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An analysis of heart rate patterns in experienced middle-distance runners while interval running

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AN ANALYSIS OF HEART RATE PATTERNS IN EXPERIENCED

MIDDLE-DISTANCE RUNNERS WHILE INTERVAL RUNNING

by

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THE PROBLEM

I. INTRODUCTION

One of the best avenues available in searching for a better understanding of various aspects of the physiology of exercise is to study human function during work. Experimentation with different forms of physical exercise not only aids in a better understanding of how man functions during specific work tasks, but it also leads to a more exact knowledge of what activities to prescribe or administer when specific results are desired.

Studies of the physiological changes in man have been confined primarily to the laboratory with the use of a step test, bicycle ergometer, or treadmill as a means of exercise. Only recently have subjects been studied during actual training routines, and with few exceptions, these studies have recorded the recovery heart rate after an exercise bout (7, 11, 25, 31, 44). Telemetered measures of the heart rate response during the entire exercise and recovery period may produce more useful data. Telemetry of the commonly accepted interval running method permits an analysis of heart rate response to this type of exercise and the physiologic recovery from it.

By selecting a certain physiologic phenomenon, such as heart rate, and measuring it while experimenting with a specific training regimen, it may be possible to obtain some insight into the type of work needed when specific performance adaptations are desired. For example, the influence that a specific training regimen, such as a specific increment in pace has upon the heart rate may be determined.

Balke (15) reports that a limitation of optimal cardiovascular and respiratory function exists when a heart rate of 180 beats per minute is reached, which, according to Asmussen and Nielsen (3), is considered to approximate the rate at which maximum or near maximum cardiac output and oxygen consumption are approached. Balke refers to this heart rate level as the optimal work capacity. The optimal work capacity is achieved when energy output and oxygen uptake are balanced at an optimum. Balke reported that the optimal work capacity was exceeded near the 180 heart rate since a sudden rise in anaerobic work occurred at this point. The term, optimal, represents a level of physical activity which is approximately 50 per cent of the limitation of human work capacity, with no cumulative effects of physical fatigue from day to day. Also, Wyndham (51) suggests that the maximum level of oxygen intake for prolonged endurance effort is roughly 50 per cent of the individual's maximum oxygen intake. As a result, this type of work may be repeated daily for a number of weeks. Moreover, Nagle and Bedecki (39) state that the 180 heart rate tests the end point of exercise by observation and measurement rather than the subject's will to cooperate.

Nagle and Bedecki (39) report that a linear relationship existed between ventilation and heart rate up to a heart rate of 170 beats per minute. Between the rates of 170 and 180 beats per minute the ventilation function increases out of proportion to the increase in heart rate. Also, the oxygen consumption/work curve showed that an increase in anaerobic work occurred throughout the exercise period. This increase became acute between heart rates of 170 and 180 indicating the onset of physiological incompetence and deterioration in circulo-respiratory efficiency.

Gerschler (47) suggests a warm-up to bring the heart rate up to 120 beats per minute before starting interval running. Astrand (5) states that it is important to exceed a threshold of 120 beats per minute if the training is to be effective. He reports that a training tempo which loads the oxygen transport system maximally is as effective as any higher speed; but it remains to be determined whether workloads above the point of leveling off (180 beats per minute) of the oxygen uptake with increasing load contribute to the training of the oxygen transport system.

Nocker (19) states that the intensity of work must be great enough to obtain adaptation to the distress of exercise both in the muscles and in the heart. This adaptation can be gained by an intensity of exertion of at least 60 per cent and at most 80 per cent of maximal capabilities. Counsilman (17) asserts that an intensity of work of 30 to 70 per cent of maximal capability develops the heart muscle and cardiovascular endurance, whereas, an intensity above 70 per cent places greater distress on the skeletal muscles and organs other than the heart. Sharkey and Holleman (42) utilized the treadmill in studying the effects of three different training intensities on cardiovascular adaptation and found that training at near maximal heart rate levels, 180 beats per minute, was significantly better than lower heart rate levels (150 and 120 beats per minute) in increasing work capacity. Karvonen (26) found 60 per cent of the heart rate range to be the critical rate; above this level the training was effective, below it the training was ineffective. He arbitrarily set 150 beats per minute as the 60 per cent level.

Gerschler (47) and Wilt (50) suggest that 180 beats per minute represents the limit for optimum development of work capacity of the heart. Doherty (19) suggests using 160 beats per minute, and Reindell (50) states 150 beats per minute as the most favorable for the optimum development of work capacity of the heart. However, in spite of the differences, all are in agreement that the heart rate should return to 120-140 beats per minute during recovery before beginning another session of interval running.

Therefore, in order for interval running to be effective for development of cardiovascular and respiratory endurance, the heart rate should range above these hypothesized levels of the maximum heart rate range.

In view of the preceding literature, one can see the controversy over what exercise heart rate level constitutes the optimal work intensity in interval running. The limited experimental evidence and the contradictory results concerning the effects of interval running upon heart rate patterns and endurance performance has prompted this investigation.

II. THE PROBLEM

Statement of the Problem

The problem of this investigation was that of determining the effects of various distances and paces upon the heart rate patterns of experienced and pre-trained middle-distance runners. Of specific concern was the heart rate response during exercise and during recovery in relation to exercise and recovery time. An examination was made of the effects of successive interval runs on the exercise heart rate and recovery heart rate.

Purpose of the Study

The purpose of this study was to investigate heart rate patterns of middle-distance runners in an attempt to approximate the optimum workload of the various individual runners. An attempt was made to show how each subject's heart rate responded during exercise and during recovery from their individual running events. It was also a purpose of this study to determine how each subject differed in his response to training, and how the individual running times and heart rates approximated each other. An additional purpose was to compare the individual heart rate responses during each regimen of interval running to determine how much recovery time was needed to allow it to return to 140 as stated by Gerschler (47), and what paces to run to allow it to approach 180 as stated by Doherty (19), Sharkey and Holleman (42), Gerschler (47), and Wilt (50).

The results of this study should give insight into the value of this type of interval running and training, and would presumably lead to the development of improved endurance training regimens, and ultimately, improvements in performance.

III. BASIC ASSUMPTIONS

A. It was assumed that the slower paced continual running caused a greater physiological strain than the faster paced interval running, a greater loss of productive time, and a longer recovery interval.

B. It was assumed that the heart rates recorded were chiefly a result of the work being done and were only slightly affected by temperature, relative humidity, and barometric pressure.

C. Finally, it was assumed that the heart rate was a proper measure of physiological involvement resulting from the work and that this measure could be obtained with very little disturbance to the subject.

IV. LIMITATIONS OF THE STUDY

A. The number of subjects was limited to three conditioned and specifically trained middle-distance runners.

B. The heart rate was taken only once on each subject for each interval running regimen; no other physiological measures were taken.

C. Numerous extraneous variables such as living habits, personality makeup and individual traits, e.g., psychological limits, physiological limits, gait patterns, etc., were uncontrolled.

D. The ambient environment was uncontrollable, thereby lending possible error to the measures.

V. DEFINITIONS

The following terms are defined as they were used in this study.

Exercise heart rate. The highest recorded heart rate during a period of running.

Recovery heart rate. The heart rate after cessation of exercise for a specified time.

Resting heart rate. The heart rate as recorded with telemetering equipment attached to a subject who has been resting at the track for approximately one-half hour before doing any warming-up activities.

Post warm-up heart rate. The heart rate recorded by electrocardiograph after the subject had warmed-up, but before walking onto the track to begin interval running.

Workload. Work involved in the interval running technique of the Bowerman program at the University of Oregon. See training, page 35.

Physiological strain. The reaction of the heart rate to the exercise performed.

Interval training. A system of repeated efforts in which the athlete runs varied, but specified distances on a track at a timed pace alternating his runs with measured recovery periods of jogging (19, 37).

Optimal workload. The desired distance-pace needed to elevate the heart rate above 180 beats per minute, and still allow it to return to 140 beats per minute in 90 seconds, herein used to develop cardiovascular-respiratory endurance.

CHAPTER II

SURVEY OF RELATED LITERATURE

I. INTERVAL TRAINING

During the past three decades, the use of the submaximal, distance running approach to high level endurance has been displaced as the best method of training by the use of high-intensity interval training methods (12). No one person or country can be given credit for the development of interval training; however, credit for the exact measurement and organization of the various elements comprising interval training is generally attributed to Dr. Woldemar Gerschler (19, 47), coach of the famous German runner, Rudolph Harbig.

Interval training is presently used throughout the world to prepare runners for competition. It is designed to subject the human organism repeatedly to physiological strain in rhythmical waves, permitting a gradual advancement of the intensity and dosage of work (19). There is one common principle employed in this method of conditioning; i.e., a fast run is always followed by a slow run or walk. Thus, the body is always kept active through the use of "submaximal or maximal locomotion in a defined rhythmical pattern" (19).

The interval running scheme is empirically based on the assumption that repetitive performance at competitive pace or faster is the training procedure most favorable for improving the speed and the endurance of a competitive runner (19, 37). This hypothesis is based on the assumption that short, repetitive runs can be substituted for longer runs as a means to develop the capacity for endurance efforts (19). The effectiveness in attaining the objective the runner has in training, whether it be speed or endurance, is the reason which has led to the wide adoption of interval running as a form of workout. Most runners include in their training forms of endurance running which usually consist of a composite of over-distance and interval running.

Counsilman (17) states that the logic behind interval training seems sound in that the body attempts to adapt to the specific stress placed upon it. His hypothesis is as follows:

> If one trains at long distances at a slow pace, he will adapt his body specifically to the stress of swimming long distances at a slow pace. If he wishes to condition himself to go faster, he must train at a speed close to the speed he wishes to use in the race.

His body will then adjust to the type of stress imposed upon it by this fast pace. Doherty (19) claims that a faster than competitive pace puts an overload upon the circulatory system and, as with muscular strength training, produces development beyond what would be possible by doing the action at competitive pace, no matter how prolonged.

Mollet (37) indicates that interval training is favorable to the psychological well-being or attitude of the athlete as well as the development of endurance through speed. More and more work can be performed within a given period of time with fewer signs of fatigue. Increasing the amount of work performed will allow for a gradual buildup of resistance to fatigue. The varying changes of pace will result in greater amounts of stress due to increased oxygen consumption. The final outcome of the adjustment to this stress is better physical condition.

Mollet further states that the kind of condition obtained by interval training depends upon the emphasis placed on each of the factors of interval training -- the distance, speed, repetition, duration and/or action during the recovery interval; i.e., emphasizing repetitions will result in an increased ability to run a long distance. Emphasis should be placed primarily on speed, repetition, and length and action of recovery interval as the human system cannot adjust favorably if too much work is crowded into too short a period of time (18).

Interval training is thought to be an acceptable training procedure because the recovery interval allows the individual to recover from the oxygen debt incurred by the run (12, 19, 37, 50). The oxygen debt is repeatedly built up and the organism becomes capable of maintaining a stable condition or of having a lower oxygen debt during running at the competitive pace (50). Brouha (9) states that for interval training efforts, the rate of repayment of oxygen is of considerable importance. The bursts of exercise may be submaximal or maximal, so long as the athlete repays the oxygen debt. This recovery period enables the individual to produce more total work at a higher output than would a continued pace exercise, and to withstand a more intense workload in a shorter period of time than he could if subjected to a longer, lighter workload (19, 37, 50).

Conditioning for running, states Doherty (19), is primarily a matter of building resistance to the many effects of fatigue, e.g., production of lactic acid, lowered oxygen supply to the muscles, decreased sensitivity of muscle fibers to stimuli, etc. This is done by gradually increasing the amount of work that is done as muscle efficiency improves. The less the anaerobic work, the faster the recovery (9), consequently an athlete able to reach a high steady state oxygen consumption level and able to recover quickly will achieve a high level of physiological efficiency.

According to Wilt (50), Karvonen (26), and Doherty (19), the heart rate, to be effective for optimum development of cardio-respiratory exercise tolerance, must exceed 160 beats per minute during exercise, while Reindell (50) considers 180 beats per minute as maximum. Reindell considers heart enlargement to be the important factor in endurance training. Moreover, he and Nett (40) consider the period 30 seconds after cessation of exercise the most critical in development of stroke volume and, thus, physiological hypertrophy of the heart. Reindell further states that the

> ...vigorously pumping heart is induced to transport the full volume of blood through the still open peripheral arteries, thus retaining the stimulus on the heart while the skeletal musculature is recovering.

In this way, the cardiac muscle receives more training than in the continuous form of endurance training (19). Nett (40) indicates that the

> ...quick, strong extravasion of blood from the heart at the beginning of the recovery interval will not occur if the rate of the heart beat is too high.

He states that there is no buildup of a strong 'beat-volume' so that the stimulus for the physiological enlargement of the heart muscle is lacking.

Smit (45) offers the following explanation for the strong, physiologic development of the heart during interval training:

> During the loading phase the systolic pressure increases, whereas the diastolic pressure remains almost unchanged or, at most, shows only a slight drop. Simultaneously, the heart frequency increases steeply, only to drop sharply after a few seconds at the conclusion of the work, while the blood pressure amplitude remains relatively high. The significance of this is that, during the recovery phase the heart functions with a very large stroke volume, thereby rendering dilitation stimuli on the walls of the heart. At the same time this results in a strong stimulus for the development of capillaries in the skeletal musculature.

The recovery interval, according to Doherty (19), serves the dual role of recovery from the oxygen debt and development of the heart. The determinants of the length of time that is needed for a recovery interval, or whether it should be flexible or fixed, are maturity, conditioning, purpose of workout, length of time available for total workout, and the manner in which fatigue is intended to develop during a workout. According to Doherty (19), Karvonen (26), and Wilt (50) the heart rate should recover to 120-130 beats per minute within 90 seconds after cessation of exercise. If the heart rate exceeds this recovery limit, the physiological strain is too great (19, 50), and the work output must be reduced according to the variables set down by Mollet (37).

Wilt (50) states that, empirically, one minute of walking produces as much if not more recovery than two minutes of jogging: however, jogging is generally recommended as the recovery action in interval running. If jogging is used, it should be two to three times longer than the duration of the preceding fast run.

Doherty (19), quoting Reindell and Nocker, states that:

> From at least a cardiovascular standpoint, there is an optimum distance-pace for each man that will allow him to make an optimum number of repetitions and thus produce maximum development. They have concluded that this distance should not require more than sixty seconds to complete and that the exertion of doing so should permit the heart rate to drop to about 120-140 beats per minute at the end of a recovery interval of 40-90 seconds. This would mean something less than 440 yards.

Smit (45) summarizes the physiology of interval training with the following statement:

> During the loading phase, the capillaries in the musculature are opened, the heart beat and the heart stroke volume as well as the minute volume of ventilation are increased. Then the activity is stopped and the recovery phase sets in. The main part of the recovery falls within the one or two minutes of recovery during which, on the average, 60 to 80 per cent of the recovery takes place according to the intensity and duration of the work. The higher the intensity, the longer the duration of the recovery.

II. RELATED STUDIES

The relationship between the heart rate response and two different levels of workload in bicycle ergometer work was studied by Alderman (2). His subjects pedalled the bicycle ergometer four times; twice at 45.45 RPM, and twice at 54.54 RPM. The resistance was progressively increased each successive minute by the addition of one-half kilogram. The exercise was terminated at a heart rate of 180 beats per minute. He showed that 13 per cent of the difference in individual variance in heart rate response was specific to a particular workload, i.e., 87 per cent was common to the two different workloads. He based this on his intercorrelation between exercise times (r=0.933). He indicated that the common factor operated with respect to heart rate response to two different workloads within the same task, and that it operated at those heart rate responses which are most indicative of a person's capacity -- namely, the higher levels. He concluded that individual differences in heart rate response at two different workloads within the same task showed high generality.

Kozar and Hunsicker (29) used heart rate response for a given time of participation as the criterion for determining the relative strenuousness of six selected sports (handball, paddleball, tennis, badminton, volleyball, and bowling). They found that participants in all activities reached peak heart rates which did not differ significantly from each other with the exception of volleyball and bowling, which had lower heart rates.

Durnin, Brockway, and Whichter (20), in an attempt to determine the effect of different severities of training on some physical fitness measurements during a period of ten days, found that heart rates recorded during exercise provided the most consistent data. The post-exercise heart rate data showed much less uniformity. All the exercise groups had a significant improvement in their heart rate.

The heart rate response to exercise depends on the kind of exercise being performed, the duration of exercise, and whether the individual is in good or poor physical condition. Many authors (6, 9, 33, 35, 44, 46) report that, in general, the heavier the workload the higher the exercise heart rate and the longer it will take to return to the resting level. The duration of exercise also influences the heart rate recovery. For heavier work that can be maintained in a steady state, the longer the duration of exercise, the longer the recovery to the resting level.

LeBlanc (30) has shown work and recovery heart rates of man exercising at different levels of activity to be of value in judging the intensity and duration of work performed. He found that in some cases the heart rate reached a steady state, whereas in others it increased gradually until the end of the exercise. He suggests that the inability of the heart rate to remain at a steady state indicates that fatigue is experienced by the heart. The magnitude of fatigue is actually controlled by both the duration and the intensity of the work.

The chief differences in studies of heart response to exercise as stated by Morehouse and Tuttle (38), lie in the variety and strenuousness of the exercises employed and the phases of recovery used as indices. They concluded that the reliability of the heart rate for two minutes after exercise is directly related to the strenuousness of the exercise; that the post-exercise increase in heart rate above the resting level is directly related to the intensity of the exercise; and that, in general, where exercises are used to differentiate individuals on the basis of the post-exercise heart rate and the recovery time, they must be strenuous in order to give reliable results.

Faulkner and Dawson (22) determined the relationship of swimming velocity and heart rate, and found that a reasonably linear relationship existed. They concluded that the velocity-heart rate relationship may be used to compare relative efficiency among swimmers and changes in efficiency of individual swimmers during training or detraining.

III. TRAINING STUDIES

The adaptation of cardiac rate in the trained and untrained runner, prior to, during, and in recovery from selected running events was studied by McArdle, Foglia, and Patti (31). They found heart rate patterns during exercise to be similar in both trained and untrained runners. The researchers reported a significant difference in maximum heart rates of trained runners during the various track events, with further analysis indicating that higher peak heart rates were elicited in events of longer distance. They also found that in exercise of the same relative intensity, an all-out run, the recovery patterns of both trained and untrained runners were not significantly different.

Knehr, Dill, and Neufeld (27) investigated the effects of six months of treadmill training on 14 middle-distance runners at rest and at work. They found that exercise, repeatedly carried out, leads to an improved performance. In the runner this amounted to running a greater distance at the same pace, or covering the same distance more quickly, or covering the same distance at the same rate with less fatigue. They showed that if the rate of work output is kept constant, there may be an enormous increase in the quantity of work that can be done. They analyzed the heart rate during recovery and found that not only was the mean maximal heart rate at the end of the run approximately constant but also the regimen of training did not materially alter the course of the recovery heart rate.

In their recent study of heart rate responses to four different pace patterns in the one-mile run, Bowles and Sigerseth (7) reported that the heart rate response to exercise is very rapid, reaching near maximum values before 220 yards. The fast-slow pattern of running brought about a significantly higher heart rate response than did any other pace pattern during the one-mile run. They found no significant difference between heart rate recovery and pace patterns.

Orban, _et al_., (41) used heart rate response to evaluate five active subjects under three conditions of interval running and one all-out run. Each subject ran five one-minute runs of 330 yards with a controlled, active recovery interval between runs. The recovery intervals were one, two, and three minutes on three successive days. They found that the peak heart rate in each run interval was inversely related to the length of the recovery interval. The pattern of the recovery interval remained constant. The maximum rates in the interval runs differed from the continuous run only in the two terminal minutes; and the final recovery rate pattern indicated no significant differences.

The effects of intermittent and continuous running on two well-trained subjects was studied by Christensen, Hedman, and Saltin (14). They found that the use of the interval type of training allowed the subjects to complete a 30 minute exercise period, 20 minutes of running at 12.4 miles per hour on the tread-mill and 10 minutes of rest, without exhaustion. The researchers indicated that the interval training caused only a slight increase in lactic acid concentration in the blood which indicated almost total aerobic work.

Irma Astrand, _et al_., (4) investigated the physiological effect of rest pauses on non-steady state work. A physically well-trained subject rode a bicycle ergometer one hour at 2160 kpm/min. by intermittent work with 0.5, 1.0, 2.0, or 3.0 minute periods of equal work and rest. The heavy work, when split into short periods of work and rest, was transformed to a submaximal load on circulation and respiration and was well-tolerated during one hour. They found low lactic acid values associated with work of short periods. The researchers indicated that one can divide the total amount of work into suitable periods in such a way that one can induce training of large muscle groups without simultaneously loading the respiratory and circulatory organs (work with short period over long time). By choosing longer periods, for example two to three minutes, one can obtain a high training effect also on respiration and circulation.

Brouha and Radford (12) wrote that during intermittent exercise, the heart rate reaches about the same level during each period of repeated, moderate exercise, and the cardiovascular recovery reactions during the rest periods are determined by the total previous work performed. For harder work, the exercise heart rate increases further with each successive period and no steady state can be maintained throughout the total performance. When exercise is not continuous, the heart rate recovery reactions during the rest periods are determined by the previous work performed and by the duration of the preceding rest periods. For hard work, the recoveries become less and less complete for a given rest time so that the recovery reactions remain at a progressively higher heart rate level as the number of exercise periods increases. They also report that if a steady level of recovery is to be achieved, the rest periods must become longer as the exercise is repeated. As soon as the rest time becomes too short, the heart rate increases during successive periods of both work and recovery. A steady state can no longer be maintained and the subject comes closer and closer to his working capacity and his exhaustion level. By proper adjustment of the sequence, exercise-rest periods, it is possible to maintain over a long period of time a steady state of heart rate reactions during each work and recovery cycle (9).

Costill (16) studied the relationship between selected physiological variables and the average time required to run a 4.7 mile cross country course. He reported a high degree of relationship between distance running performance and maximal oxygen uptake per kilogram of weight. This he inferred is an indication of superiority in aerobic working capacity. He also reported that resting heart rates appeared to be positively related to distance running performance, but that maximal heart rates as recorded during the maximal oxygen uptake ride on a bicycle ergometer did not suggest that any relationship existed with distance running performance (r=0.54).

Knuttgen (28) investigated the oxygen uptake-pulse rate relationship on two well-trained subjects who ran at steady state with undetermined and determined stride lengths at different speeds on a treadmill. He reported that when pulse rate was plotted against oxygen uptake for the various speeds in both the determined and undetermined series, nearly linear relationships were obtained. He concluded that kinetic energy was the predominant factor in running (based on the linear relationship between oxygen uptake and velocity to the second power). Margaria *et al.*, (34) report that the net energy consumption per kilogram of bodyweight per hour and per kilometer is constant and independent of the speed of running. This is in disagreement with the opinion that in increasing the speed, more energy is used.

The premise of interval training, that of high speed work done for short periods of time with an incomplete recovery period, is opposed by McDavid (32) as being doubtful. He found that when total work on a bicycle ergometer was held constant, interval training offered no better results for endurance than a continuous-effort type of training program (based on no significant difference between mean terminal heart rates). He offered the explanation that with intermittent work, presumably under anaerobic conditions for the most part, the subject does not seem to obtain the deep lactic acid oxygen debt common to prolonged aerobic work. The rest periods seem to nullify some of the good effects of high speed work by allowing part of the oxygen debt to be repaid. Thus, the subject begins the next bout partially recovered. He states that it is assumed that the best work mode for endurance training should be the most strenuous mode. He asks the following question:

> Does any real physiological difference exist as a result of the different work patterns or does what appears to be a difference result from doing a greater amount of work with greater energy expenditure?

IV. SUMMARY

In summary, it can be seen that interval training is generally accepted as being the more favored type of training to develop speed and endurance in middle-distance runners. Interval running, acting as a catalyst, causes adaptation of the body to meet the specific distress caused by the training runs, allows the individual to recover from the oxygen debt imposed by the run, and permits more work to be performed with fewer signs of fatigue. To be effective, the interval runs may have to produce an exercise heart rate response of 180 beats per minute, and following a 40-90 second rest period, a recovery heart rate of 120-140 beats per minute. The recovery interval is thought to encourage the physiological enlargement of the heart, thereby allowing more blood to be pumped per heart beat at a slower heart rate in the well-trained individual.

Research has indicated that higher workloads elicit a higher heart rate response, that exercise heart rate patterns are similar in trained and untrained runners, and that the recovery patterns between trained and untrained runners are not significantly different. It has also been reported that the velocity-heart rate relationship is linear, and that the maximal oxygen uptake is directly and positively related to distance running performance.

CHAPTER III

METHODS AND PROCEDURES

I. SUBJECTS

Three conditioned and specifically trained middle-distance runners of the University of Montana track team acted as subjects for this study. The basis for selection of subjects was experience, competitive success, and physical condition. The physical characteristics of the subjects are shown in Table I. The middle-distance events (one-mile and three-mile) were arbitrarily chosen by the investigator and his advisor. A pilot study was conducted for the purpose of orienting the subjects with the telemetering device. The purpose and nature of the study, the expected schedule of monitoring heart rate, and the operation of the telemetering equipment were explained to each subject at the first monitoring session.

Each subject was allowed to warm-up with the electrodes and transmitter affixed each recording session, in order that he become reaccustomed to the equipment placement. Resting heart rates were recorded periodically before testing sessions, as a regular part of the testing routine. The average resting heart rates and post warm-up heart rates of each subject, as well as the mean exercise and recovery heart rates, are shown in Table II. Subject S.L. was monitored twice while interval running and once in a continual, competitive run. Subject R.V. was monitored five times while interval running but was not monitored during a

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

SUBJECT	WEIGHT POUNDS	HEIGHT INCHES	AGE YEARS
R.V.	127	68	21
S.L.	135	69	19
F.F.	150	70	22
MEAN	137	69	21

TABLE II

AVERAGE HEART RATES

SUBJECT	RESTING HEART RATE	POST WARM-UP RATE	EXERCISE HEART RATE	RECOVERY HEART RATE AT HALF-MINUTE RECOVERY INTERVALS 30	60	90	120
R.V.	59	94	193	182	164	155	147
S.L.	51	82	179	168	154	138	124
F.F.	50	88	181	166	142	133	127
MEAN	53	88	184	172	153	142	133

continuous run. Subject F.F. was monitored four times while interval running and once in a continual, competitive run.

Each subject generally participated in more than one running event during each competitive meet. Subject R.V. participated in the half-mile and mile run; subject S.L. participated in the half-mile run, mile run, two-mile run, three-mile run, and steeplechase: and subject F.F. participated in the mile run, two-mile run, and three mile run. The dates and competitive times of each subject's individual runs are shown in Table III.

II. EQUIPMENT AND APPARATUS

Radio-Electrocardiograph

The various electrical heart rate potentials of the subjects were received by a Telemedics RKG 100 Radio-Electrocardiograph system, consisting of a pair of disposable electrodes, a small Frequency-Modulated battery-operated transmitter, and a portable radio receiver used to forward the characteristic ECG waves to the recording equipment.

The electrodes. The elctrodes consisted of a patch type moleskin adhesive bandage with an electrode paste reservoir, a screen, and a contact snap fastener to connect the electrode to the flexible wires. In order to minimize muscle noise, the two electrodes were placed at right and left fifth rib, slightly lateral and inferior to each nipple.

TABLE III

COMPETITIVE TIMES OF SUBJECTS

SUBJECT	DATE	HALF MILE	ONE MILE	TWO MILE	THREE MILE	STEEPLE-CHASE
R.V.	3/30/68		4:13.8			
R.V.	4/ 6/68	1:55.5	4:16.5			
R.V.	4/20/68		4:16.9			
R.V.	4/27/68	1:54.5	4:17.1			
R.V.	5/ 4/68	1:55.6	4:15.5			
R.V.	5/11/68	1:52.1				
S.L.	3/30/68			9:42.5		
S.L.	4/ 6/68			9:48		
S.L.	4/20/68					10:10.1
S.L.	4/27/68		4:24.4			
S.L.	5/ 4/68	2:00.0		10:07.0		
S.L.	5/11/68				did not finish	
F.F.	4/ 6/68		4:17.2	9:26.5		
F.F.	4/20/68		4:22.0	9:29.0		
F.F.	4/27/68				14:07.8	
F.F.	5/ 4/68		4:22.0	9:26.0		
F.F.	5/11/68		4:19.0			

The radio transmitter. The small Frequency-Modulated radio transmitter was approximately one inch thick by three inches wide by four inches high and weighed approximately ten ounces, including the batteries. Heart signals were carried by thin flexible wires from the electrodes to the transmitter where they were amplified and transmitted to the radio-electrocardiograph. The transmitter was taped to the subject's back just above the sacrum and iliac crest.

The radio receiver. The desk model receiver was operated from a standard 115 volt 60 cycle power line. It was equipped with a channel selector switch which channeled the ECG signal to the recording instrument, a Burdick electrocardiograph.

Electrocardiograph

A Burdick EK-2 Direct-recording electrocardiograph instrument was used to obtain an accurate reading of the heart rate of each subject during exercise and during recovery. It is an electronic instrument which amplifies the varying potentials of the beating heart, and relays them to a very sensitive galvanometer. The galvanometer in turn actuates an electrically heated stylus causing it to produce a continuous record of the waves associated with the action of the heart on heat-sensitive graph paper. The vertical lines on this paper are spaced one millimeter apart, representing a time interval of 0.04 seconds. The paper drive assembly is operated by a synchronous motor. A second stylus, actuated by an independent synchronous motor, records a time pulse at intervals of one second and thus provides a ready check on the accuracy of the paper drive assembly (13). The rate of the heart beat can be determined easily from electrocardiograms, because the time interval between two successive beats is the reciprocal of the heart rate (24).

Sling Psychrometer

This apparatus consists of two thermometers, one dry bulb and one wet bulb; a swivel handle; and a protective shield. Temperature values were read from the psychrometer after it was spun through the air for about a minute. A relative humidity table compiled by the United States Weather Bureau was available from which the relative humidity could be read very easily using the temperature values from the psychrometer. This process was followed prior to each test session.

The major articles of the testing equipment are shown in Figure I.

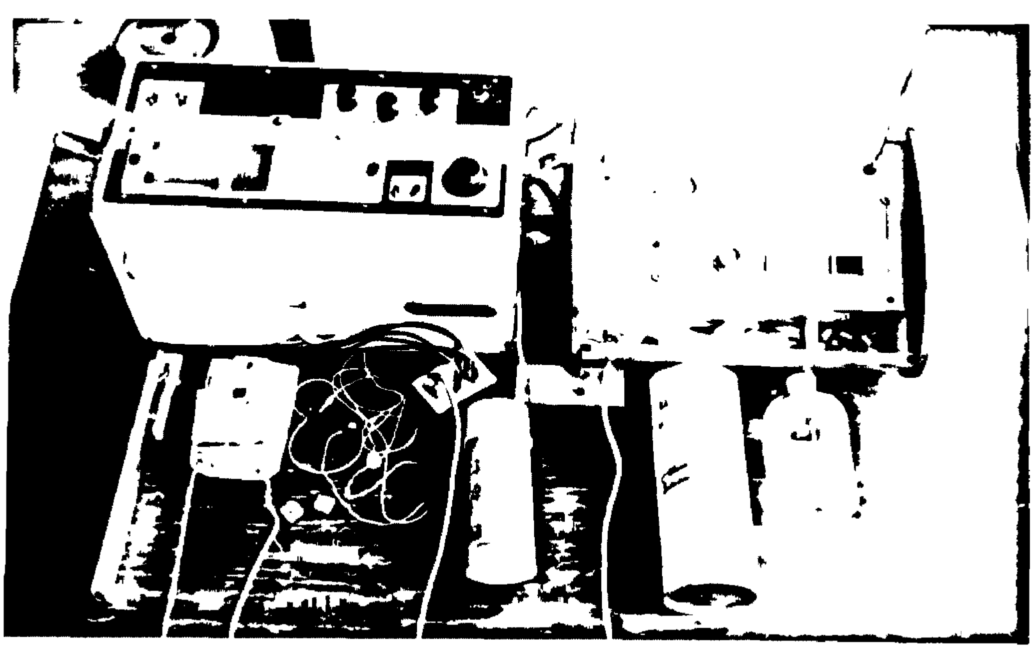


Figure I. Major Articles of Testing Equipment

III. SELECTION OF THE PHYSIOLOGICAL MEASURE

The heart rate was selected as a measure of work performance on the basis of the indicated linear relationship of the heart rate and oxygen consumption (12, 36, 43, 44, 51, 52). Much has been written concerning the use of recovery heart rate in assessing the intensity and duration of work performed. Brouha, et al., (9, 11, 12) suggest using heart rate response to evaluate the physiological strain produced by muscular work. Wahlund (49) indicates that the heart rate and respiration rate are the best factors for measuring working cardiorespiratory capacity. These same conclusions are expressed by Nocker (19), Smit (19), Diem (50), and Alderman (1). Alderman reports that as workload progressively increases, the heart rate increases linearly up to 180 beats per minute, but that this does not suggest a maximum heart rate. His correlation coefficients indicated that a recovery to 120 beats per minute is the most reliable measure of recovery heart rate.

LeBlanc (30) presents data, based on the linear correlation between oxygen consumption and heart rate at the beginning of exercise, which indicates that heart rates during exercise and recovery periods can be used for measuring work performance. The main factors involved in muscular fatigue are those concerned with the supply of oxygen to the muscles and the dissipation of heat produced by the muscles. Since the heart rate is directly affected by these circulatory changes, its use as an index of fatigue is suggested (30). Because the magnitude of fatigue is actually controlled by both the duration and intensity of the work, LeBlanc suggests that heart rate be used as an index of work output.

Wyndham (51) states that whether heart rate and oxygen intake are linearly related throughout the range of work rate depends upon whether they approach their asymptotes at the same rate when plotted against work rate. Knuttgen (28) found that for running strides of determined length, the relationship between velocity and oxygen uptake were nearly linear for various speeds.

Because of the close relationship between cardiac output and oxygen consumption during submaximal work in a relatively normal environment, Brouha and Radford (12) have stated that the:

> ...heart rate can be utilized to evaluate the stress imposed by muscular activity upon the heart and the circulation. As a single factor it quite accurately depicts the cardiovascular adjustment of the individual to muscular activity.

In support of this, Taylor (48) and later Erickson (21), found that heart rate and workload correlated 0.97 and 0.96 in two individuals.

Consolazio, Johnson, and Pecora (15) state:

> It is generally agreed that of all the measurements for testing physical efficiency, the heart rate during severe exercise seems to be the most reliable.

LeBlanc (30) reported that the heart rate was an especially good index for measuring working cardiorespiratory capacity under conditions in which the physical work was heavy and of short duration.

Brouha, *et al.*, (9, 11, 12) and Glafka (23) indicate that heart rate shows the physiological strain of the work load and environment. Moreover, Brouha and Maxfield (11) state that:

> ...not only do the heart rate responses indicate increased strain of performing an individual work period but also the rapid accumulation of strain induced with each successive cycle.

IV. EXPERIMENTAL SCHEDULE AND PROCEDURE

Testing began February 24, 1968, and extended until May 7, 1968. All testing was conducted at the University of Montana track.

The interval running schedule was held Monday and Wednesday of each week. The general sessions for interval training were supplemented with continuous running. The subjects were monitored on the average of once every other week, being advised prior to the test that they would be monitored a particular afternoon during interval running. They were requested to arrive at the track one-half hour early and rest until the electrodes and transmitter were attached.

The electrodes were placed with extreme care. The skin area was cleaned with acetone to remove excess oil and scaly skin, allowed to dry for two minutes, and then sprayed with an anti-perspirant. The electrode area was then roughened with the tip of the paste applicator and a pea-sized drop of electrode jel was applied to the site. The electrode reservoir was also filled with a pea-sized drop of the electrode jel, with the electrode then being placed over the roughened skin area. A three-inch square of adhesive moleskin was placed over the electrode, with a small hole in the center allowing the snap fastener of the electrode to protrude.

These squares were then anchored by strips of adhesive tape, the assumption being that this would further minimize electrode movement over the skin. The transmitter was encased within foam rubber, placed in the cloth carrying pouch, and taped to the back of the subject just above the sacrum and iliac crest.

After attachment, the subject was asked to remain standing and a resting heart rate was recorded. The subject then went through a series of calisthenics and short runs to insure thorough muscular warm-up before beginning interval running, and also to check the telemetering system to assure that it was in working order.

The intervals were run, with the other subjects of the study competing against the individual being tested, at a predetermined pace measured by a stop watch. The subject was informed if the pace was too slow or too fast. Usually, the rest interval was not timed, and running continued when the subject deemed himself ready.

The subjects were reassessed every two weeks before the actual competitive season as to running time in a 1320 or 2640 yard continuous run, and the pace of the intervals was changed according to his performance in that run.

All information, including the subject's name, time of day, temperature, relative humidity, barometric pressure, resting heart rate, post warm-up heart rate, exercise time and heart rate for each exercise interval, and recovery time and heart rate for each recovery interval was recorded on a standardized data sheet prepared for the purpose of this study. The data sheet appears as Appendix A. The individual subject's heart rate response to the various interval runs are shown as Appendix B. The heart rate response of the individual subjects during a continuous competitive run appears as Appendix C.

V. TRAINING

The subjects were scheduled to train twice a week at interval running, the training sessions being held between 3:30 P.M. and 5:00 P.M. Each week of the month the subjects varied the length of the interval run, yet maintained a competitive pace. The general training schedule for interval running during each month paralleled that recommended by William Bowerman, track coach, University of Oregon.

The intervals were run alternately at two times the competitive distance one week and three times the competitive distance the next week. The interval distance was not predetermined, being dependent upon the weather. Generally, if it was cold, the longer distances were used, i.e., the 660 and 880 yard intervals; and when it was warm, the shorter distances were used, i.e., the 220, 330, and 440 yard intervals. Recovery was specific to the distance of the run. Generally, three minutes were allowed in the 660 and 880 yard intervals; 220-300 yards of slow jogging followed the 440 yard interval runs; 110 yards of slow jogging followed the 330 yard interval runs; and 55 yards of slow jogging followed the 220 yard interval runs.

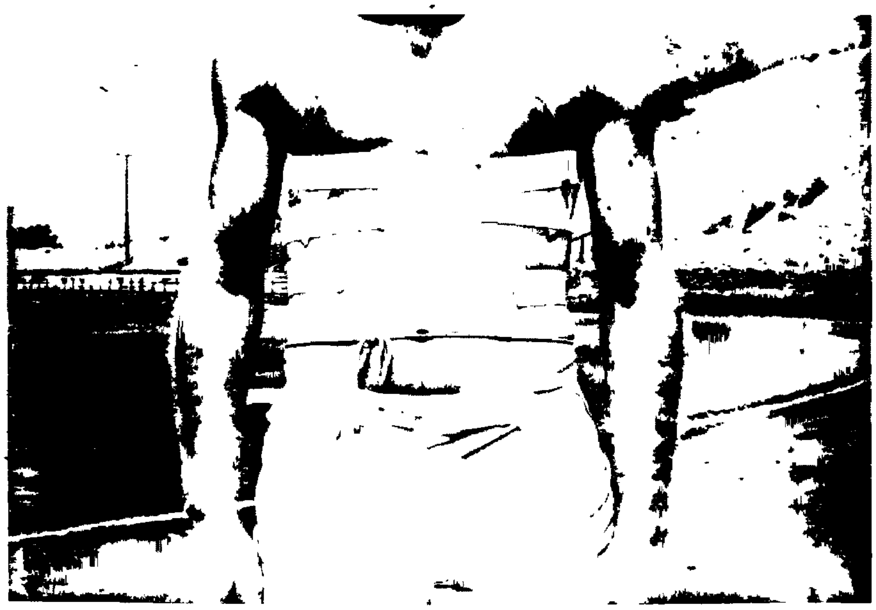


Figure 2. Front View of Subject Showing Electrode Placement

Figure 3. Rear View of Subject Showing Position of Transmitter

CHAPTER IV

ANALYSIS AND DISCUSSION OF RESULTS

I. INTRODUCTION

This chapter presents the data on heart rate patterns for training at various interval distances. The subjects, during the training season, ran both interval and continuous runs. The raw data are presented in Appendix B and C, respectively.

Statistical analysis was limited due to the nature of the study, i.e., the exclusion of random selection of subjects and interval runs, the small number of subjects chosen, and the numerous extraneous variables which surrounded each exercise and recovery period. Consequently, the results were analyzed using graphs and charts depicting individual performances, and whenever applicable, the use of the mean. Correlation between exercise heart rate and 30 second recovery heart rate was determined.

Throughout this analysis and discussion, the various interval runs were referred to as 220, 330, 440, 660, and 880; this denoting the distances in yards which were run. The recovery periods were referred to as REC 30, REC 60, REC 90, and REC 120; this denoting the time in seconds when the heart rate was measured during the recovery interval, consisting of slow jogging action.

II. ANALYSIS OF DATA

Ambient Environment

The measures of the ambient environment are presented in Table IV, page 39. It was interesting to note that when the temperature was considerably higher and the relative humidity much lower on one day (4/29/68) of interval running, the mean exercise heart rate for subject R.V. was five to seven beats per minute higher than for other days; also, the mean recovery heart rates were about ten beats per minute higher than the averages for the other interval running regimens for the same individual, with the exception of the 30 second recovery period. In spite of this elevation, the heart rate decreased at approximately the same rate as during lower ambient temperatures (See Table V).

At no other time during the running program did the heart rate for the same individual seem to vary noticeably with the ambient temperatures (See Table V).

The subjects, having been pre-trained in Missoula, Montana, were assumed to be acclimatized to the altitude. The altitude in Missoula is 3200 feet.

TABLE IV

AMBIENT ENVIRONMENTAL MEASURES ON DAYS OF TESTING

SUBJECT	DATE	TEMPERATURE	RELATIVE HUMIDITY	BAROMETRIC PRESSURE
S.L.	3/27/68	50° F.	45 %	681 mm Hg.
R.V.	4/ 1/68	42	100	675
R.V.	4/ 3/68	50	44	683
R.V.	4/11/68	47	25	681
F.F.	4/16/68	42	82	680
F.F.	4/18/68	60	34	677
F.F.	4/22/68	61	28	681
S.L.	4/24/68	59	35	685
R.V.	4/29/68	83	1	680
F.F.	5/ 2/68	66	27	682
R.V.	5/ 7/68	54	54	682

Heart Rate During Exercise

Mean exercise heart rates for each subject for the various interval runs are shown in Figure 4, page 41. Mean exercise heart rates with pace times for each subject are shown in Figure 5, page 41. Scrutiny of these graphs gives no indication that increased workload, whether it be an increase in distance or in pace, produces a higher exercise heart rate. It cannot be inferred that these heart rates were maximal as no tests to determine maximal heart rates were administered.

This does not mean, however, that the oxygen consumption measure had reached a plateau for all runs. Researchers have inferred that oxygen consumption and heart rate exhibit a linear relationship during submaximal exertions, but that at near maximum heart rate they do not exhibit this relationship. The oxygen consumption usually continues to increase even though the heart rate has reached the maximum.

Oxygen consumption could be maintained in a steady state throughout an exercise period, but a continuous increase of heart rate and cardiac output might be observed because of the increased body temperature associated with prolonged exercise.

Individual exercise heart rates with pace times are shown in Figure 6, page 42. This graph indicates that, generally speaking, a faster pace time results in a higher exercise heart rate.

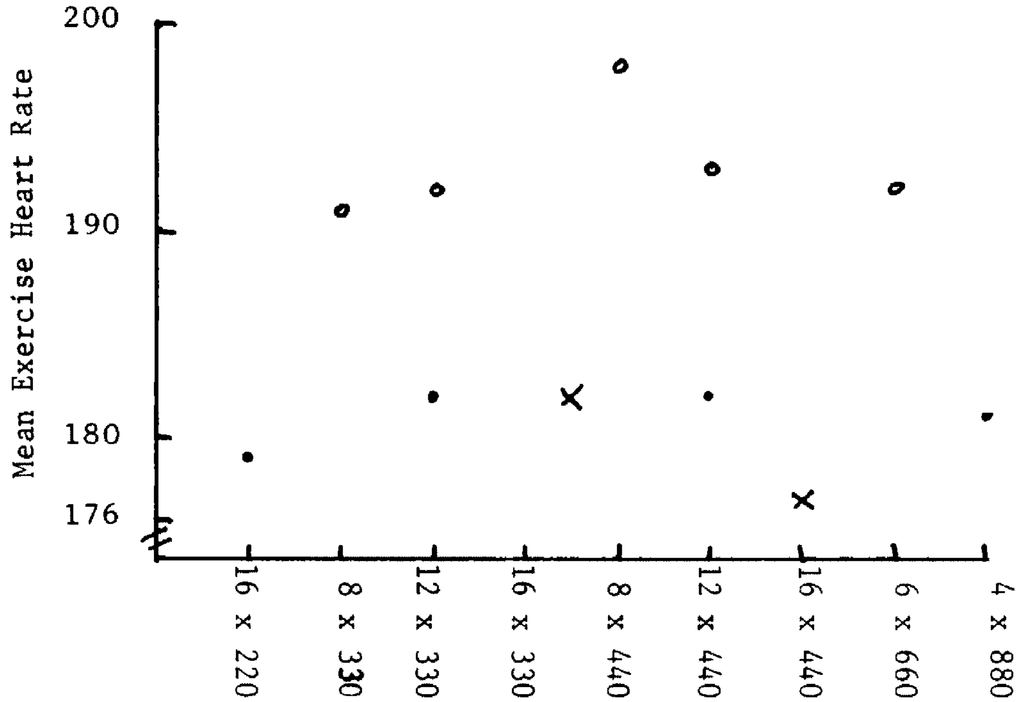


Figure 4. Mean Exercise Heart Rates for Workloads (Successive Intervals Run and Distance).

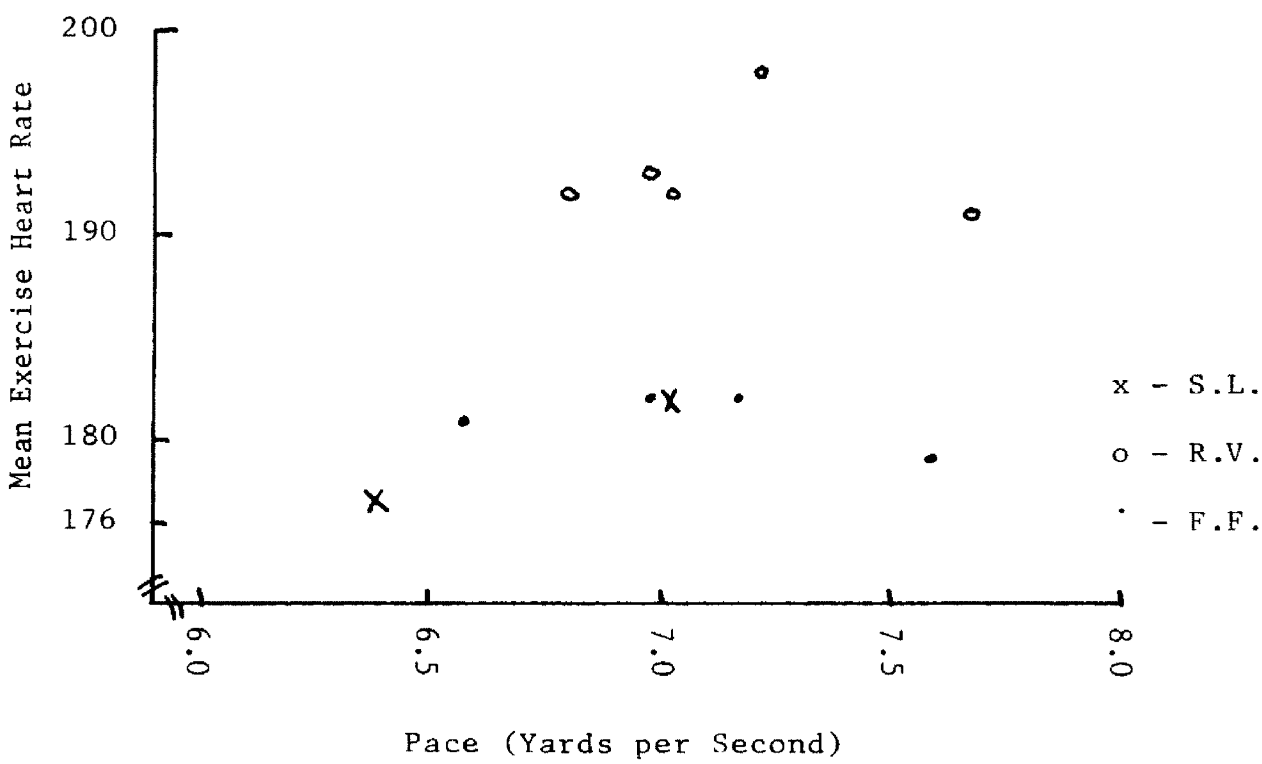


Figure 5. Mean Exercise Heart Rates with Pace.

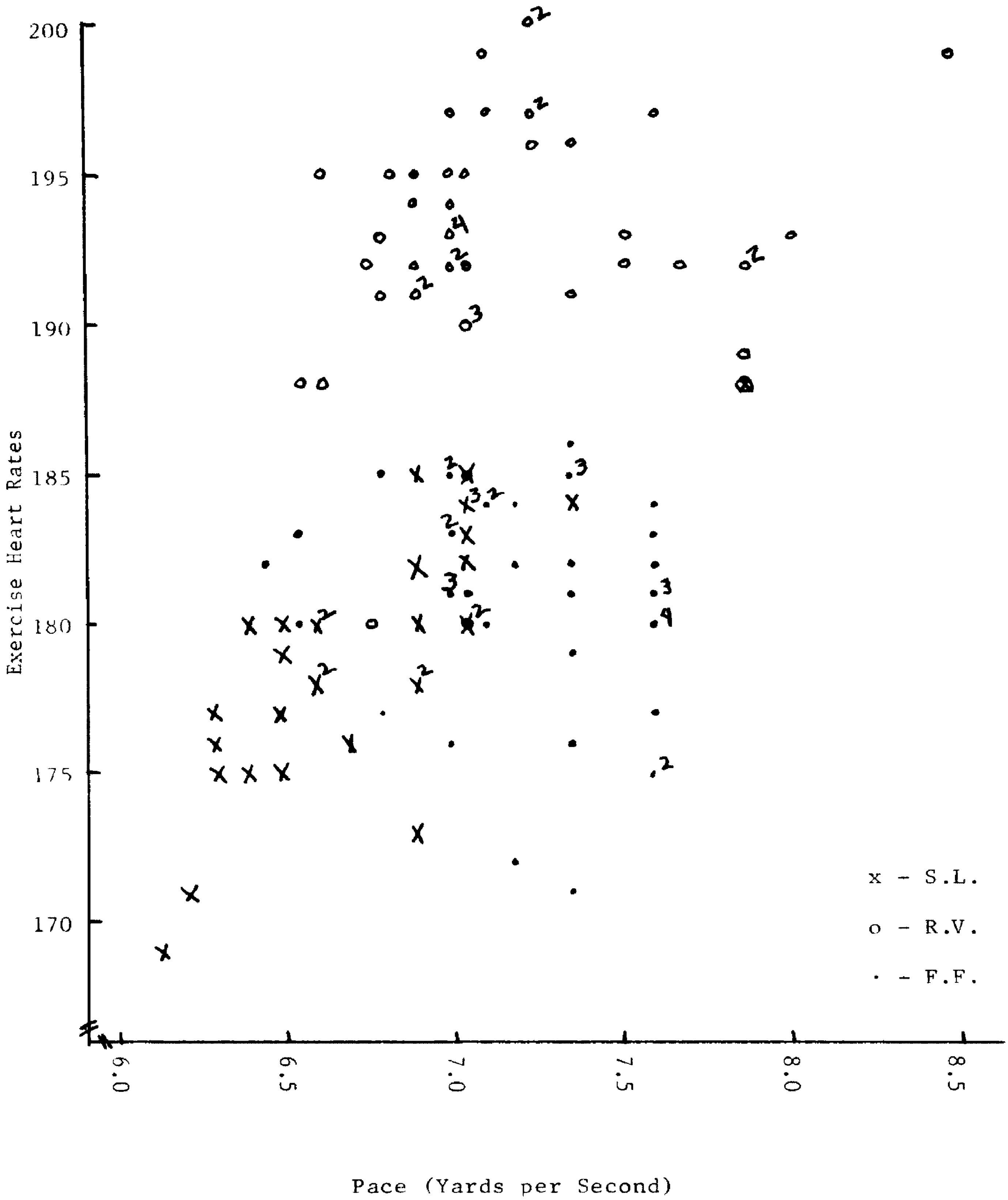


Figure 6. Composite of Exercise Heart Rates with Pace.

Table V, page 44, shows average heart rates for each subject during each interval running regimen. The heart rate of each subject tended to display approximately the same acceleration with the exercise, and deceleration with rest, regardless of workloads. These same results were reported by Alderman (2) in his study on heart rate response to bicycle ergometer work. His conclusion that a common factor operated with respect to heart rate response to two different workloads within the same task, and that it operated at the higher levels of a person's capacity might be applied here.

The individual heart rate response for each subject during each interval running regimen is presented as Appendix B. The general trend of each individual's exercise heart rate was a progression from a sub-average exercise heart rate response to an average exercise heart rate response between the second and fourth interval. After the second to fourth interval, the exercise heart rate remained relatively constant. These findings agree with Brouha and Radford only up through the third or fourth exercise interval. Brouha and Radford's (11) hypothesis was that physiological strain was cumulative from interval to interval if the recovery time was held constant. The difference in results may lie in the variance of recovery times from a set limit. Only in one instance (4/16/68) were the recovery times constant (180 seconds), and the heart rate increased through the third interval but not the fourth. However, the exercise times were increased throughout the exercise program

TABLE V

MEAN INDIVIDUAL HEART RATE RESPONSES

SUBJECT	WORKLOAD	DATE	EX TIME	PACE D/T	EX HR	RECOVERY HEART RATE AT INTERVALS 30"	60"	90"	120"	RECOVERY TIME	FULL RECOVERY H.R.
S.L.	16 x 330	3/27/68	47	7.02	182	170	159			102"	155
S.L.	16 x 440	4/24/68	69	6.38	177	165	149	138	124	159"	123
R.V.	8 x 330	5/ 7/68	43	7.67	191	180	160	149		109"	144
R.V.	12 x 330	4/ 3/68	47	7.02	192	179	161			90"	134
R.V.	8 x 440	4/29/68	61	7.21	198	180	173	162	155	168"	149
R.V.	12 x 440	4/11/68	63	6.98	193	180	162	154	143	154"	138
R.V.	6 x 660	4/ 1/68	97	6.80	192	181	165	154	144	242"	136
F.F.	16 x 220	5/ 2/68	29	7.59	179	165	137			76"	128
F.F.	12 x 330	4/18/68	46	7.17	182	165	143	131	132	127"	117
F.F.	12 x 440	4/22/68	63	6.98	182	166	142	134	122	203"	108
F.F.	4 x 880	4/16/68	134	6.57	181	166	147	135	126	180"	108

for that day, with the resultant that the exercise heart rate reached approximately the same level during each period of running.

In subject S.L., when the workload (pace of running) was diminished, peak exercise heart rates and recovery heart rates were visibly lower; however, in the other two subjects, when the number of repetitions was varied, the peak exercise heart rates and recovery heart rates were generally the same. Again, it would be helpful to the reader to remember that the exercise periods and recovery periods were not equal, that the exercise period was more nearly equal than the recovery period, and that the last interval was generally an all-out run.

The exercise heart rate was different for each individual. Subject R.V. had a mean exercise heart rate of 193 beats per minute, subject S.L. had a mean exercise heart rate of 179 beats per minute, and subject F.F. had a mean exercise heart rate of 181 beats per minute. This, however, gives no indication as to competitive performance, but might rather indicate the specialty of each runner or merely individual difference. Subject R.V. specialized in the shorter middle-distances (half-mile and mile), whereas subjects S.L. and F.F. specialized in the longer middle-distances (mile, two mile, three mile, six mile, and steeplechase).

The effect of the different paces seemed to be individually characteristic. Subject S.L. paced himself at an average of 7.02 yards per second while running 16-330 yard intervals, producing a mean exercise heart rate of 182 beats per minute; however, at a pace of 6.38 yards per second for a workload of 16-440 yard intervals, his mean heart rate response was only 177 beats per minute. This might indicate that a near competitive pace is needed to raise the heart rate above the specified 180 beats per minute. During his slower paced runs, subject S.L.'s heart rate reached 180 beats per minute; however, his recovery times were approximately constant at two minutes.

Subject R.V. paced himself for his fastest pace times at an average of 7.67 yards per second for eight intervals of 330 yards, eliciting a heart rate of 191 beats per minute. His slowest session of interval running, 6.80 yards per second while running six 660 yard intervals, produced a mean heart rate of 192 beats per minute. This similarity in heart rate would seem to indicate that he experienced little difference in heart acceleration with increase in workload. As mentioned earlier, this individual experienced greater physiological strain while running in higher temperature, lowered humidity, and in bright sunlight. It should be brought to the attention of the reader that this subject was of darker skin pigmentation than the others.

Subject F.F. paced himself at an average of 7.59 yards per second while running 16 intervals of 220 yards, eliciting a mean heart rate of 179 beats per minute. This was also his fastest paced interval. His slowest pace was 6.57 yards per second while running four intervals of 880 yards. His heart rate response averaged 181 beats per minute, only slightly higher than it was during the intervals of 220 yards.

Generally speaking, the exercise heart rate was noticeably influenced by the length of the preceding recovery period; i.e., the longer the recovery period, the lower the exercise heart rate. This agrees with the results reported by Brouha and Radford (12).

The individual heart rate response for each subject during his continuous run is presented as Appendix C. As evidenced by the data, the heart rate rose most rapidly in the first 20-30 seconds of the run. This is somewhat in agreement with the results of Bowles and Sigerseth (7).

The peak heart rate for subject S.L. eclipsed the mean heart rate for interval running (200 beats per minute compared with 182 and 177 while interval running). Conversely, subject F.F. barely reached the mean heart rates for interval running during his continuous run (180 beats per minute as compared with 179, 182, 182, and 181). Adding to this seemingly paradoxical situation are the paces of the subjects. Subject S.L. averaged 5.99 yards per second while running his continuous run, and subject F.F. averaged 6.41 yards per second while running his continuous run. Subject S.L. ran slower during his continuous run than during any interval running session (5.99 yards per second as compared with 7.02 and 6.38 yards per second). Subject F.F. also ran slower during his continuous run than he did during any interval running session (6.41 yards per second as compared with 7.59, 7.17, 6.98, and 6.57 yards per second).

This data indicates that continuous running of longer duration at a slower pace than that while interval running causes an increase in the heart rate response of the individual. The data also implies that subject S.L. experienced some physiological or psychological disturbance at the time of his continuous run. It should be kept in mind that subject S.L. ran twice the distance that subject F.F. ran.

Heart Rate During Recovery

The general trend of the mean individual recovery heart rates showed a tendency toward approximating the same heart rate when the recovery interval was the same, even with varying workloads. The one exception was the day of high ambient temperature and low relative humidity. Individually, the heart rates were rather variable, but indicated, to some degree, the strenuousness of the preceding work task, the length of the recovery period, and also the activity during the recovery interval. If the subject jogged during the recovery interval, the recovery heart rate was higher than if the subject walked or stood quietly; however, the subject indicated no difference in feeling as to decreased strenuousness of work during the succeeding exercise interval, even though he walked or stood quietly during the recovery interval, and even though the heart rate was below that of the regular recovery interval with jogging.

Figures 7-12, pages 50-51, show graphs of the mean heart rates of each subject during exercise and recovery while running the various intervals; these figures show in graphical form what is presented in Table V. Visibly evident is the near linear descent of the heart rate, which appeared to function regardless of the work-load or environmental conditions. All three subjects demonstrated this phenomonen, but in different and varying degrees.

Observation of Appendix C indicates that subject S.L. had a higher two minute recovery heart rate than did subject F.F. (162 beats per minute as compared to 122 beats per minute, respectively). This could be due in part to the doubled workload of subject S.L.

Exercise Heart Rates to Recovery Heart Rates

Subject F.F. elicited a higher mean exercise and mean recovery heart rate for the longer distance intervals; whereas subject R.V. and subject S.L. exhibited the opposite of this, in that they showed higher mean exercise and mean recovery heart rates in the shorter distances. In view of this and the close relationship of the heart rates among the various workloads per individual, one might assume that there is a common factor within the individual acting during exercise causing an increase in heart rate, and during recovery causing the heart rate to follow the same pattern regardless of workload.

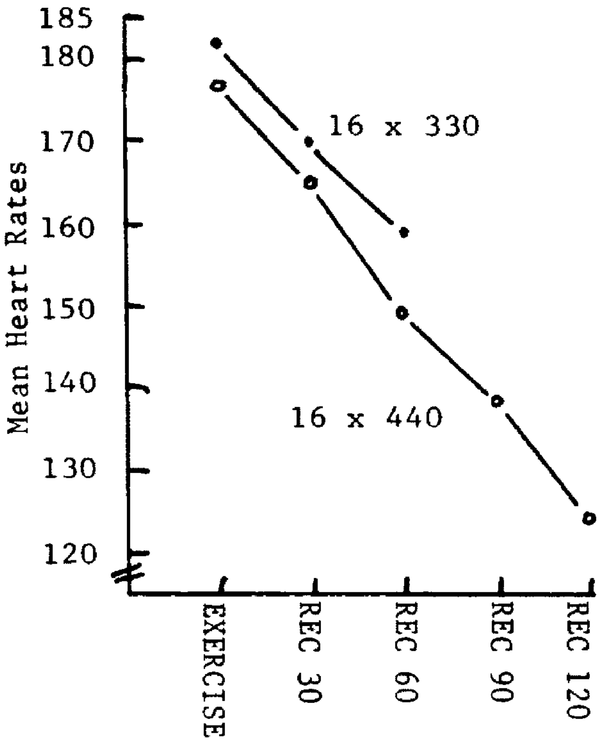


Figure 7. Mean Heart Rates - S.L.

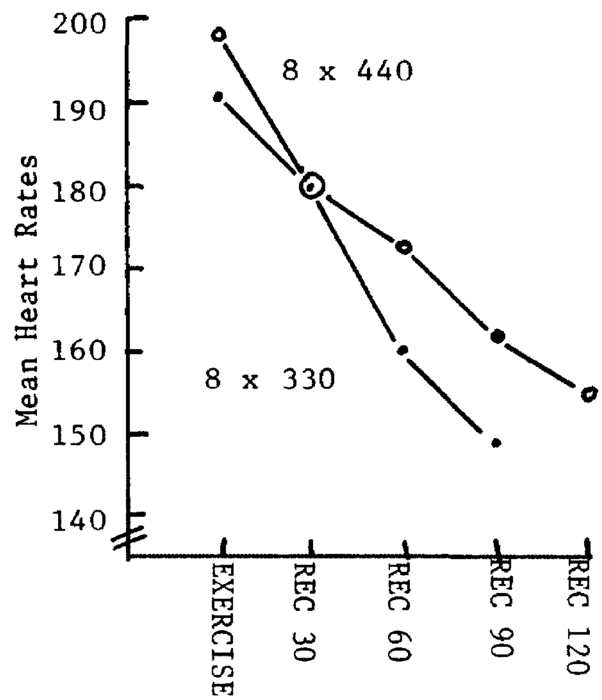


Figure 8. Mean Heart Rates - R.V.

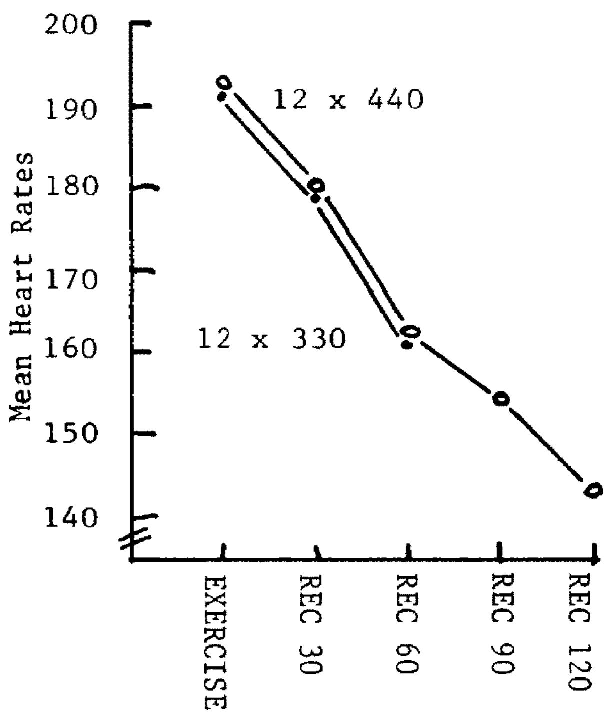


Figure 9. Mean Heart Rates - R.V.

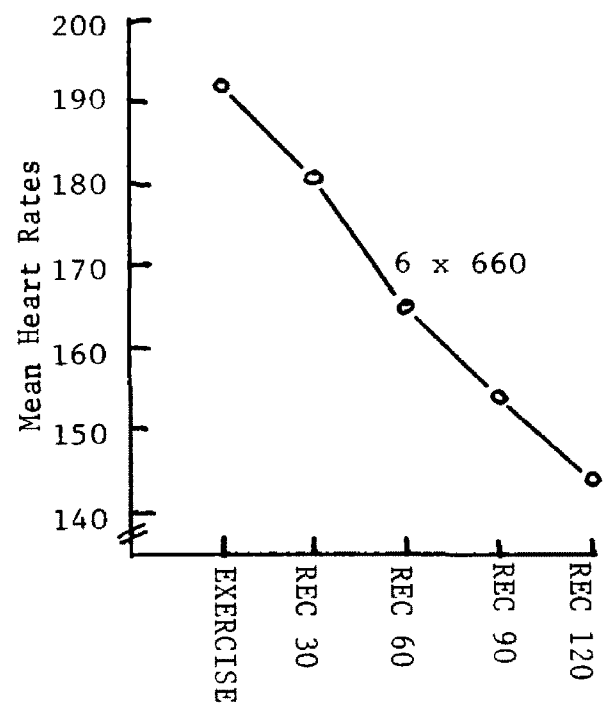


Figure 10. Mean Heart Rates - R.V.

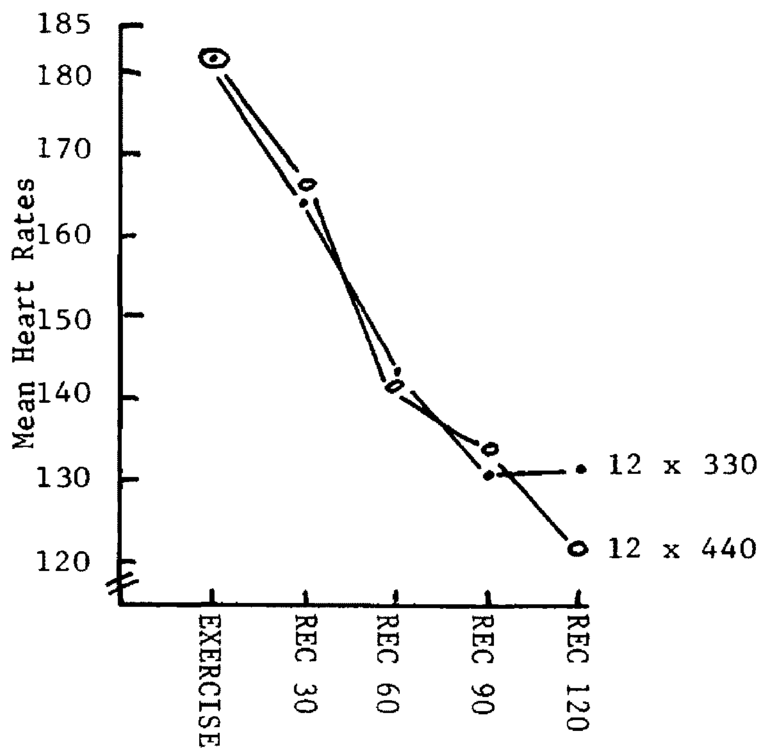


Figure 11. Mean Heart Rates - F.F.

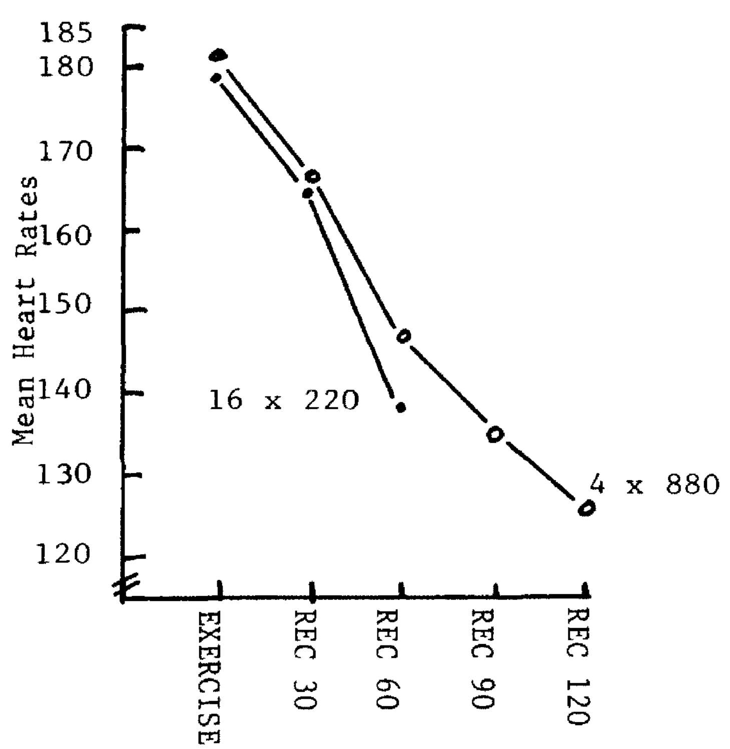


Figure 12. Mean Heart Rates - F.F.

The mean exercise heart rates with exercise times are shown in Figure 13, page 53. The mean exercise heart rates, as graphed, show no indication of increasing with decreasing exercise time. This might be explained by the fact that the subjects may presumably have reached the same steady state of heart rate for all the workloads as mentioned by Brouha and Radford (11). Individually, all three subjects show a progression to a higher heart rate with an increased pace of running.

The mean exercise heart rates with mean recovery heart rates are graphed as Figures 14-17, pages 53-54. The mean exercise heart rates, graphed with mean recovery heart rate, indicated, generally, that the higher mean exercise heart rates elicited a higher mean recovery heart rate. No particular mean recovery interval appeared much better than any other interval for predicting strenuousness of workload.

The individual exercise heart rates, graphed against the 30 and 60 second recovery interval heart rates, are shown in Figures 18 and 19, pages 55-56. These graphs may be interpreted as indicating that a positive relationship exists between exercise heart rate and the 30 and 60 second recovery heart rate. Correlation between exercise heart rate and the 30 second recovery period for subject S.L. was r=0.79; for subject R.V. r=0.73; and for subject F.F. r=0.63. It is possible that these figures could be used to predict exercise heart rates in order to obtain the desired work intensity while interval running for these three subjects.

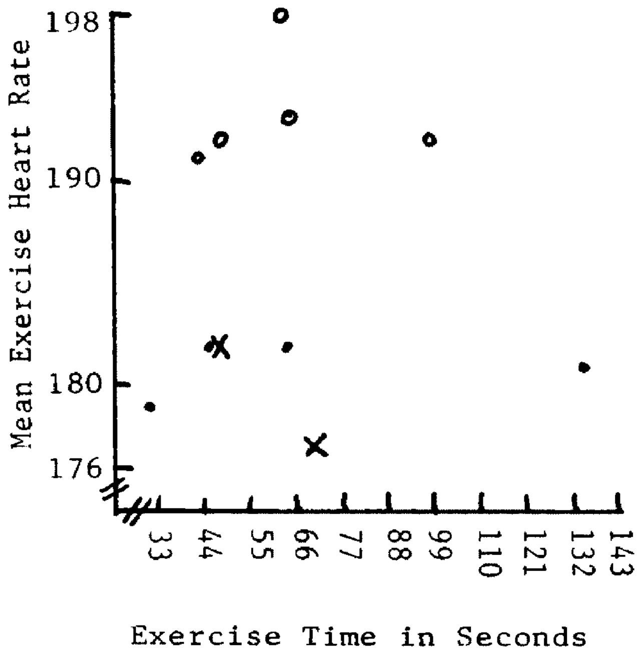


Figure 13. Mean Exercise Heart Rate to Exercise Time.

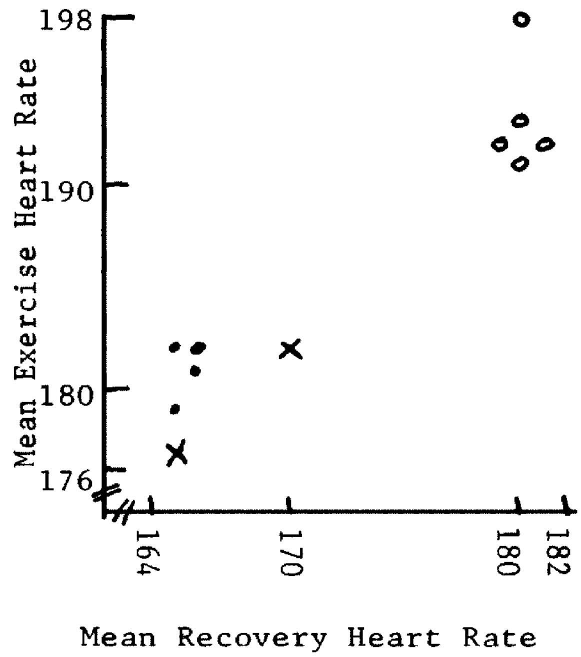


Figure 14. Mean Exercise Heart Rate to 30 Seconds Recovery Heart Rate.

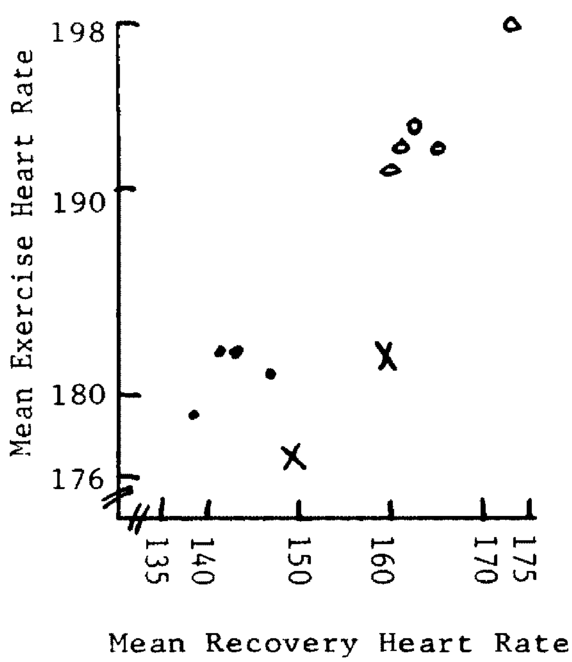


Figure 15. Mean Exercise Heart Rate to 60 Seconds Recovery Heart Rate.

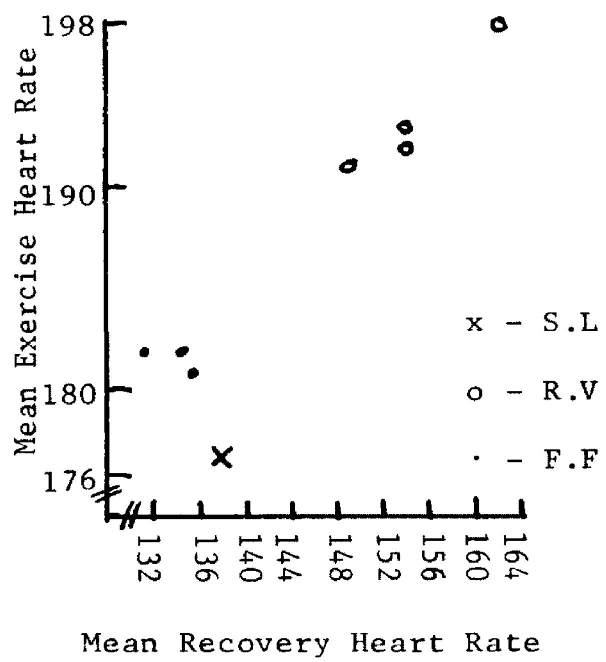


Figure 16. Mean Exercise Heart Rate to 90 Seconds Recovery Heart Rate.

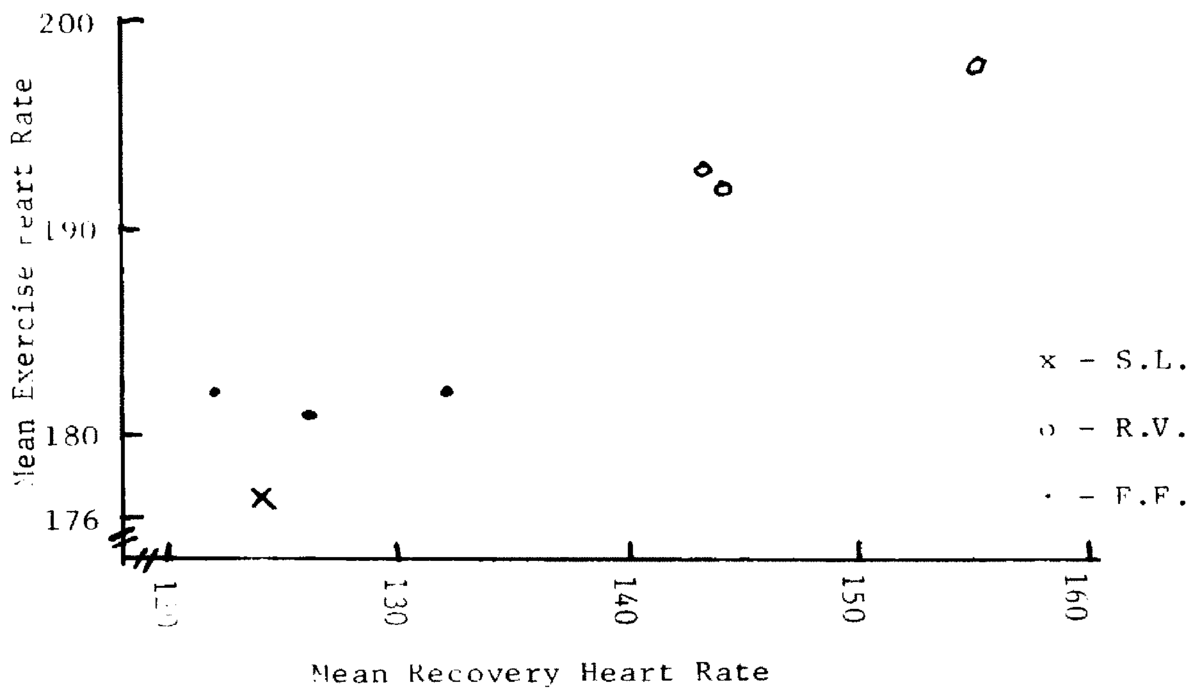


Figure 17. Mean Exercise Heart Rate to 120 Seconds Recovery Heart Rate.

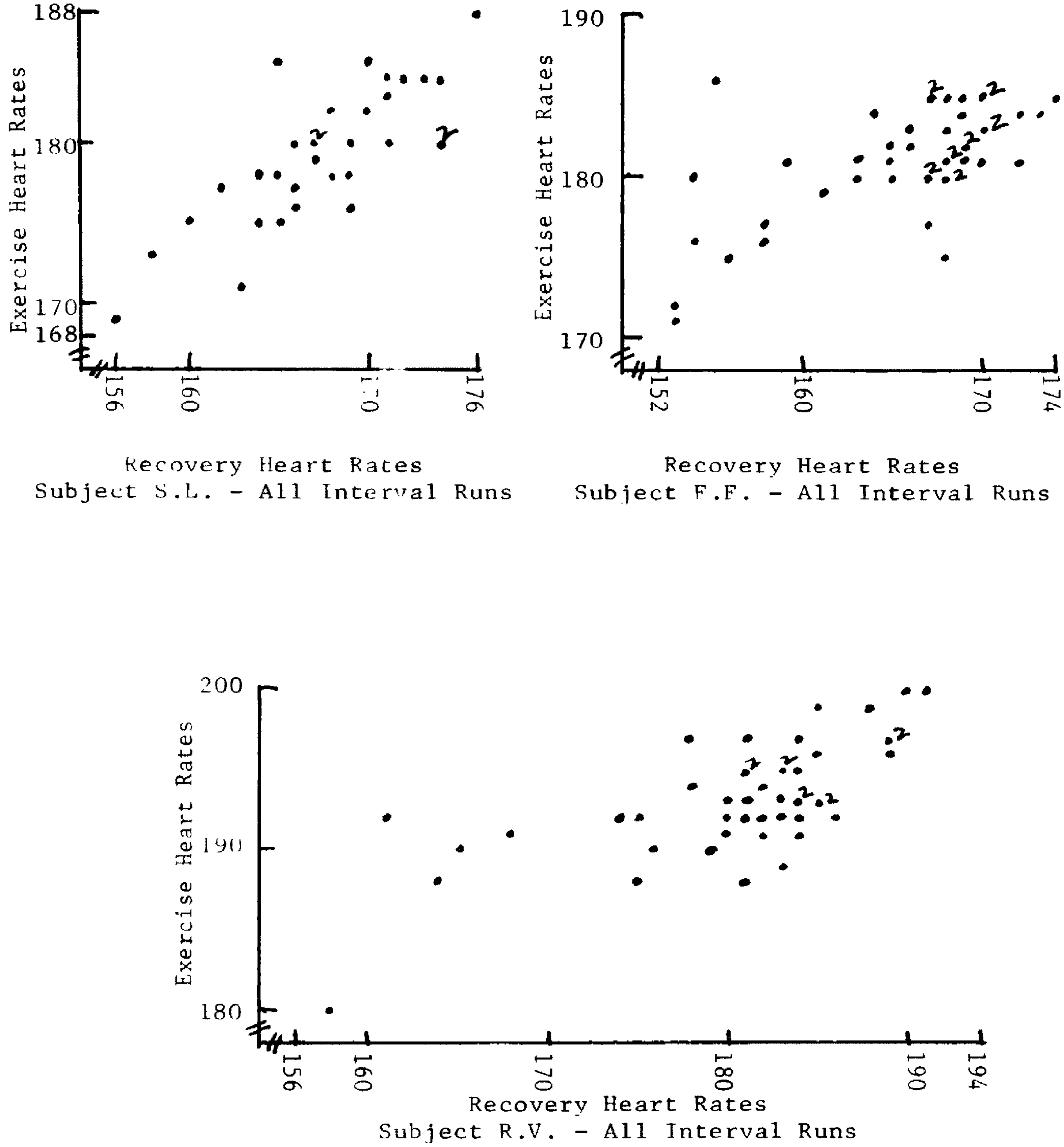
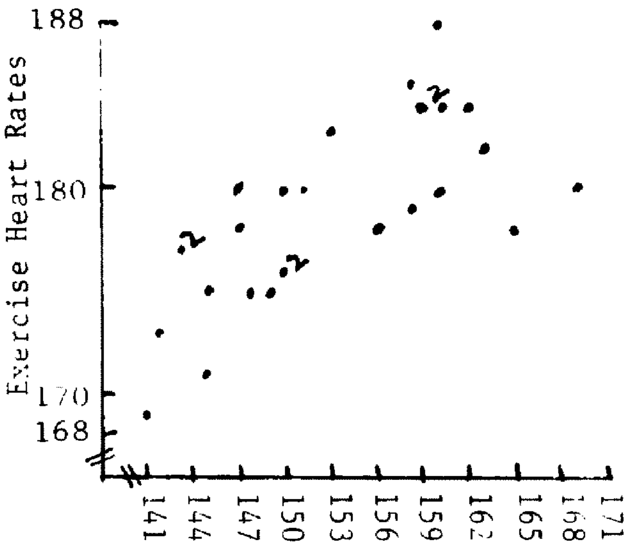
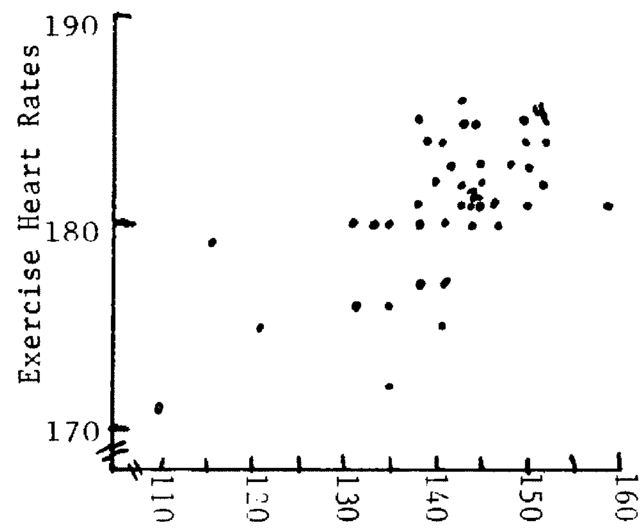


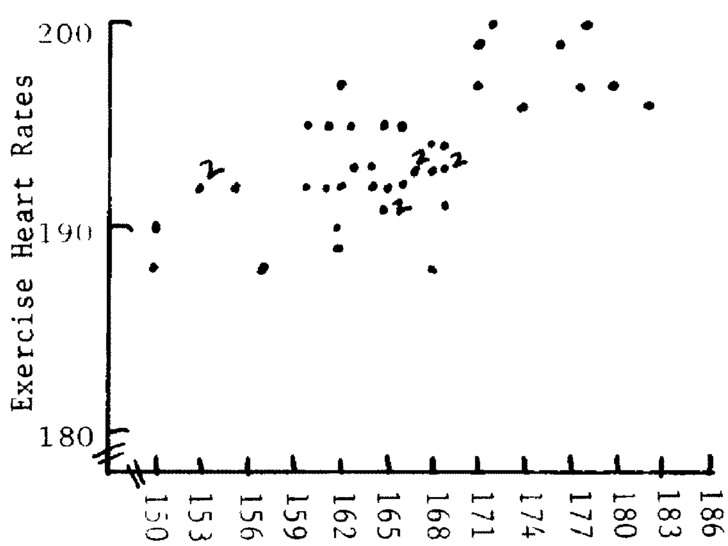
Figure 18. Individual Exercise Heart Rates to 30 Seconds Recovery Heart Rates.



Recovery Heart Rates
Subject S.L. - All Interval Runs.



Recovery Heart Rates
Subject F.F. - All Interval Runs.



Recovery Heart Rates
Subject R.V. - All Interval Runs

Figure 19. Exercise Heart Rates to 60 Seconds Recovery Heart Rates.

The mean 30 second and 60 second recovery heart rates with pace times are graphed as Figures 20 and 21, page 58. The mean recovery heart rate seemed not to be significantly related to pace times; i.e., they gave no definite indication as to intensity of workload. There was variation among the measures themselves, with the higher mean heart rates not necessarily being produced by the faster paced intervals, and vice versa.

The heart rate response of subject R.V. running 12 successive intervals of 440 yards is shown in Figure 22, page 59. This is a graphic representation of that entry in Appendix B.

III. DISCUSSION

The results of the study suggest that the exercise heart rate was a better indicator of physiological strain than was any recovery heart rate during the rest periods while interval running. Even though the rest periods were filled with some type of low physical activity (preferably jogging), variables, such as gait pattern, relaxation, motivation, emotion, and incentive, were too great to precisely control and insure the same pattern of recovery activity each time. Since the workload (distance-pace) in each regimen of interval running was generally the same, and for some recovery periods the length of rest was kept the same, the progressive increase in heart rate for those specific periods could be assumed to be due to a greater energy output.

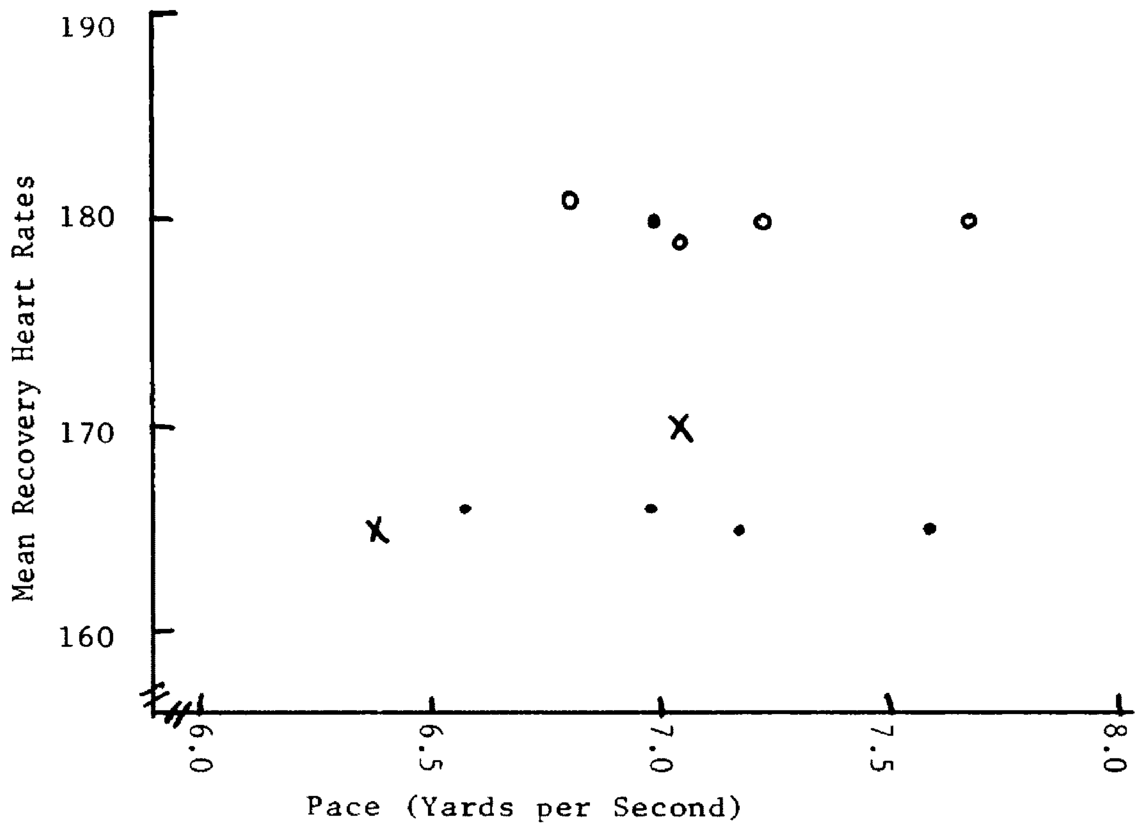


Figure 20. Mean 30 Second Recovery Heart Rate with Pace.

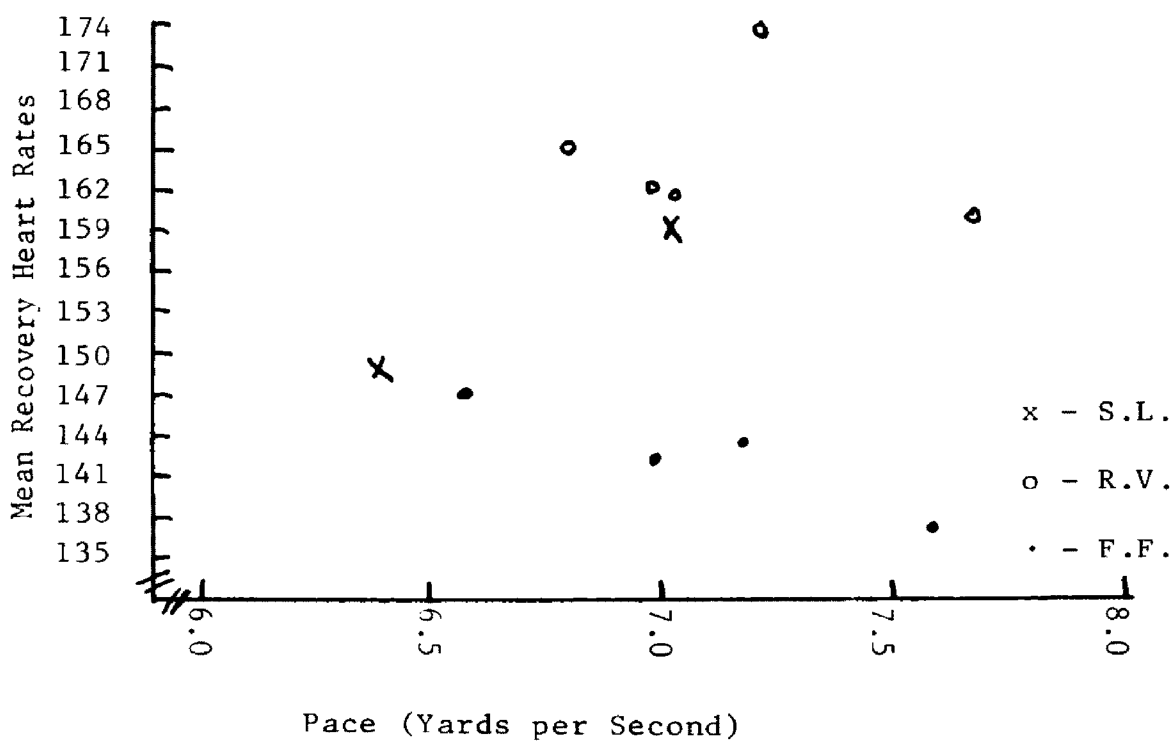


Figure 21. Mean 60 Second Recovery Heart Rate with Pace.

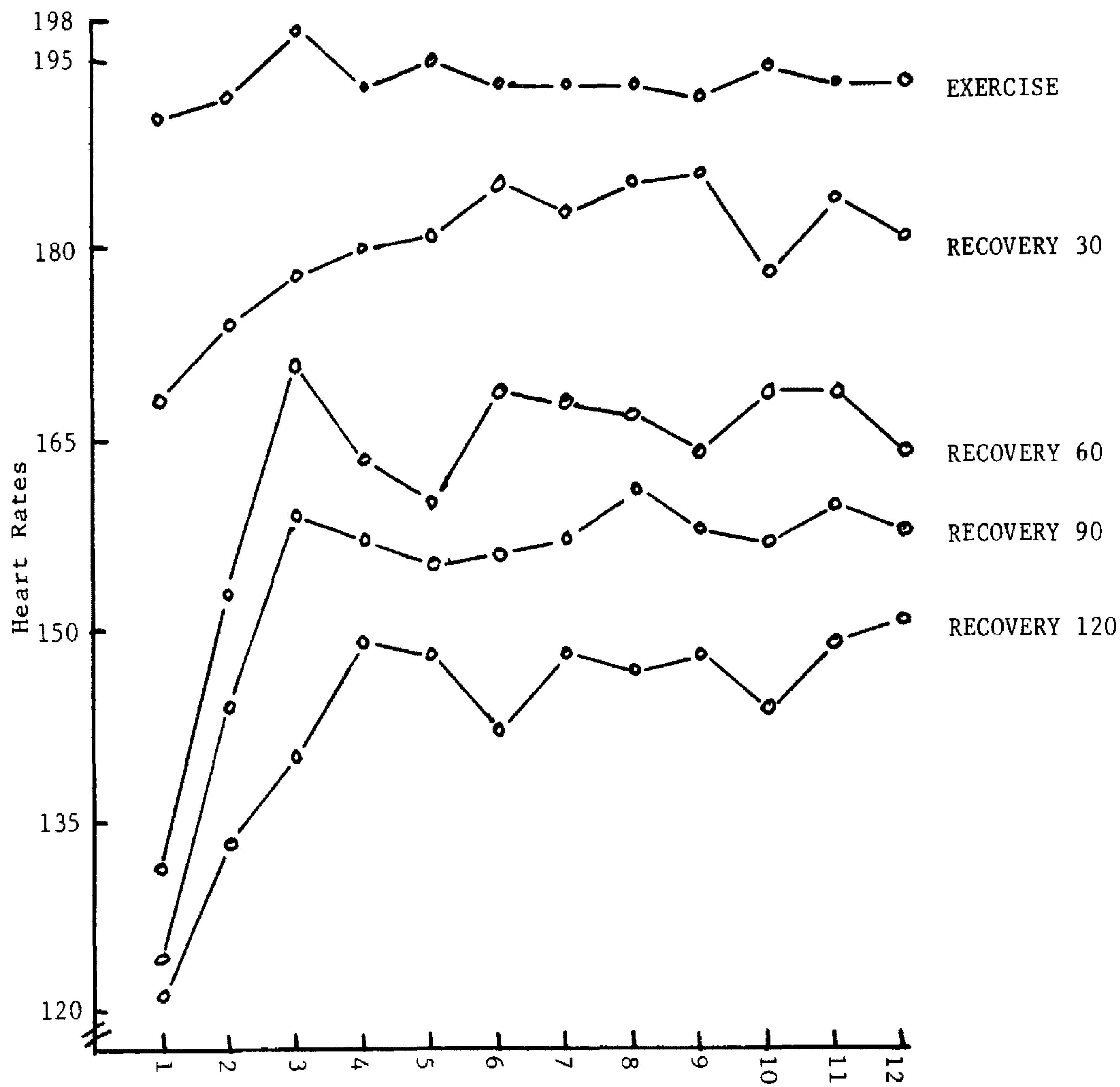


Figure 22. 12 Successive Intervals of Running 440 Yards - Subject R.V.

Also, a high recovery heart rate resulted from a high exercise heart rate, with high ambient temperatures increasing both measures in one subject tested under these conditions. The one day which caused the higher mean heart rates had ambient environment measures of 83° F., 1% relative humidity, with very sunny and clear sky conditions. In a recent study (23), it was indicated that additional radiant heat produced a greater strain than ambient heat alone. In view of this one day's record, and the fact that the other days were overcast, or slightly overcast but not with bright sunlight, it could be assumed that the multiple factors of higher than average temperature and increased radiant heat caused the greater heart rate.

Another finding in the study was that heart rate responses during exercise did not vary greatly with different workloads. This finding might be attributed to the fact that these runners were pre-trained, well-conditioned, and that they were not working at their maximal physiological capabilities. Therefore, it is assumed that they reached a steady state of heart rate while interval running. Their heart rate while interval running, however, does not necessarily indicate their maximal heart rate.

Additional findings were:

A. A nearly linear decrease in heart rate from exercise to a specified time of recovery.

B. Generality of recovery heart rates regardless of workload.

C. The effect of distance and pace on relative heart rate seems to be an individual matter in these conditioned men.

The area of concern, that of determining the optimal work intensity (desired distance-pace to cause the heart rate to slightly exceed 180 beats per minute and then return to 140 beats per minute within 90 to 120 seconds), was not secured in every case, perhaps because of the small variances in pace. However, at these paces, subject F.F. and subject S.L. conformed to these standards; subject S.L., while running at a slower pace, did not measure up to the exercise heart rate standard. Subject R.V. exceeded the standardized exercise heart rate and recovery heart rate, but this is not to say that he worked any harder than the other runners. An explanation for the difference in his heart rate response may lie in the percentage approximation of exercise heart rate elicited as compared to peak (or absolute) heart rate of the individual. Subject R.V. may have had a higher peak heart rate than subject S.L. and F.F., thereby causing an increased exercise heart rate while interval running. In other words, optimum heart rate may very well be an individual matter. This individuality in optimum heart rate may be a result of individual training efforts and the physiological reaction to it, previous running experiences, and/or hereditary factors giving a predisposition to a lower or higher heart rate. The optimal training intensity for each individual could also be relative to the level of fitness of that individual.

Individually, each subject displayed a tendency for a higher heart rate at an increased pace for his interval runs; however, subject S.L. showed this trend most consistently, with subjects R.V. and F.F. vaguely displaying the same trend for their interval runs.

Each subject showed a definite progression to higher recovery heart rates with increased exercise heart rates, with the 30 second recovery interval indicating more precisely the physiological reaction to interval running than any other recovery interval.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

The purpose of this study was to investigate heart rate patterns of pre-trained and experienced middle-distance runners while interval running, in an attempt to approximate the optimum workload of the various individual runners.

Three middle-distance track runners at the University of Montana, participating during an actual competitive season, were monitored for their heart rate during and after running their selected events. The training procedure was interval and overdistance running.

The effect of interval running on the exercise heart rates was analyzed in terms of exercise pace. Heart rate recovery was analyzed in terms of length of rest interval and exercise pace. The relationship between exercise heart rate and recovery heart rate was plotted, as was the relationship between exercise heart rate and a time-standardized recovery heart rate. Finally, the heart rate response at the beginning of the season was compared to the heart rate at the end of the season.

It was found that the exercise heart rate seemed to reach a steady state between the second and fourth interval of an interval running regimen, increased even more if the temperature was exceedingly above the average of other days, did not seem to be influenced by the length of the recovery interval, was not specific to the workload performed (providing the pace time was about average for experienced performers), and was specific for each individual subject.

It was also found that the recovery heart rate decreased almost linearly from the exercise heart rate, regardless of the workload performed. The recovery heart rate was, however, positively related to the exercise heart rate. The action during the recovery period also determined the recovery heart rate; the quieter the activity during the rest interval the lower the heart rate.

No change in heart rate was evident from the beginning of the season to the end of the season, even though a higher peak heart rate was elicited during a continuous run than was elicited during interval running.

II. CONCLUSIONS

The results of this study pointed out the following conclusions:

A. Optimum work intensity seemed to vary from individual to individual.

B. Judging from these three well-trained individuals, resting and exercise heart rates are individual characteristics.

C. Exercise heart rates, while interval running, seemed unrelated to the distance and pace of the exercise interval.

D. Recovery heart rates decreased in an almost linear fashion regardless of distance run or pace time.

E. No change in resting or exercise heart rate was evident from the beginning of the study to the end of the training period.

F. Recovery heart rate at 30 seconds and 60 seconds were positively related to the exercise heart rate.

III. RECOMMENDATIONS

Based on the results of this investigation, the following recommendations for further study are proposed:

A. Further research should be conducted in a controlled experimental environment with precisely paced exercise intervals and standardized recovery intervals so that heart rate response can be more appropriately determined.

B. Additional research should be conducted utilizing aerobic measures as well as the heart rate measure, in order that optimum work intensity and energy expenditure might be approximated.

C. Additional studies are needed to investigate and analyze heart rate patterns of the shorter distance runners and the longer distance runners, to determine if there is any difference in heart rate response to exercise among runners.

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SELECTED REFERENCES

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APPENDICES

APPENDIX A

SAMPLE DATA COLLECTION SHEET

SAMPLE DATA COLLECTION SHEET

SUBJECT:

DATE:

TIME:

RESTING HR:

POST WARM-UP HR:

TEMPERATURE:

RELATIVE HUMIDITY:

BAROMETRIC PRESSURE:

WORKLOAD:

RECOVERY:

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									
11.									
12.									
13.									
14.									
15.									
16.									
MEAN									

APPENDIX B

RAW DATA COLLECTED FROM INTERVAL RUNS

LEGEND FOR APPENDIX B

Workload indicates whether the subject was running two or three times his competitive distance, and then indicates the distance of the interval to be run. This distance is in yards.

Headings are described as follows:

Run - Successive exercise intervals

Pace - Expressed as yards per second

Ex Time - Exercise time expressed in seconds

Ex HR - Exercise heart rate

REC 30 - 30 seconds of recovery following the exercise

REC 60 - 60 seconds of recovery following the exercise

REC 90 - 90 seconds of recovery following the exercise

REC 120 - 120 seconds of recovery following the exercise

Recovery time - The time, in seconds, the subject allowed himself between consecutive exercise runs.

Full REC HR - The heart rate recorded at the completion of the recovery interval.

APPENDIX B: RAW DATA COLLECTED FROM INTERVAL RUNS

SUBJECT:	Steve Linse	TEMPERATURE:	50° F.
DATE:	3/27/68	RELATIVE HUMIDITY:	45%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	681 mm Hg.
RESTING HR:	55 beats/min.	WORKLOAD:	3 x CD - 330
POST WARM-UP HR:	91 beats/min.	RECOVERY:	110-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.88	48"	173	158	142			71"	136
2.	6.88	48	178	165				48	162
3.	6.88	48	180	169				45	164
4.	7.02	47	183	171	153			215	136
5.	6.88	48	182	170	163			60	163
6.	7.02	47	184	172	159			120	137
7.	7.33	45	184	171	159			60	159
8.	7.02	47	184	173	162			210	146
9.	7.02	47	182	168				46	167
10.	6.88	48	185	170				45	167
11.	7.02	47	184	174	160			238	130
12.	7.02	47	180	174				47	171
13.	7.02	47	185	165	158			215	146
14.	6.88	48	178	169	165			98	164
15.	7.02	47	180	174	169			60	169
16.	7.86	42	188	176	160			60	160
MEAN	7.04	47	182	170	159			102	155

APPENDIX B (Continued)

SUBJECT:	Steve Linse	TEMPERATURE:	59° F.
DATE:	4/24/68	RELATIVE HUMIDITY:	35%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	685 mm Hg.
RESTING HR:	46 beats/min.	WORKLOAD:	2 x CD - 440
POST WARM-UP HR:	73 beats/min.	RECOVERY:	300-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.11	72"	169	156	141	133	119	120"	119
2.	6.20	71	171	163	145	138	126	128	118
3.	6.28	70	176	169	150	133	132	120	132
4.	6.47	68	177	166	143	136	131	125	125
5.	6.28	70	177	162	143	131	126	126	128
6.	6.38	69	175	164	149	132	105	510	107
7.	6.28	70	175	160	145	136	125	115	125
8.	6.47	68	175	165	148	136	131	120	131
9.	6.58	67	180	167	150	138	129	120	129
10.	6.58	67	178	168	147	139	136	115	136
11.	6.38	69	180	166	147	141	126	120	126
12.	6.58	67	178	164	156	138	107	322	116
13.	6.67	66	176	166	150	145	125	114	125
14.	6.47	68	179	167	158	142	130	129	131
15.	6.47	68	180	167	151	143	133	137	120
16.	6.58	67	180	171	160	142	106	125	99
MEAN	6.42	69	177	165	149	138	124	159	123

APPENDIX B (Continued)

SUBJECT:	Ray Velez	TEMPERATURE:	54° F.
DATE:	5/ 7/68	RELATIVE HUMIDITY:	54%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	682 mm Hg.
RESTING HR:	67 beats/min.	WORKLOAD:	8 x 330
POST WARM-UP HR:	98 beats/min.	RECOVERY:	110-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	7.86	42"	188	164	150			82"	131
2.	7.86	42	192	175	153	128		90	128
3.	7.86	42	192	183	155	147		90	147
4.	7.50	44	193	184	168	160		242	130
5.	7.86	42	189	183	162			80	153
6.	7.67	43	192	184	165			82	159
7.	7.50	44	192	183	161	153		116	150
8.	7.33	45	191	184	165	157		90	157
MEAN	7.68	43	191	180	160	149		109	144

APPENDIX B (Continued)

SUBJECT:	Ray Velez	TEMPERATURE:	50^{o} F.
DATE:	4/ 3/68	RELATIVE HUMIDITY:	44%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	683 mm Hg.
RESTING HR:	55 beats/min.	WORKLOAD:	2 x CD - 330
POST WARM-UP HR:	98 beats/min.	RECOVERY:	110-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.73	49"	180	158				51"	118
2.	7.02	47	190	165	133			60	133
3.	7.02	47	190	176	162			70	136
4.	6.88	48	195	183	166			70	130
5.	7.02	47	192	182	160			73	117
6.	7.02	47	195	184	161			265	118
7.	7.02	47	190	179	150			60	150
8.	6.88	48	191	180	169			68	141
9.	6.88	48	192	181	166			74	156
10.	6.73	49	192	180	162			90	122
11.	6.88	48	194	182	168			87	154
12.	8.46	39	199	185	171			120	138
MEAN	7.04	47	192	179	161			90	134

APPENDIX B (Continued)

SUBJECT:	Ray Velez	TEMPERATURE:	83^{o} F.
DATE:	4/29/68	RELATIVE HUMIDITY:	1%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	680 mm Hg.
RESTING HR:	55 beats/min.	WORKLOAD:	2 x CD - 440
POST WARM-UP HR:	90 beats/min.	RECOVERY:	300-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	7.33	60"	196	185	174	163	147	129"	146
2.	7.09	62	197	189	180	173	145	150	144
3.	7.21	61	197	181*	143*	135*	147	150	143
4.	7.09	62	199	188	176	161	163	294	152
5.	7.21	61	197	189	178	170	173	185	153
6.	7.21	61	196	189	182	167	152	174	148
7.	7.21	61	200	191	178	172	162	145	157
8.	7.21	61	200	190	172	155	150	120	150
MEAN	7.20	61	198	188	173	162	155	168	149

*First 90 seconds of recovery recorded while subject stood quietly.

APPENDIX B (Continued)

SUBJECT:	Ray Velez	TEMPERATURE:	47° F.
DATE:	4/11/68	RELATIVE HUMIDITY:	25%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	681 mm Hg.
RESTING HR:	66 beats/min.	WORKLOAD:	3 x CD - 440
POST WARM-UP HR:	89 beats/min.	RECOVERY:	300-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.77	65"	191	168	131	124	121	137"	117
2.	6.99	63	192	174	153	144	133	120	133
3.	6.99	63	197	178	171	159	140	133	135
4.	6.99	63	193	180	163	157	149	144	142
5.	6.99	63	195	181	160	155	148	140	137
6.	6.99	63	193	185	169	156	142	333	127
7.	6.99	63	193	183	168	157	148	124	148
8.	6.99	63	193	185	167	161	147	135	143
9.	6.99	63	192	186	164	158	148	134	140
10.	6.99	63	194	178	169	157	144	149	142
11.	6.77	65	193	184	169	160	149	168	144
12.	8.00	55	193	181	164	158	151	130	143
MEAN	7.04	63	193	180	162	154	143	154	138

APPENDIX B (Continued)

SUBJECT:	Ray Velez	TEMPERATURE:	42° F.
DATE:	4/ 1/68	RELATIVE HUMIDITY:	100%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	675 mm Hg.
RESTING HR:	52 beats/min.	WORKLOAD:	2 x CD - 660
POST WARM-UP HR:	95 beats/min.	RECOVERY:	3 minutes

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.60	100"	188	175	157	150	144	180"	140
2.	7.59	87	197	184	172	152	148	225	136
3.	6.80	97	195	181	163	151	146	275	138
4.	6.60	100	195	183	165	150	142	333	138
5.	6.53	101	188	181	168	156	145	260	134
6.	6.88	96	191	182	165	158	140	180	128
MEAN	6.83	97	192	181	165	154	144	242	136

APPENDIX B (Continued)

SUBJECT:	Fred Friesz	TEMPERATURE:	66° F.
DATE:	5/ 2/68	RELATIVE HUMIDITY:	27%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	682 mm Hg.
RESTING HR:	54 beats/min.	WORKLOAD:	2 x CD - 220
POST WARM-UP HR:	95 beats/min.	RECOVERY:	110-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	7.33	30"	171	153	110			64"	101
2.	7.59	29	175	156	121			69	87
3.	7.33	30	179	161	116			62	116
4.	7.33	30	176	158	135			62	135
5.	7.59	29	180	168	131			93	107
6.	7.59	29	177	167	141			65	140
7.	7.59	29	182	166	140			62	140
8.	7.59	29	183	168	148			164	118
9.	7.59	29	175	168	141			59	141
10.	7.59	29	180	167	138			82	120
11.	7.59	29	180	167	144			65	141
12.	7.59	29	181	168	143			70	138
13.	7.59	29	180	168	133			80	135
14.	7.59	29	181	165	144			87	133
15.	7.59	29	181	170	150			66	143
16.	7.59	29	184	172	150			60	150
MEAN	7.54	29	179	165	137			76	128

APPENDIX B (Continued)

SUBJECT:	Fred Friesz	TEMPERATURE:	60° F.
DATE:	4/18/68	RELATIVE HUMIDITY:	34%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	677 mm Hg.
RESTING HR:	51 beats/min.	WORKLOAD:	2 x CD - 330
POST WARM-UP HR:	82 beats/min.	RECOVERY:	110-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	7.17	46"	172	153	135			81"	105
2.	7.02	47	180	154	141			74	123
3.	7.33	45	182	165	143	120		96	105
4.	7.33	45	181	159	144	132	128	270	118
5.	7.02	47	181	168	145	124		102	109
6.	7.33	45	185	170	150			76	133
7.	7.33	45	185	174	150	131		98	106
8.	7.33	45	186	155	143	140	131	270	120
9.	7.17	46	182	169	145	125		98	118
10.	7.33	45	185	168	150	130		95	130
11.	7.02	47	185	170	150			80	130
12.	7.17	46	184	173	152	144	136	180	110
MEAN	7.21	46	182	165	143	131	132	127	117

APPENDIX B (Continued)

SUBJECT:	Fred Friesz	TEMPERATURE:	61° F.
DATE:	4/22/68	RELATIVE HUMIDITY:	28%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	681 mm Hg.
RESTING HR:	53 beats/min.	WORKLOAD:	3 x CD - 440
POST WARM-UP HR:	105 beats/min.	RECOVERY:	300-slow jog

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.99	63"	176	154	132	132	112	173"	94
2.	6.99	63	181	163	138	136	118	180	111
3.	7.09	62	184	169	141	133	126	132	122
4.	6.77	65	185	169	144	132	121	235	101
5.	6.99	63	181	169	146	134	120	124	120
6.	6.99	63	185	167	138	133	127	157	107
7.	6.99	63	185	167	143	136	122	187	120
8.	6.99	63	183	166	145	136	130	475	110
9.	7.09	62	180	163	135	131	125	225	124
10.	6.99	63	183	170	142	132	114	173	90
11.	7.09	62	184	164	139	130	131	190	97
12.	6.99	63	181	172	159	146	119	185	102
MEAN	7.00	63	182	166	142	134	122	203	108

APPENDIX B (Continued)

SUBJECT:	Fred Friesz	TEMPERATURE:	42° F.
DATE:	4/16/68	RELATIVE HUMIDITY:	82%
TIME:	3:30-5:00 P.M.	BAROMETRIC PRESSURE:	680 mm Hg.
RESTING HR:	44 beats/min.	WORKLOAD:	2 x CD - 880
POST WARM-UP HR:	70 beats/min.	RECOVERY:	3 minutes

RUN	PACE D/T	EX TIME	EX HR	REC 30	REC 60	REC 90	REC 120	REC TIME	FULL REC HR
1.	6.77	130"	177	158	138	132	120	180"	91
2.	6.52	135	180	165	147	134	124	180	110
3.	6.52	135	183	170	150	131	128	180	120
4.	6.42	137	182	169	152	143	131	180	112
MEAN	6.56	134	181	166	147	135	126	180	108

RUN	440 TIME	440 HR
1.	65"	170
2.	67	178
3.	66	178
4.	67	178
MEAN	66	176

APPENDIX C

RAW DATA COLLECTED FROM CONTINUOUS RUNS

LEGEND FOR APPENDIX C

Workload refers to a continuous run expressed in yards. This distance was run competitively only once.

Column headings are explained as follows:

Time - The time in seconds at which the heart rate was recorded

Heart Rate - The heart rate recorded at a specific time, as indicated under the time column.

The numbers under the time columns are explained as follows:

The negative numbers beneath the first time column refer to the number of seconds before the run began.

The positive numbers beneath the first time column refer to the number of seconds after the run began.

The positive numbers beneath the second time column refer to the number of seconds after the run began.

The negative numbers beneath the second time column refer to the number of seconds of recovery following the termination of the continuous run.

APPENDIX C: RAW DATA COLLECTED FROM CONTINUOUS RUNS

SUBJECT:	Steve Linse	TEMPERATURE:	50° F.
DATE:	2/24/68	RELATIVE HUMIDITY:	44%
TIME:	11:00 A.M.	BAROMETRIC PRESSURE:	688 mm Hg.
RESTING HR:	58 beats/min.	WORKLOAD:	2640 yard continuous run (441 sec.)*
POST WARM-UP HR:	91 beats/min.		

TIME	HEART RATE	TIME	HEART RATE
-30"	90	90"	188
-25	91	105	194
-20	128	120	188
-15	128	180	194
-10	132	240	194
- 5	134	300	200
0	136	360	194
5	150	420	194
10	158	441	194
15	167	- 15	194
20	176	- 30	186
25	177	- 45	182
30	182	- 60	178
45	188	- 75	172
60	182	- 90	167
75	188	-120	162

*Pace was 5.99 yards per second

APPENDIX C (Continued)

SUBJECT:	Fred Frieze	TEMPERATURE:	52° F.
DATE:	4/13/68	RELATIVE HUMIDITY:	42%
TIME:	11:00 A.M.	BAROMETRIC PRESSURE:	688 mm Hg.
RESTING HR:	41 beats/min.	WORKLOAD:	1320 yard continuous run (206 sec.)*
POST WARM-UP HR:	64 beats/min.		

TIME	HEART RATE	TIME	HEART RATE
-30"	58	90"	178
-25	60	105	179
-20	80	120	180
-15	84	135	177
-10	104	150	178
- 5	102	165	178
0	110	180	177
5	131	195	177
10	147	206	180
15	159	- 15	171
20	170	- 30	154
25	173	- 45	144
30	173	- 60	120
45	175	- 75	106
60	178	- 90	114
75	178	-120	122

*Pace was 6.41 yards per second