THE EFFECTS OF HEAVY OVERLOAD WEIGHT TRAINING UPON SELECTED PHYSIOLOGICAL PARAMETERS AND TREADMILL PERFORMANCE OF WELL TRAINED DISTANCE RUNNERS

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Arts in Physical Education by

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DEDICATION

This thesis is dedicated to my lovely wife, Robin. Her love, patience, unending encouragement and dedication made this work a reality.
ACKNOWLEDGEMENTS

The author wishes to express sincere gratitude to Dr. George J. Holland for invaluable assistance, encouragement and guidance. Appreciation is also extended to Dr. George Q. Rich III and Dr. William J. Vincent for their continual assistance. Special thanks are given to David Murley, Michael Goffredo, and Robin Tobin whose laboratory assistance was deeply appreciated. In addition, thanks are extended to the subjects whose time, effort, and cooperation made this study possible.
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THE EFFECTS OF HEAVY OVERLOAD WEIGHT TRAINING UPON SELECTED PHYSIOLOGICAL PARAMETERS AND TREADMILL PERFORMANCE OF WELL TRAINED DISTANCE RUNNERS

by

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Master of Arts in Physical Education

The purpose of this study was to determine the effects of eight weeks of heavy overload weight training on treadmill running time and maximum oxygen consumption levels of well trained distance runners.

Eight males from the California State University, Northridge, cross country team volunteered to participate. Hydrostatic weighing, strength testing, and treadmill max VO\(_2\) testing were performed by each subject before and after the eight week training period.

Subjects were randomly divided into two groups, experimental and control. The experimental group used a high resistance weight training program in conjunction with their usual running regimen. The control group followed
the same running routine, however, did not include the weight training.

The major findings of this investigation were as follows:

1. The experimental group showed a significant increase in body mass ($p < .10$) and fat-free mass ($p < .01$) from pre and post season testing while nonsignificant changes were found in the control group. These findings indicate that through weight training the experimental group gained muscle mass.

2. Nonsignificant changes were found in percent fat in pre and post season testing and between the two groups on post season data. This would confirm that the body mass gained by the experimental group was muscle mass, not fat.

3. No significant differences were found in either of the two groups for treadmill running time or max $\text{VO}_2$ uptake when pre and post season results were analyzed and when post season scores of the two groups were compared. This would suggest that weight training did not improve endurance running performance.

4. The experimental group showed significant ($p < .01$) increases in the pre and post season $1\text{-RM}$ strength testing scores and between the two groups when post season scores were compared. This would indicate that weight training does improve the strength of the distance runner.

It was concluded that gains produced by heavy overload weight training are not necessarily accompanied by
complimentary physiological improvement. Therefore it would seem that weight training, as used in this study, would not benefit the well trained distance runner.
CHAPTER I

Introduction

Success in competitive distance running is due to a combination of interrelated physiological, biomechanical, and psychological factors. Optimal characteristics in one of these areas will not necessarily guarantee success because of the strong interrelationship between other factors. The distance runner is trying to optimize both of these variables to achieve the best performance.

Athletes and coaches have utilized research findings concerning training modes, nutrition, flexibility, and metabolic components to enhance performance levels of distance runners. If a runner can achieve a one minute improvement in his performance as a result of a specific training technique it could represent the advantage needed to become a champion.

Weight training is a mode of training currently utilized by coaches and athletes to improve distance running performance. Current theory held by some coaches and runners is that weight training for distance runners will improve strength levels which will make running, at a certain pace, physiologically more efficient than before the weight training program. Presumably with this physiological improvement runners should not fatigue as rapidly, thus producing faster event times.
Examining the characteristics of elite distance runners makes it evident that large muscle mass is not a distinctive characteristic for success. Pollock, Gettman, Jackson, Ayers, Ward, and Linnerud (1977), and Costill, Bowers, and Kramer (1970) found distance runners averaged 61.1 kg (N = 20) and 64.2 kg (N = 114) in weight with 7.5% and 4.7% body fat respectively.

Members of other sports which have been tested weighed considerably more than distance runners. Swimmers averaged 78.9 kg (N = 7) with 5.0% fat (Novak, Hyatt, & Alexandria, 1968) and baseball players averaged 83.3 kg (N = 10) and 14% fat (Forsyth & Sinning, 1973).

One of the reasons for the difference between these athletic groups is the hypertrophy of muscle due to heavy overload weight training. It has been shown that in males most forms of weight training will elicit some degree of muscle hypertrophy (MacDougall, Sale, Elder, & Sutton, 1976). Distance runners are caught in a dilemma because they desire the benefits of increased strength from weight training, however, they cannot tolerate additional body mass.

It has been shown that weight training produces a selective hypertrophy of Type II fibers (Burke, Cerny, Costill, & Fink, 1977). Elite distance runners were found to have on the average 79% Type I fibers that comprised 82.9% of the fiber area in their gastrocnemius muscle (Costill, Fink, & Pollock, 1976b), while a group of shot
putters had 62.3% Type II fibers that comprised 66% of the fiber area (Costill, Daniels, Fink, Krahenbuhl, & Saltin, 1976a). Endurance training seems to increase Type I fiber area while weight training seems to increase Type II fiber area. Since the oxidative potential of Type II fibers is extremely low (Eberstein & Goodgold, 1968), an increase in Type II fiber area, due to weight training, presumably would not increase the oxidative potential of the muscle in relation to the increased mass.

MacDougall, Sale, Moroz, Elder, Sutton, and Howald (1979) showed that weight training induced muscle hypertrophy also results in decreased mitochondrial volume density. Muscles would then have a lower oxidative potential after weight training, which could possibly decrease performance. The above study demonstrated there was a 26% reduction in mitochondrial volume density in the triceps of six males following six months of intensive weight training.

Another function that should be considered when analyzing distance running performance is lactate production by skeletal muscle cells. Increased lactate production by the exercising muscle is thought to be a contributing factor to fatigue (Karlsson, 1971). It has been shown that lactic acid is primarily produced by the Type II fibers (Ivy, Withers, Handel, Elger, & Costill, 1980), with Tesch, Sjodin, and Karlsson (1978) finding a correlation of .91 (P < .01) between Type II fiber proportions and the rate
of lactic acid accumulation. Hypertrophy of Type II fibers through weight training might possibly result in an increased rate of lactic acid production.

A review of the above research would tend to support the contention that weight training and distance running do not compliment each other. The many interacting variables prevent definite conclusions at this time concerning potential benefits of weight training for distance runners. The present study is designed to examine the physiological effects of a systematic weight training program upon elite distance running performance.

Importance of the Study

There has been minimal research conducted in the area of weight training for distance runners. Many coaches, athletes and popular training literature advocate weight training programs for distance runners, however, the definitive effects of heavy resistance weight training on distance running performance have not been determined.

Statement of the Problem

To determine if heavy resistance weight training has an adverse or beneficial effect on the performance of highly trained distance runners.

Hypothesis

Heavy resistance weight training will not improve endurance treadmill performance or the max VO$_2$ of highly trained distance runners.
Limitations

1. Training sessions had to be limited to an eight-week period to coincide with the competitive cross country season and to standardize running workouts.

2. Weight training was conducted twice weekly even though most studies recommend three training sessions per week. This schedule was necessitated by competition, travel, and time constraints of the subjects.

3. Due to equipment limitations, changes in mitochondria density, capillary density, muscle fiber composition, enzyme and glycogen levels could not be determined.

Delimitations

1. This study was designed to analyze changes associated with a weight training program for distance runners. By having subjects of the same cross country team completing identical training sessions, weight training could be applied as an independent variable.

2. Fatigue during strength testing sessions was held to a minimum by a rotation process which gave ample rest between work bouts and varied the muscle groups being used.

3. All pre and post testing was done in short time spans to eliminate extra training by subjects.

Definition of Terms

Anaerobic Threshold: Level of work, or O2 consumption, just below that at which metabolic acidosis and associated changes in gas exchange occur.
BTPS: Volume of gas expressed as body temperature (usually 37°C), ambient pressure (barometric pressure), and saturated with water vapor pressure of 47 mm Hg.

Fat Free Mass: Body weight minus weight of adipose tissue.

Heavy Overload Weight Training: Systematic progressive resistance weight training program utilizing maximal isotonic muscle contractions for increased neuromuscular strength function.

Highly Trained Distance Runner: Runners who have trained year round for several years averaging 50 miles or more per week with 10 kilometer times ranging from 30 to 34 minutes.

Hydrostatic Weighing (densitometric): Indirect method for determining body weight composition by computing body density (ratio of body weight to body volume) by underwater weighing.

Max VO2: Period in time when the subject's oxygen consumption shows no further increase with additional increases in workloads. It represents the individual's capacity for aerobic resynthesis of ATP.

Muscle Fibers: Classified into three major groups, (1) Type I or Slow Twitch (ST) - generate energy through aerobic energy transfer, low activity level of myosin ATPase, slow speed of contraction, large and numerous mitochondria, and fatigue slowly. (2) Type IIA or Oxidative Glycolytic (FOG) - generate energy through both
oxidative and glycolytic systems, low activity level of myosin ATPase, fast speed of contraction, and medium fatiguability. (3) Type IIB or Fast Glycolytic (FG) - generate energy through short term glycolytic system, low activity level of myosin ATPase, fast speed of contraction, smaller and less numerous mitochondria, and quickly fatiguable.

One Repetition Maximum (1-RM): Dynamic method of measuring muscular strength where a maximum amount of weight is lifted one time during performance of a standard weight-lifting exercise.

Percent Body Fat: The percentage of total body mass composed of adipose tissue.

STPD: Volume of gas expressed under standard conditions of temperature (0°C), pressure (760 mm Hg) and dry (no water vapor).

The remainder of this thesis research report is organized into four chapters: a review of related literature; research methodology and design; analysis of data; and summary, conclusions, and recommendations.
CHAPTER II

Review of the Related Literature

Principles of Strength Development

Muscular strength is the maximum force or tension generated by a muscle or muscle groups. Strength development involves adaptation of the muscle cells as well as a nervous system adaptation. These adaptations are dependent on the systematic overloading of the neuromuscular system.

Research by Morpurgo in the 1800s was the first to examine effects of strength gains. He reported increases in muscle size as a result of resistance training were due to the enlargement and not the increase in number of muscle cells. No research since then has disputed this concept.

Strength improvement is achieved through two systems: central nervous system adaptation and hypertrophy of muscle cells. In young individuals, neural factors account for the greatest part of early strength gain during the first three to four weeks of training, after which hypertrophy accounts for virtually all of the strength gains (Moritani & DeVries, 1979).

It has been well documented that maximal muscular contractions are the most effective way to increase muscular strength (Berger & Hardage, 1967; Cotten, 1967;
Several accepted training modes are all based on this basic principle. These training modes include: isometric, isotonic, eccentric, variable resistance, isokinetic, and numerous combinations of each.

Isometric, eccentric, and variable resistance training modes are all based on the principle that muscles contracting to overcome a fixed resistance are changing in length.

Results of research on these strength training modes have shown that for optimal strength development one should: (1) utilize four to eight repetitions per set (Berger, 1962); (2) use three sets; and (3) train at least three times per week (Komi & Buskirk, 1972).

Isometric training involves muscle contraction while maintaining a constant length. Isometrics were popularized during the early 1950s by Hettinger and Muller (1953). Studies since then have demonstrated that maximum contractions performed 3 to 6 seconds at least three times a week result in the greatest strength gains (Clark, 1974).

Isokinetic strength training provides muscular overload at a pre-set speed. An isokinetic effort encounters an equal and opposing force throughout the full range of motion. Limited research supports the concept that isokinetic strength training may be the most efficient means of increasing strength (McArdle, Katch, & Katch, 1981).
Muscle Fiber Composition Studies

More than a century ago researchers observed differences in force-velocity producing properties of rabbit skeletal muscles of differing gross morphology. Since then links between the morphological characteristics, in terms of distribution of distinct muscle fiber types have been firmly established.

Dubowitz and Pierce (1960) were pioneers in typing human muscle fibers into two broad categories, Type I and Type II. Eberstein and Goodgold (1968) classified these two fiber types according to their contractile properties as slow twitch (ST) and fast twitch (FT). Dubowitz and Burke (1973) further subdivided Type II fibers into Type IIA and Type IIB according to their relative oxidative capacity (see Table 1).

Research indicates man is born with a fixed percent of the two major fiber types which is not modified throughout the life cycle. Bell (1980) examined six-year-old children and found no differences in distributions of fiber types from a normal adult population. Training does not modify the relative proportions of Type I and Type II fibers. Studies involving endurance training (Gollnick, Armstrong, Saltin, Saubert IV, Sembrowitz, & Sheperd, 1973a), sprint training (Thorstensson, Sjodin, & Karlsson, 1975), anaerobic activities (Thorstensson, Hulten, Dobelin, & Karlsson, 1976), and strength training (Thorstensson, 1977) demonstrated no major fiber type changes.
Table 1
Muscle Fiber Classification

<table>
<thead>
<tr>
<th>Muscle Type Classification</th>
<th>Anatomical Classification</th>
<th>Histochemical Classification</th>
<th>Fiber Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I or Slow Twitch</td>
<td>red</td>
<td>SO</td>
<td>slow contraction, oxidative, most fatigue resistant</td>
</tr>
<tr>
<td>Type IIA or Fast Twitch</td>
<td>white</td>
<td>FOG</td>
<td>fast contraction, oxidative glycolytic, fatigue resistant</td>
</tr>
<tr>
<td>Type IIB Fast Twitch</td>
<td>intermediate</td>
<td>FG</td>
<td>fast contracting, glycolytic, very fatigable</td>
</tr>
</tbody>
</table>

SO = Slow Oxidative
FOG = Fast Oxidative Glycolytic
FG = Fast Glycolytic

Training did produce changes in oxidative capacity of muscle fibers where Type IIA fiber characteristics were modified to Type IIB (Anderson & Henricksson, 1977a; Costill, Coyle, Fink, Lesmes, & Witzman, 1979; Jansson & Kaijser, 1977; Nygaard, 1976).

Animal studies have shown muscle fiber splitting due to weight training. Gonyea, Erickson, and Bonde-Peterson (1977) produced fiber splitting in cat flexor carpi radialis muscles while Ho, Roy, Taylor, Heusner, Von Huss, and Carrow (1977) produced similar results in the adductor longus muscle of the rat. In Gonyea's (1980) study he
reported high resistance training in cats increased numbers of Type IIA and Type IIB fibers by 11% and Type I fibers by 9%. Low resistance training did not induce fiber splitting. No muscle fiber division has been demonstrated in human muscle.

The manner in which muscle fiber types specifically affect athletic performance is still unknown. Researchers have not determined if training changes muscle types or if a person's predisposed fiber type directs a person into a certain mode of sport.

There have been numerous studies which attempted to relate fiber types and performances in various sports. Table 2 is a summary of several studies that investigated different groups of athletes and muscle fiber types. Athletes involved in endurance events usually have a higher percentage of Type I fibers while athletes involved in speed or strength events have low or average Type I fiber percent. Max VO₂ levels for different athletic groups were similar except for elite distance runners, who were significantly higher. Untrained groups were significantly lower than all athletic groups. Costill et al. (1976b) found a correlation coefficient of -.62 between Type I fiber percentage and best six mile performance. Costill et al. (1976a) found a correlation coefficient of .13 between Type I fibers and max VO₂. Bergh, Thorstensson, Sjodin, Hulten, Piehl, and Karlsson (1978) found this relationship to be $r = .72$ ($p < .01$) for endurance and
strength athletes and \( r = .34 \) (\( p < .05 \)) for nonathletes, while Burke et al (1977) found it to be \( r = .29 \) for both competitive cyclists and nonathletes. Coyles, Bell, Costill, and Fink (1977) found a poor relationship between Type II fiber area percentage and best shot put performance for world class shot putters (\( r = .23 \)).

Table 2

<table>
<thead>
<tr>
<th>Activity</th>
<th>Mean % Type I Fibers</th>
<th>VO(_2) Max (ml/kg/min)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance runners</td>
<td>61.4</td>
<td>56.8</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Distance runners</td>
<td>62.0</td>
<td>80.0</td>
<td>Bergh, 1978</td>
</tr>
<tr>
<td>Distance runners</td>
<td>69.4</td>
<td>71.2</td>
<td>Costill, 1976a</td>
</tr>
<tr>
<td>Elite dist. runners</td>
<td>79.0</td>
<td>77.4</td>
<td>Costill, 1976b</td>
</tr>
<tr>
<td>Elite weight trained</td>
<td>50.2</td>
<td>56.0</td>
<td>Bergh, 1978</td>
</tr>
<tr>
<td>Elite weight trained</td>
<td>46.0</td>
<td>33.5</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Elite body builders</td>
<td></td>
<td>46.3</td>
<td>Pipes, 1979</td>
</tr>
<tr>
<td>Orienteers</td>
<td>68.8</td>
<td>50.7</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Orienteers</td>
<td>67.0</td>
<td></td>
<td>Thorstensson, 1977</td>
</tr>
<tr>
<td>Sprinters</td>
<td>24.0</td>
<td></td>
<td>Costill, 1976a</td>
</tr>
<tr>
<td>Sprinters</td>
<td>39.0</td>
<td></td>
<td>Thorstensson, 1977</td>
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<td>Sprinters</td>
<td>45.0</td>
<td>55.0</td>
<td>Bergh, 1978</td>
</tr>
<tr>
<td>Cyclist</td>
<td>61.4</td>
<td>68.2</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Cyclist</td>
<td>56.8</td>
<td>67.1</td>
<td>Burke, 1977</td>
</tr>
<tr>
<td>Swimmers</td>
<td>74.3</td>
<td>79.9</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Untrained</td>
<td>36.1</td>
<td>42.9</td>
<td>Gollnick, 1972</td>
</tr>
<tr>
<td>Untrained</td>
<td>56.0</td>
<td></td>
<td>Thorstensson, 1977</td>
</tr>
<tr>
<td>Untrained</td>
<td>52.6</td>
<td>34.4</td>
<td>Costill, 1976a</td>
</tr>
</tbody>
</table>

Enzyme Activity in Skeletal Muscles

Mitochondrion in each cell converts foodstuffs to energy and requires enzyme support for this conversion process (deVries, 1980). Succinate dehydrogenase (SDH) is an enzyme used in aerobic production of energy which reflects total mitochondrial protein. Its activity level
in muscle cells has been found to correlate with max VO2 in highly trained endurance runners (r = .79) (Costill et al., 1976b), and in competitive cyclist (r = .75) (Burke et al., 1977). SDH activity has also been shown to increase with endurance training anywhere between 20% to 350% over untrained controls (Burke, et al., 1977; Costill et al., 1976a; Costill et al, 1976b; Evans, 1979; Gollnick, Sjodin, Karlsson, Jansson, & Saltin, 1974; Henricksson & Reitman, 1976; Henriksson & Reitman, 1977; Vihko, Sarviharju, Havu, Hirsimaki, Salmimen, Rahkila, & Arstila, 1975).

Other muscle enzyme activity levels of lactate dehydrogenase (LDH), phosphofructokinase (PFK), creatine phosphokinase (CP), and myokinase have also been studied. Muscle LDH activity has been correlated (r = .74, p < .001) to Type II fiber distribution (Tesch et al., 1978). In Costill's 1976b study, LDH activity was similar for distance runners and non-runners. In studies by Gollnick et al. (1973a) and Ericksson, Gollnick, and Saltin (1973), PFK levels increased 117% (p < .01) and 83% respectively after endurance running regimes.

Increases in activities of myokinase (20%) and CP (36%) after eight weeks of sprint type strength training were observed (Thorstensson et al., 1975). An eight-week session of progressive strength training did not produce any changes in CP or PFK (Thorstensson et al., 1976). Costill et al. (1979) demonstrated that seven weeks of 30-second isokinetic strength training significantly
increased levels of SDH, PKF, CP, and myokinase. Eriksson et al. (1973) reported increased CP levels in 11-13 year old boys after four months of training, and Karlsson, Diamont, and Saltin (1971) found lower resting concentrations of CP in a group of endurance trained students than in a group of untrained military personnel.

Muscle Glycogen Production and Utilization

Glycogen is a major energy source for exercising muscle which is metabolized during exercise and is stored in muscle cells when not being utilized (Hultman, 1967). Many studies have shown these stores of glycogen can be increased as much as 250% above pretrained levels with endurance training (Bergstrom, Hermansen, Hultman, & Saltin, 1967; Ericksson et al., 1973; Gollnick, Armstrong, Saubert IV, Sembrowich, Shepherd, & Saltin, 1973b; Gollnick, Armstrong, Sembrowich, Shepherd, & Saltin, 1973c; Gollnick, Piehl, Saubert IV, Armstrong, & Saltin, 1972b; Morgan, Cobb, Short, Ross, & Gunn, 1971; Viho et al., 1975). MacDougall, Ward, Sale, and Sutton (1977) reported that heavy resistance strength training increased glycogen stores by 66%.

The rate of muscle glycogen utilization seems to vary according to an individual's level of training. In studies by Evans (1979) and Gollnick et al. (1973c) it appears that trained athletes use approximately one-third less of their available glycogen stores than untrained individuals.
In 1965 Henneman and Olson developed the selective recruitment theory, which states that motor units are composed of the same fiber types and are innervated by motor neurons with different thresholds for each fiber type. Recent research shows this to be an important concept since rates of glycogen utilization in human skeletal muscle varies with mode and intensity of work. It appears that glycogen utilization variability is due to different recruitment patterns of muscle fiber types. Essen and Kaijser (1976) and Gollnick et al. (1972b) reported with high intensity work Type II fibers lost glycogen first. Costill, Gollnick, Jansson, Saltin, and Stein (1973) and Gollnick, Piehl, and Saltin (1974) found primary reliance upon Type I fibers during low intensity work, with Type II fibers being recruited after Type I fibers were depleted of their glycogen stores. During exercise requiring energy expenditures greater than maximal aerobic power, both fiber types appear to be utilized continuously (Gollnick et al., 1974). Secher and Nygaard-Jensen (1976) further refined this hypothesis when they found Type IIB fibers are recruited extensively during maximal work and glycogen is depleted from them first.

It has been postulated that if low muscle cell glycogen content is responsible for fatigue at the end of a distance run then muscle fibers should be totally depleted of glycogen. However, studies by Costill, Sparks, Gregor, and Turner (1971); Costill, Bowers, Branam, and
Sparks (1971); and Karlsson et al. (1971), found only a small reduction in glycogen from Type II fibers while distance runners experienced severe fatigue at the end of long runs.

**Muscle Mitochondria Activity**

Since mitochondria are energy conversion centers in muscle cells, it is believed that with an increased mitochondria volume and density there would be an increased oxidative capacity of the cell. Research has confirmed that assumption. In studies by Hoppler, Luthi, Clausen, Weibel, and Howard (1973), and Kiessling, Pilstrom, Bylund, Saltin, and Piehl (1974), mitochondria density correlated significantly with max VO$_2$ ($r = .86$ and $r = .92$). Vihko et al. (1975) found a .82 correlation between mitochondria volume in Type I fibers and max VO$_2$ in well trained biathletes (cross country skiing and rifle shooting) and controls. Bell (1980) found a .72 correlation between mitochondria volume density and distribution of Type I fibers in six-year-old children.

MacDougall et al. (1979) concluded that six months of intensive conventional heavy resistance training resulted in the reduction of the mitochondria volume density by 26% and mitochondria volume to myofibrillar volume ratio by 25%. Buchtal and Schmalbruch (1970) reported that muscle contraction times lasting longer than 60 milliseconds corresponded with the proportion of fibers rich in mitochondria.
Muscle Capillary Density

The capillary bed in skeletal muscle provides the final pathway for delivery of oxygen, nutrients, and hormones along with providing means for removing heat and metabolic by-products.

There is still disagreement on effects of training on capillarization. Much of this controversy is due to variable laboratory methods for measuring muscle cell capillary concentrations. Several studies show favorable effects of endurance training on capillarization of skeletal muscle cells. Brodel, Inger, and Hermansen (1977) found the number of capillaries per muscle as well as the capillaries per square millimeter of muscle averaged 40% greater in endurance athletes than in untrained counterparts. This was almost identical to the 41% difference in max VO₂ between groups. Other studies with separate untrained and endurance-trained groups have also shown that higher max VO₂ corresponds with an increased capillary density (Anderson, 1975; Hermansen & Wachtlova, 1971; Ingjer & Brodal, 1978; Saltin, Henriksson, Nygaard, & Anderson, 1977). Other studies show no change in size or number of capillaries after endurance training (Maxwell, White, & Faulkner, 1980; Saltin, Blomovist, Mitchell, Johnson, Wildenthal, & Chapman, 1968).

Most research indicates endurance athletes usually have a higher percentage of Type I muscle fibers (see Table 2). Anderson (1975), Anderson and Henricksson
(1977b), and Ingjer (1978) showed there was a higher capillary supply around the Type I fiber than around the Type II fibers.

**Muscle Hypertrophy**

Morpurgo (1887) is credited with being the first to demonstrate muscle fibers respond to exercise by fiber enlargement without an increase in fiber number. More recent studies have revealed muscle hypertrophy seems to be caused by an increase in both number and size of enclosed myofibrills and is therefore largely the result of an increase in contractile protein (MacDougall et al., 1976).

In 1973 Saltin suggested that endurance or strength training may result in selective hypertrophy of Type I or Type II fibers respectively. This has been demonstrated in several studies. Burke et al. (1977) found the area of both Type II and Type I fibers of competitive cyclist to be significantly larger than in controls, with Type I fiber area being significantly larger than Type II fiber area. Costill et al. (1976a) found that track athletes, on the whole, have significantly \( p < .05 \) larger Type II fibers than Type I fibers with sprinters and distance runners having 73.2% and 37.5% area of Type II fibers in the gastrocnemius muscle. In another study by Costill et al. (1976b), it was found that both fiber types were larger in distance runners than in controls and elite distance runners had Type I fibers 29% larger than Type II fibers while comprising 82.9% of the muscle mass. The muscle fibers of
world class shot putters were 35% larger than those of untrained men (Coyle et al., 1977). Thorstensson, Larsson, Tesch, and Karlsson (1977) also found that sprinters had 50% (p < .05) larger Type II fibers than Type I fibers; also their Type II fibers were significantly larger than sedentary controls.

In the early studies on muscle hypertrophy it was reported that repeated testing of strength of skeletal muscles results in an increase in test scores in the absence of measurable hypertrophy (Bowers, 1966; Coleman, 1969; DeVries, 1968; Hellebrandt, Parrish, & Houtz, 1947). Delorme and Watkins (1948) postulated these strength increases were due in part to motor learning and partly to muscle growth or hypertrophy. Moritani and DeVries (1979) have shown that in young individuals neural factors account for the greatest part of strength gains in the first three or four weeks, after which hypertrophy accounts for virtually all of the strength gain.

It has also been shown that when only one limb is trained, the paired untrained limb improves significantly in subsequent retest of strength but without evidence of hypertrophy (Coleman, 1969; Hellebrandt et al., 1947; Moritani & DeVries, 1979).

Lactic Acid Production

A byproduct of energy metabolism in skeletal muscle is lactate (DeVries, 1980). Plasma lactate concentrations are the result of: (1) rate of formation of lactate in working
muscles; (2) rate of cellular utilization and excretion of lactate; and (3) diffusion of lactate from muscle to blood (Jorfeldt, 1971; Poortmans, Bossche, & Leclercq, 1978; Strom, 1949).

It has been suggested that lactate accumulation may cause muscle fatigue (Simonsson, 1971). This lactic acid accumulation causes acidosis by shifting the acid-base balance (Osnes & Hermansen, 1972; Sahlin, Harris, Nylind, & Hultman, 1976). In prolonged exercise excess lactic acid is oxidized and acidosis does not occur (Astrand, Hallback, Hedman, & Saltin, 1963; Costill, 1970; Costill & Fox, 1969; Karlsson, 1971; Karlsson, Diamont, and Saltin, 1968). If acidosis does occur it has been demonstrated that there is an inhibition of fat utilization, which would produce a greater reliance on carbohydrate metabolism (Boyd, Giambo, Mager, & Lebowitz, 1974; Hultman, 1967).

Another common finding is that individuals can exercise up to a critical intensity with little or no accumulation of lactate in plasma (Margaria, Edwards, & Dill, 1933; Nagle, Robinhold, Howley, Daniels, Baptista, & Stoedefalke, 1970; Wasserman, Whip, Koyle, & Beaver, 1973; Davis, Vodak, Wilmore, Vodak, & Kurtz, 1976). However, when this critical intensity is surpassed, lactate begins to accumulate exponentially (Hermansen & Stenvold, 1972; Saltin & Karlsson, 1971). Runners appear to set a race pace which allows for utilization of the largest possible VO\textsubscript{2} which just avoids the exponential rise in plasma

Physically trained individuals have lower blood lactate concentrations than untrained individuals at the same absolute and relative work rates during submaximal exercise (Ekbolm, Astrand, Saltin, Stenberg, & Wallström, 1968; MacDougall, 1977; Saltin, Hartley, Kilbom, & Astrand, 1969). Experienced runners can utilize approximately 70% of their max VO₂ before lactate begins to accumulate in the plasma (Costill, 1970; Costill, Thomason, & Robert, 1973).

Lactic acid is preferentially produced by Type II fibers (Essen & Haggmark, 1975; Tesch et al., 1978). Tesch et al. (1978) found a correlation of .91 (p < .001) between lactate content of Type II fibers and percentage of Type II fibers in muscle cells.

Donovan and Brooks (1982) recently found adaptations from endurance training is not upon production of lactate, but upon its clearance from the blood. Endurance training adaptations remove lactate from blood faster than in untrained controls. Metabolic clearance of lactate in endurance trained animals was 37% and 107% greater than in controls during easy exercise and hard exercise respectively.
CHAPTER III

RESEARCH METHOD AND DESIGN

The purpose of this investigation was to compare and analyze physiological parameters of running performance on a treadmill between two groups of highly trained members of the California State University, Northridge cross country team. The experimental group added high resistance weight training to their normal training regimen. The control group followed a normal training routine which excluded any overload weight training.

Included in this chapter are selection and grouping of subjects, instrumentation, strength training procedures, description of experimental techniques, and methods of statistical analysis.

Overview of Experimental Design

Physiological data were collected in the Exercise Physiology Laboratory, California State University, Northridge. Strength assessment was conducted at the outdoor weight training facility adjacent to the track and field facility.

Physiological changes were observed during an eight-week period of the 1981 fall cross country season. Experimental and control groups of highly trained distance runners participated in identical running training sessions.
with one group concurrently participating in a monitored, high resistance weight training program. Five to ten minutes of uphill treadmill running was administered for each subject with strength and body composition measurements taken at the commencement and conclusion of an eight-week period.

Parameters used for analyses of group differences included: $\text{VO}_2\text{max} \, \text{l/min}; \text{VO}_2\text{max} \, \text{ml/kg/min}; \text{VO}_2\text{max} \, \text{ml/kg FFM/min};$ running time of the treadmill, fat free mass; percentage of body fat and strength levels for designated weight lifting protocols.

Statistical procedures employed in this investigation were: (1) analysis of covariance to determine pre and post season differences of each group and differences between groups on post season testing results; (2) Tukey's Honestly Significant Differences to determine levels of significance. These procedures were performed on data of strength levels, body composition, and selected physiological parameters. The .1 level was established as the level of statistical significance.

Selection and Grouping of Subjects

Subjects who volunteered to participate in this study were 12 members of the California State University, Northridge 1981 men's varsity cross country team. Four of the subjects were unable to complete the study due to illness or injury. Subjects completing the study were considered to be highly trained distance runners.
All subjects abstained from lifting weights and did not engage in any outside activities that required lifting heavy loads for twelve weeks prior to commencement of testing.

Subjects were randomly divided into two groups, control and experimental, through a process of assigning each subject a number, mixing these numbers in a container, then drawing them one at a time. First number drawn was placed in control group, second one drawn being placed in experimental group. This alternating placement of subjects was done until all subjects were assigned to one of the two groups.

Group I: Controls (N = 4). Subjects completed their normal cross country training program. They were instructed not to participate in any weight training or other activities that involved neuromuscular overload.

Group II: Experimental (N = 4). Subjects participated in their normal cross country training program. They concurrently participated in a monitored heavy resistance weight training program two sessions per week. This program consisted of weight training with free weights and the Universal Machine Gym facility. Subjects trained with eight different lifts: bench press, leg press, bicep curls, hamstring curls, pull downs, leg extensions, military press, and upright rowing.
**Instrumentation**

The following laboratory instrumentation was used for determination of maximal aerobic capacity:

Quinton motor-driven treadmill model #24-72
Collins triple "J" one-way breathing valve and mouthpiece
Hewlett-Packard silver-silver chloride floating electrodes
Hewlett-Packard 150B electrocardiograph
Hewlett-Packard 7803A oscilloscope monitor
Creme Redux conduction electrode gel
Parkinson-Coewn CD4 gasometer and mixing chamber
Huntsman suspension helmet for valve and mouthpiece
Scientific Products S/P Interfit 50cc oiled glass syringes
Instrumentation Laboratory Micro 13 pH/Blood Gas Analyzer.

The following laboratory instrumentation was used for body composition assessment:

Densitometric tank designed by Dr. George Q. Rich III, at California State University, Northridge
Chattillion 15 kg spring-loaded scale
Collins 6-liter water spirometer
Sponge rubber noseclip
Detecto medical balance scale for measuring body weight.
The following instruments were used for strength assessment:

Universal Gym multi-station weight training machine model #24-72
York barbells, 30 pounds through 140 pounds.

Strength Training Procedures

Weight training was conducted with free weights and a Universal Gym facility during two sessions per week. Each session consisted of lifting three sets of weights. A set consisted of lifting weight at each of the prescribed stations. These lifts were: bench press, leg press, bicep curls, hamstring curls, pull downs, leg extensions, military press, and upright rowing.

Subjects initial weight lifted was determined by using 75% of 1RM. Subjects were instructed to lift the prescribed weight at each station until exhaustion. If the number of repetitions was over ten for all three sets, subject used a weight one increment heavier the next session.

Performance was recorded in a training log for each weight training session.

Experimental Techniques

This investigation was designed to measure changes in strength levels, body composition (body density, percent body fat, fat-free mass) and maximal oxygen uptake of highly trained cross country runners. Testing was conducted at the commencement and conclusion of the 1981 collegiate cross country season for both groups of runners.
Hydrostatic Weighing

Measurement of body density was conducted for determination of fat-free mass and percent body fat. Prior to hydrostatic weighing, measurements of body weight and vital capacity were completed.

To facilitate measurement of vital capacity subjects were instructed to stretch the upper body with flexibility drills and deep breathing. A nose clip was utilized to prevent air leakage. After a maximal inhalation, a maximal exhalation was performed into a 6-liter water spirometer. During maximal exhalation subjects flexed forward at the waist to encourage maximum expulsion. This procedure was repeated three times and an average of the trials determined. To calculate residual volume, average vital capacity was converted to BTPS using the conversion factor for spirometer water temperature. Vital capacity BTPS was multiplied by .24 to obtain residual volume (Wilmore, 1969).

Subjects were then seated on a swing in the hydrostatic tank with legs crossed, hands gripping swing at the hips, head just above the water. After four or five hyperventilations, subject maximally exhaled with mouth open then moved their head underwater slowly, by bending forward. After completely expelling air all subjects sat motionless for several seconds while the underwater weight was read from a scale. This procedure was repeated five times and an average calculated from the last three trials.
Calculation of body density and body fat were based upon the equations given by Brozek, Grande, Anderson, and Keyes (1963).

\[ Db = \frac{Ma}{Ma-Mw} - \frac{(RV + VGI)}{Dw} \]

\[ \text{Fat} \% = \frac{4.570}{Db} - 4.142 \times 100 \]

In the preceding formulas:

- \( Db \) = density of body
- \( Ma \) = mass in air (kg)
- \( Mw \) = mass in water (kg)
- \( Dw \) = density in water
- \( RV \) = residual lung volume
- \( VGI \) = volume of gas in intestinal tract (.115)

Strength Testing Procedures

Each subject was tested for one repetition maximum weight lifting capacity at eight different stations. A safe and reasonable beginning resistance for each subject was determined by subjective interview and evaluation.

Each subject then proceeded by trial and error to determine whether the beginning resistance at the eight stations was truly a maximum effort. If the subject succeeded in lifting the beginning weight he would then increase resistance by one weight increment, until the lift could not be completed through the full range of motion. If the subject could not lift the initial weight through the full range of motion he would decrease the resistance by an increment until the lift could be conducted properly. Each subject followed this procedure for each of eight lifts.
To minimize fatigue a rotation procedure was followed where each subject completed their initial effort then rested while the other subjects lifted their initial attempt. If a second, third, fourth, etc. lift were needed the same rotation was followed for each round until all subjects had reached their max for that lifting exercise. Only one trial was permitted at a given weight for each subject on each exercise.

To minimize local muscle fatigue during testing a prescribed order of lifts was followed: bench press, leg press, bicep curls, hamstring curls, pull downs, leg extension, military press, and upright rowing.

Strength Testing Protocols

**Bench Press.** Subjects assumed the back lying position on a bench, feet on floor, lifting-bar handles in line with top of armpit, hands placed on lifting-bar handles so angle formed by lower and upper arm at elbow was approximately 90 degrees. Criteria for a successful lift were: (1) elbows had to lock in an extended position; (2) back had to remain on the bench; (3) lift had to be one continuous motion.

**Leg Press.** Subjects were positioned on the seat of the leg press machine with hands gripping handles next to hips and balls of feet on foot plates. Seat was adjusted forward or backward so angle formed by lower and upper legs was approximately 90 degrees. Criteria for a successful lift were: (1) knees had to lock in straight
position; (2) buttocks could not move from seat; (3) lift had to be one continuous motion.

**Bicep Curl.** Subjects stood with back, buttocks and heels against vertical wall, arms were extended, hanging at sides, shoulder width apart with hands facing out at hips. Weighted barbell was placed in the subject's hands. Criteria for a successful lift were: (1) weight had to be curled in an arc up to chest with arms bending at elbows; (2) back had to be kept flat against wall; (3) arms could not touch sides of body; (4) lift had to be one continuous motion.

**Hamstring curl.** Subjects assumed prone position on bench with hands gripping sides of bench next to head and legs were hooked under lifting roller just above heel on lower leg. Criteria for a successful lift were: (1) lifting roller was pulled in an arc so it touched buttocks; (2) pelvis and stomach had to remain on the bench; (3) lift had to be one continuous motion.

**Pull-down.** Subjects assumed seated position on floor with legs straight in front, arms straight in a V-position above head with hands gripping handles on pull-down bar. Criteria for a successful lift were: (1) body had to be in stationary position at beginning of lift; (2) weight had to be pulled down so bar touched middle of posterior neck; (3) buttocks had to remain on the floor; (4) lift had to be one continuous motion.
**Leg Extension.** Subjects assumed seated position on bench with back in vertical position, hands gripping sides of bench at hips, and legs hooked behind lifting roller on front of leg just above ankle. Criteria for successful lift were: (1) subject's back remained in vertical position; (2) legs were straight with knees locked; (3) hamstring area of leg raised slightly off bench; (4) buttocks remained on bench; (5) lift was one continuous motion.

**Military Press.** Subjects assumed seated position on stool so front of shoulder was in vertical alignment with back of lifting handles; hands were placed on lifting handles so lower and upper arms formed approximately a 90 degree angle at elbow. Criteria for successful lift were: (1) arms were straight with elbows locked; (2) back remained straight; (3) lift was one continuous motion.

**Upright Rowing.** Subjects assumed standing position with back, buttocks and heels of feet against vertical wall, arms were straight with hands next to each other resting on front of thighs with knuckles pointing out. Weighted barbell was placed in subject's hands. Criteria for successful lift were: (1) subject had to pull weight vertically so knuckles of thumbs touched bottom of chin; (2) back and buttocks could not move away from wall; (3) lift had to be one continuous motion.

**Treadmill Test**

Treadmill work bout was performed until exhaustion, in order to obtain max VO₂. Subjects were required to run
until they could no longer accommodate an increased work-load. They were instructed to indicate by raising the preferred index when they perceived their inability to continue work for no longer than one minute. During the test subjects were verbally encouraged by laboratory technicians throughout the work bout to maximize effort.

Gas samples (50cc in volume) were collected in oiled glass syringes from an expired gas mixing chamber every minute after the third minute of work bout. Heart rate was monitored with Hewlett-Packard 150B electrocardiograph during the last ten seconds of each minute and the EKG tracing continuously observed with a Hewlett-Packard oscilloscope. Minute ventilation was recorded during all phases of warmup and work with gas temperatures recorded from a thermometer located in intake hose of the gasometer. Subjects performed 5-10 minutes of static stretching immediately before the treadmill test. Treadmill test protocol was adapted from Astrand (1977). Speed and grade increases are indicated in Table 3.

**Analysis of Gas**

Gas samples collected in 50cc oiled glass syringes during all work periods were analyzed for oxygen and carbon dioxide volumes with an Instrumentation Laboratory Micro 13 pH/Blood Gas Analyzer. True percent oxygen and carbon dioxide production were then calculated. Oxygen uptake and carbon dioxide production were determined at STPD. VO₂ max was expressed as liters per minute, milliliters
Table 3
Graded Treadmill Protocol

<table>
<thead>
<tr>
<th>Minute</th>
<th>Speed (mph)</th>
<th>Incline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td>11</td>
<td>9.3</td>
<td>5.25</td>
</tr>
<tr>
<td>12</td>
<td>9.3</td>
<td>5.25</td>
</tr>
<tr>
<td>13</td>
<td>9.3</td>
<td>5.25</td>
</tr>
<tr>
<td>14</td>
<td>9.3</td>
<td>7.9</td>
</tr>
<tr>
<td>15</td>
<td>9.3</td>
<td>7.9</td>
</tr>
<tr>
<td>16</td>
<td>9.3</td>
<td>7.9</td>
</tr>
<tr>
<td>17</td>
<td>9.3</td>
<td>10.6</td>
</tr>
<tr>
<td>18</td>
<td>9.3</td>
<td>10.6</td>
</tr>
<tr>
<td>19</td>
<td>9.3</td>
<td>10.6</td>
</tr>
<tr>
<td>20</td>
<td>9.3</td>
<td>13.25</td>
</tr>
</tbody>
</table>

per kilogram of body weight and milliliters per kilogram of fat-free mass.

Statistical Analysis

Analysis of covariance was employed to determine differences between pre and post season results for each group and post season results between each control and experimental group. These tests were performed for the following parameters: percent fat, fat-free mass, VO$_2$ max l/min, VO$_2$ max ml/min/kg, VO$_2$ max in ml/min/kg of FFM, 1-RM strength levels for each exercise, and running time on the treadmill.
Tukey's Honestly Significant Differences test was performed on the results of the analysis of covariance to determine significant differences.

The null hypotheses were tested at the .10 level of significance.
CHAPTER IV

Analysis of Data

The purpose of this study was to investigate the effects of an eight-week heavy resistance weight training program on body composition, strength, maximum oxygen uptake, and treadmill running time in highly trained distance runners.

With the small number of subjects in each group, large differences were seen in pre season mean scores for all tests. To compensate for these differences, analysis of covariance was performed on all data to adjust control and experimental pre season means to a common point. A more accurate analysis of post season scores could then be performed. Tukey's Honestly Significant Difference test was performed to determine levels of significance.

Description of Subjects

Twelve male subjects participated in the investigation with four unable to finish due to illness or injury. Subjects were randomly divided into two groups: control, who participated only in a running program; and experimental, who participated in a weight training program and running program.

The subjects' physical characteristics are shown in Table 4. T-tests indicated no significant differences
between the control and experimental groups in age, body weight, height, max \( \text{VO}_2 \) and percent body fat.

**Table 4**

Pre Season Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Controls (N = 4)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>21</td>
<td>1.414</td>
<td>19 - 22</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>62.75</td>
<td>7.590</td>
<td>54.7 - 70.0</td>
</tr>
<tr>
<td>Height, cm</td>
<td>175.9</td>
<td>4.314</td>
<td>170.2 - 180.3</td>
</tr>
<tr>
<td>Max ( \text{VO}_2 ), ml/kg/min</td>
<td>73.6</td>
<td>5.401</td>
<td>68.6 - 82.9</td>
</tr>
<tr>
<td>Percent fat</td>
<td>7.0</td>
<td>2.176</td>
<td>4.6 - 9.3</td>
</tr>
<tr>
<td><strong>Experimental (N = 4)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>21</td>
<td>0.816</td>
<td>20 - 22</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>65.78</td>
<td>5.880</td>
<td>58.0 - 71.7</td>
</tr>
<tr>
<td>Height, cm</td>
<td>179.7</td>
<td>3.179</td>
<td>175.3 - 182.9</td>
</tr>
<tr>
<td>Max ( \text{VO}_2 ), ml/kg/min</td>
<td>73.2</td>
<td>5.424</td>
<td>68.6 - 72.5</td>
</tr>
<tr>
<td>Percent fat</td>
<td>8.3</td>
<td>2.128</td>
<td>5.4 - 10.5</td>
</tr>
<tr>
<td><strong>Overall (N = 8)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>21</td>
<td>1.115</td>
<td>19 - 22</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>64.26</td>
<td>6.190</td>
<td>54.7 - 71.7</td>
</tr>
<tr>
<td>Height, cm</td>
<td>177.8</td>
<td>4.054</td>
<td>170.2 - 182.9</td>
</tr>
<tr>
<td>Max ( \text{VO}_2 ), ml/kg/min</td>
<td>73.4</td>
<td>5.468</td>
<td>68.8 - 82.9</td>
</tr>
<tr>
<td>Percent fat</td>
<td>7.7</td>
<td>2.106</td>
<td>4.6 - 10.5</td>
</tr>
</tbody>
</table>

Participation requirements were: 1) being a highly trained distance runner; 2) being a member of the California State University, Northridge men's cross country team; 3) having abstained from any weight training for 12 weeks prior to commencement of testing.

**Body Composition Data**

Subjects were tested pre and post season for body mass, percent fat, and fat-free mass. Body composition
data is reported in Appendix B. Means for both groups on all three parameters examined are shown in Table 5.

Table 5

<table>
<thead>
<tr>
<th></th>
<th>Pre Season</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mass (kg)</td>
<td>% Fat</td>
<td>FFM (kg)</td>
</tr>
<tr>
<td><strong>Experimental</strong></td>
<td>65.8</td>
<td>8.3</td>
<td>60.2</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>62.8</td>
<td>7.0</td>
<td>58.4</td>
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<table>
<thead>
<tr>
<th></th>
<th>Post Season</th>
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<tbody>
<tr>
<td></td>
<td>Mass (kg)</td>
<td>% Fat</td>
<td>FFM (kg)</td>
</tr>
<tr>
<td><strong>Experimental</strong></td>
<td>68.3</td>
<td>6.75</td>
<td>63.7</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>63.1</td>
<td>5.9</td>
<td>59.3</td>
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<table>
<thead>
<tr>
<th></th>
<th>Change</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mass (kg)</td>
<td>% Fat</td>
<td>FFM (kg)</td>
</tr>
<tr>
<td><strong>Experimental</strong></td>
<td>+2.3</td>
<td>-1.6</td>
<td>+3.5</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>+1.2</td>
<td>-1.2</td>
<td>+0.9</td>
</tr>
</tbody>
</table>

Significant differences were found in the experimental group's results pre and post season body mass (p < .10) and fat-free mass (p < .01). No significant differences were found for any of the variables in the control group's scores or for the experimental group's percent fat pre and post season results.

Significant differences were found in body mass (p < .10) and fat-free mass (p < .05) when post season scores of the two groups were compared (see Figures 1 and 2). No significant difference was found in percent fat for the post season scores of the two groups.
Figure 1. Analysis of covariance of pre and post season body mass means
Figure 2. Analysis of covariance of pre and post season fat-free mass means
Treadmill Running Time Data

Subjects were tested pre and post season for treadmill running time. The experimental group's mean time was 7.75 minutes pre season and 8.5 minutes post season, with a +.75 minute mean change between pre and post season. The control group's mean time on the pre season test was 8.25 and 8.75 on the post season test, with a mean change of +.50 minutes.

No significant differences were found in either group when pre and post season results were analyzed and when post season scores were compared.

Maximum Oxygen Uptake Data

Subjects were tested pre and post season for maximum oxygen uptake in l/min, ml/min/kg, and ml/min/kg of FFM. Raw data for maximum oxygen uptake can be found in Appendix B. Means for both groups for all three parameters examined are reported in Table 6.

Analysis of covariance for all three variables on pre and post season results found no significant differences for both control and experimental groups. No significant differences were found between control and experimental groups on post season maximum VO₂ uptake in l/min, ml/min/kg, ml/min/kg of FFM (see Figure 3).

Strength Training Data

Subjects' strength levels for 1-RM were tested both pre and post season. Specific weight lifting exercises which subjects were tested on included: bench press, leg
Table 6
Maximum Oxygen Uptake Means

<table>
<thead>
<tr>
<th></th>
<th>Pre Season</th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>l/min</td>
<td>ml/min/kg</td>
<td>ml/min/kg</td>
<td>FFM</td>
</tr>
<tr>
<td>Experimental</td>
<td>4.8</td>
<td>73.2</td>
<td>79.8</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>4.6</td>
<td>73.6</td>
<td>79.2</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Post Season</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>l/min</td>
<td>ml/min/kg</td>
<td>ml/min/kg</td>
<td>FFM</td>
</tr>
<tr>
<td>Experimental</td>
<td>4.9</td>
<td>72.5</td>
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<tr>
<td>Control</td>
<td>4.7</td>
<td>75.2</td>
<td>77.4</td>
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<tr>
<td></td>
<td>l/min</td>
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press, bicep curls, hamstring curls, pull downs, leg extensions, military press, and upright rowing.

When combining the results of all eight exercises, the control group decreased in mean weight lifted from pre and post season by .03 pounds, while the experimental group increased by 23.09 pounds. Table 7 shows the experimental and control means and the differences pre and post season for each weight lifting exercise. Strength testing raw data is reported in Appendix B.

Significant differences were found in the experimental group's pre and post season results for all eight weight lifting exercises. The .01 level of significance was achieved for upright rowing, pull downs, bench press, hamstring curls, military press, and leg extensions while...
Figure 3. Analysis of covariance of pre and post season max VO₂ means
Table 7
Strength Testing Means

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<th>Leg Press</th>
<th>Leg Extension</th>
<th>Hamstring Curls</th>
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<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Experimental mean</td>
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<td>131.25</td>
<td>232.50</td>
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<td>102.50</td>
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<tr>
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<td></td>
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<td>Post</td>
<td>Pre</td>
<td>Post</td>
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<tr>
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<td>118.75</td>
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<td>140.00</td>
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</tr>
<tr>
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<td></td>
<td>+22.50</td>
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</tr>
<tr>
<td>Control pre-post mean difference</td>
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<td>+ 1.25</td>
<td>- 2.50</td>
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the .05 level was achieved for leg press and bicep curls. There were no significant differences found in the control group's pre and post season results for any of the weight lifting exercises.

Significant differences were found between the control and experimental group's post season scores for each of the eight weight lifting exercises. The .01 level of significance was achieved in all exercises except the leg press, which was significant at the .05 level.
CHAPTER V

Summary and Conclusions

The purpose of this investigation was to compare and analyze physiological parameters and treadmill running time for two groups of well trained members of the California State University, Northridge cross country team. One group, referred to as experimental, used a high resistance weight training program in conjunction with their usual training regimen. The control group followed the same training routine, however, did not include weight training. The results of this study as shown in Chapter IV indicate findings which follow:

Summary of Major Findings

1. Subjects in this study were comparable to elite distance runners in other investigations in body weight, percent fat, and max VO₂.

2. The experimental group showed a significant (p < .10) increase in body mass while the control group showed a nonsignificant increase in pre and post season weight.

3. Significant differences (p < .10) in body mass were observed between the experimental and control groups when post season mass was compared.
4. The experimental group showed a significant (p < .01) increase in fat-free mass while the control group showed a nonsignificant increase between pre and post season scores.

5. Significant differences (p < .05) in fat free mass were observed between the experimental and control groups when post season scores were compared.

6. Nonsignificant decreases in percent fat were found for both groups between pre and post season data. No significant differences were observed between the two groups on post season percent fat results.

7. No significant differences were found in either of the two groups for treadmill running time when pre and post season results were analyzed and when post season scores of the two groups were compared.

8. There was no significant change for the two groups from pre and post in max VO₂ l/min, max VO₂ ml/min/kg, max VO₂ ml/min/kg FFM. No significant differences were seen between the two groups when comparing the post season data.

9. The experimental group showed significant (p < .01) increases in pre and post season 1-RM scores for the different weight lifting exercises of bench press, pull downs, hamstring curls, military press, leg extensions, and upright rowing. Results for the bicep curls and leg press were significant at the .05 level.
10. No significant differences were found in the control group's strength levels from pre and post season results for all eight weight training exercises.

11. Significant differences were found between the control and experimental group's post season scores for each of the eight weight lifting exercises. The .01 level of significance was achieved in all exercises except the leg press, which was significant at the .05 level.

Conclusions

The purpose of this investigation was to investigate the effects of a heavy overload weight training program in highly trained distance runners. Although weight training has been utilized by numerous athletic populations to enhance performance, the findings of this study did not show beneficial effects on endurance running for highly trained distance runners.

Subjects in this study compared closely in physiological parameters to elite distance runners used in other studies, however, were not equal in competitive running statistics (Costill, 1970; Costill et al., 1976a; Costill et al., 1976b). Another major difference was in age. Costill's et al. (1976a) subjects' mean age was 26.2 years while subjects in this investigation had a mean age of 21.0. This age difference was possibly one of the major factors for the much higher performance levels of Costill's subjects.
The experimental group showed significant increases in both body mass (p < .10) and fat-free mass (p < .01) while the control group demonstrated nonsignificant increases from pre and post season. This concurs with most of the other literature which demonstrated several programs of weight training, utilizing maximum muscular contractions, increased male subjects' muscle mass (MacDougall et al., 1976; MacDougall et al., 1979; Wilmore, 1974).

Since there was a significant difference in post season means between the two groups and with the control group not changing significantly it was concluded that eight weeks of heavy overload weight training increases body weight and fat-free mass in distance runners.

There was no significant difference between the control and experimental group percent fat, pre or post season. This would seem to indicate that though the experimental group probably burned more calories through weight lifting, it was most likely compensated for by a higher caloric intake. Had performance improved in the experimental group with a significant decrease in fat, and no change in the controls, one could hypothesize that the increased performance was due to the weight loss of fat. Results of this investigation do not permit that conclusion.

Increases in body mass and fat-free mass which are concomitant with strength gains could possibly inhibit
high quality endurance running. Cureton and Sparling (1980) reported that in ten male subjects, excess weight totalling 7.5% of body weight decreased max VO₂ by 4 ml/min/kg. It also decreased performance in the 12 minute distance run by 200 meters. Though all body weight and fat free mass acquired through weight training was not mechanically utilized during running, that portion which was not used still must be oxygenated by blood that otherwise would be directly aiding the working muscles.

**Maximum Oxygen Uptake**

Oxygen utilization is of prime importance for distance running. Highly trained distance runners usually utilize approximately 70-80 ml/min/kg of oxygen while untrained individuals use 40 to 50 ml/min/kg (Costill et al., 1976a; Costill et al., 1976b). Small changes in these uptake levels could have marked effects on running performance. This investigation found no significant changes in either groups for max VO₂ l/min, and ml/min/kg. A significant (p<.01) decrease in max VO₂ ml/min/kg of FFM was observed in the weight trained group. This group increased fat free mass but did not demonstrate an associated increase in oxygen uptake to accomodate the increase. The decrease in max VO₂ did not seem to jeopardize overall performance since there was no corresponding decrease in max VO₂ uptake in ml/min/kg.

With the few subjects and short training time in this investigation the actual effects of changes in body
composition due to weight training on oxygen uptake is still not totally clear. Since studies have shown only small increases in max VO₂ due to weight training (Wilmore, 1974), it can be hypothesized that any large increases in body weight due to heavy weight training could be detrimental to distance running performance since there is very little concurrent rise in oxygen consumption.

Progressive overload weight training produces a significant and selective hypertrophy of Type II fibers (Prince, Hikida, and Hagerman, 1976; Thorstensson, 1976). Hypertrophy of these fibers would have little value since they would not be utilized metabolically until a finishing sprint, which is a small proportion of the total event. Studies have also shown that glycogen uptake and utilization varies with intensity of exercise and occurs selectively in Type I and Type II fibers (Costill et al., 1973; Gollnick et al., 1974; Piehl, 1974). Distance runners using heavy weight training probably develop larger glycogen filled Type II fibers which can not be utilized unless the runner is sprinting or running a shorter race such as the 800m or 1500m during which the utilization of Type II fibers is more prevalent.

Treadmill Running Time

The results of this investigation indicated no significant (p<.1) differences between the control and experimental group's pre and post season results, and post season differences between the two groups. This would
seem to indicate that even though the subjects became stronger it did not effect their treadmill running time. This nonimprovement in treadmill running time, even though the experimental group was significantly stronger, might have been caused by a significant increase in body mass and fat free mass without a corresponding significant increase in maximum oxygen uptake.

**Effects of Weight Training**

There is abundant evidence indicating weight training increases strength (Berger, 1962; Nagel and Irwin, 1960; Wilmore, Parr, Vodak, Barstow, Pipes, Ward, Leslie, 1976). Results of this study concur with this principle. The experimental group had a significant increase in 1-RM strength. Bicep curls, leg extensions, upright rowing, and leg press were significant at the .01 level of confidence. Bench press, pull downs, hamstring curls, and military press were significant at the .05 level while the control group demonstrated no significant changes.

This investigation showed that well trained distance runners using a weight training program could produce significant strength gains in a short period of time. When combining the results of all eight exercises the control group decreased in mean weight lifted from pre and post season by .03 pounds while the experimental group increased by 23.03 pounds.

It is difficult to ascertain the actual effects of these increased strength levels since several tests of
metabolic function were not conducted. The experimental group was significantly stronger than the control group at the conclusion of the study. Strength increases varied with each exercise. Most differences were probably due to initial levels of strength and individual subject motivation.

Summary and Conclusions

Eight weeks of heavy overload weight training did not effect the well trained distance runner. They became significantly stronger and gained a significant amount of fat free mass. These runners did not make significant improvements in two parameters that were of vital importance to endurance runners. These were max \( \text{VO}_2 \) \( \text{ml/min/kg} \) and treadmill running time. The results of this investigation indicate that strength gains produced by weight training are not necessarily accompanied by complimentary physiological improvement. Therefore it would seem that weight training, as used in this study, would not benefit well trained endurance runners.

Suggestions for Further Research

1. Determine the effects of high resistance weight training on high school distance runners.

2. Increase training and evaluation time in order to more accurately evaluate the long range effects of heavy resistance weight training on distance runners.
3. Classify subjects according to specific track distance running events. Performance between groups could be analyzed.

4. Compare enzyme and glycogen levels, mitochondrial density, lactate production and removal, capillary density, and muscle fiber type and size changes consequent to a weight training program.

5. Strength levels, performance, and psychological variables should be examined on a bimonthly schedule to obtain a precise evaluation of the neural effects of weight training.

6. Compare different weight training regimens using variable levels of resistance, sets, and repetitions and determine optimal training levels for distance runners.

7. Determine the effect of weight training on distance running physiological efficiency at different workloads.

8. Compare the effects of isokinetic, isometric, and variable resistance training on distance running.
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residual volumes in the assessment of body composition  
by underwater weighing. *Medicine and Science in  

APPENDIX A

Informed Consent for Exercise Testing
Informed Consent for Exercise Testing

In order to assist Timothy N. Tobin in completing his requirements for a Master's degree, I hereby consent to voluntarily engage in two maximal exercise tests, two underwater weighing and two maximal strength testing sessions. The information obtained will be used for statistical analysis in the thesis, but no individual data will be identified by name.

The exercise test that I will undergo will be performed on a treadmill. Beginning at rest the effort will be progressively increased to a maximal end point of exhaustion or asymptom limiting end points. Heart rate will be monitored and used to assess the level of work performed. The exercise testing will be preceded by underwater weighing to determine my body composition. This will require that I be submerged underwater, after a maximum exhalation, five times. During the strength testing I will lift weights until the one repetition maximum is reached for eight different lifting exercises.

I understand that I am free to terminate any portion of the testing at any time if I feel unable to continue. Oxygen uptake and other respiratory measurements will be taken during all treadmill tests.

I have read the foregoing and I understand it, and any questions which may have occurred to me have been answered to my satisfaction. I hereby acknowledge my understanding of the nature of these tests and verify that to the best of my knowledge I am in good health and possess no medical condition which would preclude my safe participation in the test program.

Signed__________________________

Date__________________________
APPENDIX B

Body Composition
Treadmill Running Time
Maximum Oxygen Uptake
Strength Testing
## Body Composition

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<tr>
<th>Group/Subject</th>
<th>Pre Mass (kg)</th>
<th>% Fat</th>
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<th>Post Mass (kg)</th>
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<th>FFM (kg)</th>
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<td>63.9</td>
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### Treadmill Running Time

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<td>Exercise C</td>
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<tr>
<td>Control X</td>
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### Maximum Oxygen Uptake

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# Strength Testing

## One Repetition Maximum

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<td>80</td>
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APPENDIX C

Hydrostatic Weighing Data Sheet
Max VO₂ Treadmill Test Data Sheet
Gas Analysis Data Sheet
Hydrostatic Weighing
Data Sheet

Subject: ________________________ Date: __________
Address: ________________________ Phone #: __________
Age: ____ Sex: ____ Mass: ____ ÷ 2.2046 = ____ kg

Vital Capacity
Trials: 1. ____ 2. ____ 3. ____ Mean: ____
Temperature: BTPS cf. ____
Vital Capacity BTPS: ____

Residual Volume
R.V. = vital capacity X .24
= ______ x .24
R.V. = ______

Hydrostatic Weighings
Tare Weight: ____ kg H2O Temo.: ____ c. DbH2O: ____
Trials: 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
6. ____ 7. ____ 8. ____ 9. ____ 10. ____
Wt. ± Tare: 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
6. ____ 7. ____ 8. ____ 9. ____ 10. ____
Mean Hydrostatic Wt.: ______ (MW)

Calculations

Density = {MA
__________
MA-MW
DbH2O - (R.V. + .115)

%Fat = ________________
4.570
___________________
Db
-4.142 X 100

Fat = Mass X %Fat
= _____ X ____
Fat = ____ kg
FFM = Mass - Fat
= _____ - ____
FFM = ____ kg
# Max VO₂ Treadmill Test Data Sheet

Experimenters: __________________________Date: __________________________  
Subject: ___________________________ Age: ___ Height: _____ Weight: ____  

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Gas Analysis Data Sheet

Subject: ___________________________ Date: ____________

True barometric pressure: ______ MMHG

Corrected barometric pressure: ______ MMHG

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