152.64	112.00	96.96
44	270	528	627.36	345.60	204.96	191.20	193.44	178.80	162.56	130.72	107.28	75.64
13	309	312	612.00	496.64	360.96	240.80	181.92	142.40	131.36	122.72	119.36	143.20
48	234	542	523.84	348.64	259.68	231.84	156.96	197.92	187.52	171.20	160.32	154.04
8	245	563	551.36	409.12	272.96	164.96	136.88	156.00	144.72	128.64	117.12	117.28
25	296	513	597.12	432.00	292.16	213.44	158.88	162.08	124.48	150.24	135.52	136.64
1	244	528	646.40	530.24	409.12	358.56	359.36	315.04	290.88	318.40	279.04	229.60
41	237	350	487.36	282.72	157.44	146.88	113.44	98.40	96.96	79.20	69.76	59.36

APPENDIX B.--Non-trained.

Animal Number	Weight	Static Strength	Dynamic Work									
			1	2	3	4	5	6	7	8	9	10
27	304	390	790.56	591.36	365.60	169.12	84.16	153.60	132.48	120.96	115.04	97.44
15	328	470	664.96	436.64	264.16	188.32	154.40	150.08	119.84	75.04	42.56	38.40
39	295	423	612.96	441.16	288.00	206.88	159.84	154.24	154.88	149.44	142.40	126.40
18	349	260	679.44	415.60	368.24	328.32	291.68	276.16	268.88	247.60	212.32	155.20
38	321	292	707.52	549.92	429.28	375.36	339.52	434.88	332.16	344.64	317.28	336.00
47	323	438	637.12	486.40	327.36	231.36	201.12	180.16	173.60	173.92	172.00	169.28
26	373	320	839.52	568.32	392.64	338.56	296.32	243.52	238.24	217.44	196.48	162.56
6	353	320	609.92	451.20	301.28	264.96	201.92	175.36	178.40	157.12	154.56	154.56
11	325	460	652.80	515.84	336.48	250.24	220.16	237.44	212.32	201.12	206.56	202.56
22	342	468	686.88	511.20	394.08	297.76	254.40	199.20	194.24	183.36	151.84	121.12
14	329	454	704.32	370.88	283.84	200.80	184.32	182.72	168.96	137.28	115.04	108.96
42	294	364	596.00	360.48	258.08	225.12	193.60	160.80	148.16	126.72	120.96	112.96
35	340	336	592.32	510.72	412.48	210.08	127.52	75.04	69.76	63.76	71.12	76.24
19	288	320	626.56	304.00	149.84	99.76	57.84	37.76	45.20	70.48	92.64	100.80
30	353	401	656.80	419.52	221.12	185.68	184.16	165.44	121.52	88.40	56.56	39.76
23	333	350	712.16	487.20	331.52	243.36	210.72	189.44	173.60	172.32	153.28	154.24
2	322	513	664.48	400.80	215.52	172.48	160.16	144.32	124.00	119.04	137.92	190.88
31	338	542	762.24	599.52	431.68	355.68	292.48	248.16	222.72	213.92	192.88	178.64

APPENDIX C.--One way analysis of variance with the exercise group as the category variable.

Dynamic Work Dependent Variable	F-Statistic	Probability
One	14.84	0.0005*
Two	2.63	0.114
Three	0.35	0.554
Four	0.14	0.707
Five	0.21	0.648
Six	0.13	0.712
Seven	0.75	0.390
Eight	0.57	0.453
Nine	0.81	0.373
Ten	0.64	0.428
One/Wt	1.22	0.275
Two/Wt	3.98	0.054
Three/Wt	4.41	0.043*
Four/Wt	7.60	0.009*
Five/Wt	6.13	0.018*
Six/Wt	5.10	0.030*
Seven/Wt	8.10	0.007*
Eight/Wt	6.31	0.017*
Nine/Wt	6.77	0.014*
Ten/Wt	5.76	0.022*

*Statistically significant at < 0.05 level.