OXYGEN DEBT AND CHANGES IN OTHER SELECTED VARIABLES DURING AN EXHAUSTIVE RUN ON A MOTOR-DRIVEN TREADMILL

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ABSTRACT

OXYGEN DEBT AND CHANGES IN OTHER SELECTED VARIABLES DURING AN EXHAUSTIVE RUN ON A MOTOR-DRIVEN TREADMILL

By

Gerald Michael Nester

Six trained Michigan State University athletes ranging in age from 19 to 21 years ran different random sequences of tests. One ran in each sequence to exhaustion. This was accomplished by running up a 9-degree grade at 10 m.p.h. on a motor-driven treadmill. Oxygen debt accumulation as well as heart rate, oxygen uptake, oxygen pulse, and oxygen requirement were studied in order to determine the pattern of progression which results in what is termed exhaustion. The means and standard deviation were used to describe the results. Two methods of analyses were used. The first method examined only the exhaustive run. The second method used a new technique where by a series of runs which progressively increased in intensity and included the exhaustive run could be examined in what is termed a calculated composite run to exhaustion.

The study indicated that heart rate, oxygen uptake, and oxygen pulse are related to the rate and size of the

accumulation of oxygen debt. Both the alactacid and lactacid oxygen debt accumulation may be seen in the rapid early rise in value followed by a slight adjustment in accumulation, and another rapid increase which leveled off near exhaustion. When two subjects who ran the longest period of time and two subjects who ran the shortest period of time were compared with all subjects individual differences were noted. These differences were most apparent during the latter stages of the test sequences. The study indicated that a possible new approach to oxygen debt research has been found with the calculated composite technique.

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By

Gerald Michael Nester

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DEDICATION

To Rosemary, for understanding those things which make a man's life important.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

Introduction

The accumulation of an oxygen debt allows an individual to convert stored chemical energy into mechanical energy anaeraobically. This process is well known and is considered to be the basis for an individual to do severe or maximal work [1, 3, 7, 8, 9, 10, 12, 13,] . However, there has been little quantitative evidence which shows the pattern of oxygen debt accumulation during specific intervals of exhaustive exercise and recovery.

Statement of the Problem

The purpose of this study was to determine the pattern of oxygen debt accumulation during an exhaustive run on a motor-driven treadmill by trained individuals. Progressive changes in heart rate, oxygen uptake, and oxygen pulse also were studied.

Limitations of the Study

Due to considerations of time, laboratory personnel, and available equipment, the subjects were limited to six trained Michigan State University athletes. Only one run sequence per man was used. Therefore, an approach other than a descriptive interpretation of results or trends could not be undertaken.

Since the individuals selected for this study were from only two sports, hockey and track, it should be noted that differences in the types of athletic activity undertaken and the resultant differences in the physical and mental conditioning necessary for the particular sports involved may have produced unknown limiting factors. In addition, the attempt to achieve maximal effort was possibly limited by a number of intervening conditions which were impossible to control, even though the individuals were trained varsity athletes [15].

Studies of this nature serve as pilot work for future research. Thus, it is with this intent that the study was designed and the conclusions were drawn.

Definition of Terms

The following terms were used in this study:

Oxygen Debt. "Oxygen debt" is used to denote the amount of oxygen consumption during a recovery period which is in excess of that used at rest and which is necessary to reverse the anaerobic reactions of prior exercise.

Maximal or Exhaustive Exercise. "Maximal" or "exhaustive" exercise is used to denote a level of exercise at which the cardiovascular and respiratory systems are unable to provide the oxygen necessary for the involved muscles.

Anaerobic Reaction. "Anaerobic reaction" is used to denote a metabolic or chemical reaction that can take place without simultaneous sufficient intake of oxygen.

Resting Level Value. The "resting level value" is used to denote the mean value of any given variable during a five-minute period of rest on three randomly selected days, on which the subject was not stressed before or after the rest period.

Oxygen Cost of Exercise. The "oxygen cost of exercise" is used to denote the sum of the oxygen debt of exercise plus the oxygen intake during the task.

Oxygen Pulse. "Oxygen pulse" is used to denote the amount of oxygen being supplied to the body per heart beat.

Oxygen Uptake. "Oxygen uptake" is used to denote the volume of oxygen per minute being utilized by the body from inspired air taking into consideration standard temperature and pressure corrections.

CHAPTER II

RELATED LITERATURE

The purpose of this study was to determine the pattern of oxygen debt accumulation and the pattern of changes in other related variables during a maximal run on a motor-driven treadmill by trained subjects. The results of previous studies dealing with the relationships of oxygen debt and maximal exercise were reviewed.

During the performance of severe exercise, a point is quickly reached when the body converts stored chemical energy into mechanical energy. This process is made possible by the accumulation of an oxygen debt [4].

The accumulation of an oxygen debt begins when a point is reached where the circulation of an individual can no longer supply the needed oxygen at a rate which will meet the metabolic requirements of the working muscles [9, 11] and continues until the anaerobic chemical processes within the body have produced concentrations of lactic acid ranging between three and four percent [10].

Hill and his collaborators [7] found that immediately after the cessation of exercise, the individual begins repaying the oxygen debt. The amount of oxygen debt is best measured by collecting expired air for a set period of time during the recovery period immediately following the conclusion of exercise [4]. The volume of the expired sample, the percent of each gas present in the sample, and the amount of oxygen used in excess of the resting requirement are the factors which are used to calculate the actual amount of oxygen debt.

Taylor [9] and Dill [3] pointed out that the trained athlete is capable of producing a much larger oxygen debt than the untrained person. Karpovich [10] reported that:

> In the severest forms of exercise something over 22 liters of oxygen may be required to provide the energy used in one minute. This is an impossible accomplishment for the respiratory and circulatory systems, which even in a well-developed athlete may supply only between 4 and 5 liters in a minute. By contracting an oxygen debt of 18 to 19 liters, the demand for 22 liters a minute can be met. The largest oxygen debt reported was 22.8 liters, after a 10,000-meter race.

Prior to 1924, it was generally believed that a quantitative relationship between oxygen debt and lactic acid production acted as a check for normal physiological recovery after severe exercise [7, 10]. Margaria and others [12], however, have stated that this is only partially correct. They pointed out that payment of oxygen debt involves two distinct factors: first, an initial period of recovery during which there is a rapid fall in oxygen intake after the cessation of exercise; and second, the prolonged remainder of recovery occurring after extended or maximal exertion.

Margaria and his associates [12] and as well as others [1, 2, 3, 4, 5, 7, 8, 9, 10, 13, 15] labeled the two components of recovery as an alactacid oxygen debt and a lactacid oxygen debt. The first phase of recovery, or the period of the alactacid oxygen debt, is the rapid component which is due to the oxidative removal of lactic acid in the working muscles. In other words, the alactacid oxygen debt is an expression of an oxidative process in which the energy liberated is spent in repaying the amount of energy set free anaerobiacally during exercise. Huckabee [8] points out that during this time, oxygen debt is a linear function of oxygen intake because of the oxidation of substances (Pyruvate + DPNH $\leftrightarrows$ Lactate = DPN) furnishing energy for the resynthesis of the phosphagen split during muscular contraction. The phosgene split is also the contributing factor which causes the actual amount of alactacid oxygen debt to be proportional to the extra amount of oxygen consumption per minute in exercise. Robinson and his collaborators [13] found the oxygen cost of the first minute of severe exercise to be higher than that for the second minute; but on running to exhaustion, the oxygen requirement increased to a value fifty per cent greater than that in the first minute of the run or exercise.

The second phase of the recovery period, or the lactacid oxygen debt, is the slow component which involves the removal of lactic acid from the blood. According to Margaria and his associates [12] this phase is not appreciable until the oxygen intake is equal to or greater than 2.5 liters per minute. It increases slowly at first and then increases rapidly until the curve becomes vertical at a point which corresponds to the maximum metabolic rate. According to Hill [7], the concentration of lactic acid, on the other hand, behaves as a linear function of the extra oxygen consumption per time interval of recovery which is dependent on the sum of: (a) the basal oxygen consumption, (b) the oxygen consumption attributed to oxidation of lactic acid, (c) another exponential function of time occurring at a fast rate, and (d) the oxygen consumption decreasing very slowly during recovery.

It is during the lactacid oxygen debt payment that there is an increase in the resynthesis of glycogen from the lactic acid. The subsequent payment of the lactacid debt follows the same rate as the lactacid removal; each process is a logarithmic function of time [15].

The concentration of lactic acid in an individual's blood during the recovery period was at one time considered to be an indication of the total oxygen debt, and the removal of lactic acid was assumed to be the rate of payment indicator [10]. Huckabee [8], however, noted that the respiratory-cardiovascular lag in lactacid oxygen debt payment was not attributed primarily to the lactate mechanism. Therefore, there appears to be no reliable metabolic explanation for the slow phase of oxygen debt payment. Karpovich [10] also has noted that it does not appear that energy for resynthesis of substances which were broken down during severe exercise has anything to do with real oxygen debt.

Regardless of the mechanisms involved in oxygen debt payment, both the total oxygen debt and the lactacid debt are related to the intensity and duration of work. It follows then that the alactacid debt is also dependent upon the intensity and duration of work. In other words, the lactacid oxygen debt and alactacid oxygen debt in severe activity are contracted concurrently [12].

CHAPTER III

RESEARCH METHODS

The purpose of this study was to describe the pattern of oxygen debt accumulation and changes in related variables during an exhaustive run on a motor-driven treadmill at 10 m.p.h. up a 9-degree grade by trained athletes.

Experimental Design

Six trained Michigan State University varsity athletes ranging from 19 to 21 years of age were choosen for the study from a group of twelve volunteers. The men were selected so that scheduling could be maintained at given intervals during the morning hours from 7 a.m. to 12 noon without conflict. Four of the subjects were distance runners and two men were hockey defensemen.

For a period of one week prior to the actual data collection, the subjects ran a 5-minute warm-up run at 5 miles per hour on a zero-degree grade, rested 15 minutes and ran for 1 minute up the 9-degree grade at 10 miles per hour with a 15-minute recovery period following The week permitted the subjects to become familiar with both running on the treadmill and the necessary collection equipment which was used.

The first actual run was an exhaustive effort. This enabled the laboratory personnel to determine the approximate maximum running time for each subject. Two 15-second intervals were added to each subject's initial run time in order to allow for factors which could permit the runners later to surpass their first exhaustive efforts. Table 3.1 illustrates all possible tests for the subject who performed for the longest period of time. The other subjects had similar, but fewer test runs since their times to reach exhaustion were shorter. Each subject's run sequence was randomized so that the mean effects of training were as negligible as possible.

TABLE 3.1--All possible tests for the subject who performed the longest period of time.

1.	5-minute warm-up with recovery period
2.	5-minute warm-up with recovery period
3.	5-minute warm-up with recovery period
4.	5-minute rest period
5.	5-minute rest period
6.	5-minute rest period
7.	15-second run with recovery period
8.	30-second run with recovery period
9.	45-second run with recovery period
10.	1-minute run with recovery period
11.	1-minute 15-second run with recovery period
12.	1-minute 30-second run with recovery period
13.	1-minute 45-second run with recovery period
14.	2-minute run with recovery period
15.	2-minute 15-second run with recovery period
16.	2-minute 30-second run with recovery period
17.	2-minute 45-second run with recovery period
18.	3-minute run with recovery period

Table 3.2 shows the gas collection periods during each of the 15-minute standard recovery periods.

TABLE 3.2--Gas-collection intervals for the standard recovery period

1.	Ten 15-second intervals	2 1/2 minutes
2.	Five 30-second intervals . .	2 1/2 minutes
3.	One 10-minute interval . . .	10 minutes
		15 minutes

Each subject ran a 5-minute warm-up and then rested for 15 minutes before each test except the six special periods which involved only the warm-up runs and the rest periods. The subjects were not told which run they would do until just before the warm-up. It was hoped that this would cause the individuals to be prepared for a maximum effort each day.

Collection of expired air was accomplished by the use of a Triple-J respiratory valve into which the runners breathed. The valve was connected to a series of Douglas bags which were changed during inspiration after each gas collection interval. The air collected in each of the Douglas bags was analized for percent of oxygen and carbon dioxide using Beckman Oxygen and Carbon Dioxide analyzers. After the analysis, the remaining air was evacuated by means of a Kofranyi Volume Meter and appropriate corrections were made for temperature, pressure, and the volumes of gas extracted by the oxygen and carbon dioxide analyzers.

Standard exercise electrodes and leads were placed on the subject and connected to a Sanborn Polygraph outlet to record the subject's heart rate. The heart rate was recorded during the entire run and for selected intervals during the standard recovery period. These recovery intervals were the first 5 1/2 minutes, 6 minutes 30 seconds to 7 minutes, 8 minutes 30 seconds to 9 minutes, 10 minutes 30 seconds to 11 minutes, 12 minutes 30 seconds to 13 minutes, and 14 minutes 30 seconds to 15 minutes.

As mentioned previosuly, only a descriptive interpretation of results or trends can be considered; therefore, means and standard deviations were used for heart rate, oxygen uptake, oxygen pulse, oxygen debt and oxygen requirement.

The rate of oxygen debt accumulation for each run was found by dividing the recovery oxygen uptake for each run by the length of that run in minutes.

Further analyses of the oxygen debt data as well as the data on heart rate, oxygen uptake, oxygen pulse, and oxygen requirement were accomplished by using the maximum time of the exhaustive run of each subject as his 100 percent base effort and finding 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent levels of the maximum run time. The mean values for the two subjects who ran the longest and shortest periods of time also were found.

In addition to the analyses of the maximum run, a calculated composite run was found by using 10 through 90 percent levels of maximum run time for the selected varibles. This was accomplished by using the maximal run as the 100 percent base and calculating the given percent levels from the series of test runs which were partitioned into 15-second intervals. This technique enabled the mean and standard deviation values to be studied as subjects were progressively tested during their entire sequence of runs leading to exhaustion. Again, the means were calculated for the two subjects who ran the longest and shortest periods of time in addition to the mean and standard deviation values for all subjects.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of the study was to determine the pattern of oxygen debt accumulation in trained varsity athletes during an exhaustive maximal run on a motor-driven treadmill at 10 m.p.h. up a 9 degree grade. Progressive changes in heart rate, oxygen uptake, and oxygen pulse also were studied.

Each of six subjects performed a different random sequence of selected tests shown in table 3.1.

Results

The group means and standard deviations, along with the mean values of the two subjects who ran the longest period of time and the mean values of the two subjects who ran the shortest period of time, are presented for the maximal run and the calculated composite run in graphical and tabular form. The results of the heart rate data are found on pages 15-21, oxygen uptake on pages 22-28, oxygen pulse on pages 29-35, oxygen debt on pages 36-41, and oxygen requirement on pages 42-43. The discussion follows the tables and graphs.

TABLE 4.1--Heart rate per minute value for 5-minute rest.

Time	Mean	Standard Deviation
1'00"	65.1	10.6
2'00"	63.2	10.2
3'00"	63.5	9.3
4'00"	64.5	8.4
5'00"	64.5	9.1

TABLE 4.2--Heart rate per minute value for 5-minute warm-up and 15-minute recovery.

Time	Mean	Standard Deviation
1'00"	125.3	13.7
2'00"	136.2	14.2
3'00"	137.5	16.3
4'00"	138.4	12.4
5'00"	139.9	13.7
15"	123.4	22.1
30"	107.1	18.2
45"	91.1	14.6
1'00"	87.1	13.7
1'15"	85.3	13.0
1'30"	84.5	13.2
1'45"	83.9	15.6
2'00"	82.0	12.8
2'30"	79.0	13.7
3'00"	81.5	11.7
3'30"	80.0	12.4
4'00"	78.0	11.2
4'30"	77.3	9.7
5'00"	75.7	9.6
5'30"	78.8	11.6
6'30"	77.3	13.3
8'30"	74.1	9.1
10'30"	74.1	11.8
12'30"	72.9	9.0
14'30"	73.2	9.7

TABLE 4.3--Heart rate per minute value for maximum run considering all subjects, the two subjects who ran the longest time, and the two subjects who ran the shortest time based on the per cent of maximum run time.

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects Who Ran Longest	Means for the two Subjects Who Ran Shortest
10	110.2	29.0	141.2	80.3
20	146.6	16.4	162.0	134.7
30	159.5	14.8	168.5	154.0
40	164.8	13.9	171.6	164.7
50	169.5	11.6	174.0	171.6
60	176.0	4.1	177.7	175.9
70	176.3	3.2	176.1	177.1
80	182.5	4.5	180.4	188.2
90	186.7	7.0	185.5	193.0
100	184.8	4.9	181.7	190.7

TABLE 4.4--Heart rate per minute value for calculated composite run to exhaustion considering all subjects, the two subjects who ran the longest time, and the two subjects who ran the shortest time based on the per cent of maximum run time.

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects Who Ran Longest	Means for the two Subjects Who Ran Shortest
10	103.2	22.2	119.6	80.4
20	146.5	16.9	147.4	132.8
30	157.0	6.5	157.2	153.3
40	170.6	6.2	168.8	168.1
50	173.1	6.6	176.2	176.0
60	175.7	4.3	172.3	178.4
70	178.8	6.1	176.8	180.0
80	176.8	3.3	176.0	180.0
90	184.9	11.1	179.7	185.8
100	184.8	4.9	181.7	190.7

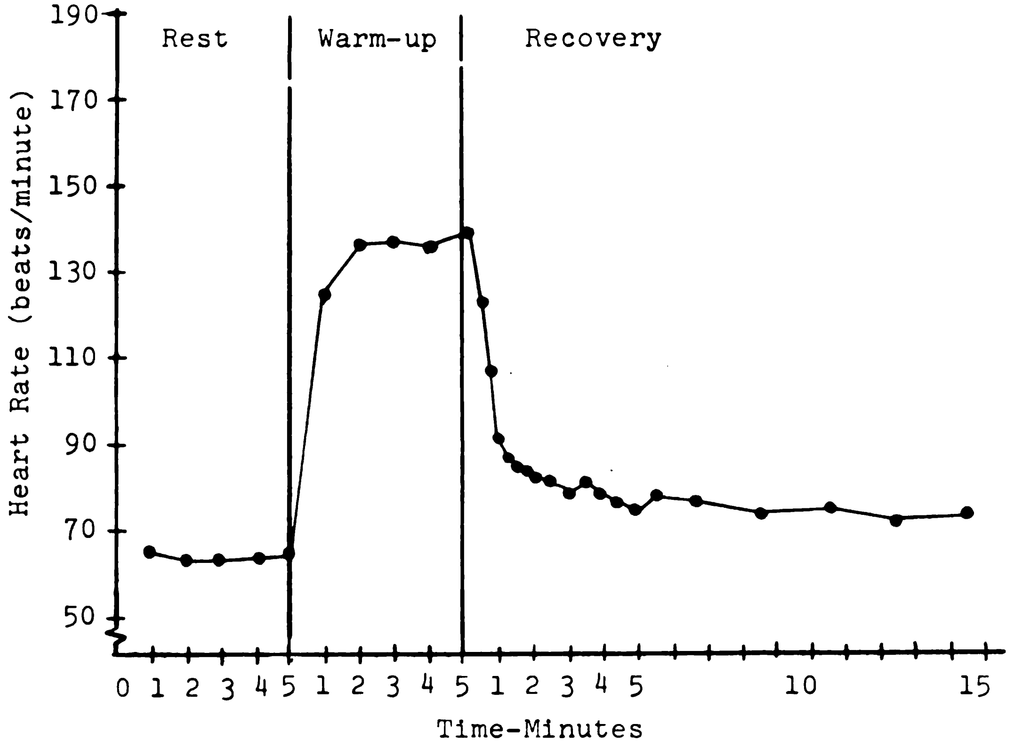

Figure 4.1.--Heart rate per minute value for 5 minute rest, 5 minute warm-up and 15 minute recovery.

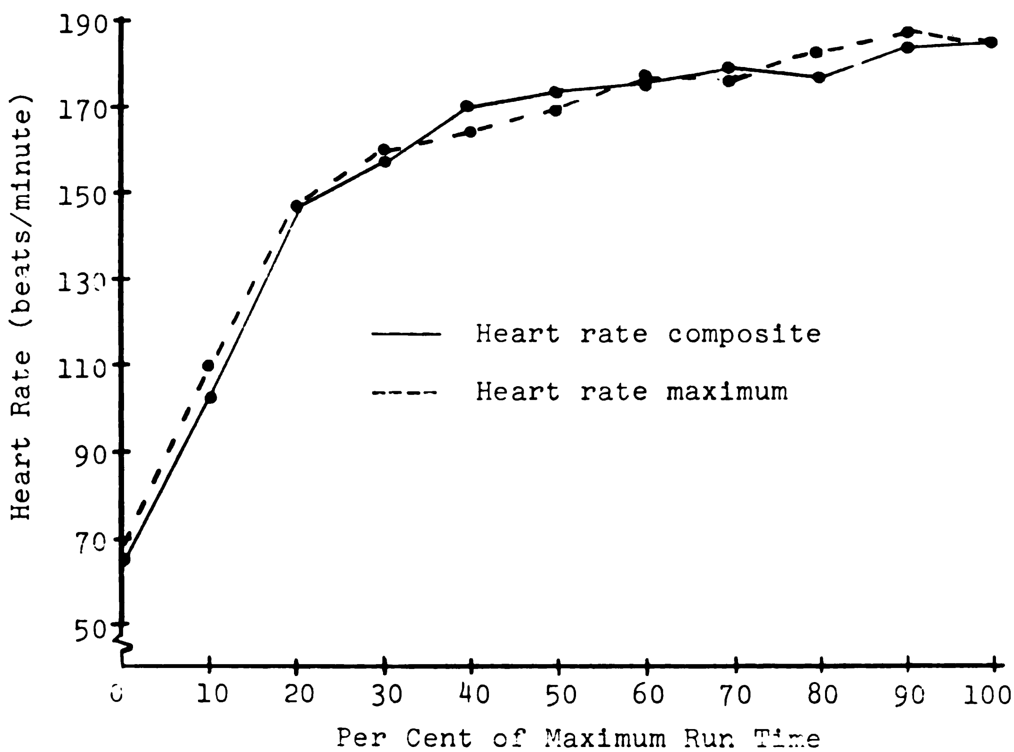

Figure 4.2.--Heart rate for maximum run and for calculated composite run.

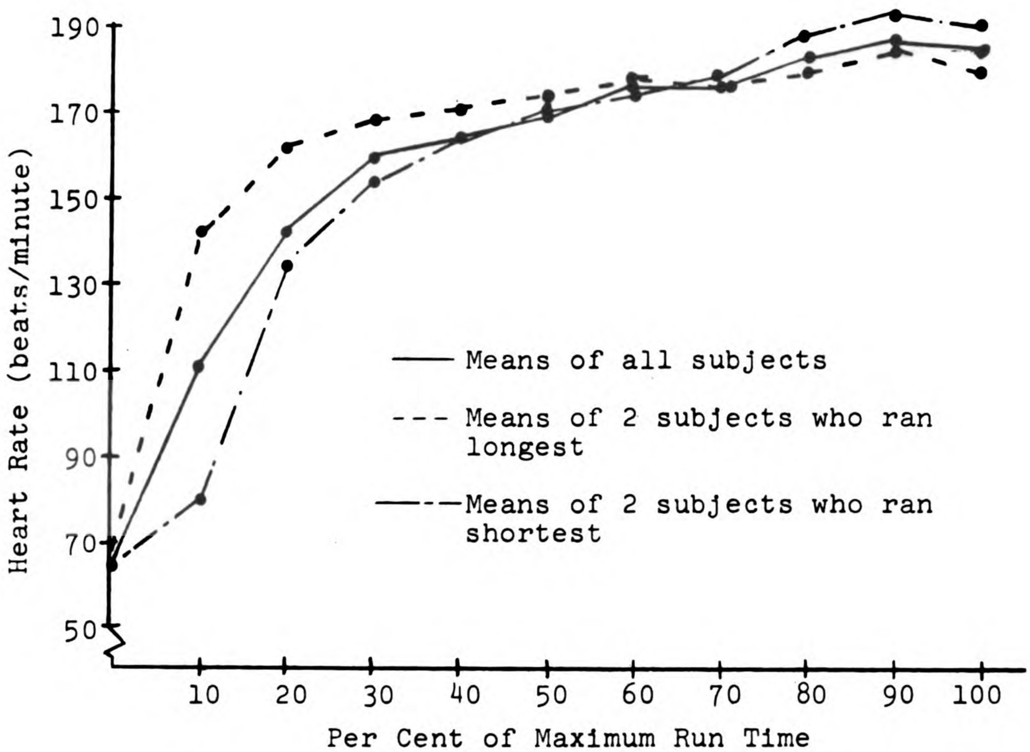

Figure 4.3.--Heart rate for maximum run considering means of all subjects, the 2 subjects who ran the longest, the 2 subjects who ran the shortest.

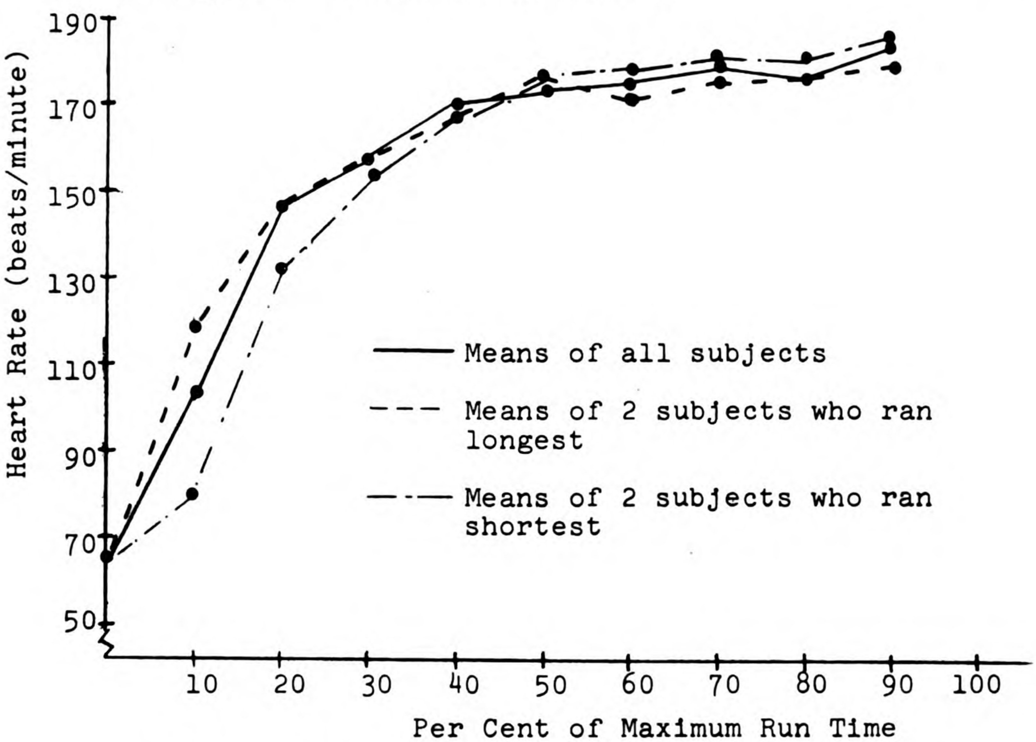

Figure 4.4.--Heart rate for calculated composite run considering means of all subjects, the 2 subjects who ran the longest, the 2 subjects who ran the shortest.

TABLE 4.5--Recovery heart rate per minute value for 10% run, 50% run, and 100% run.

Time	Mean	Standard Deviation	Time	Mean	Standard Deviation
		10% Run			
15"	116.6	27.0	3'30"	60.9	5.0
30"	109.8	16.0	4'00"	63.0	8.1
45"	98.2	12.1	4'30"	59.0	6.0
1'00"	74.5	11.2	5'00"	62.0	9.0
1'15"	66.8	6.0	5'30"	65.6	8.6
1'30"	65.6	5.7	6'30"	65.2	10.2
1'45"	61.6	4.6	8'30"	64.4	5.6
2'00"	59.4	8.1	10'30"	60.1	6.1
2'30"	60.8	6.5	12'30"	61.8	3.1
3'00"	59.6	8.1	14'30"	60.7	4.7
		50% Run			
15"	170.5	8.0	3'30"	91.5	14.3
30"	165.0	12.4	4'00"	90.3	12.7
45"	149.8	15.6	4'30"	88.5	11.6
1'00"	127.2	16.3	5'00"	90.0	8.4
1'15"	118.5	17.1	5'30"	85.5	8.7
1'30"	109.5	15.1	6'30"	88.8	16.3
1'45"	105.2	15.0	8'30"	85.4	11.4
2'00"	100.4	21.0	10'30"	84.8	3.9
2'30"	96.5	18.7	12'30"	86.7	3.3
3'00"	93.4	15.7	14'30"	83.0	5.1
		100% Run			
15"	183.3	4.8	3'30"	113.2	13.3
30"	174.0	16.2	4'00"	109.6	15.8
45"	167.6	8.3	4'30"	106.6	18.5
1'00"	155.3	10.9	5'00"	109.8	15.5
1'15"	148.6	12.6	5'30"	108.9	17.6
1'30"	141.2	20.4	6'30"	109.0	14.1
1'45"	136.1	16.3	8'30"	112.1	14.1
2'00"	131.1	16.9	10'30"	107.4	12.7
2'30"	119.3	15.1	12'30"	106.2	8.7
3'00"	117.0	13.4	14'30"	107.3	11.9

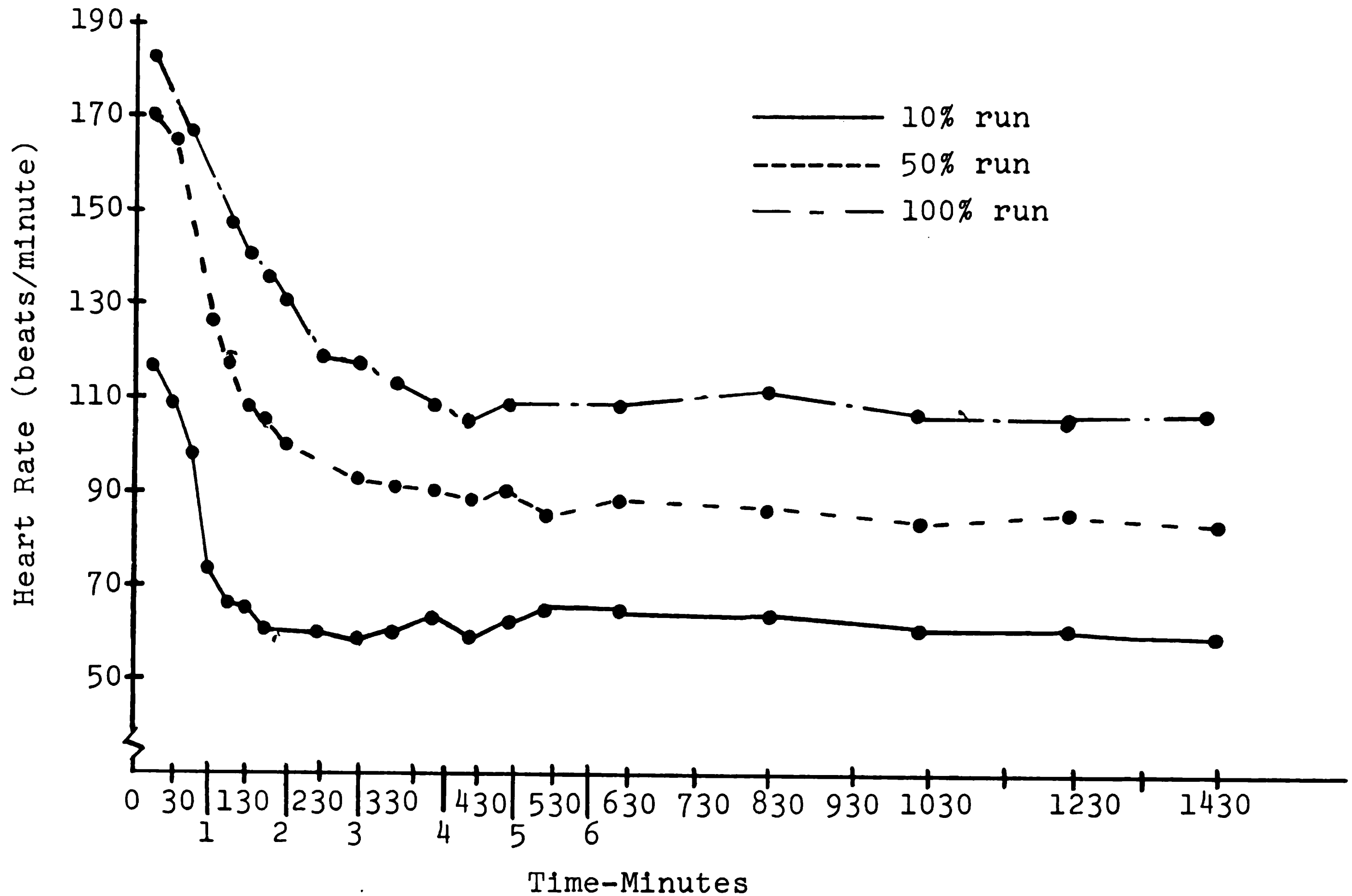

Figure 4.5.--Recovery heart rate for 10% run, 50% run, and 100% run.

TABLE 4.6--Oxygen uptake per minute value for 5-minute rest.

Time	Mean	Standard Deviation
1'00"	0.367	0.135
2'00"	0.367	0.097
3'00"	0.309	0.046
4'00"	0.311	0.035
5'00"	0.305	0.043

TABLE 4.7--Oxygen uptake per minute value for 5-minute warm-up and 15-minute recovery.

Time	Mean	Standard Deviation
1'00"	1.310	0.514
2'00"	1.704	0.577
3'00"	1.985	0.467
4'00"	2.094	0.613
5'00"	1.821	0.748
15"	1.510	0.668
30"	1.288	0.647
45"	1.178	0.697
1'00"	0.961	0.625
1'15"	0.674	0.597
1'30"	0.358	0.147
1'45"	0.404	0.208
2'00"	0.476	0.505
2'30"	0.328	0.129
3'00"	0.444	0.440
3'30"	0.327	0.150
4'00"	0.405	0.272
4'30"	0.264	0.146
5'00"	0.273	0.124
10'00"	0.255	0.113

TABLE 4.8--Oxygen uptake per minute values in liters for maximum run considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time based on the per cent of maximum run time.

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects Who Ran Longest	Means for the two Subjects Who Ran Shortest
10	1.101	0.502	1.285	0.816
20	1.968	0.822	2.405	1.624
30	3.022	0.796	3.590	2.130
40	3.541	0.550	3.880	3.113
50	3.911	0.350	3.970	3.693
60	4.279	0.216	4.295	4.212
70	4.424	0.141	4.565	4.348
80	4.195	0.218	4.235	4.103
90	4.263	0.289	4.390	4.119
100	4.272	0.397	4.090	4.343

TABLE 4.9--Oxygen uptake per minute values in liters for calculated composite run to exhaustion considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time based on the per cent of maximum run time.

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects Who Ran Longest	Means for the two Subjects Who Ran Shortest
10	0.984	0.202	1.105	1.053
20	1.884	0.581	2.095	1.389
30	2.236	1.198	2.283	2.072
40	2.839	1.113	2.697	2.865
50	3.188	0.724	3.412	3.228
60	3.846	0.646	4.293	3.916
70	4.111	0.297	4.264	4.335
80	3.742	0.744	4.278	3.364
90	3.642	0.552	3.119	4.029
100	4.271	0.397	4.090	4.341

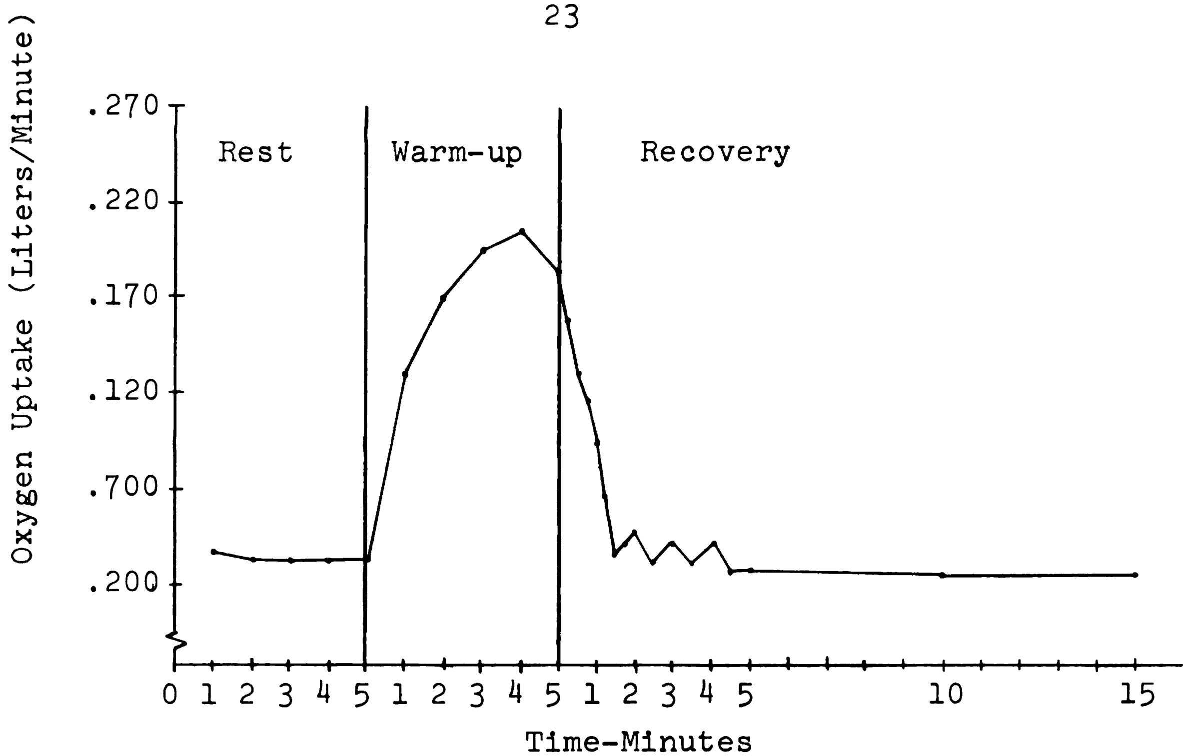

Figure 4.6.--Oxygen uptake per minute values for 5 minute rest, 5 minute warm-up, and 15 minute recovery.

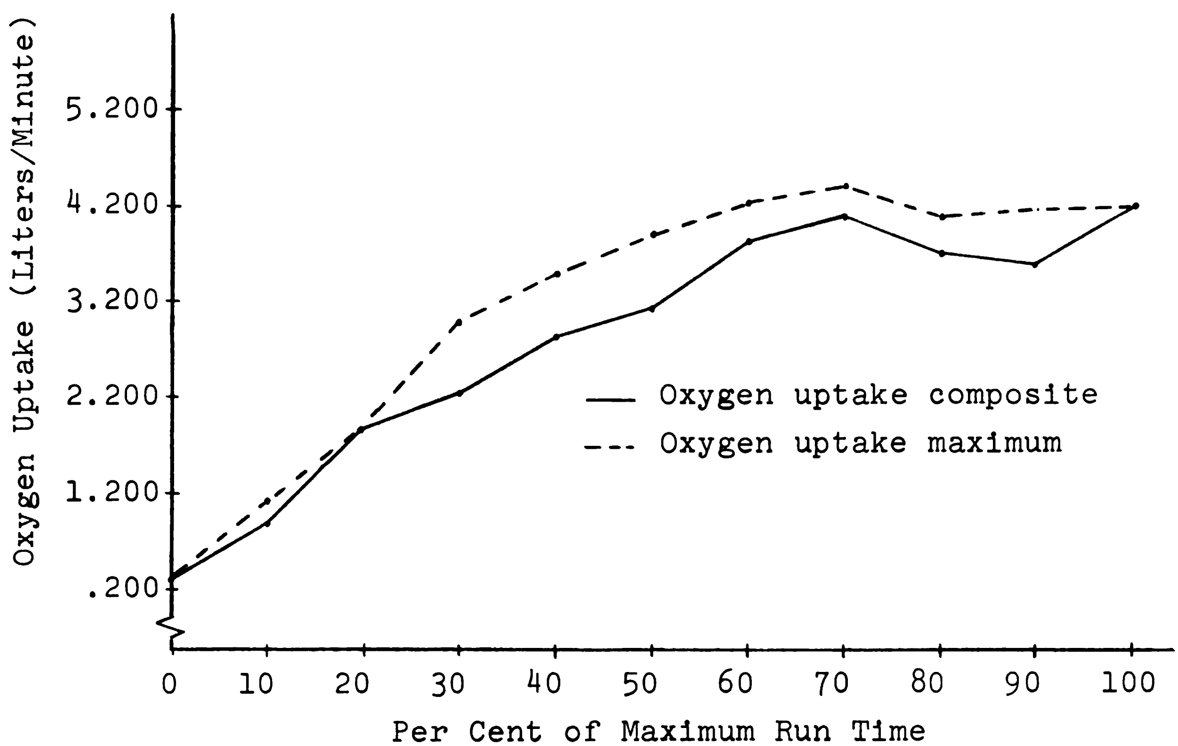

Figure 4.7.--Oxygen uptake for maximum run and for calculated composite run.

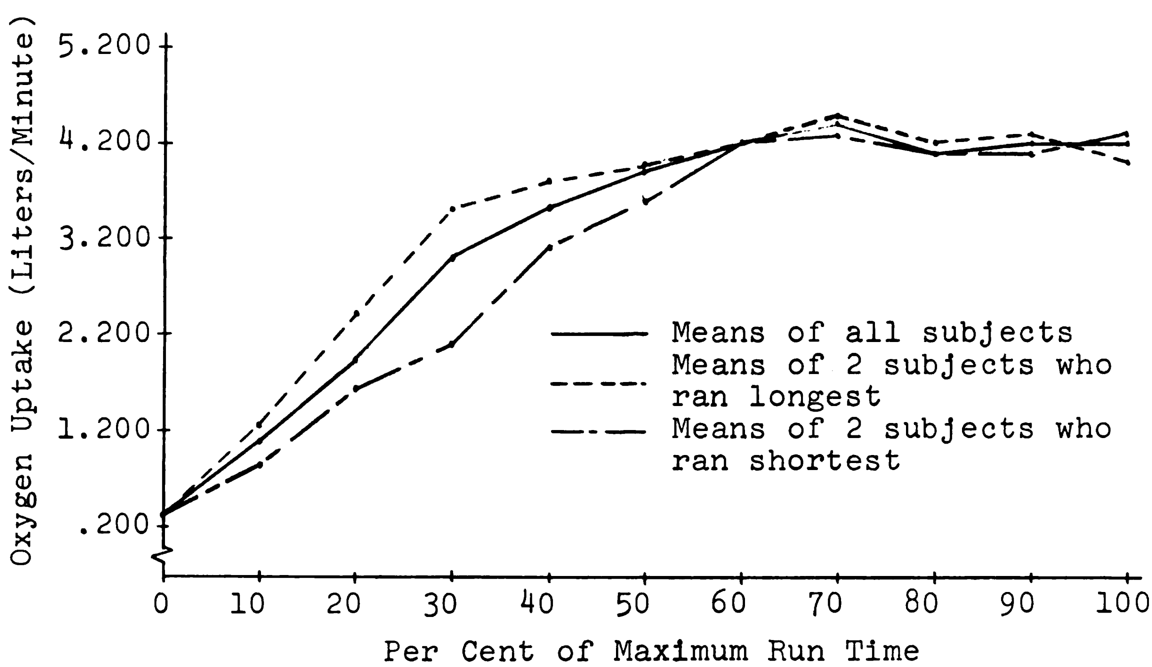

Figure 4.8.--Oxygen uptake for maximum run considering means of all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

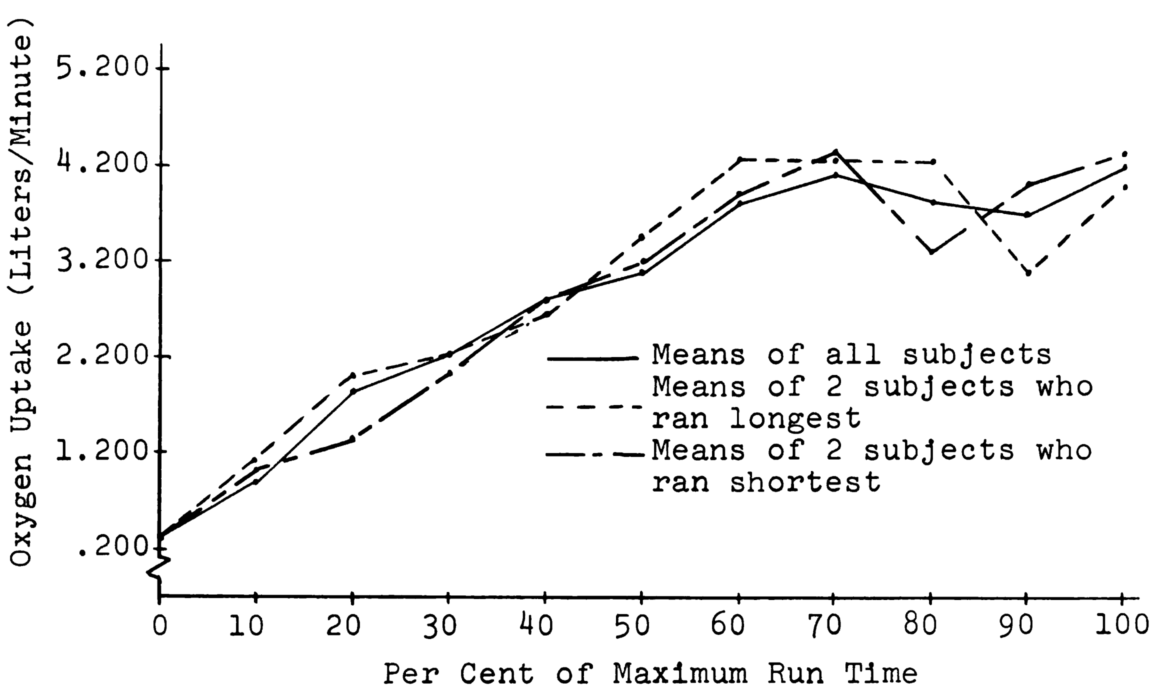

Figure 4.9.--Oxygen uptake for calculated composite run considering means of all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

TABLE 4.10--Recovery oxygen uptake per minute value in liters for 10% run, 50% run, and 100% run.

Recovery Time	Means	Standard Deviation	Recovery Time	Means	Standard Deviation
		10% Run			
15"	1.107	0.333	2'30"	0.366	0.137
30"	1.286	0.338	3'00"	0.290	0.144
45"	1.117	0.091	3'30"	0.209	0.072
1'00"	0.826	0.320	4'00"	0.199	0.072
1'15"	0.608	0.177	4'30"	0.218	0.059
1'30"	0.514	0.114	5'00"	0.245	0.070
1'45"	0.361	0.119	10'00"	0.207	0.074
2'00"	0.273	0.131			
		50% Run			
15"	3.370	0.748	2'30"	0.656	0.250
30"	3.096	0.964	3'00"	0.623	0.258
45"	2.262	0.561	3'30"	0.640	0.122
1'00"	1.511	0.600	4'00"	0.648	0.114
1'15"	1.113	0.321	4'30"	0.559	0.151
1'30"	1.289	0.514	5'00"	0.539	0.057
1'45"	1.215	0.531	10'00"	0.240	0.036
2'00"	0.654	0.260			
		100% Run			
15"	3.400	0.627	2'30"	1.084	0.221
30"	3.026	0.409	3'00"	1.007	0.134
45"	2.556	0.193	3'30"	0.792	0.117
1'00"	1.756	0.284	4'00"	0.745	0.171
1'15"	1.812	0.945	4'30"	0.796	0.073
1'30"	1.080	0.456	5'00"	0.788	0.107
1'45"	1.047	0.275	10'00"	0.495	0.100
2'00"	0.865	0.320			

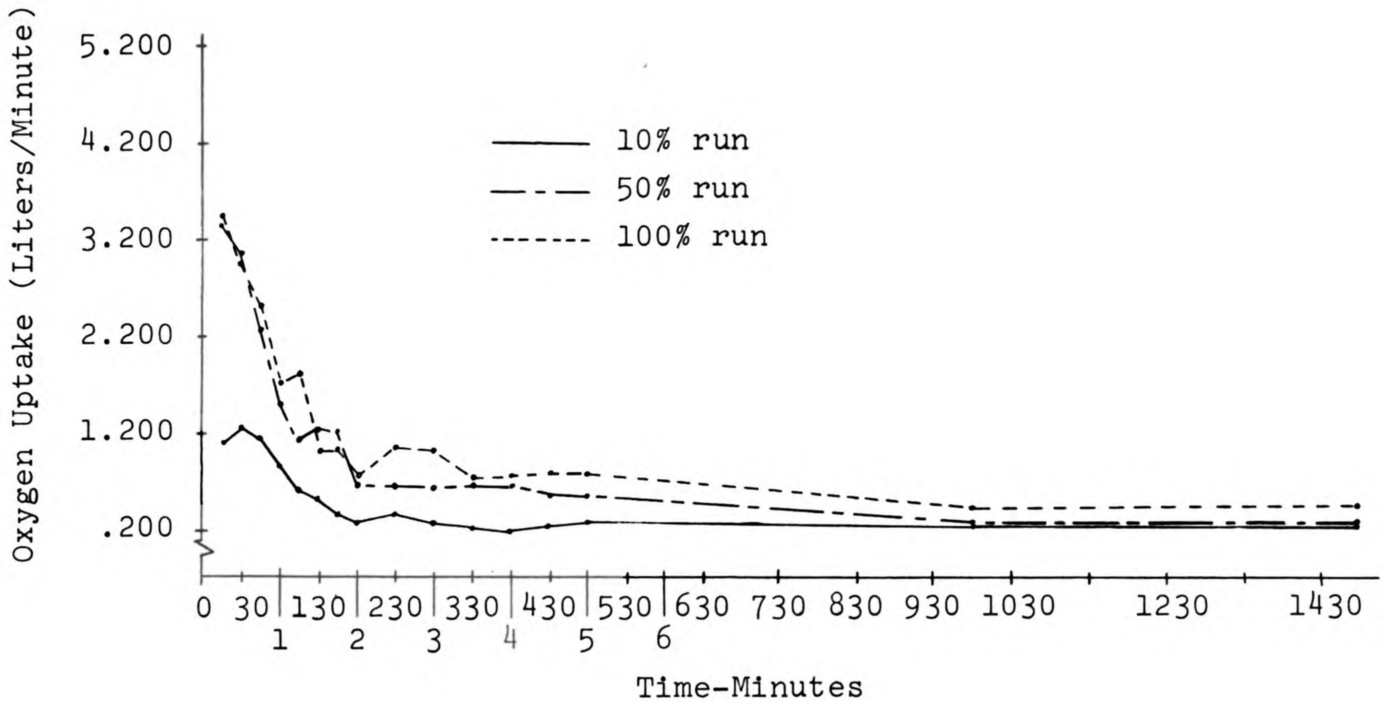

Figure 4.10.--Recovery oxygen uptake for 10% run, 50% run, and 100% run.

TABLE 4.11--Oxygen pulse value for 5-minute rest

Time	Means	Standard Deviation*
1'00"	0.006	
2'00"	0.005	
3'00"	0.005	
4'00"	0.005	
5'00"	0.005	

*Standard deviation was not calculated for oxygen pulse. The means of the resting level, warm-up and 15-minute recovery for heart rate and oxygen uptake were used.

TABLE 4.12--Oxygen pulse value for 5-minute warm-up and 15-minute recovery.

Time	Means	Standard Deviation*
1'00"	0.011	
2'00"	0.013	
3'00"	0.014	
4'00"	0.015	
5'00"	0.013	
15"	0.011	
30"	0.010	
45"	0.011	
1'00"	0.011	
1'15"	0.008	
1'30"	0.004	
1'45"	0.005	
2'00"	0.006	
2'30"	0.004	
3'00"	0.006	
3'30"	0.004	
4'00"	0.005	
4'30"	0.003	
5'00"	0.004	
10'00"	0.003	

*Standard deviation was not calculated for oxygen pulse. The means of the resting level, warm-up and 15-minute recovery for heart rate and oxygen uptake were used.

TABLE 4.13--Oxygen pulse values in ml. for maximum run considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time based on the per cent of maximum run time.

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects who Ran Longest	Means for the two Subjects Ran Shortest
10	0.0129	0.0035	0.0092	0.0129
20	0.0176	0.0041	0.0148	0.0155
30	0.0221	0.0037	0.0214	0.0191
40	0.0241	0.0029	0.0226	0.0229
50	0.0249	0.0026	0.0228	0.0250
60	0.0255	0.0010	0.0242	0.0260
70	0.0250	0.0011	0.0260	0.0247
80	0.0231	0.0009	0.0235	0.0227
90	0.0240	0.0015	0.0237	0.0229
100	0.0231	0.0022	0.0225	0.0228

TABLE 4.4--Oxygen pulse values in ml. for calculated composite run to exhaustion considering all subjects the two who ran the longest time, the two subjects who ran the shortest time based on the per cent of maximum run time

Per Cent	Means for All Subjects	Standard Deviation	Means for the two Subjects Who Ran Longest	Means for the two Subjects Who Ran Shortest
10	0.0090	0.0028	0.0092	0.0117
20	0.0126	0.0074	0.0073	0.0155
30	0.0161	0.0075	0.0145	0.0222
40	0.0194	0.0066	0.0162	0.0234
50	0.0210	0.0042	0.0194	0.0234
60	0.0238	0.0018	0.0249	0.0234
70	0.0213	0.0041	0.0241	0.0142
80	0.0191	0.0033	0.0227	0.0178
90	0.0203	0.0039	0.173	0.0227
100	0.0189	0.0083	0.0225	0.0197

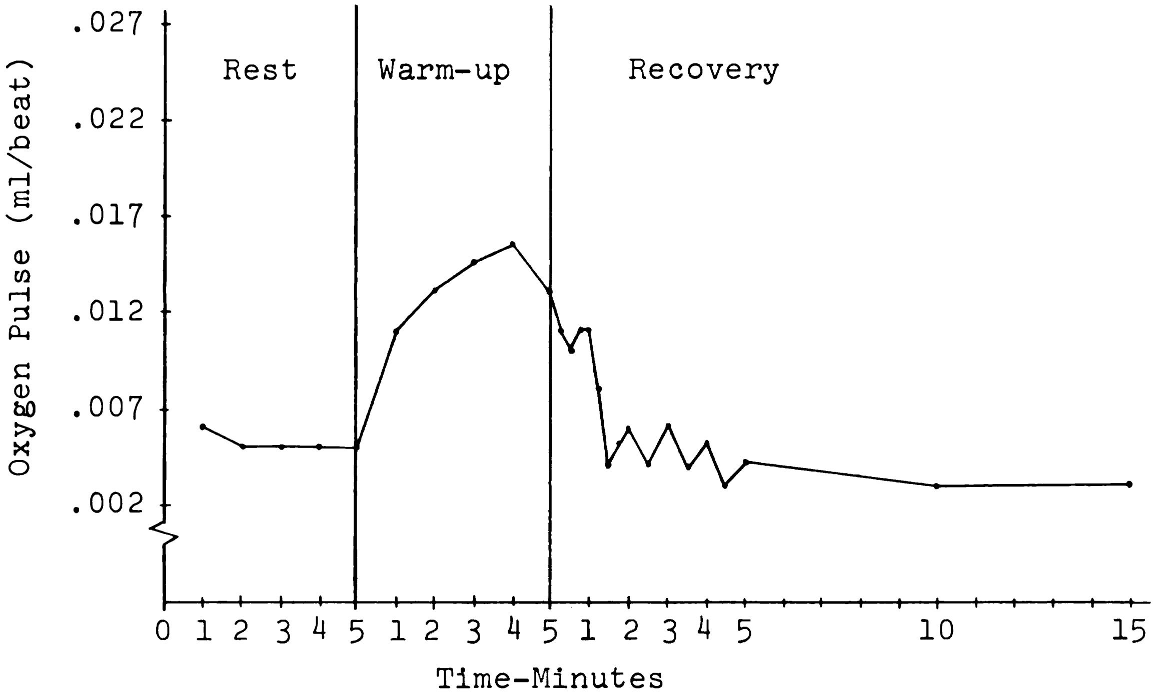

Figure 4.11.--Oxygen pulse value for 5 minute rest, 5 minute warm-up, and 15 minute recovery.

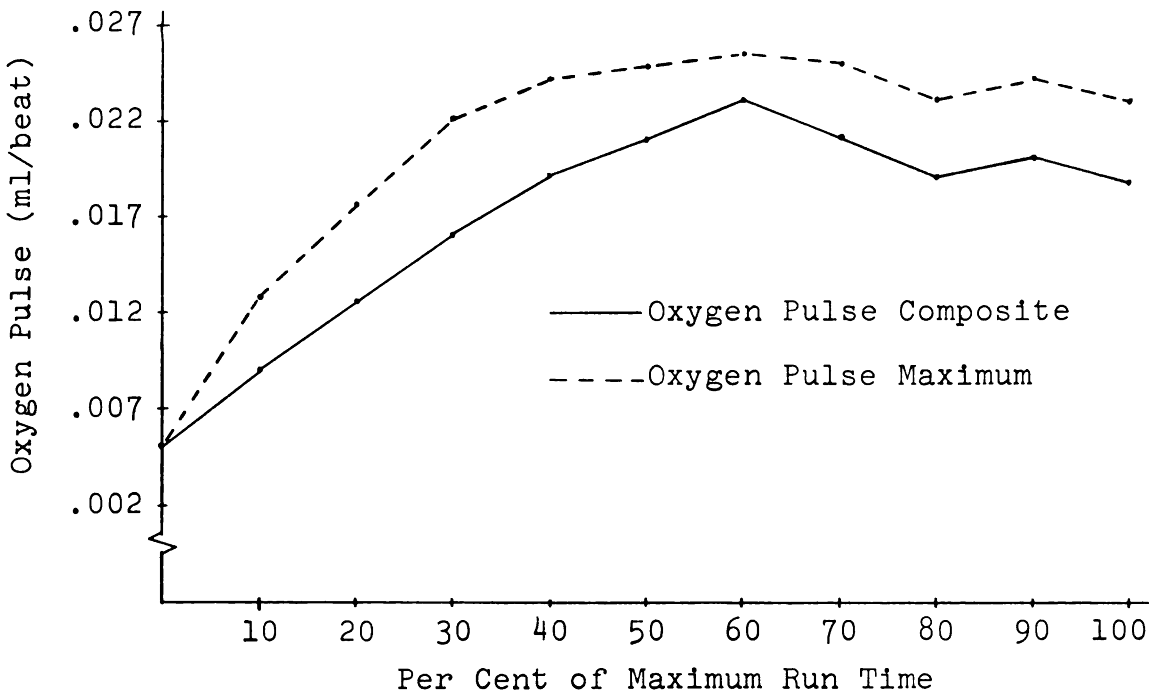

Figure 4.12.--Oxygen pulse for maximum run and for calculated composite run.

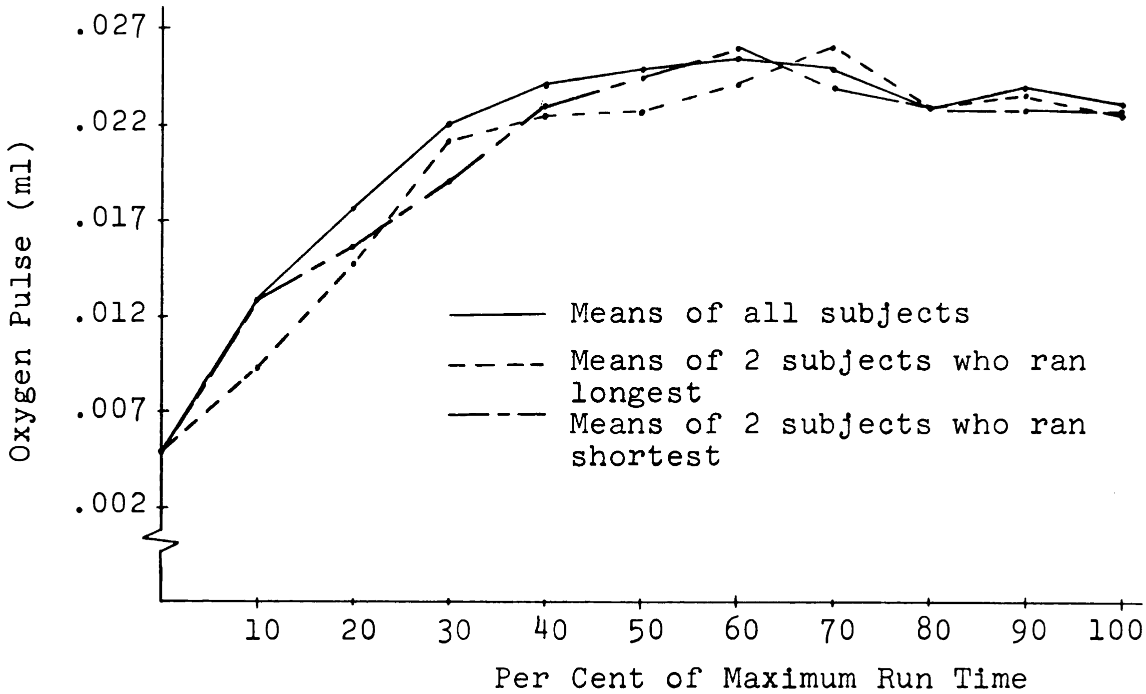

Figure 4.13.--Oxygen pulse for maximum run considering means of all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

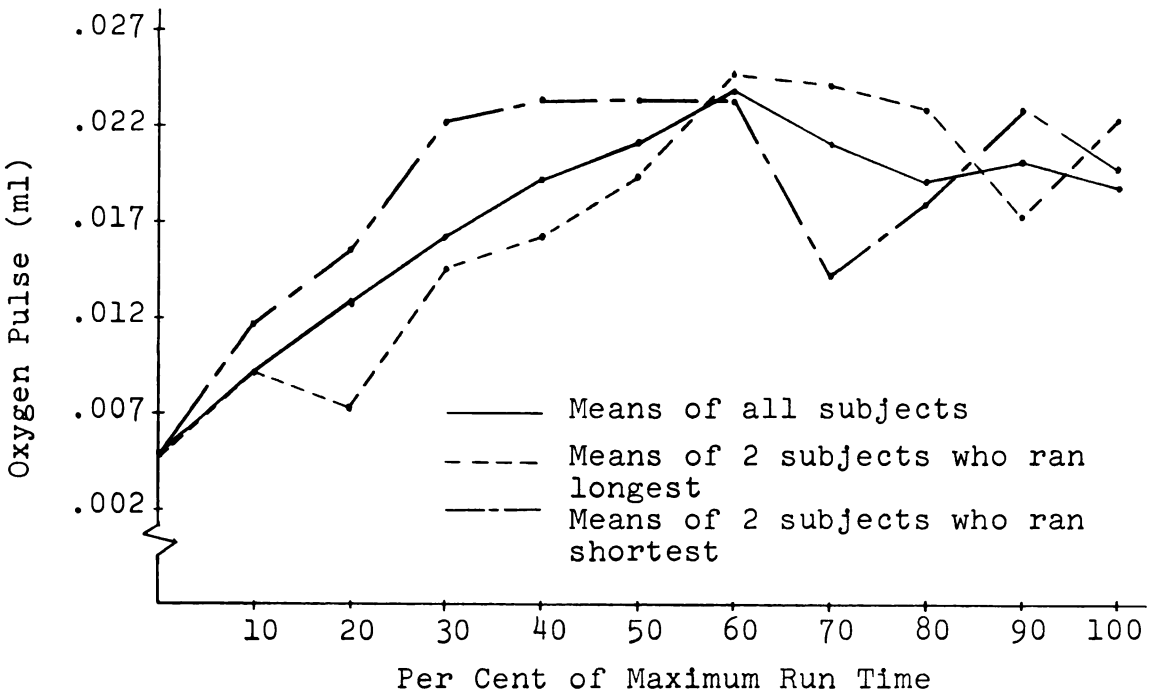

Figure 4.14.--Oxygen pulse for calculated composite run considering means of all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

TABLE 4.15--Recovery oxygen pulse value in ml. for 10% run, 50% run, and 100% run.

Time	Means	Standard Deviation	Time	Means	Standard Deviation
		10% Run			
15"	0.0094	0.0042	2'30"	0.0055	0.0019
30"	0.0116	0.0023	3'00"	0.0045	0.0014
45"	0.0113	0.0012	3'30"	0.0033	0.0009
1'00"	0.0115	0.0029	4'00"	0.0029	0.0008
1'15"	0.0091	0.0022	4'30"	0.0035	0.0009
1'30"	0.0072	0.0024	5'00"	0.0034	0.0010
1'45"	0.0057	0.0022	10'00"	0.0074	0.0085
2'00"	0.0047	0.0027			
		50% Run			
15"	0.0193	0.0038	2'30"	0.0076	0.0031
30"	0.0157	0.0044	3'00"	0.0069	0.0028
45"	0.0147	0.0030	3'30"	0.0071	0.0011
1'00"	0.0116	0.0054	4'00"	0.0078	0.0006
1'15"	0.0129	0.0076	4'30"	0.0065	0.0006
1'30"	0.0166	0.0078	5'00"	0.0053	0.0013
1'45"	0.0132	0.0068	10'00"	0.0097	0.0095
2'00"	0.0068	0.0037			
		100% Run			
15"	0.0179	0.0030	2'30"	0.0094	0.0016
30"	0.0168	0.0020	3'00"	0.0079	0.0008
45"	0.0142	0.0022	3'30"	0.0069	0.0013
1'00"	0.0113	0.0015	4'00"	0.0073	0.0018
1'15"	0.0117	0.0062	4'30"	0.0078	0.0011
1'30"	0.0071	0.0029	5'00"	0.0062	0.0016
1'45"	0.0073	0.0022	10'00"	0.0068	0.0033
2'00"	0.0073	0.0027			

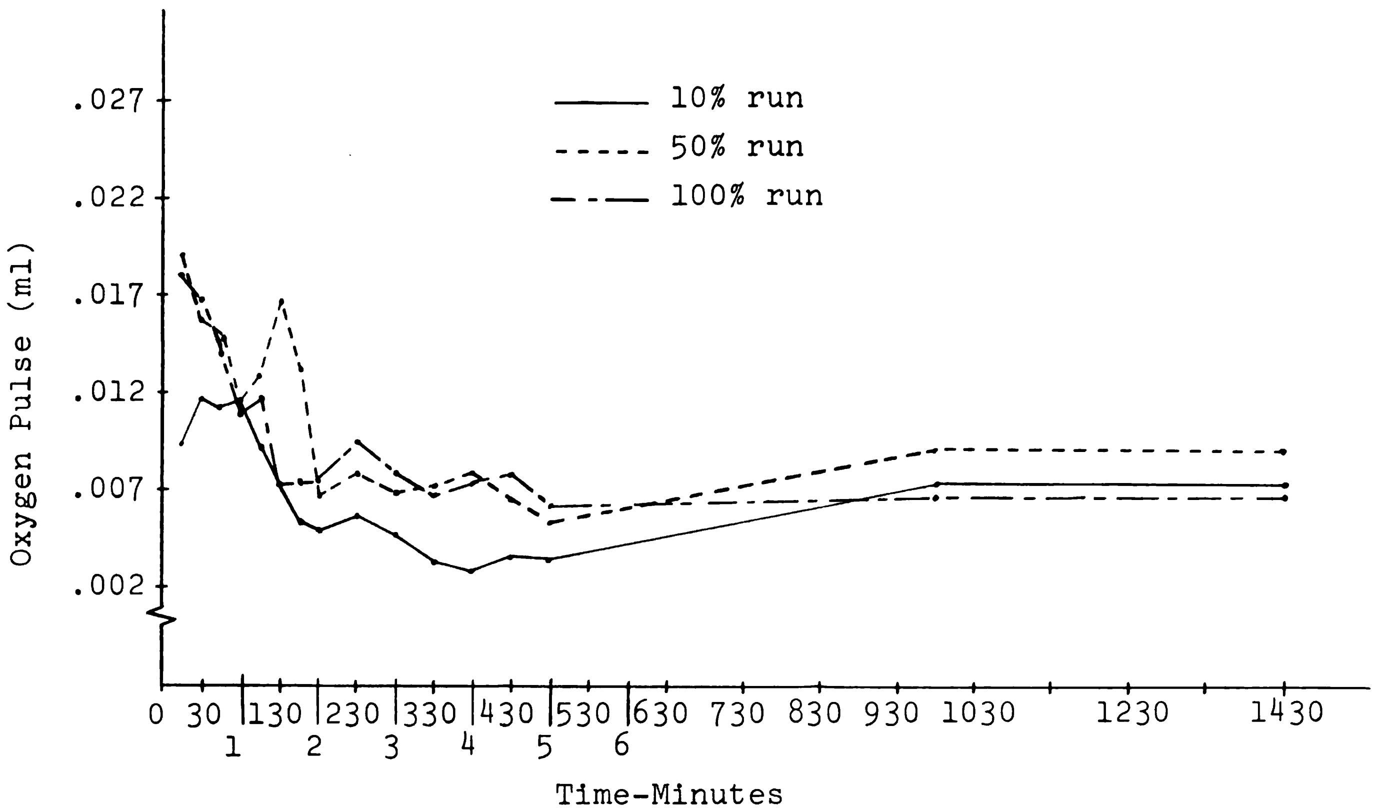

Figure 4.15.--Recovery oxygen pulse for 10% run, 50% run, and 100% run.

TABLE 4.16--The mean rate of net oxygen debt accumulation for the calculated composite run (oxygen debt in liters per minute divided by the per cent of maximum run) considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time.

Per Cent	Means of All Subjects	Means of the Subjects Who Ran Longest	Means of the two Subjects Who Ran Shortest
10	5.300	6.180	4.000
20	12.465	15.680	13.530
30	8.630	10.570	9.953
40	9.620	10.972	11.305
50	6.272	6.112	7.884
60	8.571	10.441	8.826
70	7.847	8.491	9.605
80	7.862	8.621	8.117
90	6.984	6.885	7.063
100	5.813	5.834	5.327

TABLE 4.17--The mean net oxygen debt in liters during the calculated composite run considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time.

Per Cent	Means of All Subjects	Means of the Subjects Who Ran Longest	Means of the two Subjects Who Ran Shortest
10	0.895	1.491	0.826
20	3.006	3.262	3.266
30	3.397	3.293	3.588
40	4.627	4.316	5.100
50	5.002	5.057	5.185
60	6.928	6.166	5.938
70	7.276	6.753	6.082
80	7.196	7.100	6.606
90	7.208	7.646	6.642
100	7.197	7.835	6.670

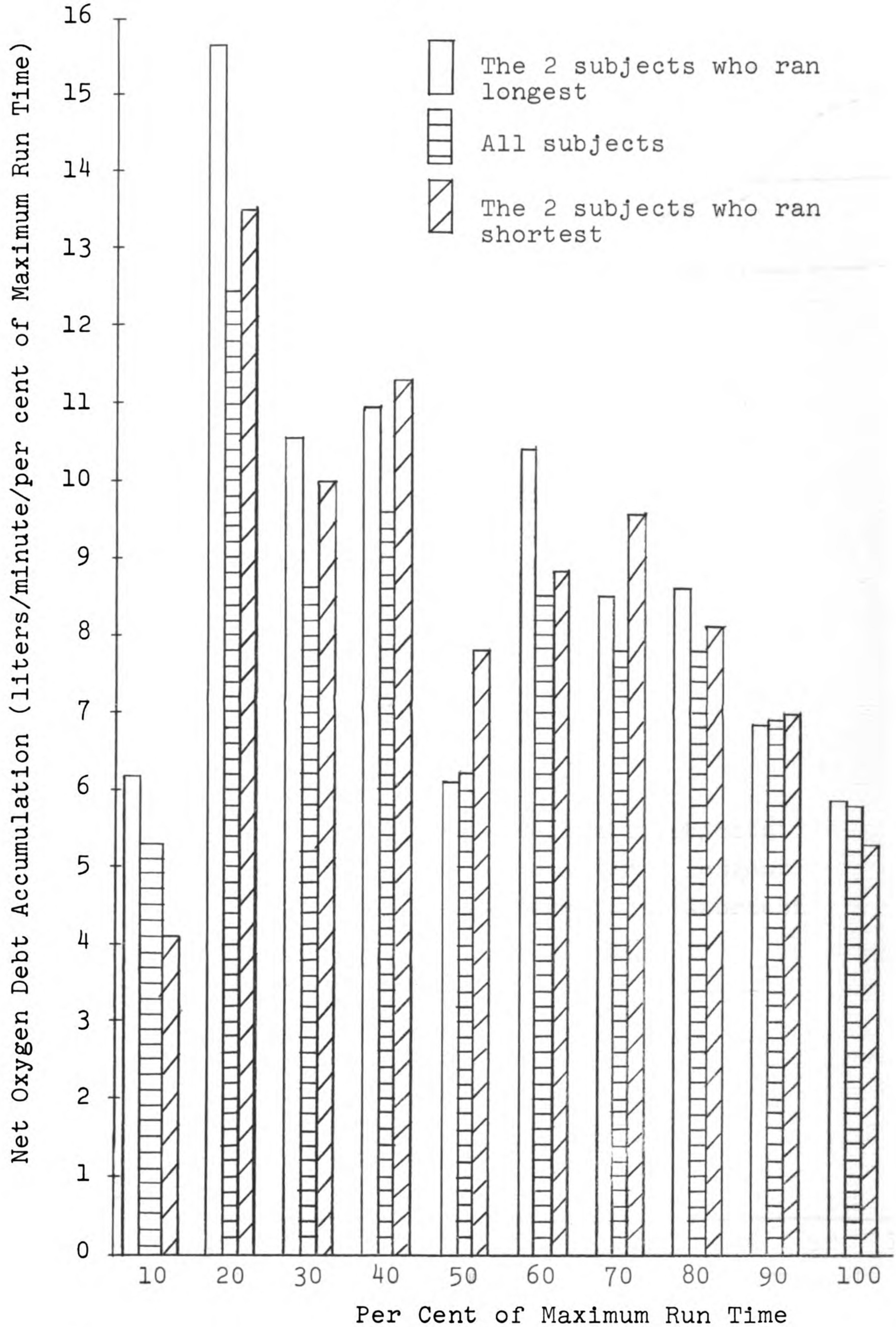

Figure 4.16.--Mean rate of net oxygen debt accumulation for calculated composite run in (Oxygen debt in liters per minute divided by per cent of maximum run time) considering all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

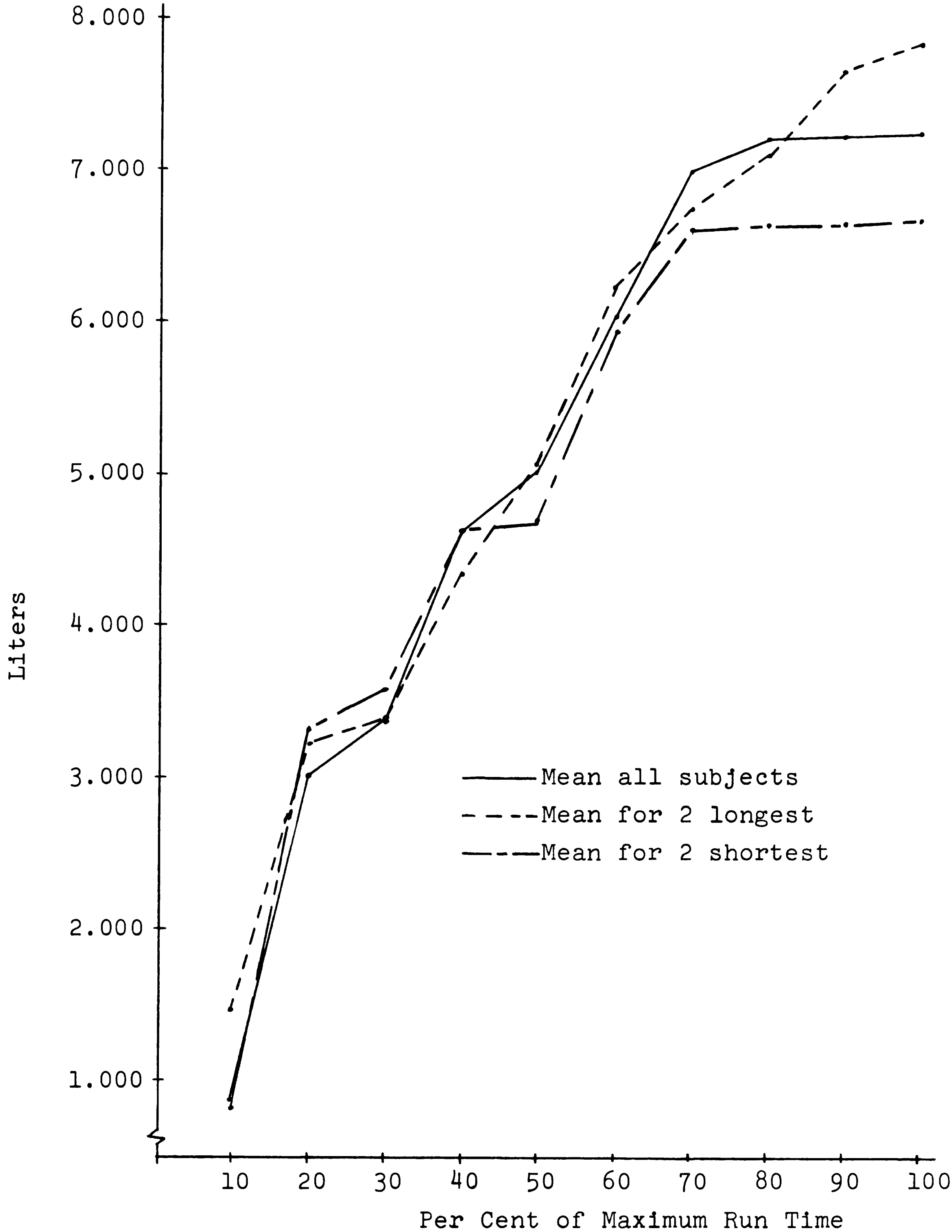

Figure 4.17.--Mean net oxygen debt accumulation in liters during calculated composite run.

TABLE 4.18--The mean rate of oxygen requirement in liters per minute during the calculated composite run considering all subjects, the two subjects who ran the longest time, the two subjects who ran the shortest time.

Per Cent	Means of All Subjects	Means of the Two Subjects Who Ran Longest	Means of the Two Subjects Who Ran Shortest
10	0.984	1.123	1.053
20	4.377	5.231	4.095
30	4.825	5.454	5.058
40	6.687	7.086	7.387
50	6.324	6.468	7.170
60	8.989	10.558	9.212
70	9.604	10.208	11.059
80	10.032	11.175	9.858
90	9.928	9.316	10.386
100	10.084	9.924	9.668

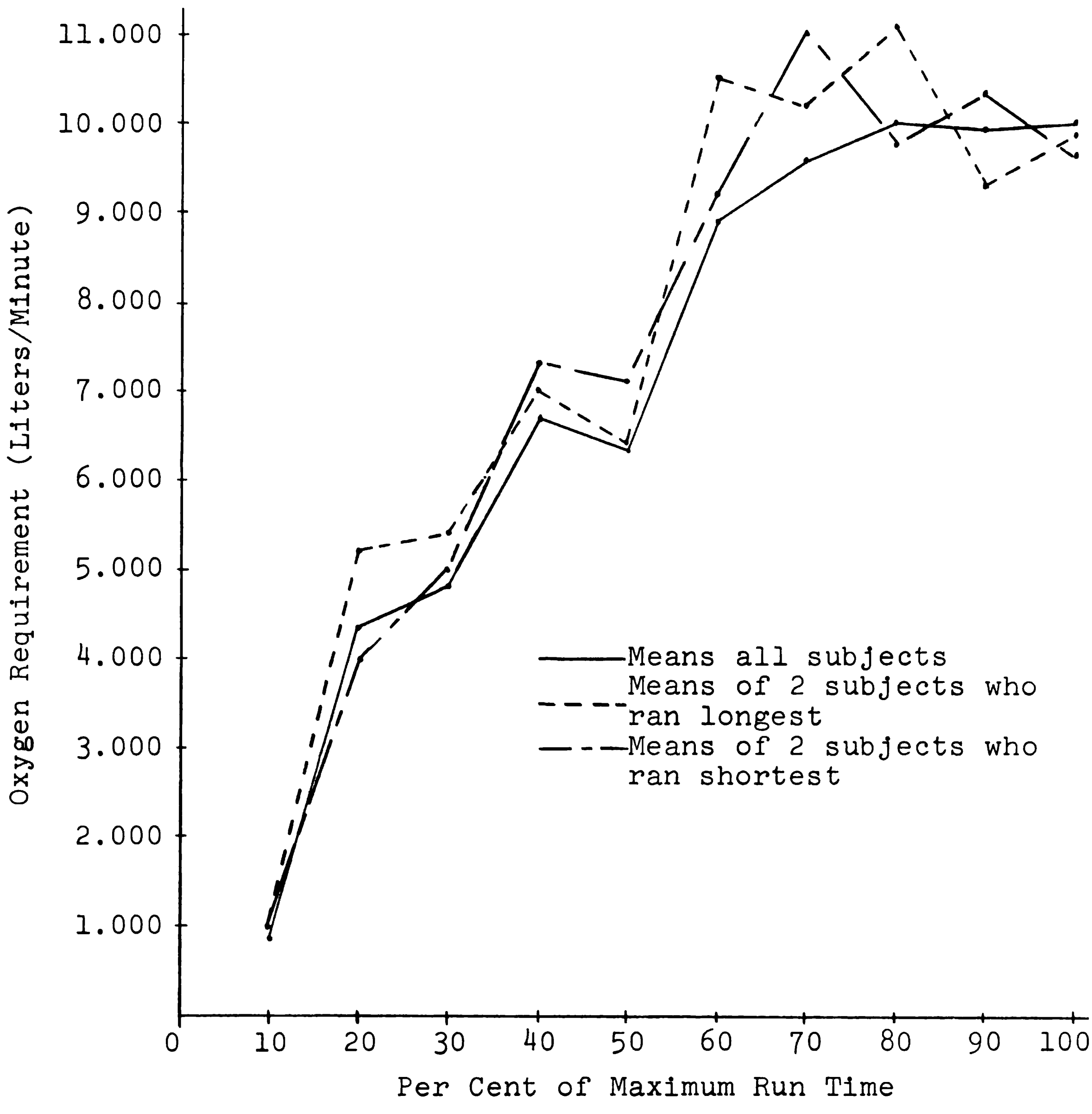

Figure 4.18.--Oxygen requirement in liters per minute considering means fo all subjects, the 2 subjects who ran longest, the 2 subjects who ran shortest.

Discussion

The results presented in Figure 4.2 and Table 4.5 indicate that the mean heart rate values increased rapidly for 30 percent of the maximum run and for 40 percent of the calculated composite run and slowly continued to increase to values of 184.8 beats per minute as the runners became exhausted. The heart rate did not reach an absolute steady state, but continued a slow upward drift with several minor fluctuations. Of particular interest was the slight increase observed between 70 and 90 percent of maximum run time for the exhaustive or maximal run. Karpovich [10] has mentioned that the greatest rise in heart rate occurs within the first 15 seconds and continues to rise for the next 45 seconds of exercise. A plateau is then reached or an occasional secondary rise may be observed when the exercise is intensive.

Mean heart rate data of the maximal run for all subjects, as well as for the two subjects who ran the longest time and the two subjects who ran for the shortest periods of time were compared. The two subjects who ran the longest period of time had the most rapid increase in heart rate during the first 20 percent of the maximum run. The two subjects who ran the longest period of time also had the highest mean heart rate until the 70 per cent level of maximum run time was reached. From the 70 percent level of maximum run time until exhaustion, the two subjects who ran the longest had a lower mean heart rate than the other two comparison groups. The two subjects who ran the shortest period of time displayed a more gradual rise in mean heart rate which surpassed and remained above the mean heart rate of the other two groups. This finding is indicated by the data for the 60 and 70 percent levels of the maximum run time.

Heart rate values for the calculated composite run, considering the mean heart rate of the same three groups, demonstrated the same general characteristics as the mean heart rate for the maximum run. However, two exceptions were observed. First, the differences between the heart rate values observed during the rapid increase phase occurred during the first 40 percent of the composite run time and were not as pronounced as those differences observed during the same period of the maximal run. Second, the changes which occurred between the 60 and 70 percent levels of the maximum run occurred between the 40 to 60 percent levels of the calculated composite run.

The results of the heart rate recovery data indicated that an increase in effort by the runners also increased the time required for the heart rate to return to the resting level. In fact, the mean heart rates at both the 50 and 100 percent levels of maximum run time never returned to the resting level in the standard 15-minute recovery period. Figure 4.5 shows that the mean heart rate at the 10 percent level of maximum run time almost returned to the resting level, but the mean heart rates for the 50 percent and 100 percent level of maximum run time were above the mean resting values by 29.7 and 43.0 beats per minute, respectively. Data collected by Brouha and Radford [9:198] dealing with severe work, tend to confirm these recovery results and show that at the end of a 25-minute recovery period the heart rate was 20-25 beats per minute higher than the resting rate. Karpovich [10] has indicated that in many instances after severe exercise the heart rate did not return to the resting level even after one or two hours of rest. It is also interesting to note that the extent to which the heart rate fails to return to the resting rate within the 15-minute recovery period appears to be related to the size of oxygen debt incurred.

Oxygen uptake was used to determine the volume of oxygen utilized per minute by the body for all run and recovery periods. This variable was also the basis for oxygen debt calculations. The data presented in Figure 4.7 and Tables 4.8 and 4.9 indicated that the mean oxygen uptake in liters per minute increased gradually until the 70 percent level of both the maximum run and the calculated composite run. At this point, the mean values of the maximum run slightly decreased and leveled off when an apparent limit had been reached at values between 4.424 and 4.272 liters per minute. This is similar to the trend reported by Taylor [9]. The mean oxygen uptake for the calculated composite run also decreased, but continued to do so until the 90 percent level of run time when the value increased from 3.642 to 4.272 leters per minute. It should be pointed out that the mean oxygen uptake for the maximum run was higher than the mean oxygen uptake for the calculated composite run except in one instance and that occurring at the 20 percent level. This observation indicated that the oxygen uptake level is dependent on the intensity of the given task, the maximum run being much more severe in nature than the series of runs used to make up the composite run.

Mean maximum run oxygen uptake data (Figure 4.8 and Table 4.8) for all subjects, as well as for the two subjects who ran the longest and the two subjects who ran the shortest periods of time were compared. In general, the two subjects who ran the longest period of time increased their rate of oxygen uptake more quickly than the others. The mean oxygen uptake values for the same two subjects were higher than the mean values for the other groups except at the 100 percent level of maximum run time. Here the mean value was the lowest of the three comparison groups.

Mean oxygen uptake data for the calculated composite run (Figure 4.9) for all subjects as well as for the two subjects who ran the longest time and the two subjects who ran the shortest periods of time, indicated the same general pattern as was evident for the maximum run, with two exceptions. In the first instance, the differences between the mean values of oxygen uptake of the three comparison groups was less pronounced for the 10 to 50 percent level of maximum run time during the calculated composite run than during the maximum run. In the second instance, there was a greater fluctuation in mean oxygen uptake between the 70 and 100 percent level of the calculated compostie run than was observed during the same period of maximum run. Again, the greater effort required for the maximum or exhaustive run was evident.

The recovery data indicated that the mean oxygen uptake decreased in relation to the intensity of the effort and the time of the runs (Figure 4.10). This observation agreed with the findings of Dill [3, 4] and Karpovich [10]. This trend also indicated that the recovery oxygen uptake is related to the size of oxygen debt incurred during strenuous exercise.

The oxygen pulse, the amount of oxygen being supplied to the body with each heart beat, increased during the first 60 percent of the maximum run and the composite run. (Refer to Figure 4.12 and Tables 4.13 and 4.14). This was due to an increase in heart rate, oxygen uptake and cardiac output. As the runners became exhausted, a further acceleration of heart rate was observed along with a leveling off, and in some instances, a decrease of oxygen uptake. Consequently, the oxygen pulse decreased. Of particular importance is the higher mean oxygen pulse for the maximum run compared to the calculated composite run. Current literature (6, 9, 10) supports the observed result that as the heart rate increases the stroke volume also increases until a limit in output per beat is reached. Then, the heart becomes inefficient in copint with the severe stress and the output per heart beat decreases as the heart rate continues to increase. Thus, while the oxygen uptake remained relatively stable the oxygen pulse diminished.

The mean oxygen pulse data of the maximum run (Figure 4.14) for all subjects, as well as for the two subjects who ran the longest period of time and the two subjects who ran the shortest period of time were generally consistent with the other findings. However, the two subjects who ran the longest and the two subjects who ran the shortest periods of time were generally below the mean values of all subjects.

The oxygen pulse data for the calculated composite run generally followed the results presented for the maximum run. This is a difficult interpretation to make, in view of the erratic fluctuations observed in the data (Figure 4.14).

Oxygen pulse data collected during the recovery period (Figure 4.15) was also erratic. However, the results generally reflected the recovery of heart rate and oxygen uptake as they began to function in an efficient manner during recovery.

The oxygen debt, which is the amount of oxygen uptake measured during the standard recovery period in excess of the amount of oxygen uptake reocrded during the same period of time at the resting level, was examined in two ways. The first approach involved the study of the mean rate of net oxygen debt accumulation for the calculated composite run measured in liters per minute divided by the percent of maximum run time. The second approach used the mean net values of oxygen debt accumulation measured in liters during the calculated composite run. Both methods of analysis involved the mean net values of all subjects, the two subjects who ran the longest period of time, and the two subjects who ran the shortest period of time.

The first method of determining oxygen debt (Figure 4.16) indicated that from the 20 percent level to the 40 percent level of maximum run time a large amount of oxygen debt was accumulated, probably due to the fact that the alactacid debt was accumulated at a much faster rate than the lactacid debt as indicated by the more gradual decline in mean net values observed from the 60 to 100 percent level of maximum run time. This early accumulation of oxygen debt would be due in part to a circulatory lag at the beginning of the exercise periods. During recovery, the oxygen debt thus accumulated was paid off rapidly as the alactacid portion of oxygen debt as defined by Hill et al. [7].

By observing the mean net values of oxygen debt accumulation measured in liters for the composite run for all groups (Figure 4.17), three trends were noted: (a) during the early stages of the run until the 40 percent level of maximum run time a rapid accumulation of oxygen debt was found,

(b) a less rapid rise in oxygen debt accumulation continued from the 40 to 70 percent level for all subjects, (c) as exhaustion was reached, a leveling off of values occurred except for the two subjects who ran the longest period of time. Trends (a) and (c) describe the two observable portions of oxygen debt as mentioned in the literature [3, 4, 11, 13, 14]. Trend (b) may be the result of the ability of the circulatory and respiratory systems to adjust temporarily to this particular stress as noticed in the slight rise of heart rate and oxygen uptake tetween the 40 and 70 percent levesl of the maximum run time. The patterns observed for two of the three groups from the 70 to 100 percent levels of the maximum run time illustrate the inability of the subjects to efficiently meet the exhaustive stress. The two subjects who ran the longest appeared to never reach the plateau observed with the other groups.

The total amount of oxygen uptake observed during the calculated composite run in excess of the resting level is what Hill [7] termed oxygen requirement or cost of exercise. Figure (4.18) shows the oxygen requirement in liters per minute for the three comparison groups. It is interesting to note that as individuals reached exhaustion, the oxygen requirement increased to a value nearly 50 percent higher than that found during the earlier stages of the run. The pattern of oxygen requirement shows that the requirement increases as the duration or stress of the exercise period increases.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the pattern of oxygen debt accumulation with trained varsity athletes during an exhaustive run up a 9 degree grade at 10 m.p.h. on a motor-driven treadmill. Heart rate, oxygen uptake, and oxygen pulse were also studied.

Six trained Michigan State University varsity athletes ranging in age from 19 to 21 years each ran a different random sequence of tests of which one was to exhaustion (refer to Table 3.1). Each subject's maximum run was considered to be his 100 percent effort. Computation of 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent levels were found for the exhaustive as well as the calculated composite run.

At the conclusion of each test run a standard 15-minute recovery period was used. Only the 10, 50, and 100 percent values of maximum run time recovery periods were used in this study for heart rate, oxygen uptake, and oxygen pulse. Oxygen debt accumulation, however, was found and based on the recovery periods of all oxygen uptake tests.

The means and standard deviations of each variable, where appropriate, were used to describe the results.

Heart rate values increased rapidly during the first 30 percent and 40 percent of maximum run time for both the exhaustive run and the calculated composite run. Both values slowly continued to increase until exhaustion at the 100 percent level of maximum run time. Slight fluctuations occurred in values obtained for the two subjects who ran the longest period of time and for the two subjects who ran the shortest period of time. Of particular interest was the lower mean heart rate value observed during the early stages of the run for the two subjects who ran the shortest period of time and with the mean values for all subjects. However, from approximately the 70 percent level of maximum run time, the two subjects who ran the shortest period of time had a higher mean heart rate than the other two comparison groups. The recovery data indicated that as the run became more intense a longer period of time was necessary in order for the heart rate to return to its normal resting level.

Oxygen uptake increased steadily until the 70 percent level of maximum run time for both the exhaustive and calculated composite runs. At this point an apparent limit had been reached. The maximum run values decreased and leveled off. The calculated composite values here decreased gradually until the 90 percent level where an increase was observed. All values for the maximum run were higher than those obtained from the calculated composite run except at the 100 percent level where they were the same. Oxygen uptake values for the two subjects who ran the longest period of time and the two subjects who ran the shortest period of time followed a pattern of progression very similar to the mean values of all subjects. The same may be said for the calculated composite run until the 70 percent level of maximum run time after which a great deal of fluctuation was observed. During the recovery period, the values decreased in a manner which suggested that greater efforts produced a correspondingly slower recovery time as well as a larger accumulation of oxygen debt.

Oxygen pulse values increased during the first 60 percent of maximum run time for both the exhaustive and calculated composite runs. Thereafter, a gradual decrease was noted until exhaustion. As was found with the oxygen uptake data, oxygen pulse values for the exhaustive run were higher than the values obtained for the calculated composite run. When the values of the two subjects who ran the longest period of time were compared with the subjects who ran the shortest period of time for the exhaustive run a very small difference was observed. However, this was not the case for the calculated composite run. Here the values fluctuated so much for the two subjects who ran the longest and shortest periods of time that only very general interpretations in terms of mean values for all subjects could be made. During the standard 15-minute recovery period, the values returned to a level which was slightly above the resting level. This indicated that oxygen pulse is also dependent on the intensity of the performance and on the size of the oxygen debt accumulation.

Analyzing the oxygen debt accumulation revealed that during the first 40 percent of the maximum run time a fairly rapid rise in accumulation occurred. From the 40 to 70 percent level, a less rapid rise was observed followed by a general leveling off in accumulation until exhaustion was reached. This early rapid rise was referred to as the alactacid oxygen debt. The later less rapid rise was referred to as the lactacid oxygen debt [7].

The oxygen requirement increased with an increase in the time of the exercise.

Conclusions

1. The results of this study indicate that the heart rate, oxygen uptake, and oxygen pulse are related to the rate and size of the accumulation of oxygen debt during an exhaustive run.

2. A rapid early rise followed by a slight temporary adjustment and another not-so-rapid rise seemed to reflect the pattern of oxygen debt accumulation in terms of the intensity of the exercise. Alactacid oxygen debt and lactacid oxygen debt may well be illustrated by the two increases in the total oxygen debt accumulation.

3. When the two subjects who ran the longest and the two subjects who ran the shortest periods of time were included, individual contributing differences were noted which limited the specific conclusions.

Recommendations

Future research concerned with oxygen debt accumulation using the exhaustive run and calculated composite run techniques should be directed along the following line:

1. Research should be undertaken which would allow for repetition fo run sequences.

2. Research should be undertaken which would study the relationships between metabolic factors such as lactate levels.

3. Research should be undertaken which would expand and possibly modify the technique of using a percent value of maximum run time to calculate the progressive changes which develop during an exhaustive or maximal run.

4. A larger, more random sample should be used.

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LITERATURE CITED

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