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Date 30 July 1980

PROGRESSIVE CHANGES IN THE PHYSICAL FITNESS OF A FEMALE LONG DISTANCE RUNNER IN TRAINING FOR THE WESTERN STATES 100

by

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ABSTRACT

The purpose of this study was to determine the progressive changes in the physical fitness of a female long distance runner during a seven-month training period in preparation for the Western States 100-Mile Endurance Run. The progressive physical conditioning was evaluated by testing 50 selected oxygen consumption, pulmonary ventilation, blood chemistry, heart rate, body composition, girth, running and bicycle performance, and strength variables at four-week intervals during the training period. A 27-year-old female marathon runner who had run for approximately three years served as the subject.

The subject trained up to ten hours a day, six or seven days per week, for a total of 30 weeks. The training program was substantially adjusted due to a knee injury. Consistent throughout the entire seven months was at least one long endurance workout each week. In addition to running, the training involved mountain climbing, cross-crountry skiing, bicycling, stair intervals, bicycle ergometer intervals, weight training, and swimming.

Beneficial changes in the physical fitness of the subject resulted from non-running as well as running training. During the seven months of training, substantial improvements were noted in $\dot{V}O_2$ max, $\dot{V}E/\dot{V}O_2$ max, submaximal HR, recovery HR, skinfold measurements, leg strength, and the bicycle ride to exhaustion. $\dot{V}O_2$ max reached and remained at peak values (66.5 ml/kg-min, as measured on the bicycle ergometer) only during the three months when LSD running was the main form of training. There was no change in maximal HR, resting HR, and girth measurements. Although there were fluctuations in values of $\dot{V}E$ max and blood chemistry parameters, no particular trend was observed.

The subject was forced to drop out of the Western States 100 due to the knee injury after covering 51.3 miles in 13 hours. It was apparent that the subject was very adequately trained for the run in consideration of the subject's condition at all points during the run and during the post-race recovery period. It was determined in analysis of the testing results and the 100-mile run that the most important prerequisites for completion of this particular ultramarathon were leg strength and submaximal working capacity.

CHAPTER I

THE PROBLEM

Introduction

The ultimate long distance running challenge lies in the Sierra Nevada Mountains of California. The Western States Trail, first traversed by the Paiute and Washoe Indians and later the Gold Rush pioneers, runs along high mountain ridges, through deep river canyons, over extensive snowfields, through a river, and up and down steep rocky pitches for 100 miles. In addition, temperature extremes of 25 to 110 degrees Fahrenheit may be encountered during the summer months.

To run 100 miles in this rugged high altitude terrain requires an extraordinary degree of fitness. Several months of intense, specific training must precede an event such as this.

Strenuous training, such as that which is necessary to run the Western States 100, has rarely been studied and documented. Many studies have innumerated the effects of moderately strenuous training programs (2, 13, 21, 140, 164). Endurance running training has usually meant covering from one to five miles per workout, from three to six times per week (51,63, 86, 104, 111, 115, 125, 143, 151). Effects of training involving strenuous workouts of much longer duration (i.e. three to ten hours) is relatively unknown.

A majority of training studies have merely tested subjects before and after a short duration training program (12, 39, 50, 73, 86,

111, 139, 143, 164). A longitudinal study over a period of several months, with periodic testing of many physiologic parameters, would enable a more significant assessment of the changes taking place (67).

Another weakness of existing training research is the lack of relating observed changes to changes in training methodology. Distance runners are difficult to control over long periods (126). Consequently, existing research consists of descriptive studies of long distance runners (20, 22, 27, 29, 30, 91, 156). It is difficult to separate genetic endowments from the effects of training. Are the observed values primarily a result of heredity or of training?

Furthermore, data concerning the effects of strenuous training specifically on the female athlete are scarce.

> Probably the single most important thing that is holding back the development of women athletes today is the lack of knowledge in the population at large concerning how hard women should work in developing their athletic potential. Research efforts to assess the physiological responses and adaptation of the female to strenuous physical effort must be commensurate with the increased participation of females in athletics (89).

This study seeks to fill the relative absence of data on female athletes through a longitudinal case study. Periodic testing of many parameters compared training methods to measured changes during the course of seven months of intense endurance training.

Statement of the Problem

The general problem of this study was to determine the progressive changes in the physical fitness of a female long distance runner

during a seven-month training period in preparation for the Western States 100.

Specific Objectives

1. To determine the progressive changes in oxygen consumption, pulmonary ventilation, blood chemistry, heart rates, body composition, girths, running and bicycle performance, and strength that occurred during a seven-month training period, as measured by a selected battery of tests.

2. To ascertain correlations among individual fitness measures.

3. To compare test item results with training changes.

4. To evaluate performance in the Western States 100 in relation to test data collected.

Delimitations

This study was delimited to the case study of the physical fitness of one female long distance runner during a seven-month period from December 1979 through June 1980 in Bozeman, Montana, while she was training for the Western States 100. The progressive physical conditioning was evaluated by testing 50 selected oxygen consumption, pulmonary ventilation, blood chemistry, heart rate, body composition, girth, running and bicycle performance, and strength variables at four-week intervals during the training period.

Limitations

1. Since this investigation is an individual case study, group generalizations cannot be drawn, although trends may be indicated.

2. Weather and climatic conditions influenced training and testing.

3. Injuries limited training and testing at various times.

4. The test results where appropriate are assumed to represent maximum efforts on the part of the subject. Every effort was made so that this would be the case.

5. Due to the strenuous nature of the training program, training fatigue has possibly affected some of the testing results.

6. With the absence of a control subject, changes in physical fitness levels are assumed to be due to the training program.

General Terms and Definitions

1. Physical fitness. Physical fitness refers to the capacity to work hard over a long period of time without decreased efficiency (67) and with rapid recovery from the effects of the exertion (105).

2. Long distance runner. For the purpose of this study, long distance runner refers to a female runner with two years of marathon experience who entered a 100-mile run for the first time.

3. Progressive. Progressive refers to the passage of time in four-week increments over a period of seven months.

4. Training. Training is defined as daily, scheduled sessions of exercise of varying intensity.

5. Western States 100. The Western States 100 is a 100-mile endurance run over the Sierra Mountains from Squaw Valley to Auburn, California. It involves a total elevation gain of 17,040 feet and a total loss of 21,970 feet. The race is run primarily over remote backwoods trails and fire roads, usually with half of it being traversed at night. Additional factors to contend with during the Western States 100 include vast temperature extremes, bears, and rattlesnakes.

6. Aerobic. Aerobic means in the presence of a sufficient supply of oxygen.

7. Running. For the purpose of this study, running means road, trail, and mountain running.

8. Fartlek. Fartlek refers to a style of training employing frequent changes of pace with no fixed pattern.

9. Intervals. Intervals are defined as short bouts of repeated, intense effort alternating with periods of light activity or rest.

10. Stair intervals. Stair intervals refer to a type of anaerobic training involving intense, ascents of stairs, followed by recovery on the descent.

11. Bicycle ergometer intervals. Intervals on the bicycle ergometer refer to brief, intense periods of exercise with high resistance and high pedal frequency, alternating with rest periods.

CHAPTER II

REVIEW OF RELATED LITERATURE

For this investigation, the literature was reviewed in two manners. A review of the literature associated with each specific testing parameter is presented in Chapter IV, preceding the results of each test item. Included in this chapter is a more general review of strenuous training studies on runners. The purposes for this method of review are:

1) to provide the reader with a background of research on strenuous training so that the scope of this investigation can be put in perspective; and

2) to summarize training test parameter research in proximity to the results of this study for comparative analysis.

There are countless studies relating the effects of moderate training on various physical fitness parameters. Most studies measure the effects of training three days per week for 30 minutes per workout (39, 50, 51, 63, 84, 151). Most relevant to this study, though, is research dealing with the effects of strenuous training. For the purposes of this review, strenuous training is defined as training involving at least five workout sessions per week and at least 15 miles of running per week. The following review of literature will be concerned with strenuous training studies involving runners.

Three athletes in training for the two-mile run were followed

during a season of spring athletics by Schneider and Havens (129). Hemoglobin concentration and the number of red corpuscles were found to increase. The number of leucocytes and platelets remained unchanged, while the lymphocyte index increased. No change was found in total oxygen capacity or total blood volume.

Dawson (40) performed an intensive study on himself over a three-year period during which he engaged in running, gymnastics, bicycling and tennis. He studied the effects of training on resting heart rate and blood pressure. Resting heart rate was found to be slower, especially the noon and afternoon pulses. Morning and evening heart rates declined, but not as significantly as noon and afternoon rates. The daily curves of blood pressures were not obviously altered. The systolic pressure was found to rise more rapidly and much higher in the trained state, along with a great increase in pulse pressure.

Gemmil (55) followed two track athletes through the initial stages of training and found that total ventilation increased, total oxygen for the exercise decreased, and respiration rate and diastolic blood pressure after exercise were reduced.

Tuttle and Walker (144) tested 14 high school track men before, in the middle, and at the end of a season of training. An attempt was made to determine the effects of a season of training and competition on the response of the hearts of high school boys. After a training program of 1.5 to 2 hours of daily jogging, sprinting, and distance

running, recovery pulse was improved and recovery time was reduced. The training program had no effect on resting heart rate and heart rate for the first 30 seconds immediately following exercise.

Robinson (123) studied nine college men who trained for middle-distance running for 28 weeks. Maximal oxygen consumption measured on a treadmill run to exhaustion improved from 52.8 to 60.2 ml/kg-min. Blood lactic acid concentration at rest increased from 13.2 to 18.0 mEq/l.

Nine college students were studied by Robinson and Harmon (125) over a six-month period during which they engaged in a strenuous running program. Blood lactic acid, total plasma protein, blood glucose, alkaline reserve, hemoglobin oxygen capacity, and alveolar carbon dioxide tension remained unchanged. A greater tolerance for stress, though, was indicated by an increased ability to accumulate lactic acid during anaerobic work. Blood lactate during submaximal running was significantly decreased after training.

A comparison was made by Pepper (34) using 40 track athletes and 42 students taking a body-building course over an eight-week period of training. Both groups decreased in all heart rate measurements but heart rates immediately after exercise and during recovery were most significantly affected. Systolic blood pressure was shown to decrease with training, while diastolic blood pressure slightly increased. It was concluded from this research that there was little difference in

the effect of the track and body building programs in terms of magnitude of improvement, although track training lowered the post-exercise heart rates more than body building.

In an individual case study using himself as the subject, Cureton (34) measured changes in fat, heart rate, oxygen consumption, girths, strength, and hemoglobin over a 12-month period. Six months of complete inactivity preceded the study. Only the first three months of the study involved strenuous training: daily endurance running and swimming, pulley weights, and conditioning exercises. Peak fitness was reached after the first three months of training. Body fat, girths and weight were significantly reduced. The all-out treadmill run had increased to its highest level after three months. It was concluded that the peak of physical condition is reached more quickly in some aspects of fitness than in others. Strength reached a peak several months after strenuous training was terminated and hemoglobin was still gradually rising a year after starting the training. Breath holding after standard stepping exercise was reported to be a sensitive test paralleling the state of training.

Four years later at age 47, Cureton (35) was again tested before and after five weeks of training. During the final week of the study he ran six miles per day during the week and swam five miles continuously on the weekend. Lying and standing pulse rates declined significantly to 50 beats per minute. Basal metabolic rate rose substantially,

while body weight and fat were reduced. The changes indicated a stronger heart and greater blood flow in the resting state.

Kristufek (86) determined the effects of a daily three-mile run for a seven-week period on one subject, using an extensive battery of 102 test items. Adipose tissue, girths, pulse rates, and basal metabolism decreased with training. Maximal oxygen intake, back and leg strength, breath holding ability, vital capacity, blood pressures and heartogram scores all showed significant improvements. The subject's ability to run at a fast pace was not improved with this type of long slow distance running. It was concluded that the continuous rhythmical movements involved in endurance running burn excessive calories, produce more blood flow through the heart while opening the blood vessels, and increase muscle tone and strength.

The effects of distance running after a training program of ten weeks duration was studied by Bernauer (12). Cardiac output, running performance and muscular endurance increased significantly. Improvements were also noted in the area under the brachial pulse wave, systolic amplitude, diastolic amplitude, diastolic surge, and heart rate as measured by the heartometer.

Hornof and Kremer (67) carried out one of the most intensive training studies ever reported, on Emil Zatopek, the great Czechoslovakian distance runner. The investigation was started in 1944 when Zatopek was 22 years old. Periodic physical fitness measurements were

taken on Zatopek over the next eight years. Numerous anthropometric and cardiovascular variables were studied including muscular girths, physique, resting heart rate, electrocardiograph intervals, heart x-ray, lung x-ray, and performance tests. Physique measurements remained quite constant. He was found to have a typical linear physique well-adapted to endurance running. On performance tests Zatopek consistently made a superior showing.

The effects of strenuous running training upon cardiac output was studied by Michael (97) on three subjects who were tested every four weeks during twelve weeks of training and eight weeks of detraining. Subjects ran five days per week, with the training program consisting primarily of 220-, 440-, and 880-yard intervals run at maximum speed. Oxygen intake, pulse rate, and stroke volume improved during training and were all reversed during detraining. Fatigue was theorized as the cause for declines in oxygen intake, minute volume, and stroke volume during the first four weeks of training. Four weeks after training had stopped a "delayed rise" was also observed in oxygen intake and minute volume.

The great marathon runner Clarence DeMar was studied in detail by Dill (43). Laboratory studies revealed exceptionally superior cardiovascular and respiratory systems with a low basal heart rate, low blood pressure, and large vital capacity. Numerous studies were made on DeMar when he was in his prime as a marathon runner between ages 34

and 42. He was also tested at age 49 when he was measured to have a maximal oxygen consumption of 60 ml/kg-min, one of the highest observed at that age. Recovery of heart rate and blood pressure were also seen to be very rapid. Hemoglobin concentration and other blood properties were found not to be substantially different from those of untrained men.

Adams (1) studied the members of a college track team before, in the middle, and at the end of a season of training and competition. Five out of six skinfold measurements were significantly less at the end of the season, although no changes were observed in any of the girth measurements, resting heart rate, vital capacity, or maximum breathing capacity. However, recovery pulse counts were found to be reduced. No significant change in any of the measurements taken occurred between midseason and the end of the season. A steady level of training was reached at seven weeks, after which no further improvement took place in those particular test variables. Improvements in competitive performances, though, were noted among the majority of the track team members after midseason. Physiological changes not reflected in the measurements taken were still occurring. Improvements in performance were attributed to further refinements of the neuromuscular system and to progressive training of the central nervous system.

One of the most comprehensive studies was carried out in the Soviet Union by three researchers at Tartu University (147). Nine

specific training routines were studied, ranging from long steady runs to fartlek to uphill intervals. Runners took 100-, 400-, and 800-meter time trials at the start of the training period and again six weeks later. They were also checked for physiological changes including oxygen uptake and heart volume. The general conclusion reached was that no one training system should be used exclusively: "the utilization of only one of the training methods results in an intensified development of only one function, sometimes even to the detriment of other functions" (147).

Effects of eight weeks of strenuous preseason training were observed on 22 varsity basketball team members (17). Workouts involved cross-country and interval running and weight training. Body weight, skinfolds, hemoglobin, blood sugar, diastolic blood pressure, and recovery heart rate were all significantly decreased. Increases were measured in physical working capacity, maximal oxygen consumption and leg and upper arm strength.

Training studies on female athletes are scarce. Recently more attention has been given to the effects of strenuous physical activity of the female runner, but these have mainly been descriptive in nature (20, 22, 46, 48, 156). Few studies have actually studied female runners throughout a period of training.

One of the few longitudinal running studies was done by Knowlton and Weber (85) on a young woman during a 17-month period in which

she was training for the mile and two-mile events. Her training consisted of intervals and frequent runs longer than five miles. The subject reached a highly trained state for middle distance competition, although there were several setbacks due to the university schedule and injuries. Noticeable improvements were observed in her cardiovascular response to a submaximal bicycle test and maximal treadmill run. Training reduced resting heart rate, body weight, and basal metabolic rate, but had no effect on hemoglobin concentration. None of the data suggested that the strenuous level of training had any harmful effect on the subject. The training program was considered to be extremely severe by convention for female runners. Many of the results of the experiment parallel results obtained on training males.

Brown and others (18) studied the effects of a strenuous cross-country training program and competition on girls eight to thirteen years old before the season and after six and twelve weeks of training and competition. Training sessions were held four or five days per week and lasted from one to two hours. Competition in .75 to 1.5 miles took place every Saturday for the last eight weeks of the study. The most significant change was the increase in maximal oxygen consumption, 18 percent at six weeks and 26 percent at twelve weeks. Maximal and submaximal heart rates showed a decline with training, although these changes were also observed with the controls. No detrimental effects were observed, other than slight unexplained weight loss in two of the

younger girls. It was concluded that preadolescent girls are capable of adapting to endurance running in a manner similar to adults.

Often pre-training fitness levels are unclear, as is quantification of the training programs. There is a wide variety in parameters tested and very little consistency in testing procedures. Standardized procedures, documentation of training programs, evaluation of pre-training levels and prior activity, and longer periods of investigation would seem to enhance training research studies and help to make valid comparisons possible. The review of the literature most closely related to this study indicated that more high quality research is needed to discover the changes which occur throughout the course of strenuous training, especially in female runners.

CHAPTER III

PROCEDURE

The material in this chapter is presented under the following headings:

1. Research Method.
2. Subject.
3. Training Program.
4. Daily Log.
5. Testing Battery.
6. Testing Schedule.
7. Testing Equipment.
8. Testing Procedures.
9. Analysis of Data.

Research Method

This research was conducted as a longitudinal case study. It was designed to measure the progressive changes in the physical fitness of a female long distance runner in training for the Western States 100-Mile Endurance Run. A testing battery of 50 items was used to test one subject over a period of seven months at four-week intervals.

Subject

A 27-year-old female long distance runner, who had run for approximately three years and trained for racing approximately two

years, served as the subject for this investigation. In the two years prior to the beginning of this study, the subject had completed seven marathons, including a 2:59:34 best. During that time she consistently trained for long distance running by logging 7150 miles, with an average of about 75 miles per week. Weekly mileage ranged from 60 to 110 miles per week. The subject did not train intensively for the two months prior to the beginning of this study, averaging about 30 miles of running per week during that time. The author served as the subject of this investigation.

Training Program

Training for the Western States 100-Mile Endurance Run on June 28, 1980, was the experimental factor. The subject trained up to ten hours a day, six or seven days per week, for a total of 30 weeks, for this event on a base of previously described training.

The training program consisted of workouts designed to increase central and peripheral circulatory factors, in addition to muscular strength primarily of the lower extremities.

Since this study spanned three different seasons, the weather often dictated flexibility in duration and type of training. The training program was substantially adjusted due to a knee injury sustained just prior to the beginning of this study and a reinjury during the fifth month of training. Running was intended as the main form of training but was not a regular part of training until after the third

testing period. Consistent throughout the entire seven months, however, was at least one long endurance workout each week (mountain climbing, bicycling, running, cross-country skiing).

The first testing period occurred after one month of very limited training due to injury. After the first testing period, the subject began intense non-running training consisting of one long aerobic workout (cross-country skiing or mountain climbing), bicycle ergometer intervals, stair intervals, swimming, and weight training. This type of training was used for the first two months. The subject resumed running on February 1, after completion of the third testing period. During the following three months of training, the week's training schedule included one long run of up to 50 miles, one additional long workout of bicycling or cross-country skiing, hill runs, fartlek runs, bicycle ergometer intervals, and weight training. During a 50-mile run the injury reoccurred to cause a substantial reduction in running mileage. The final two months of training primarily involved hiking, bicycling, and mountain climbing, with very limited running.

A detailed description of the training program for the entire seven months is included in Appendix B.

Daily Log

A daily log was kept to record training data, heart rate, weight, sleep, and caloric intake. An attempt was made to avoid unusual deviations in sleeping and eating patterns.

Weight was taken each morning soon after waking and prior to eating or training. Heart rate was determined through palpitation of the carotid artery immediately after waking. Heart rate was again taken 15 minutes after training was completed and weight was measured immediately after training whenever possible. Total calories were estimated for each meal so that daily caloric intake could be calculated. Caloric values were obtained from the United States Department of Agriculture Bulletin No. 72, Nutritive Values of Food.

Data from the daily log is included in Appendix C.

Testing Battery

The testing parameters are as follows:

1. Maximal oxygen consumption ($\dot{V}O_2$ max).
2. Maximal pulmonary ventilation ($\dot{V}E$ max).
3. Ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$).
4. Basal metabolic rate (BMR).
5. Blood chemistry.
    a. Red blood cell count (RBC).
    b. Hemoglobin (Hb).
    c. Hematocrit (Hct).
6. Heart rate
    a. Resting (HR rest).
    b. Maximal (HR max).

c. Submaximal (HR submax).

d. Recovery (HR recov).

7. Body composition.

a. Triceps skinfold (TR).

b. Subscapular skinfold (SU).

c. Abdominal skinfold (AB).

d. Suprailiac skinfold (SI).

e. Thigh skinfold (TH).

f. Calf skinfold (CA).

g. Cheek skinfold (CH).

h. Percent body fat (PF).

i. Total body weight (BW).

j. Lean body weight (LBW).

k. Fat weight (FW).

8. Girths.

a. Calf (CA).

b. Thigh (TH).

c. Upper arm (UA).

d. Forearm (FA).

e. Chest (CH).

f. Abdominal (AB).

g. Gluteal (GL).

9. Bicycle ride to exhaustion.

10. Running time trial.

11. Strength.

    a. Leg press.

    b. Leg extension.

    c. Leg curl.

Testing Schedule

Testing took place every four weeks during the seven-month training period. The starting date of each test period is shown in Table 3.1. The five-week period prior to initiation of testing was used as a trial period during which all of the tests were performed and procedures were standardized. The trial period was used to familiarize the subject with testing, reduce anxiety, minimize the learning effect, and establish a realistic testing schedule.

A standardized sequence of testing was followed during each testing period. The testing schedule is shown in Table 3.2. Preconditions necessary for several tests were strictly adhered to. These are explained in further detail under the individual testing procedures.

Testing Equipment

Ergometers. A mechanically-braked Monark bicycle ergometer (BE) was used for the maximal oxygen consumption and one of the submaximal HR tests. The other submaximal test was performed on a motor-driven treadmill (TM) with adjustable grade and speed (Quinton 18-54).

Table 3.1

Testing Periods

Number	Starting Date
Trial	October 28, 1979
1	December 2, 1979
2	December 30, 1979
3	January 27, 1980
4	February 24, 1980
5	March 23, 1980
6	April 20, 1980
7	May 18, 1980
8	June 15, 1980

Table 3.2

Testing Schedule

Day	Time	Test
Monday	7:00 A.M.	Girths
	8:00 A.M.	Blood
	9:00 A.M.	BE HR
Tuesday	7:30 A.M.	BMR
	8:00 A.M.	Skinfolds
	8:30 A.M.	$\dot{V}O_2$ max
Wednesday	7:00 A.M.	Time trial
Thursday	9:00 A.M.	TM HR
	11:00 A.M.	Strength
Friday	8:00 A.M.	Ride to exhaustion

Due to availability of equipment, testing was performed at two different locations. Since oxygen consumption equipment was located in the same laboratory as the BE, the test for $\dot{V}O_2$ max was performed on the BE, rather than the TM.

Oxygen consumption. Oxygen consumption was determined by the open circuit method. The subject breathed through a rubber mouthpiece connected to a Collins Modified Otis-Kerrow Valve. A metal and sponge-rubber spring-type noseclip was used. The expired air was fed through a plastic hose into a 350-liter tissot tank (Collins Chain-Compensated Gasometer).

Gas analysis was determined by means of a Beckman E-2 oxygen analyzer and a digital LB-2 carbon dioxide analyzer. Gas analyzers were calibrated using certified gas (Matheson Gas Products for O_2, Beckman for CO_2).

A Gralab Universal Timer was used to time, while a metronome (Seth Thomas E500-000) was used to keep pedaling frequency constant.

Blood chemistry. Red cell count and hematocrit were determined automatically through use of a MCV, Hct, RBC Counter (Coulter Model ZBI). The Coulter Hemoglobinometer was used to measure hemoglobin concentration.

Heart rate. Heart rate was monitored through radio telemetry while work was performed on the BE. A two-lead system was used which placed one electrode on the sternum as a ground and the other in the

standard V-5 position on an intercostal space. Double-backed adhesives were used to hold the electrodes in place. Electrode paste (Redux Creme) filled the well in the electrodes in order to transmit the electrical signal from the skin to the electrodes.

An ECG-EMG-EEG FM Transmitter (Narco FM-1100-E2), attached at the subject's waist, transmitted the signal to the physiograph (Narco Physiograph Six) through a bio-telemetry receiver (Narco FM-1100-7). Ten consecutive ECG tracing complexes on the paper recorder were measured with a metric ruler. Paper speed was constant at 2.5 meters per second.

Heart rate was also monitored through a five-lead system during a submaximal run on the treadmill. Electrodes, pre-filled with electrode gel, were placed on the right and left clavicle, the right and left lower rib, and the V-5 position. Direct wire leads carried the signal to the Burdick EK-4 Electrocardiograph. On the paper recorder three successive R-spikes were measured with a precalibrated ruler to determine HR. The CS-515 Monitor also provided instant digital readout of HR.

Skinfolds. Skinfold measurements were taken with the Lange skinfold calipers. Body weight was measured on an upright Detecto scale.

Girths. A plastic tape measure was used for determination of girths.

Strength. The Universal Gym apparatus was used in the determination of strength. The leg press, leg extension, and leg curl stations were used.

Testing Procedures

Tests were administered by Dr. Robert Schwarzkopf, Director, Human Performance Laboratory, who used identical procedures each time.

Maximal oxygen consumption. Maximal oxygen consumption was determined by a discontinuous test using the open circuit method on the bicycle ergometer. Strenuous muscular work was avoided on the day preceding the test. The test commenced with the subject as near to the true resting state as possible.

The procedure of Albert Craig (31) was followed. Pedaling frequency was constant at 60 revolutions per minute. Three five-minute intervals at 360, 720, and 900 kilopond meters per minute (kpm/min) were followed by a five-minute rest. A five-minute bout at 1080 kpm/min was followed by a second five-minute rest. Gas was collected for one minute during the fifth minute at each resistance. The final two gas collections were during the last 30 seconds of a 2.5-minute interval at 1440 kpm/min and a two-minute interval at 1530 kpm/min. The final two bouts were separated by a ten-minute period.

The oxygen and carbon dioxide analyzers were calibrated prior to each test using standardized gases. For determination of gas content, expired air was permitted to flow through the analyzers for several

minutes before a reading was made.

Standard calculation procedures were followed for computation of $\dot{V}O_2$ max in liters per minute (l/min) and milliliters per kilogram per minute (ml/kg-min), corrected to standard temperature and pressure dry (STPD). See Appendix D for calculation procedures followed. It was determined that $\dot{V}O_2$ max was reached if there was no further increase in oxygen uptake despite an increase in workload, or there was less than a 2.1 ml/kg-min increase (134).

Basal metabolic rate. For measurement of basal metabolic rate (BMR), the subject arrived at the laboratory at 7:00 A.M. on testing day in a 12-hour post-absorptive state with no prior muscular exertion. The subject reclined in a relaxed state on a foam-covered table and breathed into the rubber mouthpiece. Room temperature was kept between 65-70 degrees Fahrenheit. Gas was collected for 15 minutes and then analyzed using oxygen consumption and gas analysis procedures previously described. Calculation procedures for computation in cubic centimeters per minute (cc/min) and kilo-calories per hour (kcal/hr) appear in Appendix E. Body surface area was found using the DuBois nomogram (49) so that BMR could be expressed in kcal/hr/m^2. The Harris-Benedict Standards (49), based on body weight, age, and stature, were used to determine deviations above or below normal.

Blood chemistry. The subject arrived at the Marsh Laboratory at 8:00 A.M. in a post-absorptive state. A five-milliliter blood sample

was drawn and manually diluted each time by the same laboratory technician. Standardized blood analysis procedures were used to determine a complete blood count which included the following: red blood cell count, hemoglobin, and hematocrit.

Heart rate. Heart rate was determined through radio telemetry during a replicated submaximal session on the bicycle ergometer. The subject pedaled at 720 kpm/min for nine minutes. HR was recorded three times at three-minute intervals. At the end of nine minutes the subject stopped pedaling and remained seated. Recovery HR was recorded at 30 seconds, one minute, and two minutes after cessation of exercise.

On the treadmill, HR was recorded during a submaximal run using a five-lead system. Resting HR was recorded after the electrodes were placed and the subject was seated. Grade on the TM was set at 2.5% and remained constant throughout the test. The subject warmed up for three minutes at three miles per hour (mph), after which the speed was increased to six mph, subsequently to seven mph, and finally eight mph. Exercise HR was measured during the last 20 seconds at each TM speed. A recovery HR was recorded following completion of the run, at 30 seconds, one minute, and two minutes, during which the subject was seated.

Body composition. Skinfold measurements taken with the Lange skinfold calipers were used to determine body composition. Standardized procedures were used as described by Keys (80, 81). Three measure-

ments to the nearest 0.5 mm were taken, with an average of the three used as the score. All measurements were performed on the right side of the body.

Sites of the skinfolds were as follows:

1. Triceps (TR) -- Vertical fold on the posterior line halfway between the tip of the acromion process and the olecranon process, arm hanging at side.

2. Subscapular (SU) -- At the tip (inferior angle) of the right scapula, on a 45-degree line laterally downward.

3. Abdominal (AB) -- Horizontal fold one centimeter to the right of the umbilicus and parallel to the long axis of the body.

4. Suprailiac (SI) -- Vertical fold on the right midaxillary line just above the crest of the ilium.

5. Thigh (TH) -- Vertical fold on the anterior right thigh in the midline, halfway between the patella and the greater trochanter.

6. Calf (CA) -- Vertical fold in the midline of the right calf at the level of maximum circumference.

7. Cheek (CH) -- Horizontal fold beneath the right temple at the level of the nostrils.

Density was computed from the skinfolds using the following two formulas:

1. $D = 1.0764 - 0.00081(SI) - 0.00088(TR)$ (Sloan)

2. $D = 1.0852 - 0.0008(SI) - 0.0011(TH)$ (Pollock)

The formula used to calculate percent body fat is that of Keys and Brozek (81): $PF = 100(4.201/D - 3.813)$

Girths. Measurements of girth were taken using the procedures of Andersen (4) and Scott (131) at the following locations:

1. Calf -- bare right calf at point of maximum girth.
2. Thigh -- gluteal fold (angle made by the curve of the gluteus maximus with the near vertical line of the thigh.
3. Upper arm -- bare right arm midway between the tip of the acromion and the tip of the olecranon.
4. Chest -- maximum around thorax over breasts.
5. Abdomen -- minimum girth around abdomen.
6. Gluteal -- horizontally at position of largest circumference.
7. Forearm -- largest circumference below the elbow.

Bicycle ride to exhaustion. The subject pedaled the bicycle ergometer to exhaustion at 1080 kpm/min, trying to keep a pedaling frequency of 60 rpm in time with the metronome. A three-minute warm-up at 360 kpm/min preceded the test. Exhaustion was determined as the point at which the subject discontinued the proper pedaling rhythm for more than five seconds at a time (17).

Time trial. A time trial was performed on the same fairly flat, seven-mile loop. The subject avoided strenuous training on the day prior to each trial. Stretching and a short jog preceded each time trial so that the subject could run all-out. A male marathon runner

who was capable of running a faster time accompanied the subject to encourage as fast a time as possible.

Strength. A measurement of strength was made by determining the one-repetition maximum (19) for three different leg exercises: leg press, leg extension, and leg curl. The subject warmed up with stretching exercises for ten minutes. At the pre-determined weight for each exercise, the subject performed six repetitions and then one repetition at successively higher workloads until the maximum was reached. One minute rest was allowed between each test and the order remained constant.

Analysis of the Data

Progressive values of each test variable were graphed and objectively presented in Chapter IV. Trends were compared with those noted during other training studies.

Test item results were analyzed with respect to changes in training, specificity of training, and other influencing factors. Performance in the Western States 100 was also evaluated in relation to test data collected and training.

CHAPTER IV

RESULTS

The findings are objectively presented in Chapter IV. Chapter V contains a complete discussion of all results. Data in this chapter are presented under the following headings:

1. Maximal Oxygen Consumption.
2. Maximal Pulmonary Ventilation.
3. Ventilatory Equivalent for Oxygen.
4. Basal Metabolic Rate.
5. Blood Chemistry.
6. Heart Rate.
7. Body Composition.
8. Girths.
9. Bicycle Ride to Exhaustion.
10. Time Trial.
11. Strength.

Maximal Oxygen Consumption ($\dot{V}O_2$ max)

Maximal oxygen consumption has received wide acceptance as the primary determinant of cardio respiratory endurance capacity (7, 8, 39, 105, 127, 134) and is known to improve with endurance training (17, 18, 51, 63, 73, 86, 116, 125, 153). Any change in aerobic capacity should be reflected in a central (stroke volume) or peripheral adapation (arterio-venous oxygen difference). It is generally accepted that

initial adaptation appears to be due to increased central capacity as shown by increased stroke volume values (8, 32, 134). Secondary adaptation over a longer period of time appears to be due to peripheral mechanisms causing an increased arterio-venous oxygen difference. Many studies have reported approximately equal increases in stroke volume and arterio-venous oxygen difference (8, 32, 64). Increased extraction of oxygen by the working muscles appears to play as great a role in the increase in $\dot{V}O_2$ max with training as does the increase in maximal cardiac output.

$\dot{V}O_2$ max during a treadmill test has been shown to be at least seven percent greater than when performed on a bicycle ergometer (4, 100, 120, 134). Performance on a bicycle is commonly affected by weakness in the quadriceps and often a subject ceases cycling before the true centrally limited $\dot{V}O_2$ max is reached. Data on a BE may be increased by seven percent to make the figures comparable with those obtained on a TM (118, 134). Figures from this study appearing in parentheses include a seven percent increase. A significantly greater discrepancy in $\dot{V}O_2$ max values on a TM and a BE was found by Brown and others (20) studying six world or national class distance runners after three to four months of running 50-100 miles per week. $\dot{V}O_2$ max was 52.6 ml/kg-min on the BE and 68.8 ml/kg-min on the TM, a difference of 25 percent.

Normal college-age females are found to have an average $\dot{V}O_2$ max of about 40.0 ml/kg-min (46). $\dot{V}O_2$ max of female athletes are seen to

be substantially higher than this figure (Table 4.1). Long distance runners consistently have been measured at about 60 ml/kg-min. The highest value obtained to date on an adult female athlete is 74.0 ml/kg-min on Gusakova, the Russian Olympic cross-country skier, in 1964 (108). Brown and others (18) have recently reported values of 70.0 and 78.3 ml/kg-min on 10- and 12-year-old sisters involved in cross-country running.

$\dot{V}O_2$ is known to increase with training, but there is great diversity in the magnitude of gains in $\dot{V}O_2$ max in response to physical training (Table 4.2). According to Shephard (134) the largest gain in $\dot{V}O_2$ max due to training (and in the absence of preliminary bed rest) is about 20 percent. Gains have been observed to range from 0 percent to 93 percent (119). The great variation in change due to training is a result of many factors, for example, prior fitness level, intensity of exercise, frequency of exercise, and duration of training period. Either a low beginning fitness level or a high intensity training program seems to have caused the most notable changes in $\dot{V}O_2$ max. It is very difficult to compare the magnitude of changes among studies because of the lack of quantification of the many variables which affect $\dot{V}O_2$ max.

$\dot{V}O_2$ max in this study was shown to change significantly during the training period (Figure 4.1). The subject's minimal training during the first month was accompanied by a substantial drop in $\dot{V}O_2$ max (12 percent). During the following two months of non-running training, $\dot{V}O_2$

Table 4.1

Maximal Oxygen Consumption and Maximal Pulmonary Ventilation of Female Athletes

Investigator	# Subjects	Age	Subjects	$\dot{V}E$ max l/min (BTPS)	$\dot{V}O_2$ max ml/kg-min
Brown et al (18)	12	8-13	Distance runners	67.6	61.3
Brown et al (20)	6	15-26	National or world class distance runners	114.1	52.6 (BE) 68.8 (TM)
Burke & Brush (22)	13	15-16	Distance runners	101.71	63.24
Drinkwater & Horvath (48)	15	16-18	Track athletes	90.9	51.1
Hermansen & Andersen (66)	5	22-27	Norwegian cross-country skiers	99.0	55.0
Maksud et al (90)	13	15-30	Olympic speed skaters	96.5	46.1
Plowman (118)	--	---	Cross-country skiers	97.9	58.0
Saltin & Åstrand (127)	10	15-28	Best Swedish athletes	111.8	61.8
Wilmore & Brown (156)	11	24-37	Long distance runners	108.9	59.1
Dearborn	1	27	Long distance runner	121.2	66.5 (71.1)

Table 4.2

Response of Maximal Oxygen Consumption to Physical Training

Investigation	# Subjects	Age	Sex	Subjects	Training (duration, type, frequency)	$\dot{V}O_2$ max (ml/kg-min) start	$\dot{V}O_2$ max (ml/kg-min) finish	CHANGE
Atomi et al (9)	9	18-20	F	Sedentary coll. stu.	8 wk, BE, 2-4/wk	33.8	41.9	+ 24%
Brown et al (18)	12	8-13	F	Long dis. runners	12 wk, R, 5/wk	43.1	54.1	+ 26%
Burke & Franks (21)	16	16-18	M	Non-athletes	10 wk, BE, 3/wk	44.59	54.08	+ 21%
Cunningham & Hill (32)	17	21-48	F	Sedentary	9 wk, R, 4/wk	26.0	35.2	+ 34%
Davis et al (39)	9	40-45	M	Sed. middle-aged	9 wk, BE, 3/wk	31.1	40.0	+ 29%
Eisenman & Golding (51)	8	12-13	F	Normals	14 wk, R, 3/wk	38.1	44.8	+ 18%
Eisenman & Golding (51)	8	18-21	F	Normals	14 wk, R, 3/wk	42.7	49.6	+ 16%
Lesmes et al (87)	8	18-22	F	Healthy, untrained	8 wk, R, 4/wk	37.0	44.2	+ 19%
Lesmes et al (87)	8	19-21	F	Healthy, untrained	8 wk, R, 2/wk	40.6	44.9	+ 11%
Milesis et al (98)	59	20-35	M	Sedentary	20 wk, R/W, 3/wk	45.4	53.1	+ 17%
Pedersen & Jorgensen (116)	6	21-25	F	Healthy, sedentary	7 wk, BE, 2/wk	41.5	46.7	+ 13%
Pollock et al (120)	26	30-47	M	Sed. middle-aged	20 wk, BE, 3/wk	38.7	41.7	+ 8%
Pollock et al (120)	26	30-47	M	Sed. middle-aged	20 wk, R, 3/wk	36.8	41.1	+ 12%
Wirth et al (162)	17	19-23	F	Nor. coll. students	10 wk, BE, 3 wk	34.6	38.9	+ 11%
Withers (163)	7	18-29	F	Aust. lacrosse players	12 wk, R, 6/wk	44.0	52.9	+ 20%

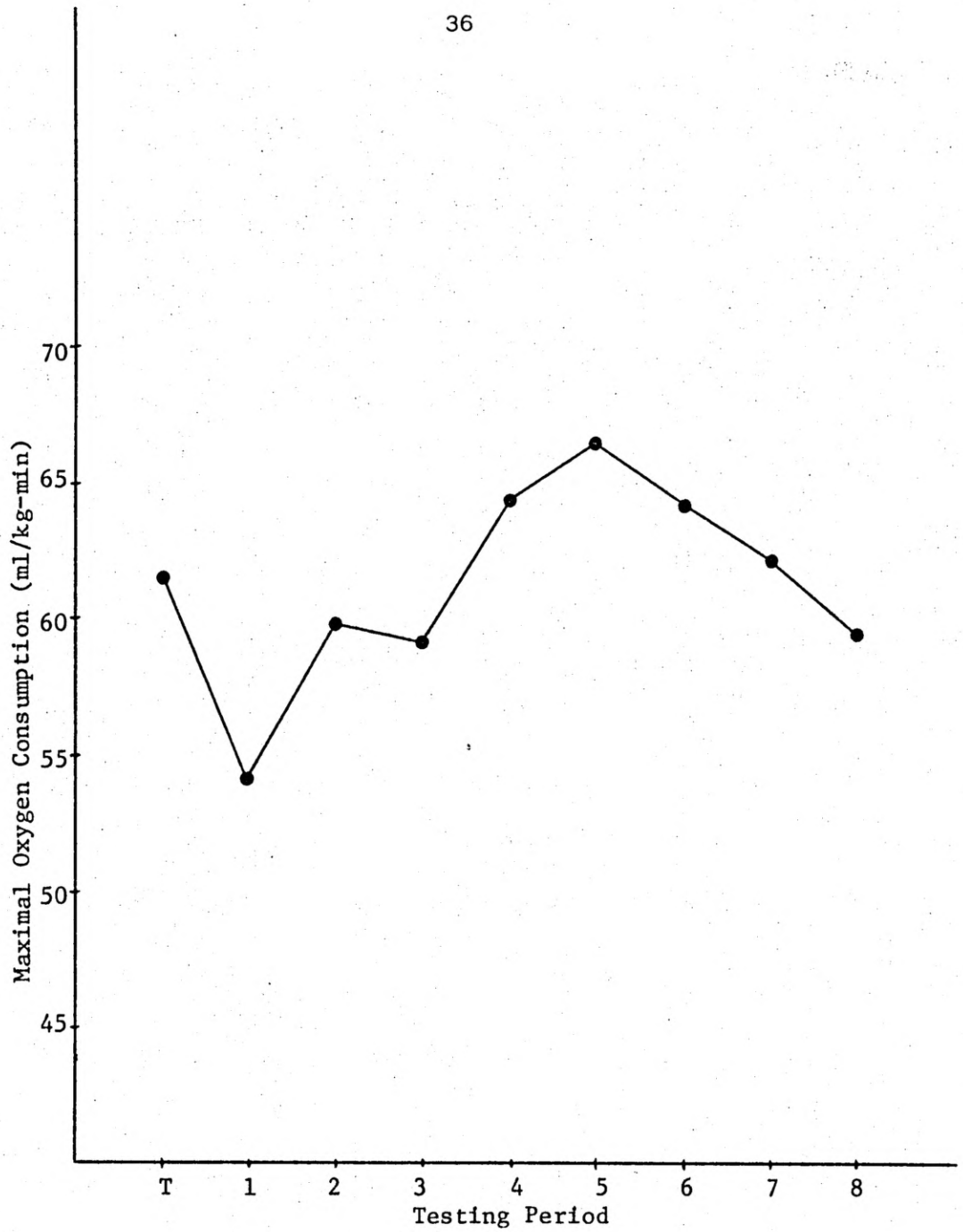


Figure 4.1. Maximal Oxygen Consumption.

max nearly increased back to trial levels. During this initial two-month period, training was primarily high intensity, with a small endurance component. Resumption of endurance running in the third month produced a significant increase in $\dot{V}O_2$ max. A peak value was reached during testing period #5, 66.5 ml/kg-min (71.1 ml/kg-min). A 23 percent increase in $\dot{V}O_2$ max was noted over the first four months of training. Running was reduced substantially in the final two months of training with a corresponding decline in $\dot{V}O_2$ max.

Maximal Pulmonary Ventilation ($\dot{V}E$ max)

Maximal pulmonary ventilation reflects the ability to move gas in and out of the lungs. A positive correlation exists between maximal $\dot{V}E$ and $\dot{V}O_2$, but $\dot{V}E$ max cannot be used for prediction of $\dot{V}O_2$ max. It has been suggested that $\dot{V}E$ max is actually not a well-defined performance variable (8, 118) and that the numbers are greatly influenced by body size.

$\dot{V}E$ max for normal females is about 40 l/min at age ten and about 85 l/min at age 20 (118). Table 4.1 shows comparative data on female athletes. The highest value observed for a female runner is 125.4 l/min (156). A 19-year-old swimmer is reported to have the largest $\dot{V}E$ max recorded for a female athlete to date, 148.4 l/min (118). Male athletes typically have $\dot{V}E$ max values considerably higher than females. Costill (30) found ten elite male marathoners to range from 144.7 to 181.2 l/min.

$\dot{V}E$ max has generally been shown to increase with endurance training (21, 39, 57, 64, 157). Pechar and others (115) reported 7.7 percent, 4.6 percent, and 4.2 percent increases with eight weeks of BE and TM training on college-age males. Grimby (57) noted a significant increase in $\dot{V}E$ max along with a higher $\dot{V}O_2$ max. Pollock (119) suggests that $\dot{V}E$ max will generally increase 10-20 percent unless values are rather high to begin with, and this increase has usually been seen to take place during the first six to ten weeks of training. In contrast, $\dot{V}E$ max was found by Brown and others (18) to be unchanged with 12 weeks of cross-country running, even though $\dot{V}O_2$ max showed a 26 percent increase. Subjects were in a partial state of training at the beginning of the study.

In this study $\dot{V}E$ max did not show any particular trend (Figure 4.2). It did not appear to increase with training. A significantly lower value of 105.5 l/min was measured during testing period #1 after one month of little training. The highest value attained by the subject, 121.2 l/min, was observed during the final testing period. Similarly high values of $\dot{V}E$ max, 118.5, 118.4, and 118.2 l/min, though, were also measured during testing period #5, the trial, and testing period #3, respectively.

Ventilatory Equivalent for Oxygen ($\dot{V}E/\dot{V}O_2$)

The ventilatory equivalent for oxygen is a measure of ventilatory efficiency, the amount of air ventilated for a given oxygen consumption. A greater respiratory efficiency (lower $\dot{V}E/\dot{V}O_2$ value) means

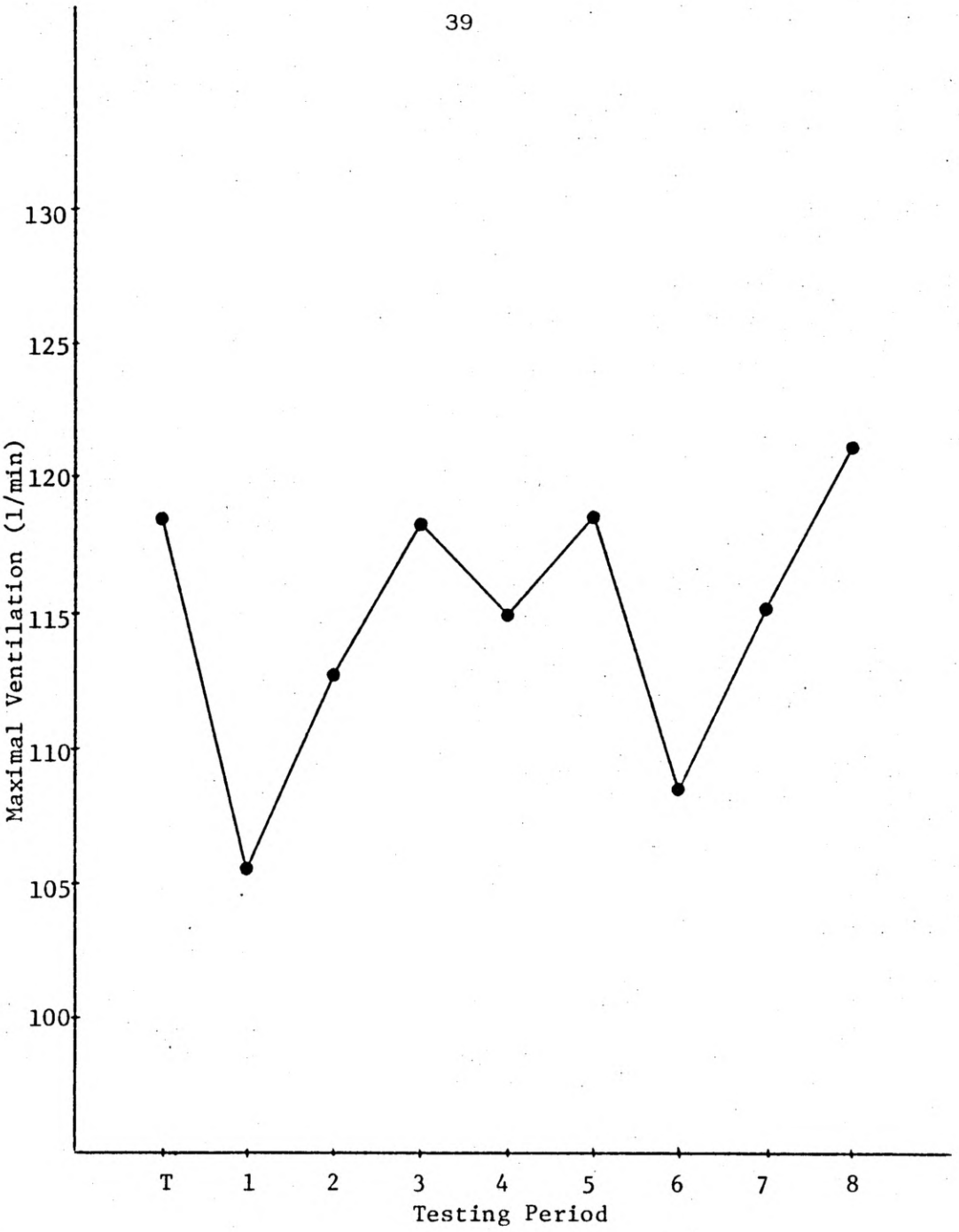


Figure 4.2. Maximal Pulmonary Ventilation.

that a smaller volume of air is necessary to obtain the same $\dot{V}O_2$, associated with a greater ability to extract oxygen. Endurance athletes are theorized to have lower exercise $\dot{V}E$ per unit metabolic rate than non-athletes or non-endurance athletes (92), a result of endurance athletes breathing less at comparable exercise intensities. There is very likely a genetic component.

Submaximal $\dot{V}E/\dot{V}O_2$ has been seen to decrease with endurance training (39) or remain unchanged (57, 115). $\dot{V}E/\dot{V}O_2$ at a submaximal workload decreased from 27.3 to 25.3, an 8 percent decrease, in nine middle-aged males undergoing BE endurance training for nine weeks (39).

$\dot{V}E/\dot{V}O_2$ at maximal levels has previously been shown to decrease or remain unchanged. Davis (39) has reported a 6 percent decrease over a nine-week endurance training program in middle-aged males. Grimby (57) reported no improvement in $\dot{V}E/\dot{V}O_2$, although significant changes occurred in $\dot{V}E$ max and $\dot{V}O_2$ max.

In this study $\dot{V}E/\dot{V}O_2$ was determined from BE test data. For comparison, values at 900 kpm/min are considered representative of submaximal $\dot{V}E/\dot{V}O_2$, and 1440 kpm/min values are used as maximal $\dot{V}E/\dot{V}O_2$. During the training period $\dot{V}E/\dot{V}O_2$ at maximal levels was seen to change more than at submaximal levels (Figure 4.3). A significant and steady decline in $\dot{V}E/\dot{V}O_2$ max was observed during the first five months of training (17 percent). In the final two months of training, a substantial rise (19 percent) in $\dot{V}E/\dot{V}O_2$ max was measured, while no real change occurred in the submaximal values.

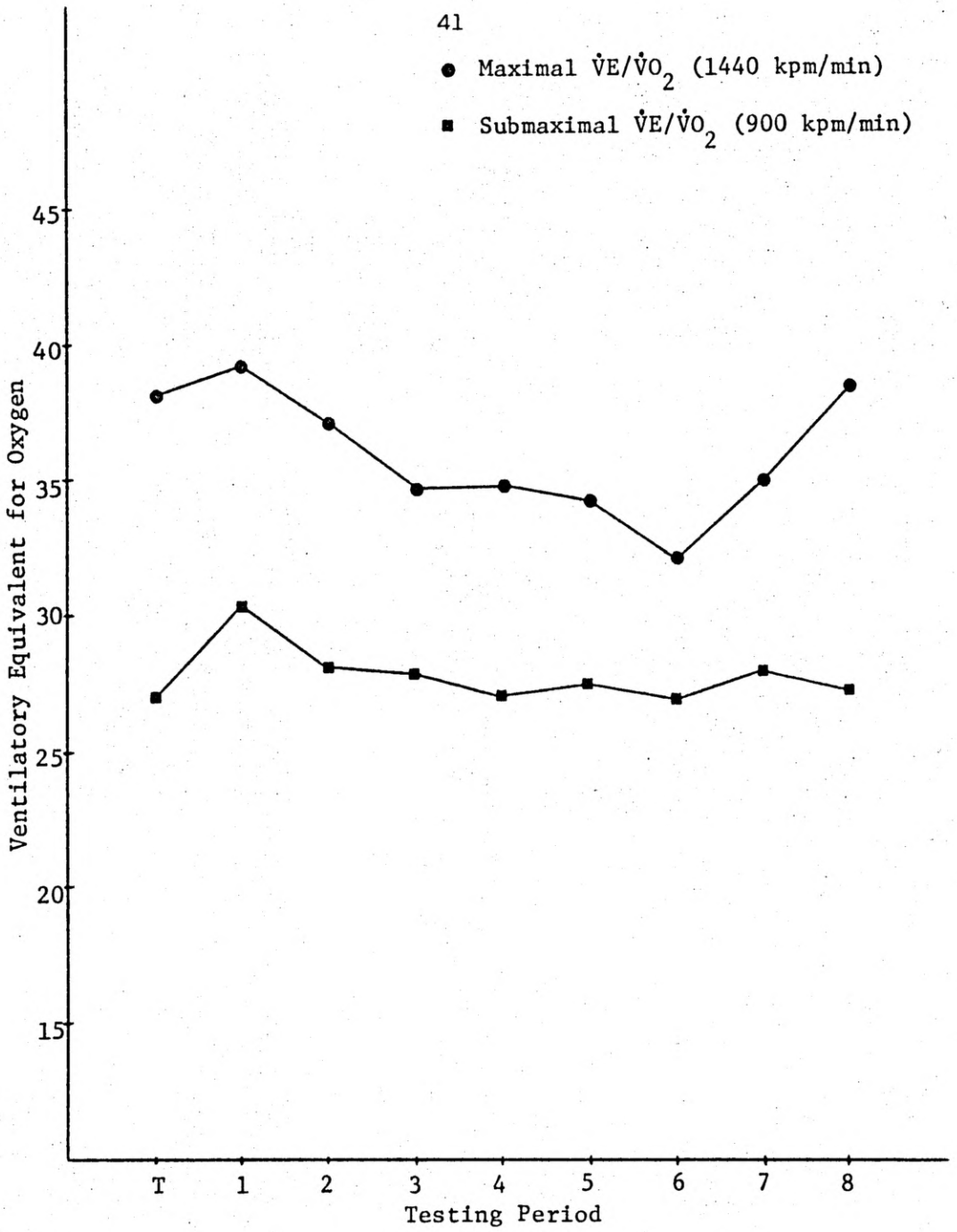


Figure 4.3. Ventilatory Equivalent for Oxygen.

Basal Metabolic Rate (BMR)

Basal metabolic rate, or resting oxygen consumption, reflects the velocity of blood flow and is a good measure of circulation rate (34). In studies performed on groups, there is relative uniformity among individuals, BMR usually falling within 10 percent of normal (49). There is also relative constancy in values found on individuals repeatedly tested over long periods of time. In studies performed on one individual, BMR has not differed more than 15 percent from normal and usually not more than 10 percent (49).

It is most evident from a review of literature that there are great differences among studies concerning the direction and magnitude of change in BMR while undergoing physical training. Increased blood flow shown to accompany increased activity sometimes causes a rise in BMR during periods of training (10, 34, 67). However, many studies have found conflicting evidence (85, 86, 128, 141).

One interpretation of the conflicting findings is offered by Schneider and Foster (128). When BMR is increased, muscle mass supposedly increases due to physical activity before any increase in cellular efficiency occurs. The added protoplasm increases the total oxygen requirement of the body. But if efficiency in cellular metabolism exceeds the effect of increasing lean body weight, the rate can be lowered. BMR remains unchanged if the increase in cellular efficiency is counterbalanced by the new production of muscle tissue.

Many studies have reported a decline with training. Kristufek (86) reported a decrease in BMR from -13 to -26 percent of normal over seven weeks of endurance running. He attributed the decline to increased relaxation, better circulatory efficiency, and a drop in body surface area. (It appears to this author that an increase, rather than a decrease, in body surface area would have occurred in Kristufek's training study with the decline in body weight, skinfolds, and girths which also took place.) Schneider and Foster (128) found seven of nine athletes in one experiment to experience a significantly lower BMR during training. Decreases of 4.4 to 14.9 percent were noted from swimming, football, basketball, and track training. They concluded that cellular efficiency exceeded the effect of the increase in muscle mass to cause a lowered rate.

Many studies, though, have indicated a higher BMR during and after training. It has been suggested that some of the emotional strain of training is reflected in the measurements, along with improved circulation (35). Baldwin (10) has shown that psychic stimulations affected BMR during a season of football training and competition, causing a higher BMR as the season progressed. A higher BMR was also noted as the time for critical games approached. Heusner (67) showed an increase with swimming training of 4.7 kcal/hr/m^2, although the change was only a slight one and still within the normal range of values. In another case study extending over a period of five years (35), it

was clearly shown that BMR increased with endurance training and closely paralleled the measures of blood flow.

BMR has also been observed to respond to many other factors, many of which are often not taken into consideration when reporting results. Steinhaus (141), Cureton (34, 35) and DuBois (49) have given excellent summaries. Values typically 5 percent higher in winter than in summer have been found. Cureton (35) has stated that the most important point of control in the testing of athletes seems to be eliminating very severe workouts the day before a BMR test. He found excessively high BMR's on tests performed the days after hard workouts. The lowest figures according to Krogh and Lindhard (49) reportedly are obtained after a diet rich in carbohydrates. Cureton has noted the reverse (35). In addition, premenstrual rise is found in some women (49). Extreme ectomorphy in body build also seems to affect BMR values. Highly trained ectomorphs have typically been seen to have BMR's well below those with greater mesomorphy/endomorphy (35). The need for more carefully controlled and standardized research is evident in regard to BMR testing.

During this study BMR was seen to decrease from 39.2 kcal/hr/m^2 to 34.0 kcal/hr/m^2 (Figure 4.4). The most significant change during any period was during the first month. A decrease of 3.8 kcal/hr/m^2 (9.4 percent) was measured. With the exception of the initial reading, the subject's BMR did not differ more than 2.8 percent from normal,

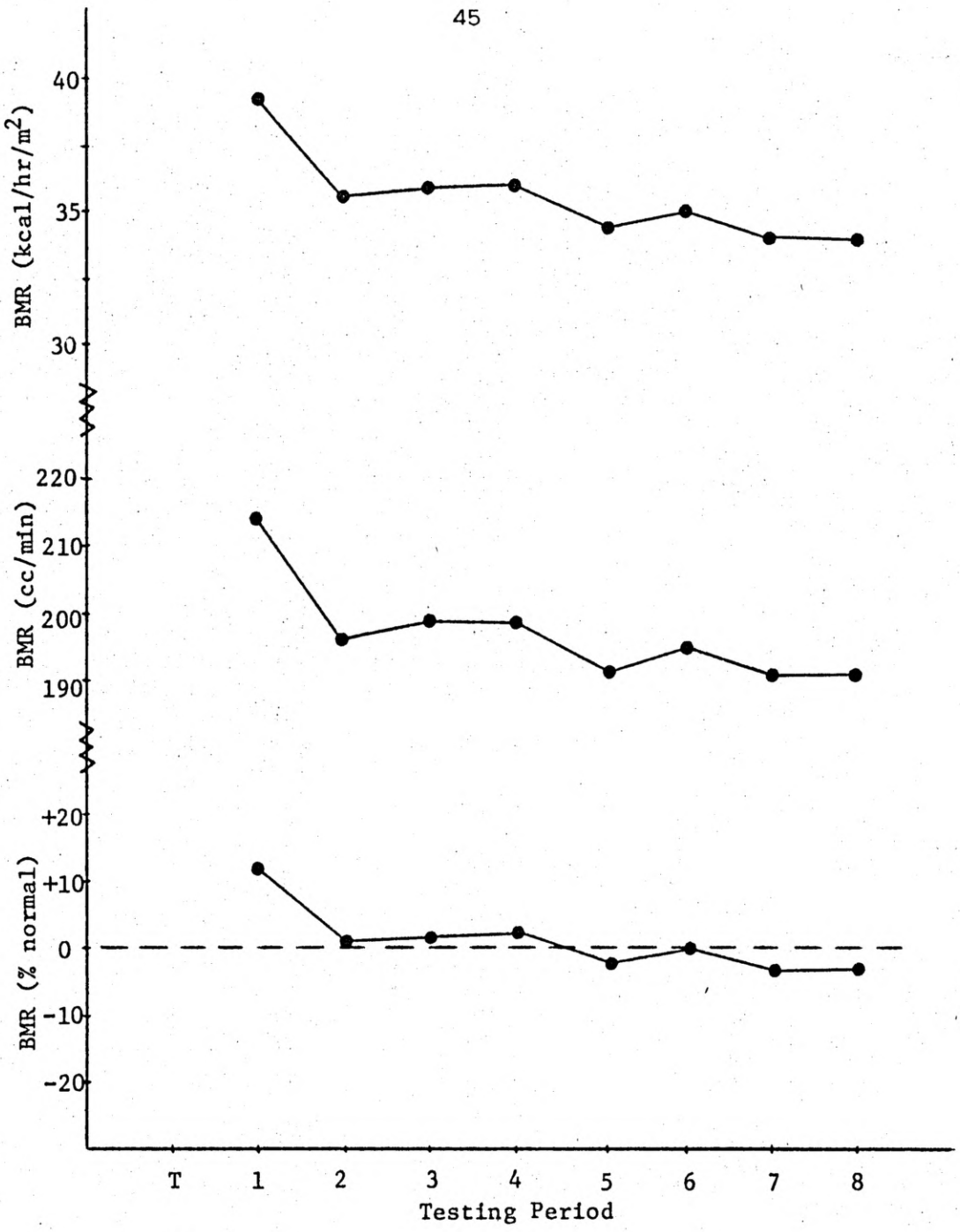


Figure 4.4. Basal Metabolic Rate.

although a generally decreasing trend was noted during the seven months.

Blood Chemistry

The three measures of blood chemistry used in this study, red blood cell count (RBC), hemoglobin (Hb), and hematocrit (Hct), are closely related. A change in RBC normally is accompanied by a corresponding change in both Hb and Hct (121). RBC refers to the number of red blood cells per cubic millimeter (mm^3) of blood. Hb is the part of the red blood cell that has a dissociable bond with oxygen. Values for Hb in this study are reported as a concentration in grams per decaliter (g/dl). Hct reflects the percentage of the blood that is solid matter.

There is a great difference between males and females with regard to these particular blood chemistry values. RBC in normal females is about $4.8 \times 10^6/mm^3$ as compared to $5.4 \times 10^6/mm^3$ for males (8). Average Hb in females is generally considered to be about 13.7 gm/dl (8), 30 percent smaller than males. Values recorded by Holmgren (71) and Hannon (62) on women are 13.09 gm/dl and 13.6 gm/dl, respectively. Dewijn (42) reported an average value of 14.35 gm/dl on 43 trained female athletes on the Netherlands Olympic Team. He also indicated that values below 12 gm/dl suggest anemia and possible iron deficiency. Females usually have average Hct readings of 42 percent as opposed to 47 percent in males (8). An average value of 40.3 percent was found in a study involving eight normal college females (62).

Astrand (7) has stated that the Hb concentration represents an excellent resting measure of fitness. Others (43, 44, 125) have concluded that blood in the resting state is not necessarily an important factor, since blood values of superior male athletes differ very little from the normal range of variation in untrained men.

There are conflicting reports in the literature concerning blood chemistry changes with training (Table 4.3). It seems widely accepted that endurance training increases the total blood volume and the total amount of Hb in the body (72, 83, 111), but that there is a much more variable influence on concentration of Hb (134).

Factors most commonly influencing these blood chemistry parameters in association with physical training include dilution, severe exertion, menstrual periods, dehydration, and amenorrhea. The first three generally result in lower or unchanged values. An increase in total blood volume, which has repeatedly been shown to result from training, without a corresponding increase in RBC acts to dilute Hb concentration. Severe exertion has been theorized to cause a temporary destruction of RBC (34) due to higher body temperatures. Yoshimura (121) noticed that the greatest effects are evident about three days after the start of heavy exercise, an occurrence which he has labelled "sports anemia." A rebound seems to occur within a few days, sometimes to even higher levels. Schneider and Havens (129), though, have concluded that lower readings are a result of a stagnation in some of the

Table 4.3

Blood Chemistry Responses to Physical Training

Investigator	Subjects	# Sub-jects	Age	Sex	Training (duration, type, frequency)	Hb*	Hct*	RBC*
Brown et al (17)	Col. basket-ball players	32	--	M	8 wk, R, 6/wk	-	NC	
Cunningham & Hill ((32)	Sedentary	17	21-48	F	9 wk, R, 4/wk	NC		
Cureton (34)	Sed. adult	1	43	M	6 mo., R, --	+		+
Heusner (67)	Sed. past Olympic swimmer	1	26	M	23 wk, SW, 6/wk	-		+
Holmgren et al (72)	Normal adults	87	28-47	M/F	12 wk, R, 4/wk	-		
Knowlton & Weber (85)	Long dis-tance run-ner	1	--	F	17 mo, R, 6/wk	NC		
Oscai et al (111)	Sed. adults	14	26-64	M	16 wk, R, 3/wk	-	-	NC
Rasch et al (121)	Quantico Phy-sical Train. Platoon	16	--	M	4 wk, R, 6/wk	NC	NC	NC
Schneider & Havens (129)	Athletes train-ing for 2-mi run	2	--	M	3 mo, R, 6/wk	+		+
Wirth et al (162)	Nor. coll. students	17	19-23	F	10 wk, BE, 3/wk	NC	NC	

*Key: NC = no change
+ = increase
- = decrease

capillaries due to extreme fatigue, rather than a destruction of RBC.

On the other hand, physical activity slightly accelerates the rate at which RBC are produced (61). If there is a greater increase in RBC in proportion to the blood volume increase, counts could be elevated. Dehydration could similarly affect blood chemistry, causing higher concentrations.

There has been particular interest in the female athlete with regard to blood chemistry. DeWijn (42) found that about 25 percent of his female athlete subjects possessed lower than normal RBC counts during training and/or competition. By comparison, only 8-9 percent of sedentary females and male athletes showed the same tendencies. On the other hand, it has been suggested (54) that prolonged amenorrhea could result in a higher Hct, possibly acting as a packed RBC infusion, thus increasing the endurance performance of amenorrheic females (see Chapter V).

During this study no particular trend was observed in blood chemistry measures (Figure 4.5). Substantially lower RBC, Hb, and Hct were again found during periods #6 and #7. Values for all three parameters did not deviate substantially from accepted average values for females.

Heart Rate (HR)

Resting. Resting HR is a measure of circulation in the resting state and has been used as a determinant of physical fitness levels

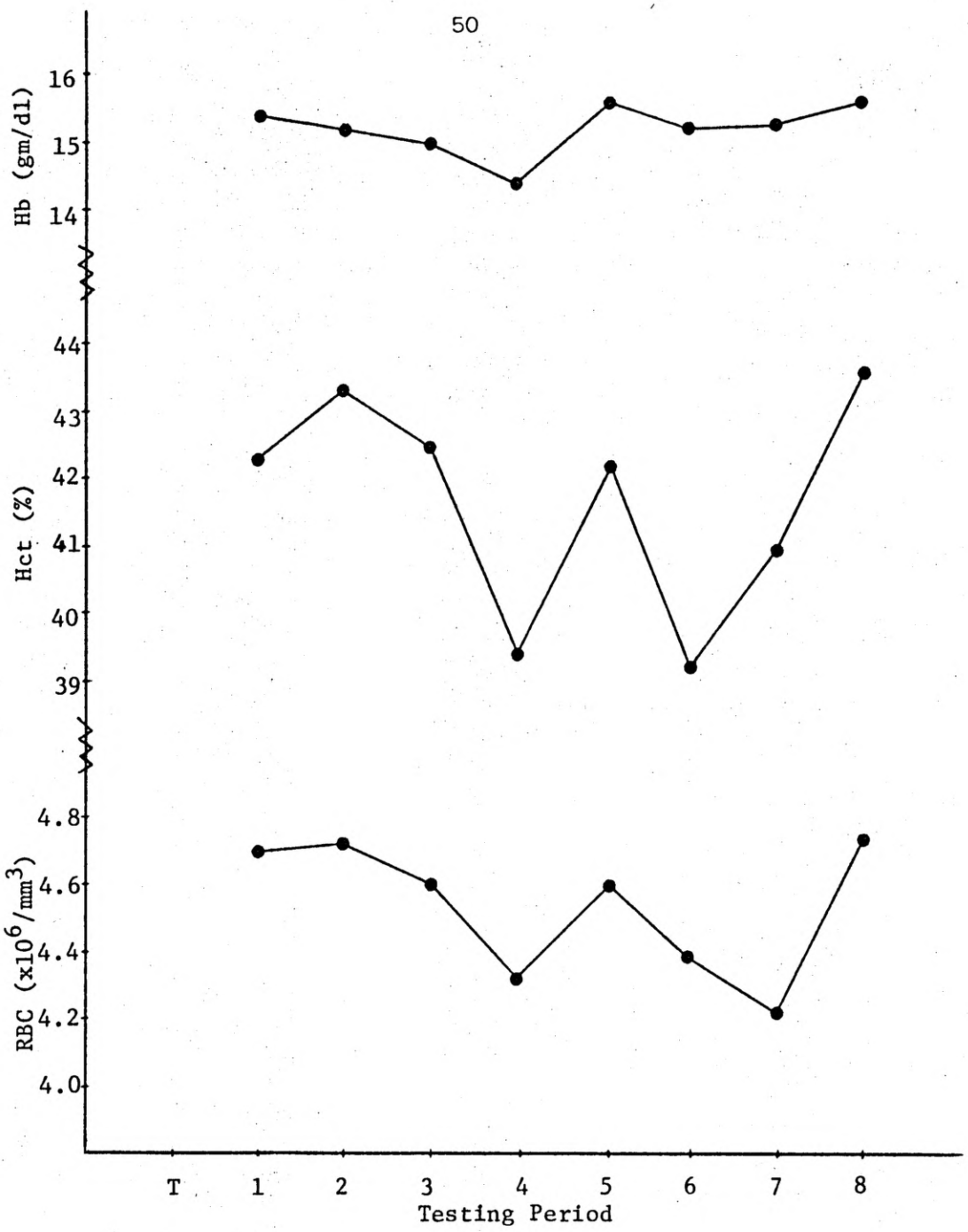


Figure 4.5. Blood Chemistry.

(65). Low resting HR's are seen in endurance athletes (Robinson), but also in healthy non-athletes (43). A low resting HR is probably chiefly genetic, although it is influenced to some extent by training.

Numerous studies have noted a decrease in resting HR with progressive physical training (3, 16, 63, 65, 67, 71, 85, 86, 120, 143). Kristufek (86) noted a 20 percent decrease with seven weeks of endurance running. The magnitude of cited change in the literature was dependent upon the initial fitness level.

However, resting HR was seen not to change in two studies (1, 17). Athletes were observed to be in a partial state of training at the beginning of the studies. A college varsity track and field team (1) trained and competed for three months with no change in resting HR. With eight weeks of preseason conditioning for basketball season, there was also no change in resting HR observed in college males (17) for a similar reason.

Resting HR's in the 40's are not unusual among endurance athletes. Resting HR in one female distance runner (85) ranged from 39-52 bpm over a 17-month period of training. Internationally renowned male distance runners (44) were found to average 54 bpm while in training, ranging from 36-62 bpm. While detrained, resting HR ranged from 47-78 bpm.

During this study, resting HR did not change significantly. The subject was in a partial state of training at the beginning of the

study, with resting HR averaging 45 bpm at that time. In addition, there may have been other factors prohibiting finding a true resting value (see Chapter V for further discussion).

Maximal. Maximal heart rate (HR max) is the highest HR reached during very strenuous exercise. HR max is not usually affected by training, although the level of effort required to produce it is increased. Wilmore and Sigerseth (160) reported HR max to be independent of endurance performance.

HR max varies with age more than it does with training (7, 8). In reports on female athletes of approximately the subject's age (71, 90, 118, 136), values ranged from 187-194 bpm. In one study (20), HR max was measured both on the BE and the TM on elite female long distance runners. Testing mode perhaps makes a difference, as a HR max of 193 bpm was measured on the TM, as compared to 188 bpm on the BE. It has been suggested that the lower maximal HR in cycling exercise is due to the early development of muscle fatigue in the lower extremities (100).

HR max has repeatedly been shown to be unaffected by training (39, 51, 87, 116, 136), regardless of the beginning fitness level of the subjects. Only one conflicting report was found in the literature. Pechar and others (115) found HR max to be significantly lower in all of his groups after eight weeks of training on the BE and the TM. Possibly this is a result of the large error factor in measuring HR max after exercise.

Maximal HR was consistently about 187 bpm as measured during the test for $\dot{V}O_2$ max on the BE (Figure 4.6). Only during the final test in June was a higher HR max (193 bpm) observed, when all submaximal HR's were also seen to be quite high. HR max was also apparently reached during the TM run, although the test was originally intended to be entirely submaximal. Maximal HR found on the TM was consistently 190-200 bpm (Figure 4.7), with the exception of one testing period.

Submaximal. Since an endurance run is performed at a submaximal level, it is important to consider submaximal measures which could help explain variance in endurance. Many studies have explained performance results exceeding prediction from $\dot{V}O_2$ max by observing low submaximal HR's. Submaximal exercise HR has been shown to be reduced with training (32, 53, 59, 60, 151). A lower HR response to exercise indicates an improved cardiovascular system, representing a greater stroke volume and/or arterio-venous oxygen difference. This reflects, in part, a more efficient transport mechanism for delivering blood to the working muscles (138, 152).

It is well-accepted that training reduces HR submax at a given workload (60, 87). Ten weeks of jogging at least three times per week produced significant reductions in exercise HR of middle-aged men (151). Decreases of 8.3 to 12.8 bpm were observed for the six-minute submaximal test. Other studies using the Astrand submaximal test observed similar results (84, 85, 143). Wenger (154) found HR submax to be reduced after

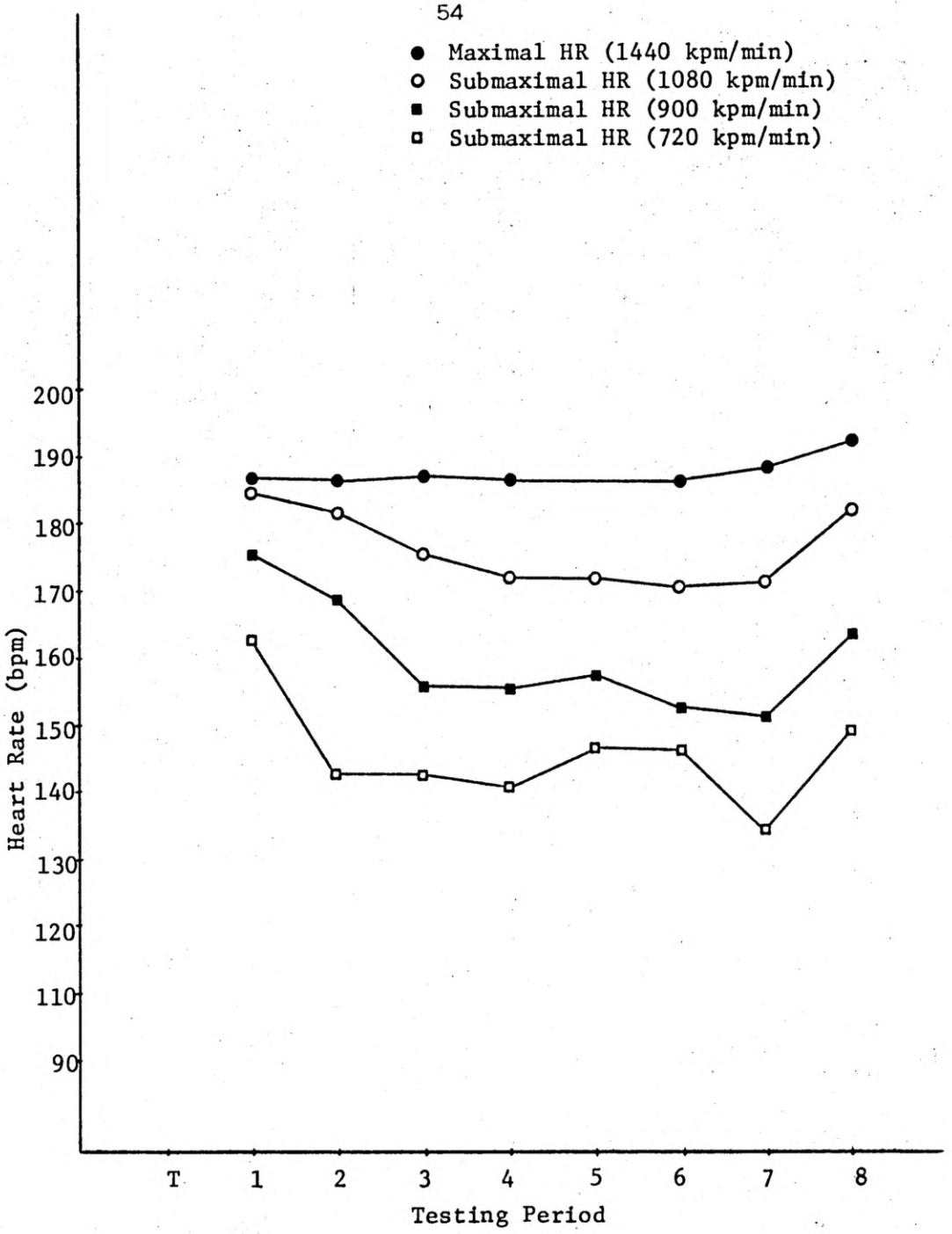


Figure 4.6. Heart Rate During Test for Maximal Oxygen Consumption.

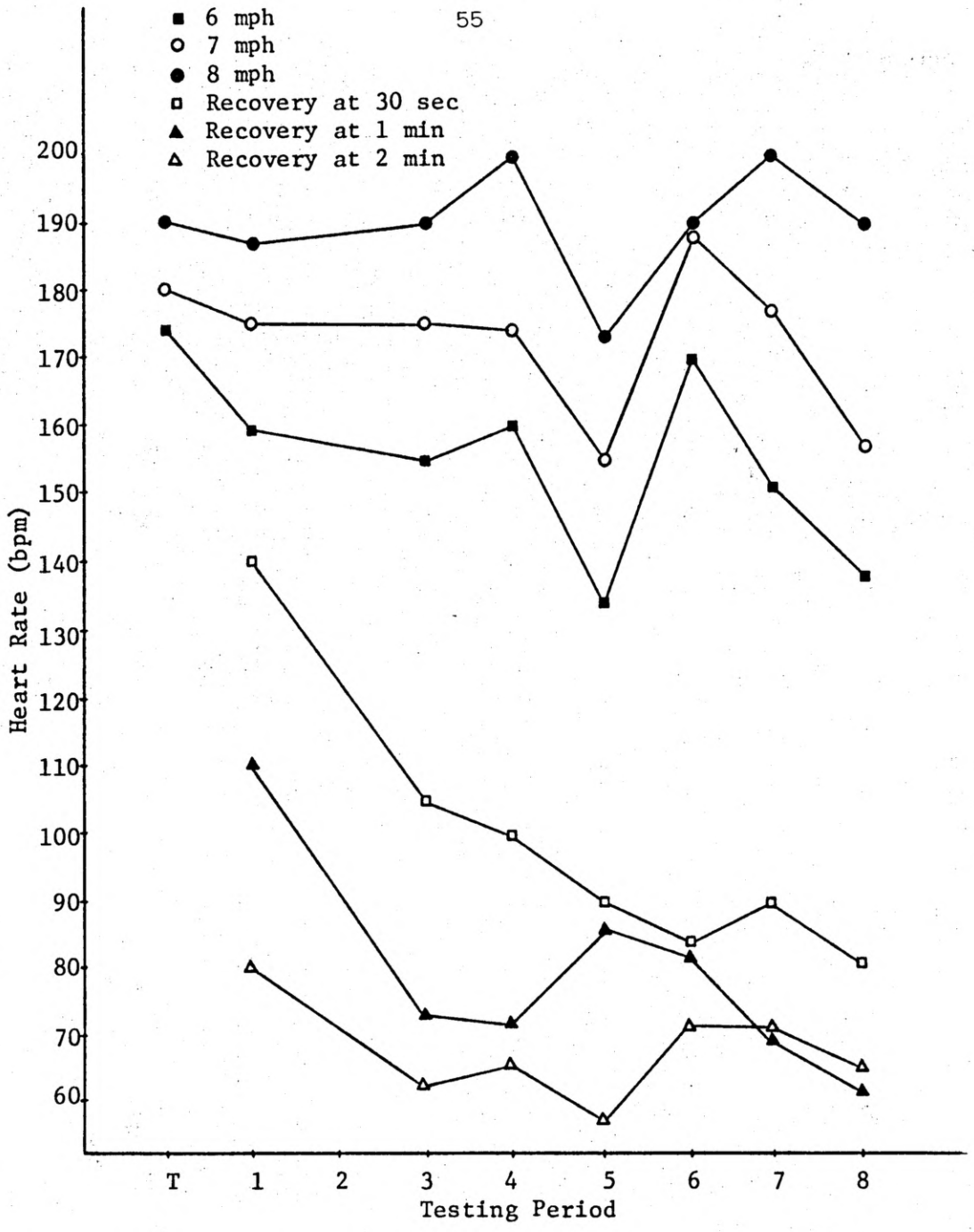


Figure 4.7. Heart Rate During Submaximal Treadmill Exercise and Recovery.

training, with much greater absolute reductions in HR occurring in the group with a low initial fitness level.

Submaximal HR responds similarly to training changes in superior athletes. An Olympic canoeist (6) improved physical condition through cross-country running and skiing with a corresponding lower submaximal HR. HR was seen to rise when training was limited to paddling alone and then again when a broken rib hindered training.

HR submax was measured for this investigation both on the TM and the BE. HR responses to the two modes of testing were very different. Specificity of training and testing (see Chapter V) is a possible explanation for some of the difference.

TM HR showed a very slight decline over the first three months while the subject was engaged in non-running workouts (Figure 4.7). The most dramatic change was a significant drop in HR submax at all three TM speeds during testing period #5, after the subject had been running for two months. HR declined 26, 19, and 17 bpm at six, seven, and eight mph, respectively.

Submaximal HR measured on the bicycle ergometer (Figure 4.8) showed a significant decrease of 36 bpm during two months of non-running training, between testing periods #1 and #3. The BE was used frequently in training during that period. During running training of the next three months, HR remained essentially unchanged on the BE. A similar

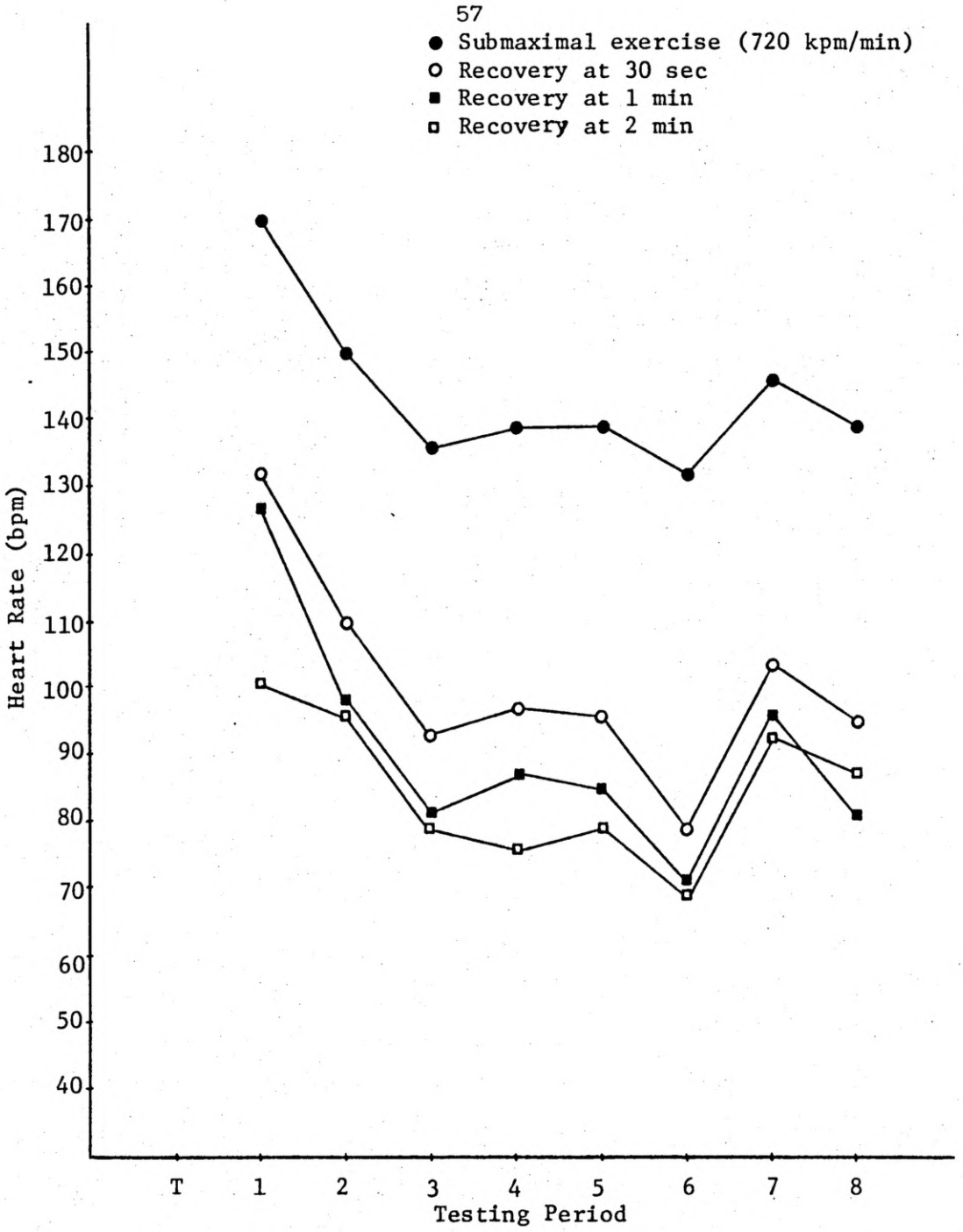


Figure 4.8. Heart Rate During Submaximal Bicycle Ergometer Exercise and Recovery.

trend was noted for HR submax measured during the test for $\dot{V}O_2$ max on the BE (Figure 4.6).

Recovery. Recovery after exercise has been found to occur more rapidly after a period of physical training (138, 151). The cardiovascular cost of an exercise can be determined by the speed with which the HR recuperates (34). Familiar "step tests" are based on this accepted physiologic principle.

Recovery is shown to be improved with physical training (16, 17, 34, 84, 86, 143, 151). During three months of track and field training and competition, Adams (1) noted a decrease only in the distance runners, in spite of already much lower beginning values. Knowlton and Weber (85) found recovery HR to significantly change in a female distance runner and observed the first reading after cessation of exercise to be the most discriminative. In addition, HR was sometimes seen to fall then rise slightly in the recovery period. Morehouse and Tuttle (106) similarly noted that there is occasionally a secondary rise in pulse rate, occurring at about 1.5 minutes after the exercise, especially after more strenuous exercises. They concluded that it is a normal but variable phenomenon.

A significant reduction in TM (Figure 4.7) and BE (Figure 4.8) submaximal recovery HR at 30 seconds, one minute, and two minutes was observed in this study. Recovery HR seemed to respond similarly on the TM and the BE. The largest decrease observed in both was between test-

ing periods #1 and #3, during intense non-running training while recovering from a knee injury. HR was seen to drop 35 bpm (25 percent), 37 bpm (34 percent), and 17 bpm (21 percent) on the treadmill and 39 bpm (30 percent), 46 bpm (36 percent), and 21 bpm (21 percent) on the bicycle ergometer during the two month period. A more gradual but significant decrease occurred on the TM with resumption of running training, especially with the 30 second recovery HR.

Body Composition

Body composition is an important factor in endurance performance, since excess fat which must be transported makes no positive contribution to performance. Amounts of subcutaneous fat, as determined by skinfold (SF) measurements, have been found to be highly correlated with endurance performance (34, 58, 77).

The normal range of percent body fat (PF) for college women of the subject's age is 20-25 percent (118). Wilmore and Behnke (155) reported 25.7 percent for 128 college-age females.

Successful female long distance runners are characterized as having little body fat (Table 4.4). It remains to be determined whether this is primarily a result of training or of inherited traits. It is difficult to separate cause and effect (11). Body fat in six world or national class women distance runners was measured to average 11.7 percent (20). A low of 6 percent was observed. Eight female runners (110) competing at the Olympic Games in Munich in 1972 had an average of

Table 4.4

Body Composition of Female Normals and Athletes

Investigator	# Sub-jects	Age	Subjects	% Fat	SKINFOLDS					
					TR	TH	CA	SU	SI	AB
Burke & Brush (22)	13	15-16	Distance runners	--	7.7	--	--	8.0	7.0	--
Katch et al (77)	--	--	Normals	25.5	16.8	28.2	22.5	16.7	23.8	--
Maksud et al (89)	26	18-21	Varsity athletes	19.4	16.2	--	--	10.6	9.9	13.5
Malina et al (91)	66	17-25	Track athletes	19.0	12.0	--	--	10.0	13.0	--
Novak et al (110)	8	20-27	Olympic runners	13.3	9.8	13.3	7.7	6.5	6.4	6.4
Sinning et al (137)	5	18-28	US Nordic ski team	16.1	13.0	19.9	21.2	8.5	11.4	10.4
Wallace (150)	31	17-42	Normals	24.8	22.4	31.6	--	14.7	9.2	14.9
Dearborn	1	27	Long distance runner	12.6	10.0	8.0	8.0	7.0	7.0	7.0

Male

13.3 percent fat. A mean relative body fat of 15.2 percent was found for 11 women long distance runners of national and international caliber and mean age of 32.4 years (156). The three best runners out of this group, on the basis of competitive performances in distances between two miles and the marathon, averaged 7.0 percent in relative body fat.

Systematic endurance training has repeatedly been shown to decrease PF (39, 86, 95, 104, 120, 150). In top athletes, significant variations in body composition occur regularly in relation to the intensity of training, although it is relatively less apparent than in untrained or obese subjects (114). The changes in body composition during training often take place without noticeable changes in body weight (BW) (88, 104, 142). A varsity track team was seen to significantly decrease in five out of six SF measurements over a three-month season with no change in BW (1). Normal high school girls trained by walking, running, and jogging for 15 weeks and decreased the sum of SF by 16 percent with no corresponding change in BW (104). Typically no change in BW was observed when normal or trained subjects underwent a period of training. Weight is not a good guide to fat loss, possibly because fat loss can be compensated for by an increase in muscle mass due to exercise (82).

When a loss in BW during training was reported, subjects were usually obese or had been completely inactive for a period of time (39,

86, 120, 150, 163). Sedentary middle-aged women trained five days per week for 16 weeks with significant decreases in SF measurements and BW (143). Moody and Wilmore (104) found a significant reduction in the sum of SF (23.5 percent) along with a decrease in BW when obese high school girls trained for 29 weeks.

A decrease in body weight and percent fat has been theorized as one of the possible causes of secondary amenorrhea and oligomenorrhea in female athletes (37, 38, 54). Degree of physical exertion, as shown in mileage per week, has also been seen to be directly proportional to the degree and incidence of menstrual abnormality. It is theorized that there is no single amount of training, weight loss, or percent body fat that induces amenorrhea, but that each woman has a different threshold. Regular menses can be expected to return with a decrease in intensity of training and gain in body weight.

In this study, body composition changed significantly during the seven months (Figures 4.9-4.11). Six of the seven skinfold measurements decreased (Figure 4.9) and one remained unchanged. Most of the change was seen during the first three months of training. The most significant decreases in SF over the entire seven months occurred at the abdominal (44 percent), thigh (39 percent), suprailiac (39 percent), and cheek (39 percent). Substantial decreases were also observed at triceps (35 percent) and calf (20 percent). No significant change was seen in the subscapular SF. Abdominal, suprailiac, and tricep SF showed

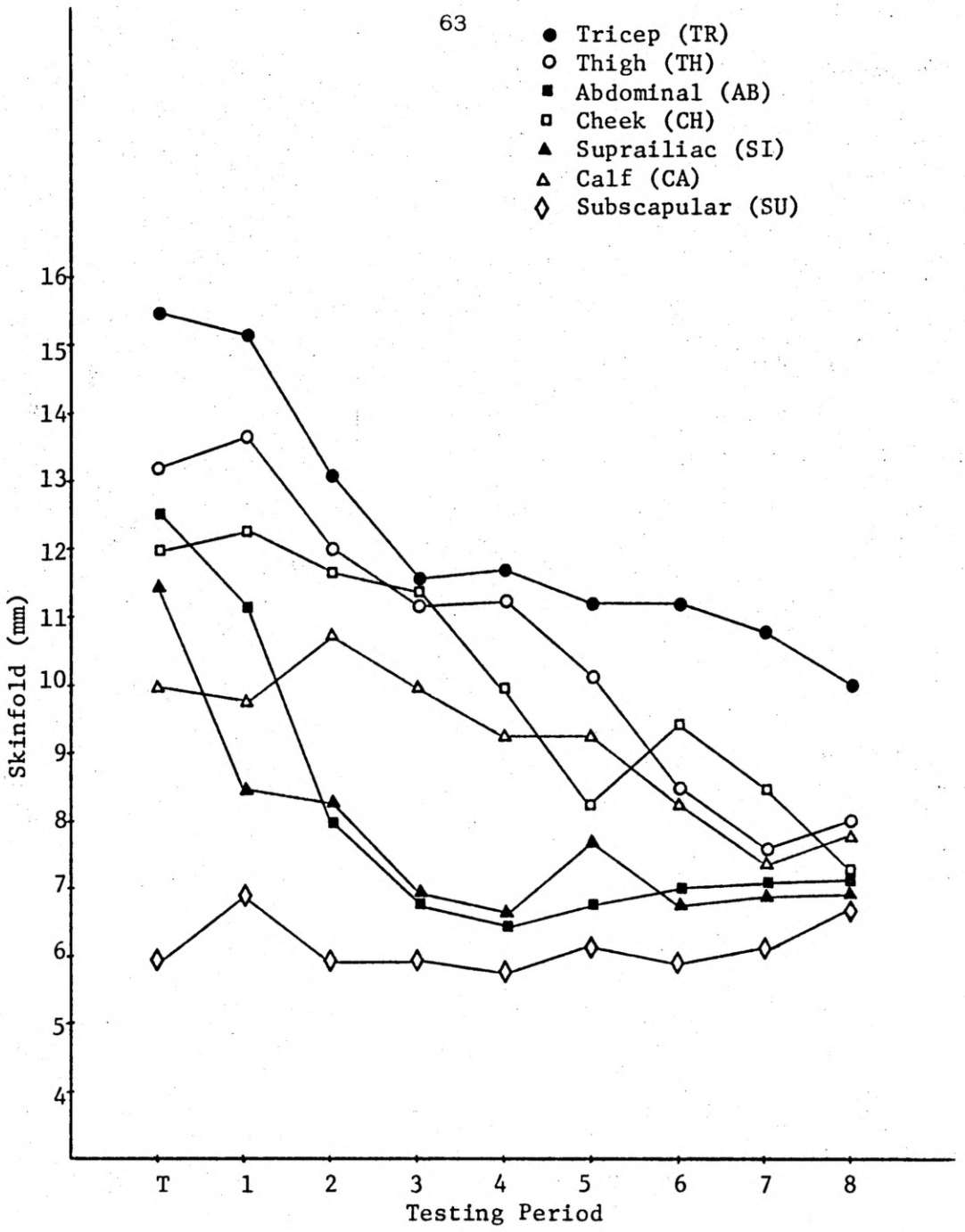


Figure 4.9. Skinfold Measurements.

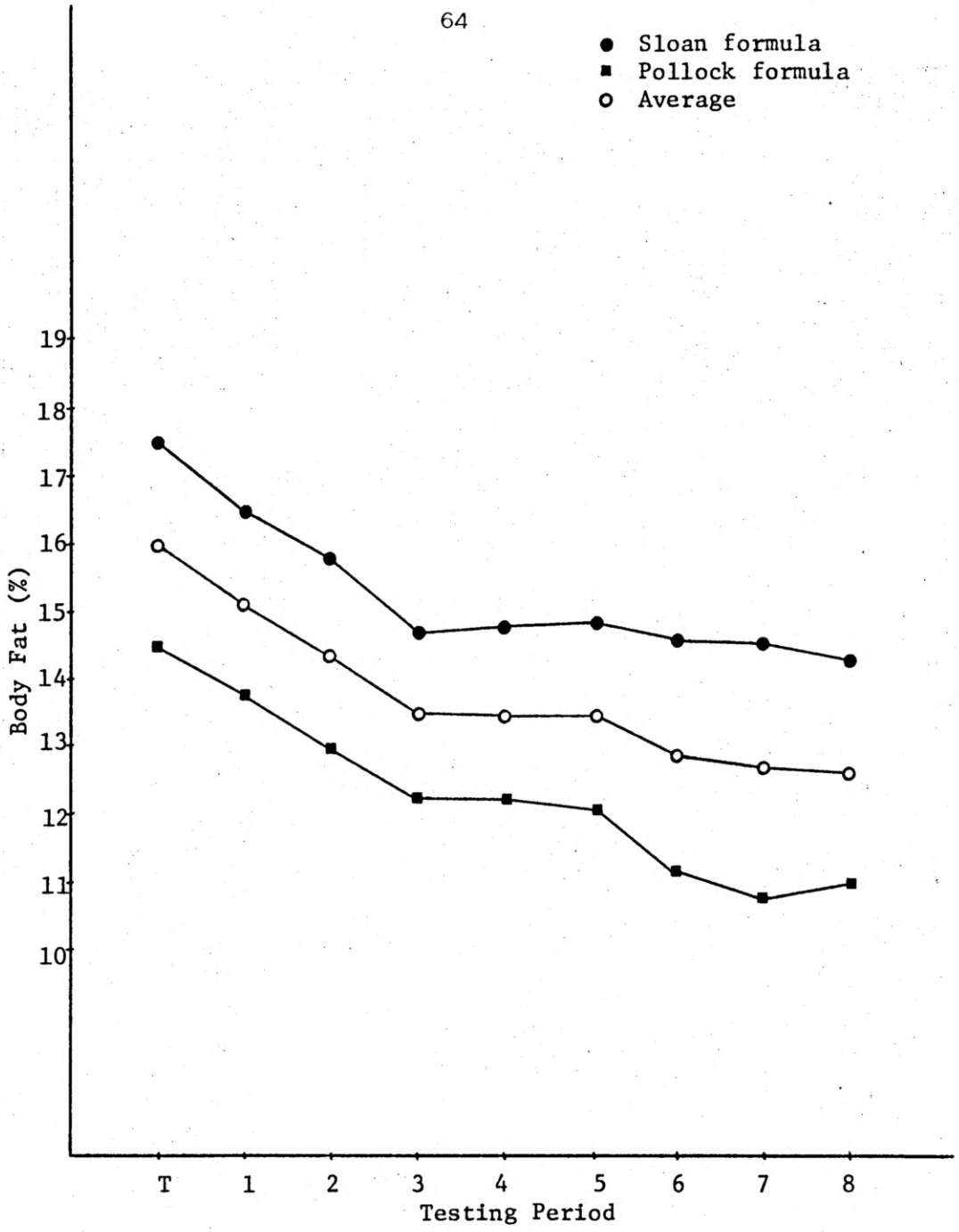


Figure 4.10. Percent Body Fat.

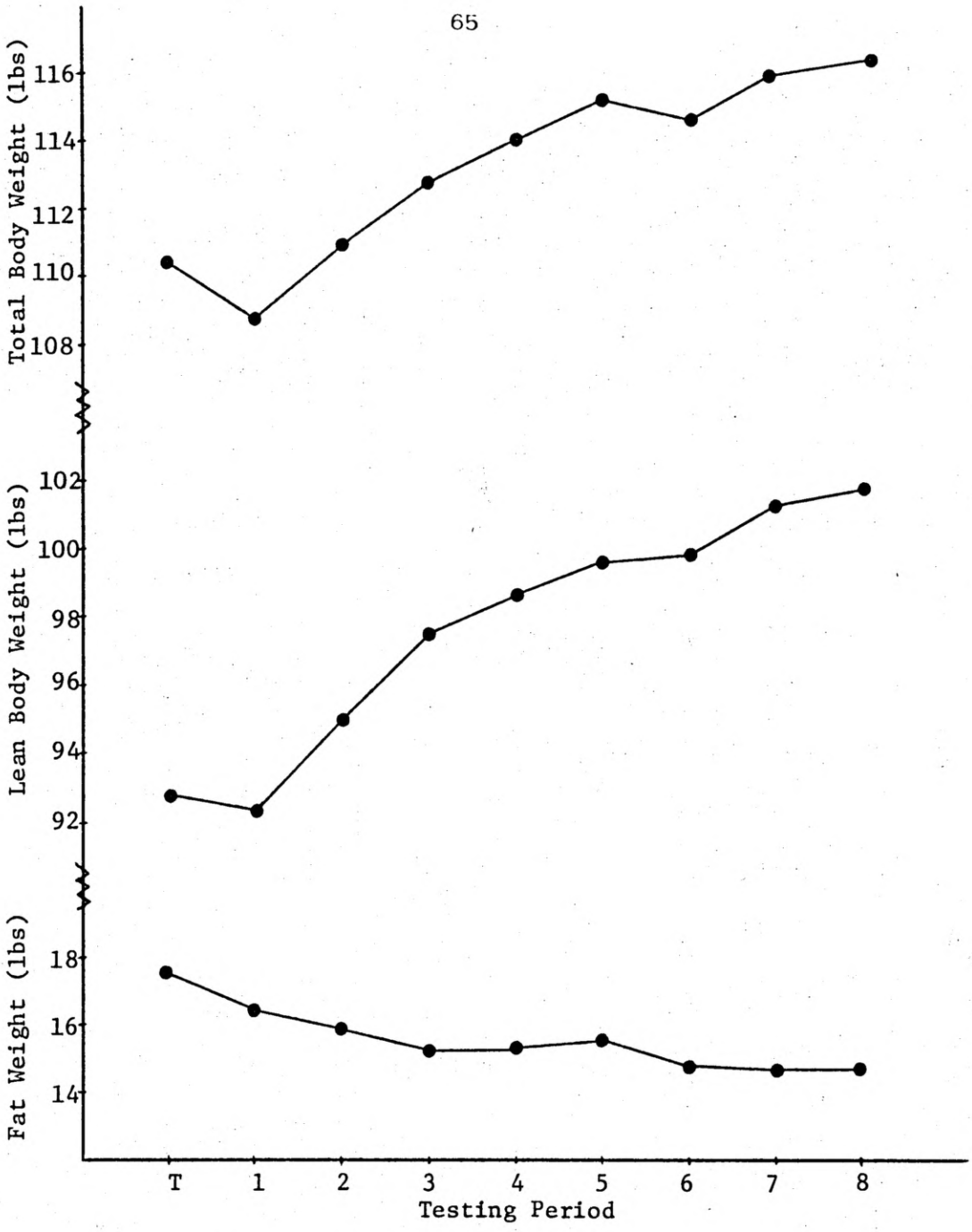


Figure 4.11. Body Composition.

most of the change during the first three months of training, while the thigh and calf decreased more gradually throughout the entire seven months. The cheek SF did not show any real change until the fourth testing period, after running had been resumed.

Percent body fat was calculated from the SF measurements as previously described. From the Sloan density formula which used the tricep and suprailiac SF, PF decreased (Figure 4.10) from 17.5 percent to 14.6 percent. The Pollock formula used thigh and suprailiac SF. Relative fat decreased from 14.5 percent to 10.8 percent, showing a larger percent improvement (26 percent) than the Sloan formula (17 percent).

Lean body weight (LBW) was calculated by subtracting fat weight (FW) from BW. Fat weight was computed using average PF and BW. BW increased almost six pounds (Figure 4.11). BW rose gradually over the seven-month period, with the exception of a decline during the first month. The subject gained a total of 8.8 pounds of LBW. A loss of almost three pounds of fat was observed during the training program. An initial loss of 1.2 pounds of fat during the first months was the most significant change, accompanying a corresponding loss of BW.

Girths

Increases in muscular strength generally are accompanied by increases in cross-sectional area. Girth measurements are the indirect assessment of cross-sectional area used in this study. Girths in some areas merely reflect changes in adipose tissue. Unfortunately, girth

measurements often do not selectively measure changes in muscle mass or fat tissue. A decrease in adipose tissue accompanying muscle hypertrophy may cause no measureable change in girth.

Muscular girths have sometimes been shown to increase with strength and weight training (2, 95). Much greater changes in muscular girths of male subjects have been observed and have been attributed to their higher plasma content of testosterone (95). During a four-week isotonic weight training program a significant increase in girth measurements, accompanied by a decrease in all SF values, was shown for male karate class members (2).

Girth measurements have been seen to decrease with endurance running training, accompanying a decline in BW and PF (34, 103, 104, 120). Cureton (34), using himself as a subject, reported a reduction of calf, thigh, gluteal, and upper arm girths associated with fat loss and a weight loss of over ten pounds. His training consisted of distance running and swimming, although he began the testing after being completely inactive for six months. In a study by Moody and others (104) only the obese group of females exhibited any significant changes in BW and girth measurements. In a case study, Kristufek (86) reported that body girths on the whole were decreased after seven weeks of endurance running, with a corresponding drop in BW and a reduction of SF measurements.

It appears that girths decreased significantly only in studies

involving obese or previously sedentary subjects. Most results tend to support the idea that increased muscle development compensates for a subcutaneous fat decrease, resulting in no change in circumference (1, 19, 113, 114). Girth and SF measurements taken on a college varsity track and field team during a season of training and competition (1) showed no significant changes in any girths, but a large decrease in SF. With six months of weight training (19), women throwing event athletes were found to show only minimal evidence of muscular hypertrophy, yet considerable increases in strength.

During this study, four girths increased (Figure 4.12), although the changes were slight: thigh (3.5 percent), gluteal (3.3 percent), forearm (2.2 percent), and calf (1.6 percent). Abdominal and upper arm girths fluctuated somewhat but remained essentially unchanged. Chest girth showed an overall decrease of 2.1 percent. Changes were noted gradually throughout the entire training period.

Bicycle Ride to Exhaustion

A reproducible work task exceeding anaerobic threshold has been used as a measure of endurance change. Use of a BE for this type of test provides an indirect measure of aerobic capacity and leg strength. These parameters have previously been shown to improve with intense endurance training.

Fardy (53) used an all-out ergometer ride in a soccer training / detraining study. Time of the ride was significantly improved at five

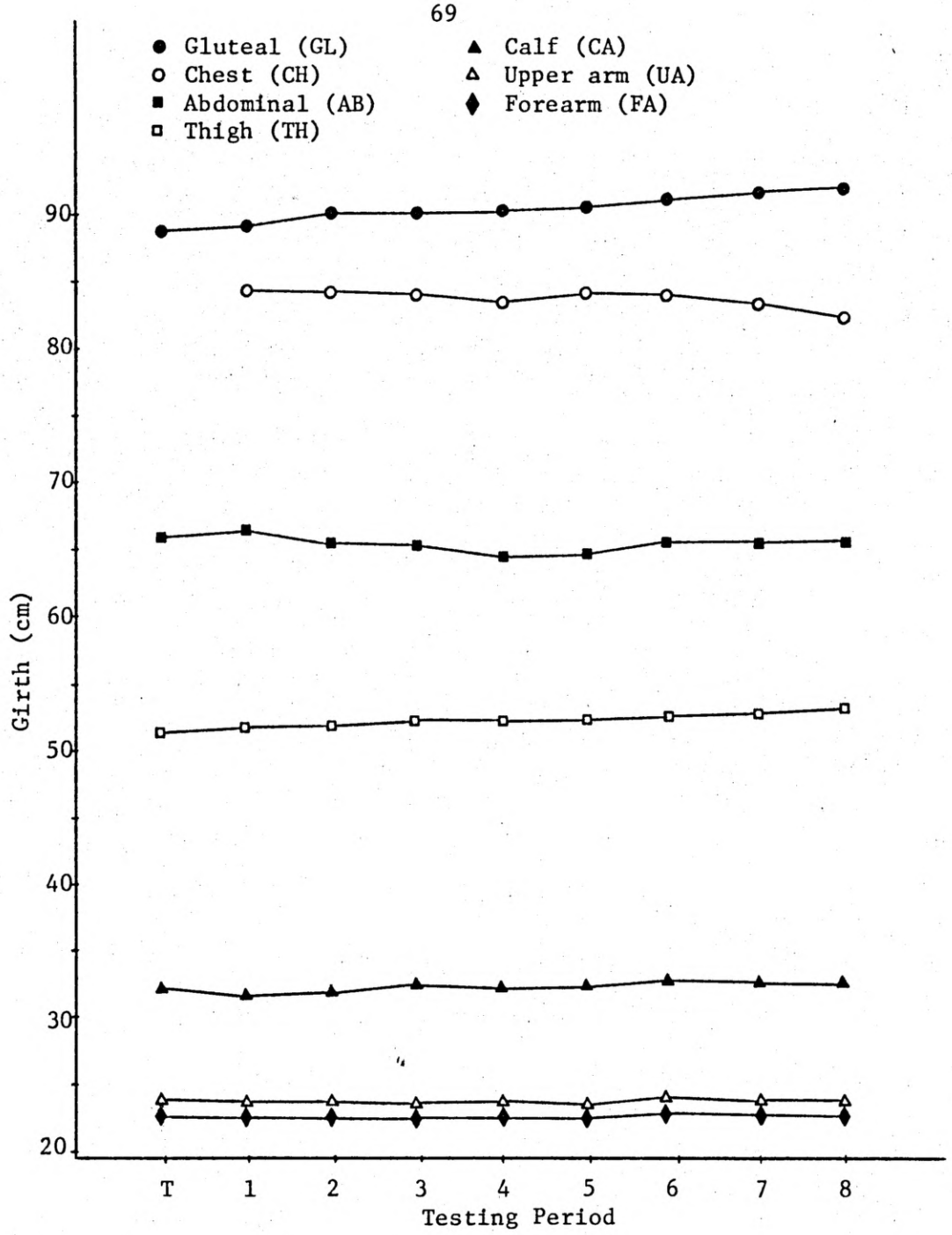


Figure 4.12. Girth Measurements.

weeks (56 percent) and at ten weeks (92 percent). Five weeks of detraining showed a significant reduction (24 percent).

Ride time at 1080 kpm/min in this study increased most significantly during the latter part of the training program, the longest ride occurring during testing period #7 (Figure 4.13). The net increase from testing period #1 to #7 of 10.2 minutes represents a 278 percent increase. A substantial drop is seen at testing periods #4 and #5 after running training was resumed. Chapter V discusses the variable results more completely.

Time Trial

The seven-mile time trial was intended as a measure of running performance and aerobic capacity. Cooper's 1.5-mile Test has been shown to be highly correlated with $\dot{V}O_2$ max (26). A longer distance was chosen for the trial in this study, as it is more specific to the event which the subject was preparing for and more of a measure of aerobic capacity than the shorter distances (8).

Running performance has been shown to improve after endurance training as measured by time trial results (84, 86). Kristufek (86) found mile run time to be improved 6 percent after seven weeks of running three miles per day. Ten weeks of cross-country training (84) produced a 9 percent increase in 28 students in a university cross-country course who covered approximately nine miles per week. Change in a run-

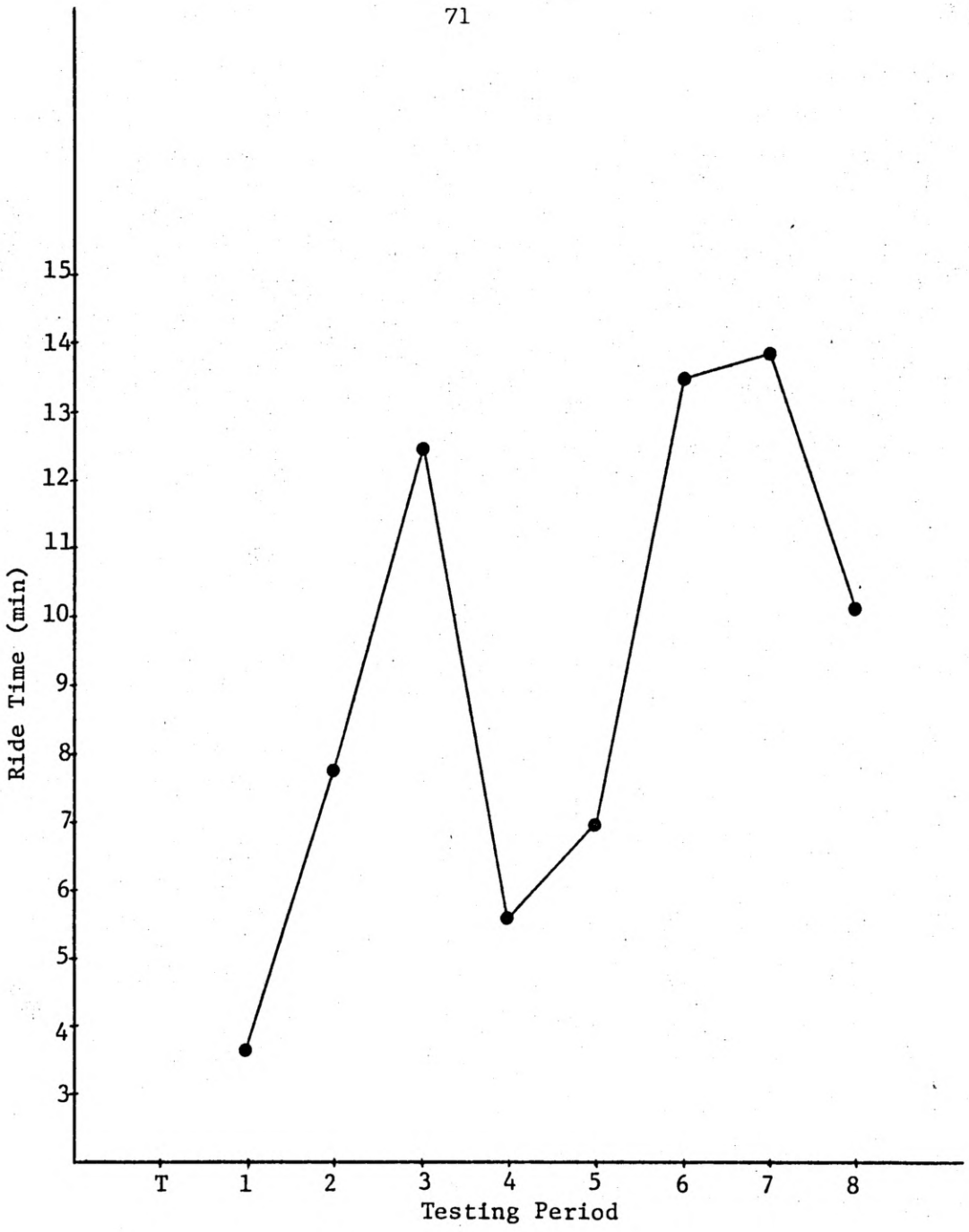


Figure 4.13. Bicycle Ride to Exhaustion.

ning time trial is greatly dependent upon initial fitness level, type and duration of training, and nature of the test.

The fastest time run by the subject, 45.5 minutes (6.5 minutes per mile), was observed during testing period #5, after two months of running training. Results of this parameter are incomplete due to injury so that no trend can be noted during the training period.

Strength

According to Cureton (34), strength is a very complex human quality involving, at least in part, will power, the number of muscle fibers recruited, and efficiency of the levers involved, to develop coordinated effort against a particular resistance. There is great variation in the means for testing strength and evaluating gains, thus making it difficult to compare reports in the literature. Strength has been reported to increase with weight training (2, 17, 19, 95) and endurance running (34, 86).

A means of testing similar to that employed in this study was also used by Brown and Wilmore (19). Strength was determined by one-repetition maximum in the bench press and half squat. Weight training was performed three times per week for six months by female throwing event athletes. Strength increased 15-44 percent in the bench press and 16-53 percent in the half squat.

Only leg strength was measured in this study, as previously described in Chapter III. There was no change in the leg press (Figure

4.14). Increases of 14 and 67 percent were observed with the leg extension and leg curl, respectively. A drop in all three tests was seen from the trial to the first testing period, after one month of very little training. After testing period #1, a slight increase was observed until testing period #4 for the leg extension and until testing period #5 for the leg curl. After testing period #5, no further increases were noted. Weight room workouts for developing leg strength were discontinued after testing period #5. The subject then relied on activities more specific to the event she was training for. The specificity of training possibly is a factor in the measuring of strength during the latter part of this study (see Chapter V).

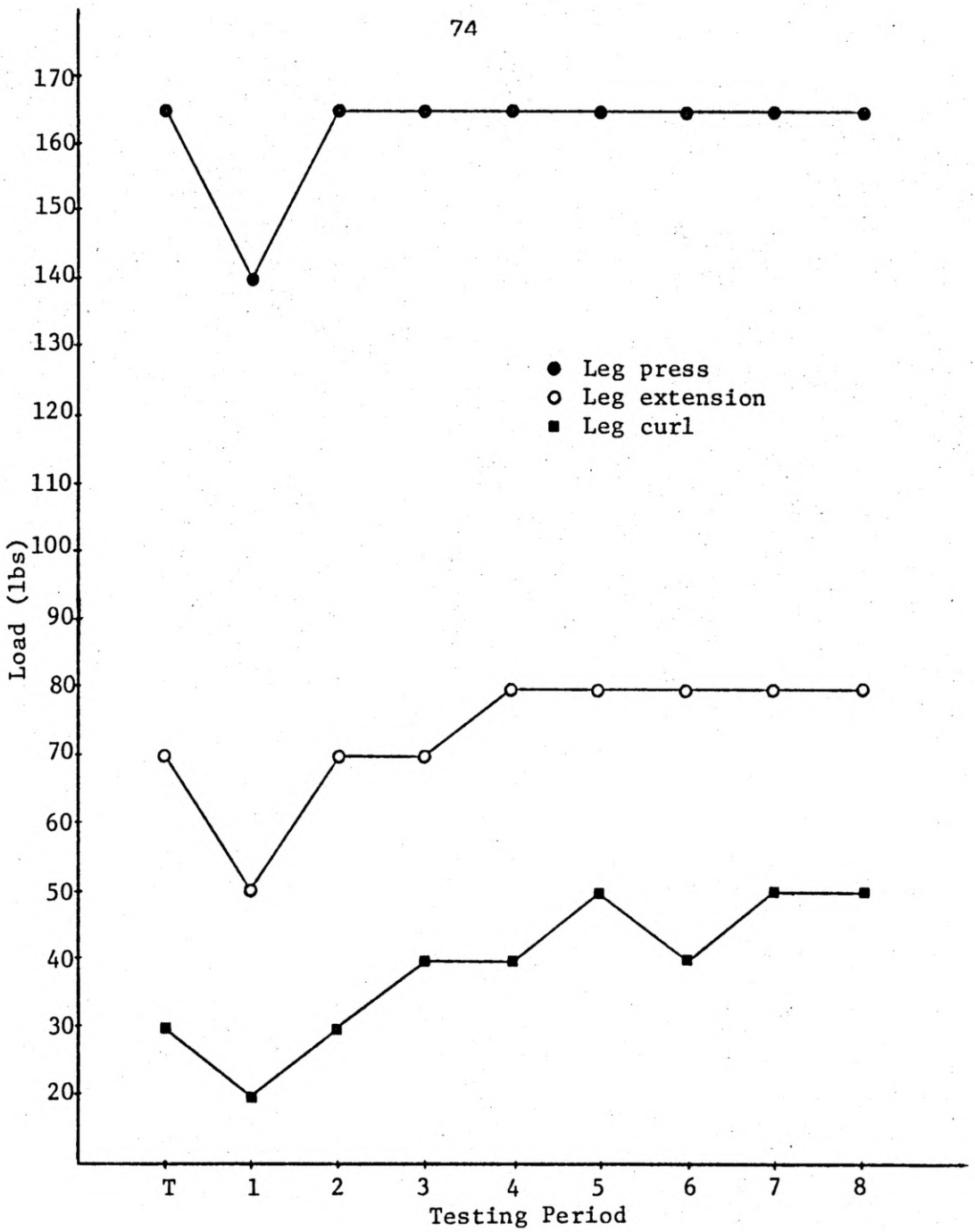


Figure 4.14. Leg Strength.

CHAPTER V

DISCUSSION

A complete discussion of all results is presented in Chapter V under the following headings:

1. Maximal Oxygen Consumption.
2. Maximal Pulmonary Ventilation.
3. Ventilatory Equivalent for Oxygen.
4. Basal Metabolic Rate.
5. Blood Chemistry.
6. Heart Rate.
7. Body Composition.
8. Girths.
9. Bicycle Ride to Exhaustion.
10. Time Trial.
11. Strength.
12. 100-Mile Run.

Maximal Oxygen Consumption

Maximal oxygen consumption was seen to vary with changes in training (Figure 4.1). Increase in $\dot{V}O_2$ max with training may be achieved by an increased stroke volume and/or arterio-venous oxygen difference (32, 68). However, the relative contributions from these factors in the present study could not be predicted.

Training of primarily bicycling raised $\dot{V}O_2$ max to 59.8 ml/kg-min (64.0 ml/kg-min), but not until regular running training was resumed did $\dot{V}O_2$ max reach a peak during this study, 66.5 ml/kg-min (71.1 ml/kg-min). Although exercise heart rates were similar during bicycling and running training, it is very possible that the intensity in cycling was lower because of a lower cardiac output. Studies have found a lower cardiac output during cycling than running when heart rates have been similar, due to a lower stroke volume (115). This could explain the lower $\dot{V}O_2$ max values during BE training. However, bicycle training has been shown to improve utilization and transportation of oxygen in the musculature of the lower extremity to a greater extent than running due to the higher intensity of cycling work on the leg muscles. This appeared to be the case in this investigation.

$\dot{V}O_2$ max values declined again during the final two months of training after a reinjury substantially reduced running mileage. More frequent long duration mountain climbing and running/walking workouts were added to the training program in an attempt to replace the running training. The lower intensity of these workouts with a corresponding lower exercise HR during this period probably was insufficient to prevent a decline in $\dot{V}O_2$ max values.

Percent changes in $\dot{V}O_2$ max with the various training periods were rather substantial, considering that the subject began in a partial state of training and was not obese. Magnitude of change in $\dot{V}O_2$

max has been shown to be greatest when subjects have begun training from a sedentary or obese state (9, 32, 39, 55). In this study the intensity, duration, and frequency of the workouts apparently were of such magnitude to cause significant changes, regardless of beginning fitness of the subject.

Discrepancy between TM and BE $\dot{V}O_2$ max values is generally regarded to be about seven percent, although this difference may vary with the state of training of the quadriceps (134). Prior to this study the subject had done no bicycle training. During the first two months of this study the subject frequently worked out on the BE. Quadriceps strength was improved during this period (Figures 4.13-4.14), hence affecting the difference which originally existed between TM and BE $\dot{V}O_2$ max values. It is impossible to determine the magnitude of the effect that training of the quadriceps had on $\dot{V}O_2$ max values, although the discrepancy probably decreased as a result.

The highest value of $\dot{V}O_2$ max recorded in this study was 66.5 ml/kg-min (71.1 ml/kg-min), considerably higher than values found for normal college-age females (46) and consistent with measurements on female long distance runners (Table 4.1). In fact, all values of $\dot{V}O_2$ max found during this study were significantly higher than those measured on normal females.

Maximal Pulmonary Ventilation

$\dot{V}E$ max did not show any particular trend during the seven months

(Figure 4.2), possibly a result of the subject's partial state of training at the beginning of the study. $\dot{V}E$ max has most often been seen to increase with training (39, 58, 64, 157), although subjects have begun the studies in an untrained state. One study on female runners who were not detrained initially showed results that are in agreement with this study (18). $\dot{V}E$ max in that particular study remained unchanged during 12 weeks of training even though $\dot{V}O_2$ max showed a 26 percent increase. Additionally, the increase in $\dot{V}O_2$ max may have partially prevented the lactic acid increase from high intensity exercise that is a stimulus for respiration (8).

Ventilatory Equivalent for Oxygen

Progressively increased maximal ventilatory efficiency was observed until testing period #6 (Figure 4.3). There was consistently a high intensity component in training during that entire period. Oxygen utilization at a maximal workload was gradually increased over these five months, although the greatest change was observed during the first two months of primarily high intensity BE training. During the final two months of the study when training was much lower in intensity, even though the duration of workouts was often greater, ventilatory efficiency at a maximal level was seen to decline. During that period the subject rarely worked out at maximum effort.

$\dot{V}E/\dot{V}O_2$ at a submaximal workload did not change significantly during training, with the exception of an increase at testing period

#1. This increase was consistent with changes in other testing parameters during that period due to the preceding month of very little training. During the final two months of training there was no increase in submaximal $\dot{V}E/\dot{V}O_2$ (indicating a lower efficiency) to correspond with the change in maximal $\dot{V}E/\dot{V}O_2$. Submaximal training during those two months, even though running was substantially reduced, apparently was sufficient to maintain efficient oxygen utilization at submaximal levels.

The lowest value of $\dot{V}E/\dot{V}O_2$ max attained by this subject was 32.3, which compares very closely with two other reports on female runners. Average values of 32.5 (156) and 32.9 (48) were calculated from the data presented in these reports. All other values reported for trained female athletes were much higher (71, 89). Slightly lower values (30.7) were found for some male marathoners (30).

Basal Metabolic Rate

A decline in BMR was observed during the seven months of training (Figure 4.4). An increase in cellular efficiency appeared to exceed the effect of increasing LBW. A high degree of relaxation often acquired during training, regardless of muscle hypertrophy (141), can also help to explain lowering of values in this study. The time of year has been shown to influence BMR readings, warmer weather lowering the readings. The final readings in this study were, in effect, taken during spring, while the first several tests were performed in the winter. The effect of season cannot be entirely disregarded.

At no time did the subject's BMR deviate substantially from normal. With the exception of the first reading (+11.9 percent of normal), BMR did not differ more than 2.8 percent from normal. Only one study was available on a female athlete to compare values. During endurance running (85), BMR values decreased from 242 to 209 cc/min over a 17-month period in a female athlete of similar size and weight. Corresponding values in this study were substantially lower, 204 to 181 cc/min, although a similar trend was noted. A higher intensity training program during this study with a corresponding greater cellular efficiency, along with a higher degree of relaxation, could help to explain the differences between the two studies.

Blood Chemistry

No particular trend was seen in blood chemistry parameters (Figure 4.5). The much lower values observed during testing period #4 and #6 possibly can be explained by the dilution factor from an increase in total blood volume or by Yoshimura's "sports anemia" (121).

The subject had resumed running as the main form of training in the month prior to testing period #4. The running training may have affected blood measures by increasing blood volume, thus causing a dilution effect. It is also possible that the subject had not adapted to the differing training mode and was suffering from training fatigue. The blood test at testing period #6 came shortly after a 50-mile run, the subject's longest workout to date. Results of this test suggest

that the severe exertion caused a temporary destruction of RBC, an occurrence labelled "sports anemia." When experimental error was considered as the cause for the low readings, it was concluded that the largest error possible (2-4 percent) in RBC determination could not explain the vast declines which occurred during testing periods #4, #6, and #7.

Compared to normal values for females, the subject's values all appeared quite normal. Hb seemed to differ the greatest, somewhat higher than all values reported on normal females and female athletes. According to DeWijn's standards (42), the subject's Hb values do not indicate any danger of anemia or iron deficiency, apparently very common in female runners.

The subject had experienced secondary amenorrhea for the two years prior to this investigation, although her menstrual cycle was fairly regular during the entire seven months of this study. Resumption of menstrual periods occurred during testing week #1. It does not appear that amenorrhea necessarily resulted in a higher Hct as suggested by Feicht (54), since the highest Hct was observed during the final testing period, at which point the subject was no longer ammenorrheic.

It appeared that the unmeasured combined effects of training, incomplete recovery, dehydration, volume dilution, amenorrhea, and the subject's menstrual cycle caused some degree of variability in results.

These and perhaps other variables have undoubtedly contributed to the inconsistencies reported in the literature.

Heart Rate

Resting. Resting HR did not change significantly during this study. Resting HR has generally been seen to decline with training (16, 72, 85, 86, 143) unless athletes were observed to be in a partial state of training at the beginning of a study (1, 17).

There are several possible explanations for no change observed during this study. Since the lowest resting HR during the last three years has typically been observed for this subject in the morning soon after waking, resting HR was determined accordingly in this study. However, it was noted midway through the research period that HR was often much lower in the evening than it was in the morning. Values in the evening were often 39-40 bpm, corresponding to values previously observed in the morning during periods of intense marathon training (37-40 bpm). It must be noted that the subject's entire routine was greatly changed just prior to this study. Since resting measures such as HR are highly subject to factors such as emotion and state of relaxation (8, 14), it appeared that a true resting HR was not observed with the morning measurements during this study. Of course, it also must be remembered that basal tests do not always determine the fitness of an individual.

In addition, the subject began the testing in a partial state of training. Since resting HR was already low (45 bpm) at the beginning the study, significant change could really not be expected. However, much lower values (37 bpm) have been observed prior to this study when the subject was highly trained. It appeared to the author that the training during most of this study was of comparable intensity, duration, and frequency to cause similar low resting HR's. Nonetheless, resting HR's in this study were seen to correspond to those previously found for endurance athletes (43, 44, 85).

Maximal. Maximal HR did not change significantly with training during this study, which is consistent with most of the literature (39, 51, 87, 116, 136). HR max on the TM was found to be higher than that measured on the BE which also has been previously reported (20, 157).

Submaximal. Submaximal HR's measured on the TM and BE were shown to vary with changes in training. Specificity of training was evidently a factor in interpreting the results.

In this study, bicycle training produced the most dramatic results on the BE test during exercise, while the effects of running training were most evident on the TM test. During the first two months of training, results seem to suggest that bicycle training produced specific effects, as seen by a decrease in HR on the BE and not on the TM. This is in agreement with other studies involving specificity of

training and testing (115, 122). Following three months of running training, HR as measured on the TM declined, while HR on the BE remained unchanged. This is not in agreement with the literature, which has generally indicated that running training produces similar changes on the TM and BE (115, 122). A possible explanation for this discrepancy lies in the preconditions for observing the effects of running training. Running training in this study began after two months of intense BE training, therefore, HR on the BE submaximal test was already at a fairly low value to begin with. Other studies have usually commenced with subjects in an untrained state.

Results of the TM test during testing period #6 appeared to be inconsistent with other data also recorded during that testing period. Movement artifacts have occasionally been known to interfere with finding a true HR (134), and it appeared to be the case during this test. The electrocardiograph recording was observed to be quite different from all other recordings, and the HR's were very difficult to measure. Absence of data during testing period #2 was due to an injury, which made it impossible for the subject to run on the TM at that time.

Heart rates on the TM during the final testing period were among the lowest recorded during this study. Even though running mileage was very low during the preceding two months, apparently the long mountain climbs and run/walks were sufficient to maintain a cardiovascular efficiency for submaximal levels.

Recovery. Recovery HR was significantly reduced with training (Figures 4.7-4.8), responding very similarly on both TM and BE tests. A more rapid and efficient physiological recovery was apparent. Results are in agreement with the literature (16, 17, 86, 143, 151).

After two months of BE training, recovery HR on both tests was seen to be significantly decreased. A further decrease was noted in both tests after three months of running training. The recovery HR tests appeared to show the cumulative effects of training over the entire period, rather than respond to specific modes and intensities of training. In fact, the lowest TM recovery HR's at 30 seconds and one minute during the entire study were recorded during the final testing period, in spite of running mileage being substantially reduced.

Other studies have observed that the first recovery HR reading after exercise is the most discriminatory (85). A similar finding was noted during this study on the TM. Occasionally a secondary rise in HR was seen (testing periods #7 and #8) as has also been reported in the literature (85, 106). Morehouse and Tuttle (106) merely concluded that it was a normal but variable phenomenon.

Often recovery was so rapid that recovery HR's were very erratic. In a few instances it was difficult to determine HR from the electrocardiograph recording after the TM test. During the trial period an equipment malfunction resulted in missing data for recovery HR's at 30 seconds and one minute.

Body Composition

Skinfold values at six out of seven sites showed an overall decrease with training (Figure 4.9), which is in agreement with the literature (39, 95, 104, 120, 150). But changes in fat weight may not be accurately represented by subcutaneous SF's, especially during intense training. This has been found to be especially true in women because of the deposition of more fat internally. It was suggested that perhaps intramuscular and internal fat stores were diminished before the subcutaneous deposits.

Measurements at the various SF sites were compared with those obtained on female runners (Table 4.4). SF values measured on this subject were very similar to those found on distance runners in the literature. SF values were also compared with two studies on typical college-age females with PF of 24.8 percent (150) and 25.5 percent (77). There was a great difference between values found on average females and the results of this investigation. All of the SF measurements on this subject were 50-76 percent less than those taken on average college-age females.

Percent body fat (Figure 4.10) was seen to decrease significantly with training, accompanied by an increase in BW (Figure 4.11). The increase in BW with a corresponding decline in PF suggests a large gain in LBW (Figure 4.11). No reports were found with such a large increase in BW and LBW during training for an endurance event. On the

contrary, many reports on endurance running training have indicated a weight loss (34, 37, 39, 86, 143).

During the three years of training preceding this study when the subject's training was primarily LSD running in preparation for marathon racing, BW was seen to decline from 123 to 110 pounds, where it had remained relatively stable for the year preceding this study. Thus BW was very low at the beginning of this study. The seven-month training program reported on in this research study, though, differs in many respects from a typical endurance running program. Due to the nature of the event that the subject was preparing for, extremely mountainous terrain with severe uphills and downhills, it was considered essential to increase leg strength and muscle mass. Throughout the course of this training study, the subject engaged in workouts designed to increase leg strength, in addition to maintaining a high aerobic capacity. Therefore, increases in BW and LBW were appropriate.

Amenorrhea has been associated with low PF and/or LSD training (37, 38, 54). Reappearance of the subject's menstrual period after two years of amenorrhea seemed to coincide with a decrease in training and increase in BW and PF. Even though the intensity of training was high during the seven months of this study and PF significantly declined (Figure 4.10), the subject's menstrual cycle remained regular. In fact, the high energy cost of total training (Appendix B) was comparable with the amenorrheic marathon training period prior to this study. However,

training mode during this investigation was quite different from previous marathon training. During training for marathon racing, running was the sole method of training, while during this training period the mode was quite varied on a monthly basis and even within each week (see Chapter III and Appendix B). Running mileage was typically not high during this investigation. Therefore, it may be speculated that high mileage LSD running may be instrumental in this condition.

Girths

No great changes were observed in any of the girth measurements. Since a girth measurement involves both lean and fat tissue, most likely the decrease in subcutaneous fat (Figure 4.9) in combination with an increase in muscular development resulted in no measureable changes in circumference.

The two girths which showed the greatest increases were the thigh and gluteal (Figure 4.12). In addition, thigh skinfold (Figure 4.9) was observed to significantly decrease, along with a large gain in LBW (Figure 4.11). It appeared that a large portion of the increase in LBW occurred in the thigh and gluteal areas. This finding is consistent with the type of training program followed. Apparently one of the primary aims of the training program, to develop leg strength and muscle mass, was accomplished. This was further substantiated by observed leg strength increases as measured on the bicycle ride to exhaustion (Figure 4.13) and the strength test (Figure 4.14). In addi-

tion, a higher resistance could also be tolerated by the subject on the BE during the test for $\dot{V}O_2$ max. During testing period #1, the subject could not continue at 1440 kpm/min for the full 2.5 minutes due to extreme leg fatigue. During testing period #3, and thereafter, the subject could pedal at 1440 kpm/min and sometimes higher for the entire time.

Women have often shown the same relative improvements in strength as men, while their low levels of androgen seem to be responsible for preventing the same degree of muscle hypertrophy (95). In this study, leg strength and muscle mass appeared to have increased, although the magnitude of the increase was not apparent by observing the changes in girth measurements.

The subject's girth measurements were compared with those taken on distance athletes of a similar age (22, 91, 110, 137). Thigh girth was typically greater than the long distance runners (22, 110) and smaller than the cross-country skiers (137). Calf girth was found to be slightly lower than values found in three studies describing endurance athletes (91, 110, 137). No significant differences were seen in gluteal, forearm, and upper arm girths among all the studies. In terms of girth measurements, the subject seemed to fit the female distance runner's norm.

Bicycle Ride to Exhaustion

Overall, the ride to exhaustion appeared to reflect the cumula-

tive effects of training over the entire period (Figure 4.13). Results indicated substantial increases in aerobic capacity and leg strength. Due to the nature of the test, results were also subject to other uncontrolled factors. Inconsistent results may be anticipated from such a protocol. In addition to leg strength and aerobic capacity, time of the ride was dependent upon the subject's ability to tolerate lactic acid buildup, threshold for pain, motivation, and perseverance. For example, a change in training does not appear to be responsible for the short ride times during testing periods #4 and #5, since aerobic capacity (Figure 4.1) and leg strength (Figure 4.14) were high. Some workouts were still performed on the BE during that time, even though running training had been resumed. Perhaps the aforementioned extraneous factors influenced the data in these two instances, rather than merely leg strength and aerobic capacity.

Time Trial

Unfortunately no conclusions could be drawn regarding the time trial, due to the absence of data from six testing periods because of injury.

Strength

Specificity of training appeared to affect results of the strength test. Strength was shown to increase on the leg curl and the leg extension until testing period #5 (Figure 4.14). At that point,

weight room workouts were entirely replaced with hill running, mountain climbing, and bicycle ergometer intervals for developing leg strength. There were no apparent increases in leg strength after testing period #5, as observed from the weight strength test. Leg strength, though, continued to increase as shown in the ride to exhaustion (Figure 4.13).

Leg press values were not seen to increase above pretraining values. Most likely this is due to the large increment in weights on the test apparatus (25 pounds). The subject felt confident of reaching a higher max, but the added 25-pound load was too large an increase.

One Hundred-Mile Run

The subject was unable to complete the 100-mile run due to reoccurrence of a knee injury. The subject dropped out of the run after completing 51.3 miles in 13 hours. The injury was a factor from the fourth hour of the run to the point at which the subject was forced to stop.

The training program, therefore, could not be evaluated in terms of the 100-mile run results, since factors other than training influenced the outcome. However, the author made speculations concerning the effectiveness of the training program through consideration of the condition of the subject during and after that portion of the run which was completed.

At no point during the run did the subject suffer from extreme fatigue or dehydration. This is substantiated by heart rate, blood

pressure, and body weight measurements taken during the run at three points: 32.0, 46.0, and 51.3 miles. Blood pressure was observed to remain constant at 110/70, an average reading for the subject. Body weight was stable at 120 pounds for the entire time. Heart rate soon after stopping at the checkpoints was measured to consistently be 100-106 bpm.

With temperatures reaching 110 degrees Fahrenheit during the run, dehydration and heat disorders were very common and the major causes for a high drop-out rate. At no point did the subject suffer any effects of the high temperatures and hot sun. Adequate precautionary measures were taken to keep body temperature down such as drinking constantly, wearing a wet hat (often filled with snow), and walking through all streams. Furthermore, at no point did the subject suffer from muscle cramps, tightness, or soreness during the run.

In terms of post-run recovery, there were no indications of fatigue, heat disorders, or illness immediately after the run or in the week following. Body weight and heart rates were not unusual, and the subject was motivated to remain very physically active.

It appeared that the subject was very adequately trained for this particular event and took the necessary measures during the run to ensure completion. A circumstance beyond the subject's control prevented her from finishing the Western States 100.

The testing results were also analyzed with respect to the run.

A high $\dot{V}O_2$ max was not necessarily important for success in a long run of this nature, since work was at a submaximal level. The subject's $\dot{V}O_2$ max had dropped slightly in the final two months of training from the reduced running mileage, although the subject's level was still well above average. In addition, maximal $\dot{V}E/\dot{V}O_2$ had also declined during the final two months. There is perhaps a minimal value of $\dot{V}O_2$ max necessary, below which performance would be hindered.

More important, though were the submaximal measures which continued to show positive results, even with very little running. Submaximal $\dot{V}E/\dot{V}O_2$ and heart rate on the TM more specifically applied to this endurance running event. Submaximal $\dot{V}E/\dot{V}O_2$ remained unchanged during the final two months, indicating that adequate submaximal ventilatory efficiency was retained. Exercise and recovery heart rates recorded on the final TM test were among the lowest recorded during the entire training period.

Leg strength was actually one of the most important factors. The subject's leg strength increased progressively as previously indicated. Even greater gains in leg strength specific to mountain climbing and running probably occurred than were measured by the available tests on the BE and the weights. No test existed to adequately measure leg strength gains that were evident during the final two months of mountain and hill workouts.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The effects of moderately intense and short duration training have been widely studied. This study helped fill the presently existing void of strenuous longitudinal training studies on female athletes.

The purpose of this study was to determine the progressive changes in the physical fitness of a female long distance runner during a seven-month training period in preparation for the Western States 100. The progressive physical conditioning was evaluated by testing 50 selected oxygen consumption, pulmonary ventilation, blood chemistry, heart rate, body composition, girth, running and bicycle performance, and strength variables at four-week intervals during the training period.

A 27-year-old female long distance runner was used as the subject for this investigation. Prior to this study the subject had run for three years and trained for marathon racing for approximately two years.

The subject trained up to ten hours a day, six or seven days per week, for a total of 30 weeks, over the course of this investigation. The training program was substantially adjusted due to a knee injury sustained just prior to the beginning of this study and a reinjury during the fifth month of training. Running was intended as the main form of training but was not a regular part of training until

after the third testing period. Consistent throughout the entire seven months, however, was at least one long endurance workout each week. The type and duration of endurance workout (mountain climbing, cross-country skiing, running, bicycling) varied according to the season, weather, and injury. During the first two months, non-running training was performed, primarily stair and bicycle ergometer intervals. Three months of running training followed, ending with reinjury during a 50-mile run. For the final two months, lower intensity hiking, mountain climbing, and run/walk training predominated.

An attempt was made to avoid unusual deviations in sleeping and eating patterns. In addition, a trial period was used to standardize procedures and familiarize the subject with the testing. Each test was given by the same administrator in the same order during each testing period. Preconditions necessary for several tests were strictly adhered to.

A complete tabulation was made of the data from all of the testing periods (Appendix A). The progressive values of each variable were graphed and presented in Chapter IV. A complete discussion of all results was presented in Chapter V.

Conclusions

Since this investigation was conducted as an individual case study, broad generalizations could not be drawn. Other subjects would not necessarily have reacted to a similar training program in the same

way. In addition, changes in some of the variables, or a lack thereof, very possibly reflected the prior training base and the preceding two years of intense marathon race training. However, trends may be indicated and noted for further study. Within the limitations of this study, the following conclusions seem justified.

1. Maximal oxygen consumption reached and remained at peak values only when running was the primary form of training. Substitution with high intensity bicycle workouts or long duration hikes was not adequate to maintain the highest levels of $\dot{V}O_2$ max.

2. Significant changes in $\dot{V}O_2$ max with varying intensities and modes of training were seen, even though the subject was in a constant state of training and could not be considered obese.

3. Maximal $\dot{V}E/\dot{V}O_2$ improved for five months in conjunction with a consistent high intensity component in training.

4. Basal metabolic rate decreased as a result of training, possibly due to greater cellular efficiency, increased relaxation, and the change of seasons.

5. It appeared that the combined effects of training, incomplete recovery, dehydration, volume dilution, amenorrhea, and the menstrual cycle caused some degree of variability in blood chemistry results. No particular trend could be seen with changes in training.

6. Submaximal heart rate as measured both on the treadmill and the bicycle ergometer significantly declined during training. Bicycl-

ing and running training were both seen to produce specific effects, as measured by heart rate declines solely on the mode of testing which was specific to the mode of training.

7. Recovery heart rates were reduced with training, responding similarly on the treadmill and bicycle tests.

8. Skinfold values were seen to progressively decline throughout the entire training period. A gain in body weight with a decline in percent body fat suggested a substantial gain in lean body weight. This was probably a result of the various workouts designed to improve leg strength and muscle mass: stair and bicycle ergometer intervals, weight training, mountain and hill workouts, and bicycling.

9. It was speculated from the data that specifically high mileage LSD running may be a prime causal factor in amenorrhea in female athletes, as opposed to a low percent body fat or mere high intensity of workouts. Energy cost of total training during this study was comparable to that observed during periods of exclusively LSD running training during amenorrhea. In addition, percent body fat again reached low levels during this investigation as it had during previous marathon training, yet the subject's menstrual cycle remained regular during the entire study.

10. An overall increase in leg strength and aerobic capacity was observed with the bicycle ride to exhaustion.

11. Leg strength improved as measured on the leg curl and leg

extension, but in general the weight tests were not an adequate measure of strength for most of this study. No test adequately measured leg strength specific to hill and mountain training.

12. Even though the training program had to be substantially adjusted from the original intention, substitution with non-running training produced beneficial changes in the physical fitness of the subject. The altered training program appeared to adequately prepare the subject for the Western States 100. It was determined that a high $\dot{V}O_2$ max was not necessarily important for success in this particular 100-mile run. Rather, submaximal working capacity and leg strength were theorized to be the most important prerequisites for completion of the Western States 100.

Recommendations

Based on the results of this research, it appears that further investigation would be profitable in the area of strenuous training on runners. The following recommendations are presented:

1. Further case studies of this nature should be conducted, studying the effects of training and detraining over a period of several years.

2. It would be valuable to include a measure of anaerobic threshold in future studies of this nature as a measure of peripheral changes that may be taking place.

3. Blood volume and total hemoglobin changes should be included in future investigations.

4. It should be determined how varying intensities and modes of exercise affect the hemodilution factor.

5. If at all possible, $\dot{V}O_2$ max should be tested on the ergometer most specific to training mode. In some instances it would be valuable to test $\dot{V}O_2$ max both on the treadmill and the bicycle ergometer.

6. It would be useful to pursue specifically the effects of training fatigue on a series of tests performed throughout a period of strenuous training.

APPENDIX A

APPENDIX A

TEST DATA

	T	1	2	3	4	5	6	7	8
$\dot{V}O_2$ max (ml/kg-min)	61.5	54.1	59.8	59.1	64.3	66.5	64.1	62.2	59.3
$\dot{V}O_2$ max (l/min)	3.10	2.69	3.05	3.06	3.30	3.46	3.35	3.28	3.14
$\dot{V}O_2$ (360 kpm/min)	0.76	0.81	0.90	0.98	0.93	0.91	----	----	0.85
$\dot{V}O_2$ (720 kpm/min)	1.51	1.55	1.57	1.58	1.67	1.59	----	1.60	1.56
$\dot{V}O_2$ (900 kpm/min)	1.97	2.05	2.08	1.99	2.06	2.15	1.94	2.00	1.99
$\dot{V}O_2$ (1080 kpm/min)	2.39	2.55	2.54	2.47	2.47	2.47	2.45	2.40	2.56
$\dot{V}E$ (360 kpm/min)	25.2	34.6	26.4	27.8	23.8	27.7	23.9	----	27.5
$\dot{V}E$ (720 kpm/min)	39.7	49.6	43.3	42.9	43.6	42.9	-----	45.1	43.1
$\dot{V}E$ (900 kpm/min)	53.2	62.4	58.6	55.5	55.7	59.2	52.4	56.1	54.2
$\dot{V}E$ (1080 kpm/min)	68.4	88.5	79.5	71.4	69.1	68.8	66.7	68.3	79.2
$\dot{V}E$ max l/min	118.4	105.5	112.7	118.23	114.9	118.5	108.4	115.1	121.2
$\dot{V}E/\dot{V}O_2$ (1440 kpm/min)	38.2	39.2	37.0	34.6	34.8	34.2	32.4	35.1	38.6
BMR (cc/min)	----	204	186	189	189	181	185	181	181
BMR (kcal/hr/m^2)	----	39.2	35.5	35.9	36.0	34.4	35.0	34.0	34.0
BMR (% normal)	----	+11.9	+1.1	+2.2	+2.5	-2.1	0	-2.8	-2.8
HR TM 6 mph	174	159	-----	155	160	134	170	151	138
HR TM 7 mph	180	175	-----	175	174	155	190	177	157
HR TM 8 mph	190	187	-----	190	200	173	190	200	190
HR TM rec 30 sec	----	140	-----	105	100	90	84	90	81
HR TM rec 1 min	----	110	-----	73	72	87	82	70	62
HR TM rec 2 min	80	80	-----	63	66	58	72	71	66
HR BE (720 kpm/min)	163	170	150	136	139	139	132	146	139
HR BE rec 30 sec	125	132	110	93	97	96	79	104	94
HR BE rec 1 min	110	127	98	81	87	85	71	96	81
HR BE rec 2 min	110	101	98	80	76	79	71	94	87
HR BE_{max} (360 kpm/min)	----	124	103	109	110	119	119	118	112
HR BE_{max} (720 kpm/min)	----	163	143	143	141	147	147	135	150
HR BE_{max} (900 kpm/min)	----	176	169	156	156	158	153	152	164
HR BE_{max} (1080 kpm/min)	----	187	182	176	172	172	171	172	183
HR BE max MAX	----	187	187	187.5	187	---	187	189	193

APPENDIX A (continued)

	T	1	2	3	4	5	6	7	8
HR resting	45	48	46	46	47	48	47	47	47
Hb (g/dl)	---	15.4	15.2	15.0	14.4	15.6	15.2	15.3	15.6
Hct (%)	---	42.3	43.3	42.5	39.4	42.2	39.2	40.9	43.6
RBC (#/mm^3)	---	4.69	4.72	4.59	4.32	4.60	4.38	4.22	4.73
TR SF (mm)	15.5	15.2	13.2	11.5	11.7	11.2	11.2	10.8	10.0
SU SF (mm)	6.0	7.0	6.0	6.0	5.8	6.2	6.0	6.2	7.0
AB SF (mm)	12.5	11.2	8.0	6.8	6.5	6.8	7.0	7.0	7.0
SI SF (mm)	11.5	8.5	8.3	6.8	6.7	7.7	6.8	7.0	7.0
TH SF (mm)	13.2	13.7	12.0	11.3	11.3	10.2	8.5	7.5	8.0
CA SF (mm)	10.0	9.8	10.8	10.0	9.3	9.3	8.3	7.5	8.0
CH SF (mm)	12.0	12.3	11.7	11.5	10.0	8.2	9.5	8.5	7.3
% Fat (Sloan)	17.5	16.5	15.8	14.7	14.8	14.9	14.6	14.6	14.3
% Fat (Pollock)	14.5	13.8	13.0	12.3	12.3	12.1	11.2	10.8	11.0
% Fat (Average)	16.0	15.1	14.4	13.5	13.5	13.5	12.9	12.7	12.6
Total BW (lbs)	110.4	108.8	111.0	112.8	114.1	115.3	114.7	116.0	116.3
LBW (lbs)	92.8	92.3	95.0	97.6	98.7	99.6	99.9	101.3	101.6
FW (lbs)	17.6	16.5	16.0	15.2	15.4	15.6	14.8	14.7	14.7
CA G (cm)	32.3	31.8	32.0	32.5	32.3	32.5	32.8	32.8	32.8
TH G (cm)	51.3	51.6	51.8	52.3	52.1	52.1	52.6	52.6	53.1
UA G (cm)	23.9	23.9	23.9	23.6	23.9	23.6	24.1	23.9	23.9
FA G (cm)	23.1	23.1	23.1	23.4	23.4	23.4	23.6	23.6	23.6
CH G (cm)	----	84.6	84.3	84.1	83.8	84.3	84.1	83.3	82.8
AB G (cm)	65.8	66.5	65.5	65.3	64.5	64.8	65.5	65.5	65.5
GL G (cm)	88.9	89.2	90.2	90.2	90.4	90.7	91.4	91.7	92.2
Ride to Exhaustion (min)	17.9	3.6	7.8	12.5	5.6	7.0	13.5	13.9	10.1
Time Trial (min)	47.9	----	----	----	49.3	45.5	----	----	----
Leg Press (lbs)	165	140	165	165	165	165	165	165	165
Leg Extension (lbs)	70	50	70	70	80	80	80	80	80
Leg Curl (lbs)	30	20	30	40	40	50	40	50	50

APPENDIX B

APPENDIX B

TRAINING DATA

Testing Period	Week	Type of Workouts	Aerobic Points	Number Training Days	R (mi)	R (hr)	H (hr)	XC (hr)	B (hr)	BE (hr)	ST (hr)	LONG WORKOUTS					
												Type	Time	Pts	Type	Time	Pts
#1	1	BE, ST, H	175	6	—	—	7.0	—	—	2.0	0.5	H	7.0	50			
	2	BE, ST, H	171	7	6	1.1	5.5	—	—	1.0	1.6	H	3.5	20			
	3	BE, ST, XC, B	276	7	1	0.1	—	2.0	4.0	3.5	0.5	B	4.0	40	XC	2.0	35
	4	BE, ST, XC, H	332	7	—	—	8.0	9.0	—	3.0	1.0	XC	6.0	75	H	7.0	50
#2	5	BE, ST, XC	248	6	—	—	—	6.0	—	2.0	1.5	XC_R	3.0	50	XC	3.0	35
	6	BE, ST, XC, SW	263	7	—	—	—	5.0	—	2.6	1.8	XC	4.5	35			
	7	BE, ST, XC, SW	250	7	—	—	—	5.0	—	2.7	1.5	XC	5.0	60			
	8	BE, ST, XC, SW	235	7	—	—	—	5.1	—	1.5	1.5	XC_R	2.6	50	XC	2.5	35
#3	9	BE, ST, R, XC	221	7	4	0.6	—	5.0	—	1.8	1.0	XC	5.0	45			
	10	R, BE, XC	227	7	25	4.0	—	4.5	—	2.0	—	XC	4.5	40			
	11	R, BE, ST, XC	255	7	21	3.1	0.6	9.5	—	0.7	0.4	XC	6.0	75	XC	3.5	35
	12	R, XC	276	7	31	4.4	—	10.0	—	—	—	XC	4.5	70	XC	5.5	50
#4	13	R, XC, BE	332	6	42	6.0	—	8.0	—	0.5	—	XC	8.0	80			
	14	R, XC, BE, ST	341	7	56	8.3	—	5.0	—	0.5	0.5	R	2.5	72	XC	5.0	45
	15	R, XC,	361	7	66	11.9	—	5.0	—	—	—	R	4.0	100	R	4.3	90
	16	R, B, XC	432	7	72	10.7	—	4.5	4.5	4.5	—	R/XC	7.5	150	R	2.7	90
#5	17	R, B, BE	298	7	40	4.2	—	—	6.0	0.3	—	B	6.0	75	R	3.1	100
	18	R, BE, ST	414	7	73	10.5	—	—	—	1.0	0.8	R	4.5	140			
	19	R, B, BE	444	7	78	11.1	—	—	7.0	0.8	—	B	7.0	75	R	5.0	140
	20	R, BE, B	423	5	93	13.0	—	—	0.6	0.3	—	R	9.0	200			
#6	21	H, B, R	229	6	8	1.5	7.0	—	5.1	—	0.3	H	6.0	50			
	22	B, R	253	6	37	7.2	—	—	5.0	0.3	—	R/B	3.5	70			
	23	B, H, BE	276	6	10	2.2	10.5	—	7.0	1.0	1.2	H	10.5	80	B	5.0	52
	24	R, H, BE	214	6	23	4.5	5.0	—	1.0	1.1	0.2	R	3.8	100	H	5.0	60

APPENDIX B (Continued)

Testing Period	Week	Type of Workouts	Aerobic Points	Number Training Days	R (mi)	R (hr)	H (hr)	XC (hr)	B (hr)	BE (hr)	ST (hr)	LONG WORKOUTS					
												Type	Time	Pts	Type	Time	Pts
#7	25	H, R	197	5	2	0.3	12.0	—	—	—	—	H	6.5	65	H	4.5	60
	26	H, R. BE	213	6	9	1.4	11.0	—	—	0.7	—	H/R	4.5	65	H	4.5	60
	27	H, R, BE	248	5	21	3.8	15.0	—	—	0.2	—	H	8.0	70	H	7.0	70
	28	H, R.	310	5	32	5.3	13.0	—	—	—	—	H	9.0	80	R	4.0	100
#8	29	R, BE	210	4	40	8.6	----	—	—	1.0	—	R	3.5	80	R	3.6	70
	30	R	355	3	72*	16.0	----	—	—	—	—	R	13.0	250			

*Includes Western States 100.

Key:
- R running
- H hiking/mountain climbing
- B bicycling
- XC cross-country skiing
- BE bicycle ergometer intervals
- ST stair intervals
- SW swimming
- XC_R cross-country ski race

APPENDIX C

APPENDIX C

DAILY LOG DATA

Test Period	Week #	Starting Date	A.M. Wt.	A.M. HR	Hours Sleep (Avg/day)	Calories/ Day
#1	1	2 Dec	108.8	48	5.4	1440
	2	9 Dec	108.9	44	6.6	1712
	3	16 Dec	110.6	48	7.4	1922
	4	23 Dec	113.0	48	7.3	1861
#2	5	30 Dec	111.4	46	6.3	1905
	6	6 Jan	111.5	46	7.0	1948
	7	13 Jan	112.4	44	6.6	2184
	8	20 Jan	113.3	45	6.5	2150
#3	9	27 Jan	113.9	48	6.7	2079
	10	3 Feb	115.2	47	6.6	2179
	11	10 Feb	113.9	49	7.1	2311
	12	17 Feb	113.7	47	6.4	2213
#4	13	24 Feb	113.7	47	7.5	2233
	14	2 Mar	115.4	47	7.0	2385
	15	9 Mar	115.5	50	8.0	2456
	16	16 Mar	116.0	48	8.1	2125
#5	17	23 Mar	114.4	48	7.5	2001
	18	30 Mar	114.4	47	6.9	2182
	19	6 Apr	114.3	48	6.9	2271
	20	13 Apr	115.2	47	6.4	2436
#6	21	20 Apr	115.0	48	7.2	2250
	22	27 Apr	116.1	47	7.6	2331
	23	4 May	115.7	47	7.1	2356
	24	11 May	116.1	48	6.9	2004
#7	25	18 May	115.9	48	7.0	2016
	26	25 May	115.6	47	7.0	2190
	27	1 June	116.0	47	6.9	2262
	28	8 June	116.8	47	7.0	2228
#8	29	15 June	116.7	50	7.0	2044
	30	22 June	117.0	47	6.9	2050

APPENDIX D

APPENDIX D

Human Performance Laboratory
Montana State University
Gas Analysis Calculations

Name _____ Age _____ Date _____

Weight (Kg)_____ Height _____ Test No. _____

Test Protocol

Kp (60 rpm)	1	2	2.5	3	4	4.25
Duration (min)	5	5	5	5	2.5	2
Sample (min)	4-5	4-5	4-5	4-5	2-2.5	1.5-2
Rest (min)			5	5	10	

Heart Rate

Volume

1. T_2 = Tissot, final
2. T_1 = Tissot, initial
3. ΔT = Tissot difference
4. ΔT x 3.244 = V_E uncorr.
5. BP = Barometric Pressure
6. T_c = Tissot Temp.
7. STPD
8. (7) x (4) = V_E Corr.

Room Air Correction

9. $CO_2\%$
10. E2
11. E2 x $^{21}/_{1000}$ = $O_2\%$
12. 100 - (9 + 11) = N_2
13. (12)/79.03 = N_2 Corr.

Oxygen Consumption

14. 20.88 x (13) = O_2 Corr.
15. (14) - (11) = O_2 Extr.
16. (15)/100 =
17. (8) x (16) = O_2 l/min
18. (17) x 1000 / BW(Kg) =
    O_2ml/Kg-min

RO

19. (9) - .03 = CO_2 prod.
20. (19)/(15) = RQ^2

APPENDIX E

APPENDIX E

BMR GAS ANALYSIS

1. T_2 = tissot, final _____
2. T_1 = tissot, initial _____
3. ΔT = tissot difference _____
4. ΔT x 3.244 = V uncorr. _____
5. BP = barometric pressure _____
6. T_c^{o} = tissot temperature _____
7. STPD
8. (7) x (4) = V corr. _____
9. E2 _____
10. E2 x $^{21}/_{1000}$ _____
11. 20.88 - (10) = O_2 ext. _____
12. $^{(11)}/_{100}$ = O_2% _____
13. (8) x (12) = VO_2 _____
14. (13)/15 = $\dot{V}O_2$ (1 /min) _____
15. (14) x 1000 = $\dot{V}O_2$ (cc/min) _____
16. (14) x $^{5kcal}/_{1}$ x 60 min/hr = $\dot{V}O_2$ kcal/hr _____

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Adams, W. C. Effect of a season of varsity track and field on selected anthropometric, circulatory and pulmonary function parameters. Research Quarterly, 39:5, 1968.

2. Alexander, J. F., Martin, S. L., and Metz, K. Effects of a four-week training program on certain physical fitness components of conditioned male university students. Research Quarterly, 39:16, 1968.

3. Alteri, R. A. The effects of interval and endurance running upon anthropometric and physiological parameters in college-aged females. Ph.D. Thesis, Middle Tennessee University, 1975.

4. Andersen, K. L., Shephard, R. J., Denolin, H., Varnauskas, E., and Masironi, R. Fundamentals of Exercise Testing. Geneva: World Health Organization, 1971.

5. Andrews, V. Women marathoners locked out. The Runner, 1:46, 1979.

6. Astrand, P. O. Ergometry--Test of Physical Fitness. Varberg, Sweden: Monark-Crescent AB.

7. _____. Human physical fitness with special reference to sex and age. Physiological Reviews, 36:307, 1956.

8. _____, and Rodahl, K. Textbook of Work Physiology. New York: McGraw-Hill Book Company, 1977.

9. Atomi, Y., Ito, K., Iwasaki, H., and Miyashita, M. Effects of intensity and frequency of training on aerobic work capacity of young females. Journal of Sports Medicine and Physical Fitness, 18:3, 1978.

10. Baldwin, F. M. and Shaw, R. J. Variations in metabolic levels as shown by oxygen consumption of football athletes throughout a playing season. Research Quarterly, 4:26, 1933.

11. Behnke, A. and Wilmore, J. H. Evaluation and Regulation of Body Build and Composition. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1974.

12. Bernauer, E. M. The effect of training in distance running on the critical flicker frequency and the stroke volume of young college males. Unpublished Master's Thesis, University of Illinois, Urbana, 1951.

13. Bird, P. J. and Alexander, J. F. Effects of an individually geared exercise program on physical fitness of adult men. Research Quarterly, 39: 857, 1968.

14. Blair, S. and Vincent, M. Variability of heart rate and blood pressure measurements on consecutive days. Research Quarterly, 42:7, 1971.

15. Brassfield, C. R. Some physiological aspects of physical fitness. Research Quarterly, 14:106, 1943.

16. Brooker, C. Use of efficiency as a measure of endurance training intensity. Research Quarterly, 39:865, 1968.

17. Brown, B. S., Moore, G. C., Kim, C. K., and Phelps, R. E. Physiological and hematological changes among basketball players during preseason. Research Quarterly, 45:257, 1974.

18. Brown, C. H., Harrower, J. R., and Deeter, M. F. The effects of cross-country running on pre-adolescent girls. Medicine and Science in Sports, 41:1, 1972.

19. _____, and Wilmore, J. H. The effects of maximal resistance training on the strength and body composition of women athletes. Medicine and Science in Sports, 6:174, 1974.

20. _____, and Wilmore, J. H. Physical and physiological profiles of champion women long-distance runners. Medicine and Science in Sports, 3:h, 1971.

21. Burke, E. J. Physiological effects of similar training programs in males and females. Research Quarterly, 48:510, 1977.

22. _____, and Brush, F. C. Physiological and anthropometric assessment of successful teenage female distance runners. Research Quarterly, 50:180, 1979.

23. Clarke, H. H. The Application of Measurement. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1967.

24. Cogswell, R. C., Henderson, C. R., and Berryman, G. H. Some observations of the effects of training on pulse rate, blood pressure, and endurance in humans, using the step test, treadmill, and electrodynamic brake bicycle ergometer. American Journal of Physiology, 146:422, 1946.

25. Consolazio, C. F., Johnson, R. E., and Recora, L. J. Physiological measurements of metabolic functions in man. New York: McGraw-Hill Book Company, 1963.

26. Cooper, K. H. The Aerobics Way. New York: M. Evans and Co., Inc., 1977.

27. Costill, D. L. Skinfold estimates of body fat among marathon runners. Medicine and Science in Sports, 2:93, 1970.

28. _____, Thomason, H., and Roberts, E. Fractional utilization of the aerobic capacity during distance running. Medicine and Science in Sports, 5:248, 1973.

29. _____, and Winrow, E. A comparison of two middle-aged ultramarathon runners. Research Quarterly, 41:135, 1970.

30. _____, and Winrow, E. Maximal oxygen intake among marathon runners. Archives of Physical Medicine and Rehabilitation, 51: 317, 1970.

31. Craig, A. Personal communication to Dr. Robert Schwarzkopf, 1968.

32. Cunningham, D. A. and Hill, J. S. Effect of training on cardiovascular response to exercise in women. Journal of Applied Physiology, 39:891, 1975.

33. Cureton, T. K. Comparison of various factor analyses of cardiovascular-respiratory test variables. Research Quarterly, 37: 317, 1966.

34. _____. Physical Fitness Appraisal and Guidance. St. Louis: Mosby, 1947.

35. _____. Physical Fitness of Champion Athletes. Urbana: University of Illinois Press, 1951.

36. _____. The Physiological Effects of Exercise Programs on Adults. Springfield, Illinois: Charles C. Thomas, Publisher, 1969.

37. Dale, E. Reproductive physiology and the female distance runner. Running, 3:12, 1978.

38. _____, Gerlach, D. H., Martin, D. E., and Alexander, C. R. Physical fitness profiles and reproductive physiology of the female distance runner. The Physician and Sportsmedicine, 7: 83, 1979.

39. Davis, J. A., Frank, M. H., Whipp, B. J., and Wasserman, K. Anaerbic threshold alterations caused by endurance training in middle-aged men. Journal of Applied Physiology, 46:1039, 1979.

40. Dawson, P. Effect of physical training and practice on the pulse rate and blood pressures during activity and during **rest**, with a note on certain acute infections and on the distress resulting from exercise. American Journal of Physiology, 50: 443, 1919.

41. Dempsey, J. A. Anthropometric observations on obese and nonobese young men undergoing a program of vigorous physical exercises. Research Quarterly, 35:275, 1964.

42. DeWijn, J. F., DeJongste, J. L., Mosterd, W., and Willebrand, D. Haemoglobin, packed cell volume, serum iron, and iron binding capacity of selected athletes during training. Journal of Sports Medicine and Physical Fitness, 11:42, 1971.

43. Dill, D. B. Marathoner DeMar: physiological studies. Journal of the National Cancer Institute, 35:185, 1965.

44. _____, Robinson, S., and Ross, J. C. A longitudinal study of 16 champion runners. Journal of Sports Medicine and Physical Fitness, 7:1, 1967.

45. Doherty, J. K. Modern Training for Running. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964.

46. Drinkwater, B. L. Physiological responses of women to exercise. In J. H. Wilmore, ed., Exercise and Sport Sciences Reviews, vol. I. New York: Academic Press, 1973.

47. _____, and Horvath, S. M. Detraining effects on young women. Medicine and Science in Sports, 4:91, 1972.

48. _____, and Horvath, S. M. Responses of young female track athletes to exercise. Medicine and Science in Sports, 3:56, 1971.

49. DuBois, E. F. Basal Metabolism in Health and Disease. Philadelphia: Lea and Febiger, 1936.

50. Durnin, J. V. G. A., Brockway, J. M., and Whitcher, H. W. Effects of a short period of training of varying severity on some measurements of physical fitness. Journal of Applied Physiology, 15:161, 1960.

51. Eisenman, P. and Golding, L. Comparison of effects of training on $\dot{V}O_2$ max in girls and young women. Medicine and Science in Sports, 7:136, 1975.

52. Fairbanks, B. Maximal oxygen uptake on a dual-drive bicycle versus a treadmill. Research Quarterly, 47:624, 1976.

53. Fardy, P. S. Effects of soccer training and detraining upon selected cardiac and metabolic measures. Research Quarterly, 40:502, 1969.

54. Feicht, C. B., Johnson, T. S., Martin, B. J., Sparkes, K. E., and Wagner, W. W. Secondary amenorrhea in athletes. Lancet, 2: 1145, 1978.

55. Fringer, M. N. and Stull, G. A. Changes in cardiorespiratory parameters during periods of training and detraining in young adult females. Medicine and Science in Sports, 6:20, 1974.

56. Gemmil, G., Booth, W., Detrick, J., and Scheibel, H. The effect of training on the recovery period following severe muscular activity. American Journal of Physiology, 96:265, 1931.

57. Grimby, G. and Saltin, B. Physiological effects of physical training. Scandinavian Journal of Rehabilitation Medicine, 3:6, 1971.

58. Gutin, B., Trinidad, A., Norton, C., Giles, E., Giles, A., and Stewart, K. Morphological and physiological factors related to endurance performance of 11- to 12-year old girls. Research Quarterly, 49:44, 1978.

59. _____, Fogle, K., and Stewart, K. Relationship among submaximal heart rate, aerobic power, and running performance in children. Research Quarterly, 47:536, 1976.

60. _____, Torrey, K., Welles, R., and Vytvytsky, M. Physiological parameters related to running performance in college trackmen. Journal of Human.Ergology, 4:27, 1975.

61. Guyton, A. C. Physiology of the Human Body. Philadelphia: W. B. Saunders Company, 1979.

62. Hannon, J. P., Shields, J. L., and Harris, C. W. Effects of altitude acclimatization on blood composition of women. Journal of Applied Physiology, 26:540, 1969.

63. Hanson, J. S., Tabakin, B. S., Levy, A. M., and Nedde, W. Long-term physical training and cardiovascular dynamics in middle-aged men. Circulation, 38:783, 1968.

64. Hartley, L. H., Grimby, G., Kilbom, A., Nilsson, N. J., Astrand, I., Bjure, L., Ekblom, B., and Saltin, B. Physical training in sedentary middle-aged and older men. III. Cardiac output and gas exchange at submaximal and maximal exercise. Scandinavian Journal of Clinical Laboratory Investigation, 24:335, 1969.

65. Henry, F. M. Influence of athletic training on the resting cardiovascular system. Research Quarterly, 25:28, 1954.

66. Hermansen, L. and Andersen, K. L. Aerobic work capacity in Norwegian men and women. Journal of Applied Physiology, 20:425, 1965.

67. Heusner, W. W., Jr. Progressive changes in the physical fitness of an adult male during a season of training for competitive swimming. Unpublished Ph.D. Thesis, University of Illinois, 1955.

68. Holloszy, J. Biochemical adaptations to exercise: aerobic metabolism. In J. H. Wilmore, ed., Exercise and Sport Sciences Reviews, vol. I. New York: Academic Press, 1973.

69. Holmer, I. Oxygen intake during swimming in man. Journal of Applied Physiology, 33:502, 1972.

70. _____, Lundin, A., and Erikson, B. O. Maximum oxygen intake during swimming and running by elite swimminers. Journal of Applied Physiology, 36:711, 1974.

71. Holmgren, A. Cardiorespiratory determinants of cardiovascular fitness. Canadian Medical Association Journal, 96:697, 1967.

72. _____, Mossfeldt, F., Sjöstrand, T., and Ström, G. Effect of training on work capacity, total hemoglobin, blood volume, heart volume, and pulse rate in recumbent and upright positions. Acta Physiologica Scandinavica, 50:72, 1960.

73. Jackson, J. H., Sharkey, B. J., and Johnston, L. P. Cardiorespiratory adaptations to training at specified frequencies. Research Quarterly, 39:295, 1968.

74. Katch, F. I. Pre- and post-test changes in the factors that influence computed body density changes. Research Quarterly, 42: 280, 1971.

75. _____, and Danielson, G. Bicycle ergometer endurance in women related to maximal leg force, leg volume, and body composition. Research Quarterly, 47:366, 1966.

76. _____, and McArdle, W. D. Nutrition, Weight Control, and Exercise. Boston: Houghton Mifflin Company, 1977.

77. _____, McArdle, W. D., Czula, R., and Pechar, G. S. Maximal oxygen intake, endurance running performance, and body composition in college women. Research Quarterly, 44:301, 1973.

78. _____, Michael, E. D., and Jones, E. M. Effects of physical training on the body composition and diet of females. Research Quarterly, 40:99, 1969.

79. Katch, V. L. and Katch, F. I. Reliability, individual differences and intravariation of endurance performance on the bicycle ergometer. Research Quarterly, 43:31, 1972.

80. Keys, A. Recommendations concerning body measurements for the characterization of nutritional status. Human Biology, 28: 111, 1956.

81. _____, and Brozek, J. Body fat in adult man. Physiological Reviews, 33:245, 1953.

82. Kireilis, R. W. and Cureton, T. K. The relationships of external fat to physical education activities and fitness tests. Research Quarterly, 18:123, 1947.

83. Kjellberg, S. R., Rudhe, U., and Sjöstrand, T. Increase of the amount of hemoglobin and blood volume in connection with physical training. Acta Physiologica Scandinavica, 19:146, 1949.

84. Knowlton, R. G. and Deutsch, D. T. Performance outcomes of cross-country running structured in a voluntary activity class. Research Quarterly, 46:371, 1975.

85. _____, and Weber, H. A case study of training responses in a female endurance runner. Journal of Sports Medicine and Physical Fitness, 8:228, 1968.

86. Kristufek, C. J. Effect of endurance training on an adult subject. Unpublished Master's Thesis, University of Illinois, Urbana, 1951.

87. Lesmes, G. R., Fox, E. L., Stevens, C., and Otto, R. Metabolic responses of females to high intensity interval training of different frequencies. Medicine and Science in Sports, 10: 229, 1978.

88. Lundegren, H. M. Changes in skinfold and girth measurements of women varsity basketball and field hockey players. Research Quarterly, 39:1020, 1968.

89. Maksud, M. G., Cannistra, C., and Dublinski, D. Energy expenditure and $\dot{V}O_2$ max of female athletes during treadmill exercise. Research Quarterly, 47:692, 1976.

90. _____, Wiley, R. L., Hamilton, L. H., and Lockhart, B. Maximal $\dot{V}O_2$, ventilation, and heart rate of Olympic speed skating candidates. Journal of Applied Physiology, 29:186, 1970.

91. Malina, R. M., Harper, A. B., Avent, H. H., and Campbell, D. E. Physique of female track and field athletes. Medicine and Science in Sports, 3:32, 1971.

92. Martin, B. J., Sparks, K. E., Zwillich, C. W., and Weil, J. V. Low exercise ventilation in endurance athletes. Medicine and Science in Sports, 11:181, 1979.

93. Massie, J., Rode, A., Skrien, T., and Shephard, R. J. Critical review of the "Aerobics" point system. Medicine and Science in Sports, 2:1, 1970.

94. Maxfield, M. E. Use of heart rate for evaluating cardiac strain during training in women. Journal of Applied Physiology, 19:1139, 1964.

95. Mayhew, J. L. and Gross, P. M. Body composition changes in young women with high resistance weight training. Research Quarterly, 45:433, 1974.

96. McArdle, W. D. and Magel, J. M. Physical working capacity and maximal oxygen uptake in treadmill and bicycle exercise. Medicine and Science in Sports, 2:118, 1970.

97. Michael, E. D. and Cureton, T. K. Effects of physical training on cardiac output at ground level and at 15,000 feet simulated altitude. Research Quarterly, 24:446, 1953.

98. Milesis, C. A., Pollock, M., Bah, M. D., Ayres, J. J., Ward, A., and Linnerud, A. C. Effects of different durations of physical training on cardiorespiratory function, body composition, and serum lipids. Research Quarterly, 47:716, 1976.

99. Milvy, P., ed. The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies. New York: New York Academy of Sciences, 1977.

100. Miyamura, M. and Honda, Y. Oxygen intake and cardiac output during maximal treadmill and bicycle exercise. Journal of Applied Physiology, 32:185, 1972.

101. Montoye, H. J., ed. An Introduction to Measurement in Physical Education. Volume 2: Growth, Development, and Body Composition. Indianapolis: Phi Epsilon Kappa Fraternity, 1970.

102. _____. An Introduction to Measurement in Physical Education. Volume 5: Laboratory Manual of Exercises. Indianapolis: Phi Epsilon Kappa Fraternity, 1970.

103. Moody, D. L., Kollias, J., and Buskirk, E. R. The effect of a moderate exercise program on body weight and skinfold thickness in overweight college women. Medicine and Science in Sports, 1:75, 1969.

104. _____, Wilmore, J. H., Girandola, R. N., and Joyce, J. P. The effects of a jogging program on the body composition of normal and obese high school girls. Medicine and Science in Sports, 4:210, 1972.

105. Morehouse, L. E. and Miller, A. T. Physiology of Exercise. St. Louis: The C. V. Mosby Co., 1948.

106. _____, and Tuttle, W. W. A study of the post-exercise heart rate. Research Quarterly, 13:3, 1942.

107. Morrow, J. R., Jackson, A. S., and Bell, J. J. The function of age, sex, and body mass on distance running. Research Quarterly, 49:491, 1978.

108. Nagle, F. J. Physiological assessment of maximal aerobic performance. In J. H. Wilmore, ed., Exercise and Sport Sciences Reviews, vol. I. New York: Academic Press, 1973.

109. Noble, B. J., Maresh, C. M., Allison, T. G., and Drash, A. Cardiorespiratory and perceptual recovery from a marathon run. Medicine and Science in Sports, 11:239, 1979.

110. Novak, L. P., Woodward, W. A., Bestit, C., and Mellerowica, H. Working capacity, body composition, and anthropometry of Olympic female athletes. Journal of Sports Medicine, 17:275, 1977.

111. Oscai, L. B., Williams, B. T., and Hertig, B. A. Effects of exercise on blood volume. Journal of Applied Physiology, 24:622, 1968.

112. Osler, T. Ultramarathoning secrets. Runner's World, 13:52, 1978.

113. Parizkova, J. Body composition and physical fitness. Current Anthropology, 9:273, 1968.

114. _____. Body Fat and Physical Fitness. The Hague: Martinus Nijhoff, 1977.

115. Pechar, G. S., McArdle, W. D., Katch, F. K., Magel, J. R., and deLuca, J. Specificity of cardiorespiratory adaptation to bicycle and treadmill training. Journal of Applied Physiology, 36:753, 1974.

116. Pedersen, P. K. and Jorgensen, K. Maximal oxygen uptake in young women with training, inactivity, and retraining. Medicine and Science in Sports, 10:233, 1978.

117. Phillips, M. Effect of the menstrual cycle on pulse rate and blood pressure before and after exercise. Research Quarterly, 39:327, 1968.

118. Plowman, S. Physiological characteristics of female athletes. Research Quarterly, 45:349, 1974.

119. Pollock, M. L. The quantification of endurance training programs. In J. H. Wilmore, ed., Exercise and Sport Sciences Reviews, vol. I. New York: Academic Press, 1973.

120. _____, Dimmick, J., Miller, H. S., Kendrick, A., and Linnerud, A. C. Effects of mode of training on cardiovascular function and body composition of adult men. Medicine and Science in Sports, 7:139, 1975.

121. Rasch, P. J., Hamby, J. W., and Burns, H. J. Protein dietary supplementation and physical performance. Medicine and Science in Sports, 1:195, 1969.

122. Roberts, J. A. and Alspaugh, J. W. Specificity of training effects resulting from programs of treadmill running and bicycle ergometer riding. Medicine and Science in Sports, 4: 6, 1972.

123. Robinson, S. Metabolic adaptations to exhausting work as affected by training. American Journal of Physiology, 133:428, 1941.

124. _____, Edwards, H. T., and Dill, D. B. New records in human power. Science, 85:409, 1937.

125. _____, and Harmon, P. M. The lactic acid mechanism and certain properties of the blood in relation to training. American Journal of Physiology, 132:757, 1941.

126. Runner's Training Guide. Mountain View, California: World Publications, 1975.

127. Saltin, B. and Astrand, P.-O. Maximal oxygen uptake in athletes. Journal of Applied Physiology, 23:353, 1967.

128. Schneider, E. C. and Foster, A.O. The influence of physical training on basal metabolic rate of man. American Journal of Physiology, 98:595, 1931.

129. _____, and Havens, L. S. Changes in the blood after muscular activity and during training. American Journal of Physiology, 36:239, 1915.

130. _____, and Karpovich, P. V. Physiology of Muscular Activity. Philadelphia: W. B. Saunders, Co., 1949.

131. Scott, M. G. and French, E. Measurement and Evaluation in Physical Education. Dubuque: Wm. C. Brown Co. Publishers, 1970.

132. Sharkey, B. Physiological Fitness and Weight Control. Missoula, Montana: Mountain Press Publishing Co., 1974.

133. _____. Physiology of Fitness. Champaign, Illinois: Human Kinetics Publishers, 1979.

134. Shephard, R. J. Endurance Fitness. Toronto: University of Toronto Press, 1977.

135. Shutz, R. W. Sampling theory and procedures. In J. H. Wilmore, ed., Exercise and Sport Sciences Reviews, vol. I. New York: Academic Press, 1973.

136. Sinning, W. E. Body composition, cardiorespiratory function and rule changes in women's basketball. Research Quarterly, 44:313, 1973.

137. _____, Cunningham, L. N., Racaniello, A. P., and Sholes, J. L. Body composition and somatotype of male and female nordic skiers. Research Quarterly, 48:741, 1977.

138. Skinner, J., Holloszy, J., and Cureton, T. K. Effects of a program of endurance exercises on physical work. American Journal of Cardiology, 14:747, 1964.

139. Sloan, A. W. Effect of training on physical fitness of women students. Journal of Applied Physiology, 16:167, 1961.

140. _____, Burt, J. J., and Blyth, C. S. Estimation of body fat in young women. Journal of Applied Physiology, 17:967, 1962.

141. Steinhaus, A. H. Chronic effects of exercise. Physiological Reviews, 13:103, 1933.

142. Thompson, C. W., Buskirk, E. R., and Goldman, R. F. Changes in body fat, estimated from skinfold measurements of college basketball and hockey players during a season. Research Quarterly, 27:418, 1956.

143. Tooshi, A. Effects of endurance jogging on cardiovascular system and body composition in midde-aged women. Paper presented at the National Convention of the American Association for Health, Physical Education, and Recreation, Minneapolis, Minnesota, April 1973.

144. Tuttle, W. W. and Walker, F. H. The effect of a season of training and competition on the response of the hearts of high school boys. Research Quarterly, 11:78, 1940.

145. Ullyot, J. Women's Running. Mountain View, California: World Publications, 1976.

146. Vanfraechem, J. H. P. and Vanfraechem-Raway, R. The influence of training upon physiological and psychological parameters in young athletes. Journal of Sports Medicine and Physical Fitness, 18:175, 1978.

147. Viru, A. A., Urgenstein, Y. U., and Pisuke, A. P. Influence of training methods on endurance. Track Technique, 47:1494, 1972.

148. VonDöbeln, W. A simple bicycle ergometer. Journal of Applied Physiology, 7:222, 1954.

149. deVries, H. A. Physiology of Exercise. Dubuque, Iowa; Wm. C. Brown Company, 1971.

150. Wallace, J. P. Responses of the composition of body fat to cardiovascular training in college women. Research Quarterly, 46: 317, 1975.

151. Wallin, C. C. and Schendel, J. S. Physiological changes in middle-aged men following a ten-week jogging program. Research Quarterly, 40:600, 1969.

152. Walters, C. E. A study of the effects of prescribed strenuous exercises on the physical efficiency of women. Research Quarterly, 24:102, 1953.

153. Weltman, A., Moffatt, R. J. and Stamford, B. A. Supramaximal training in females: effects on anaerobic power output, anaerobic capacity, and aerobic power. Journal of Sports Medicine and Physical Fitness, 18:237, 1978.

154. Wenger, H. A. and MacNab, R. B. J. Endurance training: the effects of intensity, total work, duration and initial fitness. Journal of Sports Medicine and Physical Fitness, 15:202, 1975.

155. Wilmore, J. H. and Behnke, A. R. An anthropometric estimation of body density and lean body weight in young women. American Journal of Clinical Nutrition, 23:267, 1970.

156. _____, and Brown, C. H. Physiological profiles of women distance runners. Medicine and Science in Sports, 6:178, 1974.

157. _____, Davis, J. A., O'Brien, R. S., Vodak, P. A., Walder, G. R. and Amsterdam, E. A. Physiological alterations consequent to 20-week conditioning programs of bicycling, tennis, and jogging. Medicine and Science in Sports, 12:1, 1980.

158. _____, Girandola, R. N., and Moody, D. L. Validity of skinfold and girth assessment for predicting alterations in body composition. Journal of Applied Physiology, 29:313, 1970.

159. _____, Royce, J., Girandola, R. N., Katch, F. I., and Katch, V. L. Physiological alterations resulting from a ten-week program of jogging. Medicine and Science in Sports, 2:7, 1970.

160. _____, and Sigerseth, P. O. Physical work capacity of young girls, 7-13 years of age. Journal of Applied Physiology, 22: 923, 1967.

161. Wilt, F. Training for competitive running. In H. B. Falls, ed., Exercise Physiology. New York: Academic Press, 1968.

162. Wirth, J. C., Lohman, T. G., Avallone, J. P., Sire, T., and Boileau, R. A. Effect of physical training on serum iron levels of college-age women. Medicine and Science in Sports, 10:223, 1978.

163. Withers, R. T. Physiological responses of international female lacrosse players to pre-season conditioning. Medicine and Science in Sports, 10:238, 1978.

164. Yeager, S. A. and Brynteson, P. Effects of varying training periods on the development of cardiovascular efficiency of college women. Research Quarterly, 41:589, 1970.