THE VALIDITY OF WORKLOADS AT 180 AND 190 HEART RATE AS PREDICTORS OF MAXIMAL OXYGEN CONSUMPTION OF ENDURANCE TRAINED FEMALE COLLEGE ATHLETES

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CHAPTER I

INTRODUCTION

The populace of the United States has recently witnessed a rapid increase in the number of physical activities pursued by girls and women. The growing interest in girl's athletics fostered the passage of the equal rights laws culminating with the famous Title IX of the Education Amendments of 1972. The law states:

> No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving federal financial assistance (1, p. 223).

Title IX purports to equalize opportunities between males and females who participate in school sponsored activities. It does not imply that women are the same as men, either socially or physiologically. The woman athlete was not unique to the sport world before 1972; however, Title IX "opened the doors" for the national growth of women's athletic programs. Teachers, coaches, parents, and sports enthusiasts found themselves striving to put women on a sociological, psychological, and physiological "even keel" with the men.

Measurement of physiological variables of the resting and exercising homo sapiens has been the subject of interest to many researchers. Until recently, most of this research has been done on males. The literature is replete with studies of the physiological and psychological changes that occur in the male as he ages, exercises, smokes, eats, drinks and sleeps. The exercising man has been studied with respect to every biophysical consideration that present exercise physiologists can accurately measure and in every sport or physical activity imaginable. Unfortunately, much of the research on physical performance that has enhanced the success of the male athlete has not been attempted for the women.

Many different physiological measures have been established as important for evaluating an individual with respect to physical capacities. Physical fitness, a somewhat intangible term, appears to be a combination of different components. Flexibility, strength, speed, agility, balance and endurance appear to be important variables when assessing fitness (2). Cardio-respiratory fitness, which is the ability of the heart, lungs, and vascular systems to supply oxygen to the tissues of the body, seems to be the major component of physical fitness (3). Thus, the capacity of the individual to consume oxygen will depend upon pulmonary ventilation, pulmonary diffusing capacity, blood carrying capacity, blood flow, tissue diffusing capacity, and the rate of oxygen utilization by the tissues (4).

Drinkwater (5) has stated that the best single measure of cardiovascular-respiratory fitness is maximal oxygen uptake; however, she argues that it is not a measure of physical fitness. This has been substantiated by a host of other researchers (4, 6, 7, 8). Mitchell, et al. (7) defined maximum oxygen intake (maximum oxygen consumption, VO_2max) as the point when oxygen intake per unit time has attained its maximum and remains constant owing to the limitations of the circulatory and respiratory systems. Balke and Ware (8) cited maximal oxygen consumption as the most objective criterion of work capacity.

Knuttgen (4) implied that maximum oxygen consumption is reached aerobically, and when the available oxygen transported to the tissue has been utilized, the individual goes into an anaerobic state. Throughout the literature, one finds maximum oxygen consumption to be the most frequently used measure to assess cardiovascular endurance, aerobic capacity, physical work capacity, and physical fitness (2, 3, 4, 6, 7, 8, 9).

The linear relationship that exists between oxygen intake and workload has been reported in many studies (8, 10, 11). Knowledge of the regression of oxygen consumption (VO_2) on heart rate permits an estimation of VO_2max from extrapolation of a line from a submaximal heart rate to a maximal heart rate (12). The development of regression equations for predictions of maximal oxygen consumption from submaximal heart rates led to the development of submaximal tests. In these tests, a subject does not have to work to exhaustion for a prediction of maximal work capacity. Balke and Ware (8) have constructed a regression line for data collected from these types of submaximal tests. See Appendix B.

Balke and Ware (8) added depth to the field of assessing work capacities when they experimented with 500 Air Force personnel using submaximal tests to predict maximal oxygen intake. The study validated the value of 180 beats per minute heart rate as a cut-off point for maximum oxygen intake. It was observed that, even though the work capacity usually reached well beyond that point, work was becoming increasingly anaerobic. Nagle and Bedecki (13) tested 44 male subjects in a later study and re-verified the use of 180 heart rate as a cut-off point. These studies, however, were done on males, and did not necessarily suggest that 180 heart rate would be a valid cut-off point for females. Dr. Ken Cooper, who popularized the concept of maximal oxygen consumption in his book, Aerobics, supported his assertions with research done on male volunteers (9). Although he constructed programs for women he did not accumulate sufficient data to produce their equivalent maximum oxygen consumptions. The maximal oxygen consumption regression line developed from Balke and Ware's research has been used in many laboratories to predict VO_2max from work capacity tests. This appears to result in an underestimation when used to predict maximal oxygen consumption for female subjects. Unpublished research in the Oklahoma State University human performance laboratory under the direction of Dr. A. B. Harrison has shown that when actual maximal oxygen intakes were calculated for females, they ranged from 20 to 25 per cent lower than those predicted by the Balke regression line. The values for women approached those for men only when the women were highly trained endurance athletes.

Current observations and recent research lead this author to believe that the female in general tends to reach maximum oxygen consumption at a heart rate higher than the value established for men. Even the woman athlete, though highly trained, may exhibit a tendency to reach higher heart rates than those predicted for highly trained male subjects. Therefore, the author believed it would be valuable to investigate the possibility of using a higher heart rate as a predictor of VO_2max in women athletes from Balke's established regression line.

Statement of the Problem

The purpose of this study was to determine the validity of work-loads at 180 and 190 heart rate as predictors of maximum oxygen consumption of endurance trained female college athletes.

Hypotheses

1. There will be a high correlation (.7 or better will be accepted) between time to reach 180 heart rate on the treadmill and maximum oxygen consumption.
2. There will be a high correlation (.7 or better will be accepted) between time to reach 190 heart rate on the treadmill and maximum oxygen consumption.
3. There will be no significant difference in maximum oxygen consumption between participants of different sports. Significance will be accepted at the .05 level of confidence.

Subproblems

1. To relate maximum oxygen consumption of women athletes to those predicted by the regression line developed by Balke for men.
2. To relate maximum oxygen consumption of women athletes to those predicted by adjusting the Balke regression line values by adding 25 per cent as a sex correction for women.
3. To compare scores of Oklahoma State University women athletes to those previously reported for women athletes.

4. To compare mean scores of basketball, track, swimming, and field hockey athletes with respect to maximal heart rates, maximum oxygen consumption, and maximum elevation achieved on the treadmill.

Limitations and Delimitations

1. Only Oklahoma State University women athletes from field hockey, basketball, swimming and track were used as subjects.
2. Seven of 10 volunteers were chosen from each sport, thus a true random sample was not obtained.
3. The researcher was not able to regulate the subjects' diet or activity prior to the test, except to request that the subject refrain from eating for three to four hours prior to testing and to limit vigorous activity for 24 hours prior to testing.

Assumptions

1. All subjects were assumed to be in good health and excellent physical condition.
2. All subjects were assumed to be endurance trained athletes as reflected by their participation in endurance sports.
3. The subjects were assumed to perform the all-out exercise to the maximum of their ability.
4. All subjects were assumed to have equal motivation, and the motivation produced valid data for all-out exercise.

Significance of the Study

The literature showed a limited amount of research on maximum oxygen consumption for females. This research has shown values for some groups of female athletes; however, it did not provide sufficient measurements for determining cardiorespiratory fitness of women athletes. This study was an attempt to complement the scarcity of information on maximal oxygen consumption for women. Until more research in this area has been undertaken, data on variables of women's fitness will continue to be inconclusive.

Definitions of Terms

1. Maximum oxygen consumption (VO_2max) - the maximal amount of oxygen that an individual can consume, generally reported in ml/kg/min.
2. Aerobic capacity - used synonymously with maximum oxygen consumption.
3. Cardiorespiratory fitness - the ability of the heart, lungs, and vascular systems to supply oxygen to the tissues of the body.
4. Physical Work Capacity (PWC) - the maximum level of work of which an individual is capable, usually expressed as amount of time to reach a predetermined heart rate, workload used, or in METS.
5. Aerobic - the process by which energy is expended in the presence of oxygen.
6. Anaerobic - the process by which energy is expended in the absence of oxygen.
7. Cardiorespiratory endurance - the capability of the body to perform work over extended periods of time.

8. Endurance trained athlete - an athlete whose main form of training includes overloading the aerobic system of the body, therefore increasing aerobic capacity.

9. Leveling off - the tendency of a physiological variable to approach equilibrium, neither rising nor falling.

10. Regression line - used to predict maximal work capacities from submaximal tests.

11. Nomogram - a graph that enables one to find the value of a dependent variable when two or more independent variables are known.

12. EKG (ECG) - Electrocardiography or a record of the electrical potential of the heart.

13. Submaximal work test - a work capacity test in which the subject does not have to work to exhaustion but to a predetermined workload or intensity.

14. Maximal work test - a work capacity test in which the subject must work to exhaustion at progressively increasing workloads. This is used to obtain actual values for maximum oxygen consumption.

15. Ml/kg/min - milliliter per kilogram of body weight per minute, the preferred unit for expressing maximal oxygen intake since it eliminates the factor of body size.

Description of Instruments

1. Physiograph - a multi-channel ink-writing recorder used to monitor and record heart rate during test, work and recovery (Narco Biosystems, Houston, Texas).

2. Telemetry - method by which a signal can be sent by radio waves from a battery powered transmitter to a recorder.

3. Quinton Motorized Treadmill - an apparatus with a continuously moving belt which can be adjusted to run at various speeds and inclines, thereby standardizing workloads (24-72 model).

4. Biotelemetry Transmitter - a small battery-powered device used to send a subject's heart rate via radio waves to a biotelemetry receiver.

5. Biotelemetry Receiver - an apparatus which receives heart rate signals from a small wireless transmitter.

6. Disk electrodes - devices which are attached to the skin surface and adjacent to the heart and which transduce the electrical impulses of the heart into electrical signals.

7. Tissot tank - a large stainless steel tank which was used for collection of expired air during work.

8. Sample bags - a one-liter rubber bag used to hold samples of a subject's expired air during transfer from tissot tank to gas analyzer.

9. Pulmo-analyzer - an electric instrument which was used to determine the percentage of oxygen and carbon dioxide contained in the samples of expired air. It operates on the principle of thermal conductivity (Godart: Instrumentation Associates).

10. Collins One-way Valve - a device which enables the subject to take in atmospheric air and then to expel the air into a tissot tank for measurement of lung ventilation during exercise (Collins).

11. Noseclip - device used to clamp nostrils shut.

CHAPTER II

REVIEW OF LITERATURE

The literature has shown a scarcity of research done on maximal oxygen consumption of the American female. The available information becomes even more incomplete if the subject is restricted to the female athletes. There are work capacity values for women hockey players, speedskaters, gymnasts, track athletes and basketball players, but the use of many different techniques and testing procedures are revealed when reviewing the studies. Standardization of procedures becomes difficult to achieve since very few studies have been done; thus, one finds many different measures taken and different protocol used, making interpretation difficult.

A new publication about the woman athlete, The American Women in Sport, observed that:

> . . . the few investigators who have reported data on women have been so heavily quoted and their results so frequently dragged about as cannonade in defense on one or another issue, that one can only cross one's fingers and pray that their every procedure was meticulously completed and their interpretations were blessed with clarity and reason (1, p. 403).

The fault does not lie with the researchers alone. Historically, most researchers have been male, and "our culture has evolved well-defined taboos relating to the interaction of males and females, even when one is a subject and the other an experimenter" (1, p. 404). Special problems exist when the male researcher must locate electrodes in "prohibited" areas of the female body, or take certain anthropometric measures. Profant, et al. (14) has commented on difficulties that arise in motivating women to perform maximal work tests, and Higgs (15) stated there was no doubt that a certain reluctance by many women to work at exhaustive levels of exercise existed. However, a need for more information about the female does exist. Moreover, due to the apparent physiological differences between the male and female, the researcher finds an increasing need to compare women with other women and women athletes with other women athletes.

Metheny, et al. (16) in 1942 were among the first to assess physiological determinants of work capacity of women. The study measured seven variables including heart rate and maximum oxygen consumption on active American college women. They concluded that men had a higher oxygen consumption than women, and that maximum heart rate was comparable for both sexes.

Studies of Swedish and Norwegian women were the first to reveal values for maximal oxygen consumption for women athletes. Irma and P. O. Åstrand were instrumental in the development of work tests using subjects of both sexes to assess work capacities. In 1954, Åstrand and Ryhming (17) added to the study of aerobic capacity when they devised a nomogram for calculation of aerobic capacity from pulse rate during submaximal work. In 1960, I. Åstrand's (18) work with 44 Swedish females of different ages established actual data on maximal oxygen intake for women. P. O. Åstrand, et al. (19) in a later study, found maximal oxygen consumptions for girl physical education majors. The same researchers (17, 18) found VO_2max of 39.9 ml/kg/min and 48.4 ml/kg/min for Swedish women and trained athletes, respectively.

Saltin and Åstrand (20) cited a VO_2max of 66.3 ml/kg/min for a Swedish cross-country skier, and Holmer, et al. (21) reported 55.3 ml/kg/min for VO_2max for Swedish swimmers. Hermansen and Anderson (10) reported VO_2max of 55.0 ml/kg/min and 38.0 ml/kg/min for trained and untrained Norwegian women.

Studies have shown that American women do not seem to reach levels of VO_2max equivalent to that of Swedish and Norwegian women. In 1965, Michael and Horvath (22) did the first study on American women since Metheny's initial research for assessing work performances (16). They found a VO_2max of 29.8 ml/kg/min for a group of active college women, including a VO_2max of 40.3 ml/kg/min for one of the subjects. These researchers observed that the subjects having the higher exercise capacities generally had lower heart rate levels at the submaximal work loads.

Sinning and Adrian (23) found a VO_2max of 35.2 ml/kg/min for a group of active young American women and 38.7 ml/kg/min for a group of women basketball players. Maksud, et al. (24) found VO_2max of 46.1 ml/kg/min for women Olympic speed skaters, and Larry Noble (25) reported a high of 61.77 ml/kg/min for VO_2max of a gymnast. Values for VO_2max in untrained American women ranged from 29.8 reported by Michael and Horvath (22) to 40.36 reported by Drinkwater, et al. (26) in 1975. American physical education majors seemed to achieve a little higher degree of VO_2max than their college counterparts. Macnab (27) reported a value of 39.06 ml/kg/min for a group of Canadian physical education majors, and values for American physical education majors ranged from 33.62 ml/kg/min which was reported by McArdle (28) to 41.32 ml/kg/min which was reported by Higgs (15).

The highest reported values for VO_2max have been reported for athletes. Drinkwater and Horvath (29) reported an average VO_2max of 51.1 ml/kg/min for a group of female track athletes while Wilmore and Brown (30) reported a mean of 59.1 ml/kg/min for a group of women distance runners. Values for the American woman athlete ranged from 35.75 ml/kg/min for basketball players (28) to 59.1 ml/kg/min reported for distance runners (30). In the latest study to date, Maksud, et al. (31) reported a VO_2max of 41.02 ml/kg/min for a group of American women athletes (Table I).

Wilmore and Sigerseth (39) found values as high as 63.7 ml/kg/min in 13-year-old girls which led them to the conclusion that there are no basic differences between the sexes in their physiological responses to maximal exercise. They ascertained that age, not sex, was the important determinant. This corresponded with conclusions made by Knuttgen (4) and Ikai (40). This point is questionable since there are many studies that speak of the difference in VO_2max between the sexes (5, 18, 27, 30, 41).

Drinkwater (5), in a paper that discussed the true physiological consideration of the female summed the data that had been collected and revealed her findings. She reached three important conclusions:

1. Females can reach relatively high levels of cardiovascular fitness as expressed by maximal oxygen intake through training but do not appear to be able to achieve the levels of highly trained males.

2. A trained woman can exceed an untrained male in maximal aerobic power.

3. Trained athletes, whether male or female, significantly exceed untrained subjects in the measure of cardiovascular fitness (pp. 375-386).

TABLE I

VO_2max OF WOMEN ATHLETES

Year	Reporter	Nationality	Ages $\bar{X}$	(N)	VO_2max (l/min)	VO_2max (ml/kg/min)	Max Heart Rate (beats/min)	Method
1965	Hermansen & Anderson	Norwegian	22	5	3.3	55.0	186	Bicycle
1967	Conger & MacNab	Canadian	19	40	2.53	40.7		Bicycle (pred)
1967	Saltin & Åstrand	Swedish	24	38	3.61		194.8	Bicycle
1968	Sinning & Adrian	American	20	7	2.35	38.7	187.5	Bicycle
1970	Maksud	American	21	13	2.71	46.1	192	Treadmill
1970	Miyashita	Japanese	16	18	2.75	54.0		Treadmill
1971	Drinkwater & Horvath	American	17	2	2.76	51.1	195	Treadmill
1971	McArdle	American	20	6	2.18	35.75	191	Treadmill
1972	Raven, Drinkwater, Horvath	American	16	13		48.52	193	Treadmill

TABLE I (Continued)

Year	Reporter	Nationality	Ages $\bar{X}$	(N)	VO_2max (l/min)	VO_2max (ml/kg/min)	Max Heart Rate (beats/min)	Method
1972	McArdle	American	21	6	2.7	45.0	195	Treadmill
1973	Wells	Canadian	16	12	2.47	51.3	190	Treadmill
1973	Katch	American	21	12	2.58	43.7		Treadmill
1973	Cunningham & Eynon	Canadian	15	5	2.19	40.5	189	Bicycle
1974	Wilmore & Brown	American	31	11	3.35	59.1	180	Treadmill
1974	Holmer	Swedish	17	11	3.64	55.3	201	Treadmill
1976	Maksud	American	19.7		2.53	41.02	195.1	Treadmill

Differences in maximal aerobic capacity between the male and female have formed the basis for many studies. Researchers have tried to relate physiological variables between men and women of different ages (4, 18, 26, 42), ethnic backgrounds (43), and activity levels (41, 44). Efforts to compare men and women lead researchers to express work capacities by various methods. Wells, et al. (36) expressed the concern that, when comparing men to women, oxygen uptake may be more "meaningful" when expressed per unit of fat-free body weight. Dill (41) even went so far as to suggest that aerobic capacity (VO_2max) of women may be equal to men when related to lean body weight. Wilmore and Brown (30) stated that it was evident that the female endurance trained athlete has a lower endurance capacity (as compared to male endurance athlete). However, due to the higher relative body fat for the female, the values were much closer when expressed relative to lean body weight. Macnab, et al. (27) found that in both treadmill and bicycle work tests, submaximal and maximal, men exhibited significantly higher scores than women, even when expressed in terms of fat free body weight.

There have been many attempts to explain the "sex differences" in aerobic capacity of mature men and women. Studies by Knuttgen (4) and Dill (41) concluded that the lower VO_2max of women may depend on the lower hemoglobin concentration in their blood, thereby decreasing the oxygen carrying capacity of the blood.

Macnab (27) suggested that perhaps researchers should look beyond the gross measures of work capacity and examine more closely biological variables that may be associated with differences in physical work capacity in men and women. Existing studies have provided little insight into basic physiological mechanisms and have not resolved the question as to whether one's sex is a major mediating factor in his or her physiological responses to exercise (30).

Summary

Researchers have defined the physiological variables which are important to the assessment of physical work capacity. The literature has shown that maximal oxygen consumption has been the preferred criterion when measuring work performance.

Recently, there has been an increase in the interest in the physiological variables of the female. Studies have shown the athlete to be superior to the non-athlete in terms of maximal oxygen consumption. Maximal oxygen consumptions have ranged from approximately 38.0 ml/kg/min to 55.0 ml/kg/min for Swedish housewives and Swedish athletes, respectively. Values for American women ranged from 29.0 ml/kg/min for active college women to 41.0 ml/kg/min for American basketball players. The highest values for American women approached 59.0 ml/kg/min for highly trained endurance athletes.

The literature has shown the superiority of the endurance trained woman athlete to the untrained woman in terms of maximal oxygen consumption, but the accumulation of data on the American athlete in different sports has been seriously overlooked. The recent increase in literature on women has begun to fill the void, and as a result, more definite interpretation of work capacities of the American woman athlete will result.

CHAPTER III

METHODS AND PROCEDURES

The women subjects used for this study were active members of the intercollegiate athletic program at Oklahoma State University. Volunteers were limited to participants in field hockey, basketball, swimming or track, since these sports seem to stress cardiorespiratory endurance as an important attribute. Ten volunteers were acquired from each of the four teams. Seven subjects were randomly selected from the 10 volunteers to participate in the study. The aforementioned sports were "in season" and the athletes used as subjects were engaged in some type of conditioning programs.

The test procedure was similar to that described by Balke and Ware (8). The treadmill speed was set at 3.4 miles per hour (90 m/min). This procedure seemed acceptable for this study since most of the subjects had engaged in a walking test on the treadmill previously. McArdle, et al. (35) found the Balke procedure to correlate highly ($r = .95$) with aerobic capacity in women, and treadmill testing has consistently yielded higher values for VO_2max than bicycle ergometry (40, 45, 46).

Test Procedure

The subjects reported to the Oklahoma State University Human Performance Laboratory dressed in activity clothes. They were asked to refrain from eating for three hours prior to testing, and instructed not to participate in any vigorous physical activity the day of their testing. Each subject was asked to read and sign an informed consent, after which the test procedure was thoroughly described by the researcher or assistant. Physical characteristics, such as age, height, and weight were recorded for each subject (Table II).

TABLE II

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

Team		Age	Height (cm.)	Weight (kg.)
Field Hockey	Range	18-21	163-175	54-68
	Mean	19.6	168.3	60
Basketball	Range	18-22	163-183	55-76
	Mean	19.6	174.0	66.8
Track	Range	18-21	169-182	51-75
	Mean	19.4	172.4	61.9
Swimming	Range	18-20	165-172	54-70
	Mean	19.4	169.3	61.6

Telemetry apparatus consisting of electrodes, biotelemetry transmitter and receiver, and a physiograph recorder were used to monitor the heart rate throughout the test. Disk surface electrodes were placed over the upper sternum and the lower left rib cage (V5). The electrodes were connected by wire to a small transmitter which was attached to the right rib cage area or to the left shoulder.

The subject was asked to lie on the laboratory table in a supine position while electrodes were positioned and connected to the transmitter. She was asked to rest for three to five minutes, during which time, the biotelemetry receiver and physiograph were adjusted to insure the best possible reception. A resting heart rate (V5 - EKG) and resting blood pressure were recorded on the physiograph. All loose wires were taped to the subject to improve reception.

The researcher demonstrated the proper method for mounting and dismounting the treadmill. The subjects were also familiarized with the one-way breathing valve and mouthpiece which would be used to collect expired air samples during the test. Then, the subjects were asked to step onto the treadmill belt and to begin walking. Many of the women had participated in previous treadmill testing; therefore, orientation was minimal. The subject walked at zero per cent grade until she was accustomed to the pace, but not less than two minutes. The elevation of the treadmill was raised two per cent after the first two minutes. Next, it was raised one per cent for each minute thereafter, providing a progressively increasing workload. Heart rate was monitored during the last 10 seconds of every minute. The subject was asked to walk until she could no longer continue.

Determining Oxygen Consumptions

The subject was asked to put on the noseclip and practice breathing through the one-way valve prior to gas collection. This insured that she was familiar with the procedure and also served to flush out the tissot tank, which would be used for gas collection. After the trial breathing, she was allowed to walk unhindered until the air collection started.

Expired air was collected in the tissot tank when heart rates reached 180 beats per minute, 190 beats per minute and one minute before termination of the test. The subject was asked to signal the researcher when she felt she could not go much longer, at which time, a last 30 second expired air sample was taken. As the 30 second expired air sample for each heart rate was collected in the tissot tank, ventilation volume was noted on the kymograph. A one-liter sample bag was used to collect expired air samples from the tissot tank. The expired air was analyzed with a Godart Pulmo-analyzer that had been calibrated to a Haldane. Oxygen uptake was calculated and corrected to STPD by the open circuit method described by Ricci (47). At the completion of the test, subjects stepped off the treadmill and rested on the laboratory table, where blood pressure and heart rate were monitored for approximately five minutes.

Analysis of Data

The data collected was grouped into four categories according to sports. There were seven subjects in each group. Means and standard deviations for maximal oxygen consumption and per cent grade were calculated for heart rates of 180, 190 and maximum for each group, as well as the total group.

An analysis of variance (ANOVA) was computed between groups for maximum heart rate, maximum workload, and maximum oxygen consumption.

A Pearson product-moment correlation was computed between:

1. time to reach 180 HR and VO_2max
2. time to reach 190 HR and VO_2max
3. VO_2180 and predicted VO_2max
4. VO_2190 and predicted VO_2max
5. VO_2max and Balke regression line prediction
6. VO_2180 + 25 per cent and Balke prediction

The reliability of the test procedures and the maximum oxygen consumption measures were determined by correlating test-retest scores on 10 randomly selected subjects.

CHAPTER IV

RESULTS AND DISCUSSION

The results will be discussed with respect to four groups of statistical procedures. These are:

1. Means and standard deviations within the total group of subjects.
2. Means and standard deviations between groups of subjects.
3. Significant differences between groups using analysis of variance.
4. Correlations between variables.

Means and Standard Deviations Within the Total Group

The total group means and standard deviations are expressed in Table III. The total group showed a mean VO_2max of 46.95 ml/kg/min (2.92 l/min). This value was somewhat greater than the values obtained for other American athletes. Maksud, et al. (24) reported VO_2max of 46.1 ml/kg/min for speed skaters and McArdle (35) reported 45.0 ml/kg/min for a group of American athletes. Katch, et al. (37), in a study comparing athletes to physical education majors and non-majors, found a VO_2max of 43.7 ml/kg. In general, the athletes in the present study exhibited noticeably higher values of VO_2max than other groups of American athletes. The mean maximal heart rate was 194 beats per minute, which was similar to the mean that had been reported in other studies (24, 29, 35). The treadmill grade reached by the group was 21 per cent which, when plotted on Balke's regression line, gave a predicted VO_2max of 46.5 ml/kg/min. This value was within .45 ml/kg/min of the actual mean VO_2max obtained for the group.

TABLE III

TOTAL GROUP RESPONSES DURING TREADMILL TESTS

N = 28	$\bar{X}$	SD
Maximum Heart Rate (Beats/min)	194.4	9.59
Maximum Ventilation (L/min)	71.81	8.65
Respiratory Quotient	.96	.08
VO_2180 (ml/kg/min)	37.41	6.24
(l/min)	2.34	.44
VO_2190 (ml/kg/min)	40.75	4.73
(l/min)	2.53	.33
VO_2max (ml/kg/min)	46.95	4.49
(l/min)	2.92	.32
Maximum elevation (% grade)	20.54	2.66

Means and Standard Deviations Within Groups

The means and standard deviations obtained for the four groups of athletes are shown in Table IV. The data showed interesting relationships when each group was taken and compared to the results reported by other resources. It must be remembered, however, that a small sample (N=7) was used from each sport. A larger sampling, from more than one particular set of athletes, would have been desirable for more conclusive interpretation of results.

Drinkwater and Horvath (29) have reported values of 51.1 ml/kg/min for female track athletes. Wilmore and Brown (30), in a more recent study (1974), reported values of 59.1 ml/kg/min for a group of female distance runners. The track athletes tested in the present study showed a VO_2max of 47.21 ml/kg/min. This was lower than the values previously reported for female track participants; however, the previous studies measured distance runners, whereas the present sampling consisted of hurdlers and sprinters as well as cross-country runners.

The mean VO_2max obtained for the swimmers was 47.59 ml/kg/min. This value was far below the 55.3 ml/kg/min reported for Swedish female swimmers (21), and the 54.0 ml/kg/min (33) reported for Japaneses female swimmers. However, the values for the foreign teams were reported for national female champions; whereas, though highly trained, the present group tested would not represent a sample of the best female swimmers in the United States. The swimmers in the present study compared favorably with a similar group of Canadian female swimmers tested recently by Cunningham and Eynon (38). These researchers reported a VO_2max of 40.5 ml/kg/min, but they only had five subjects in the group tested.

TABLE IV

RESPONSES DURING TREADMILL TESTS WITHIN GROUPS

Team		VO_2max (ml/kg/min)	VO_2max (1/min)	HR max (beats/min)	Elevation (% grade)	Max Vent (L/min)
Track	Range	42.80-55.85	2.36-3.74	174-198	15-27	56.49-89.95
	$\overline{X}$	47.21	2.92	187	21.4	71.06
	SD	4.78	.48	9.65	3.7	11.19
Field Hockey	Range	42.33-52.59	2.29-3.05	180-198	19-24	56.45-73.33
	$\overline{X}$	45.84	2.76	193	21.3	67.01
	SD	3.38	.25	7.29	1.8	5.37
Basketball	Range	40.79-51.94	2.84-3.44	180-204	16-23	64.91-84.98
	$\overline{X}$	47.14	3.13	197	19.9	76.80
	SD	4.63	.23	8.78	2.5	8.08
Swimming	Range	40.77-56.15	2.71-3.24	190-216	17-22	59.59-83.49
	$\overline{X}$	47.59	2.91	200	19.4	72.35
	SD	5.38	.18	8.76	2.0	7.76

The highest value reported for the subjects of this study (56.15 ml/kg/min) was reported for a swimmer. This compared favorably with averages already reported. This value was not as high as the highest maximal values found for the Swedish national female champions (21).

Difference Between Groups

The responses of the group to the maximal work test with respect to VO_2max, maximal heart rate, and maximum elevation are shown in Figures 1, 2, and 3.

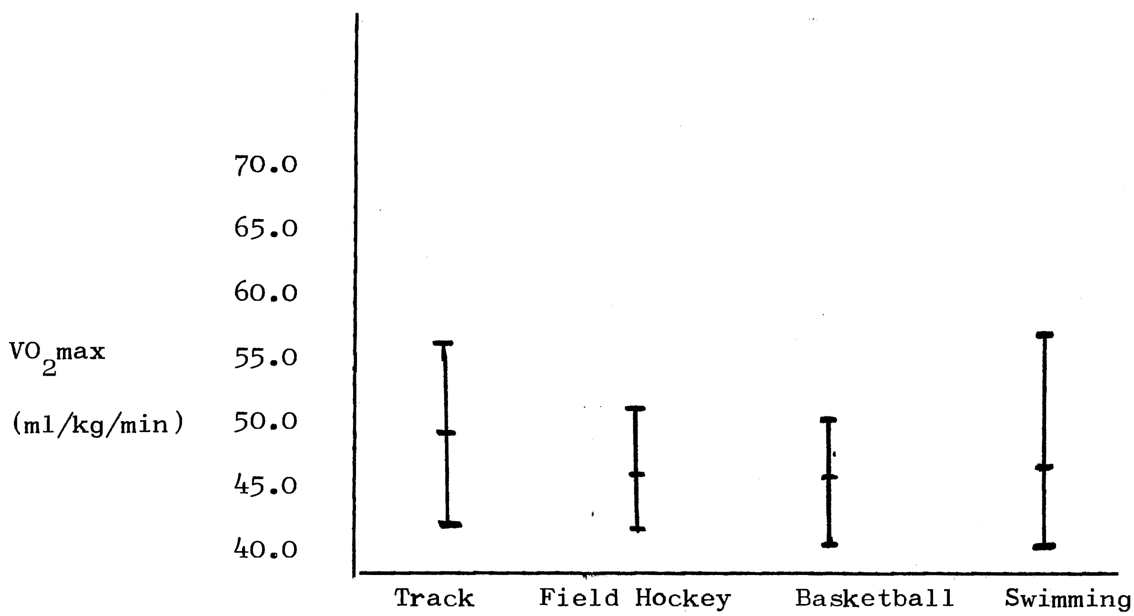

Figure 1. VO_2max During Maximal Exercise

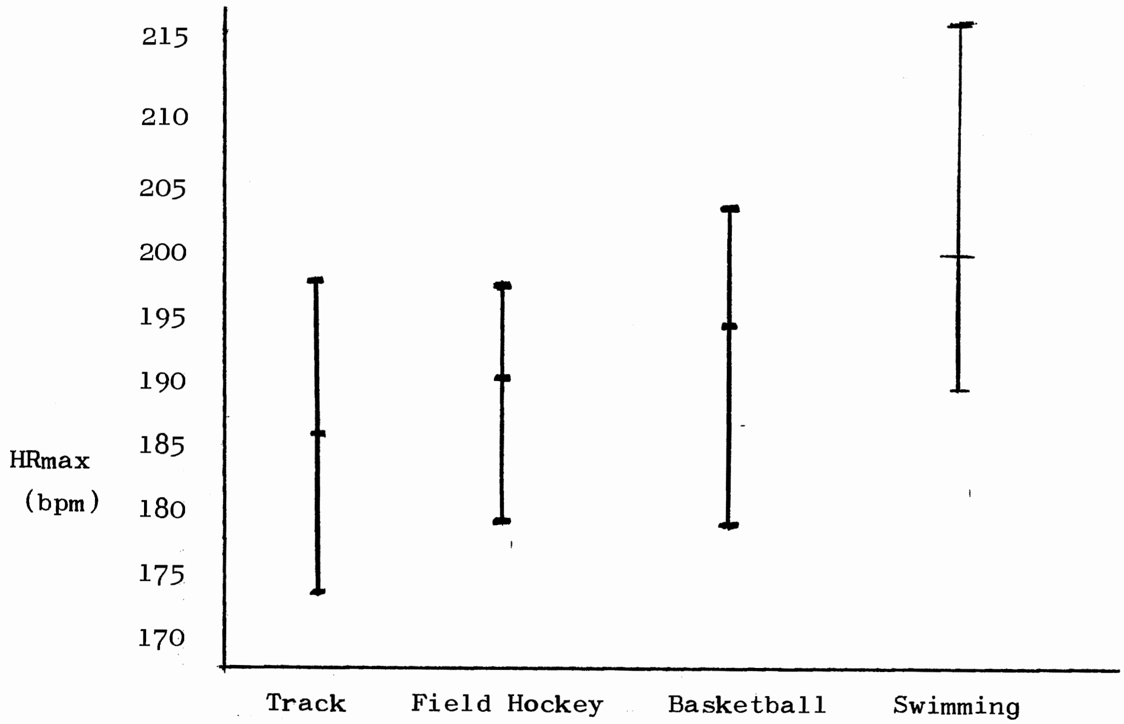

Figure 2. HRmax During Maximal Exercise

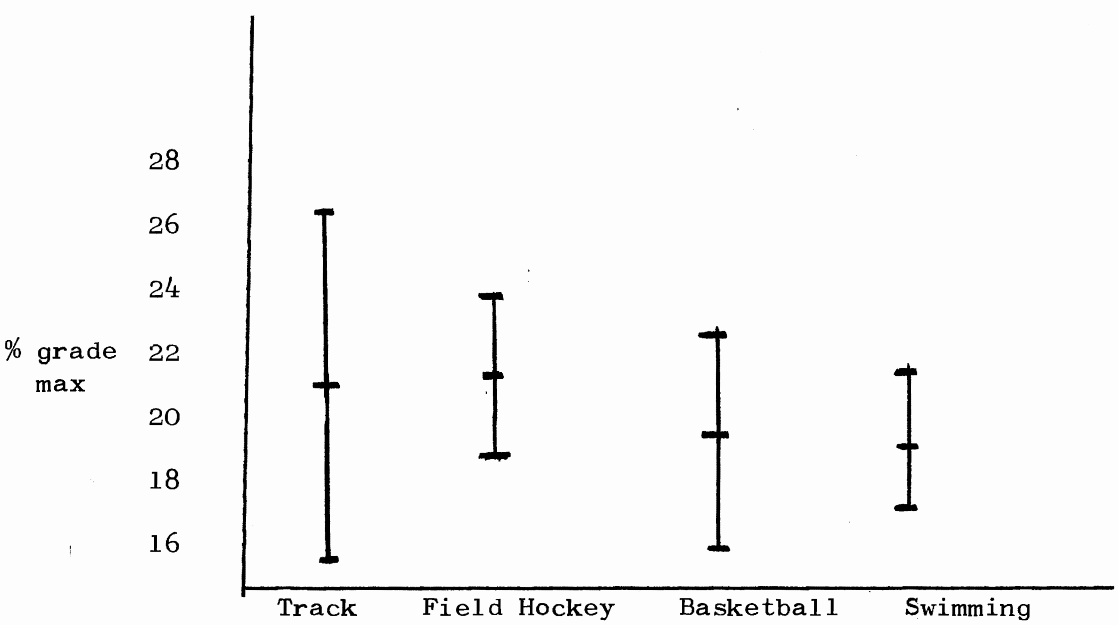

Figure 3. Maximum Elevation During Maximal Exercise

Figures 1 and 3 show comparative values between groups when considering VO_2max and maximum elevation obtained. Figure 2 shows the track athletes to have the lowest mean maximal heart rates and the swimmers to have the highest maximal heart rates.

A one-way analysis of variance (ANOVA) was calculated between the groups with respect to oxygen consumptions at 180 HR, 190 HR, maximum HR, per cent elevation reached on the treadmill, and the highest heart rate reached. The results are shown in Table V.

TABLE V

ANOVA BETWEEN GROUPS

Variable	F Value	For Significance (.05 level)
VO_2 180	1.76	3.01
VO_2 190	.69	3.16
VO_2 max	.183	3.01
HR max	3.02	3.01
Elevation	1.13	3.01

Minute ventilation increased with an increase in heart rate for all groups as shown in Figure 4. Respiratory quotients for the increase in heart rate for the groups are shown in Figure 5.

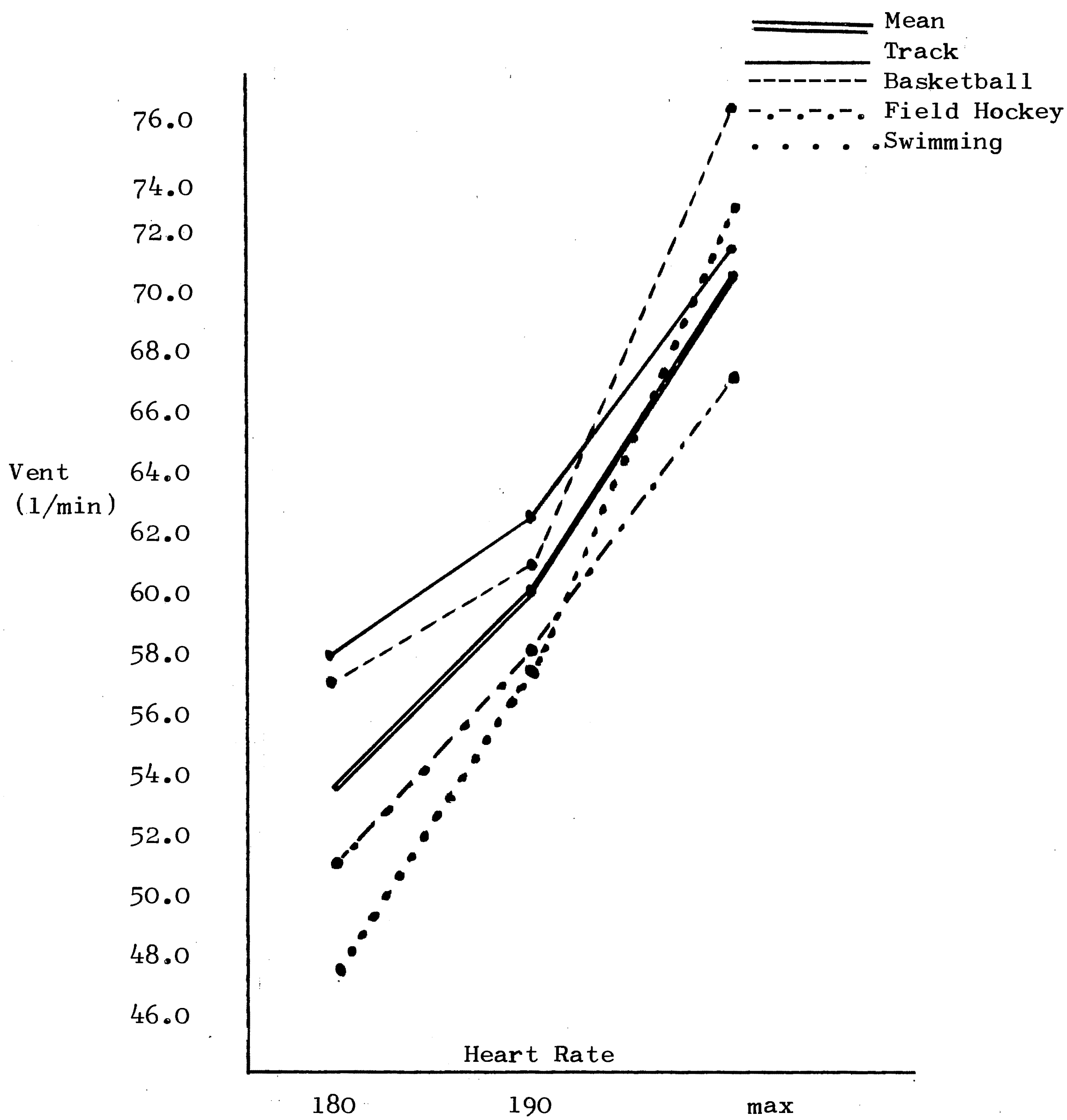

Figure 4. Minute Ventilation During Maximal Exercise

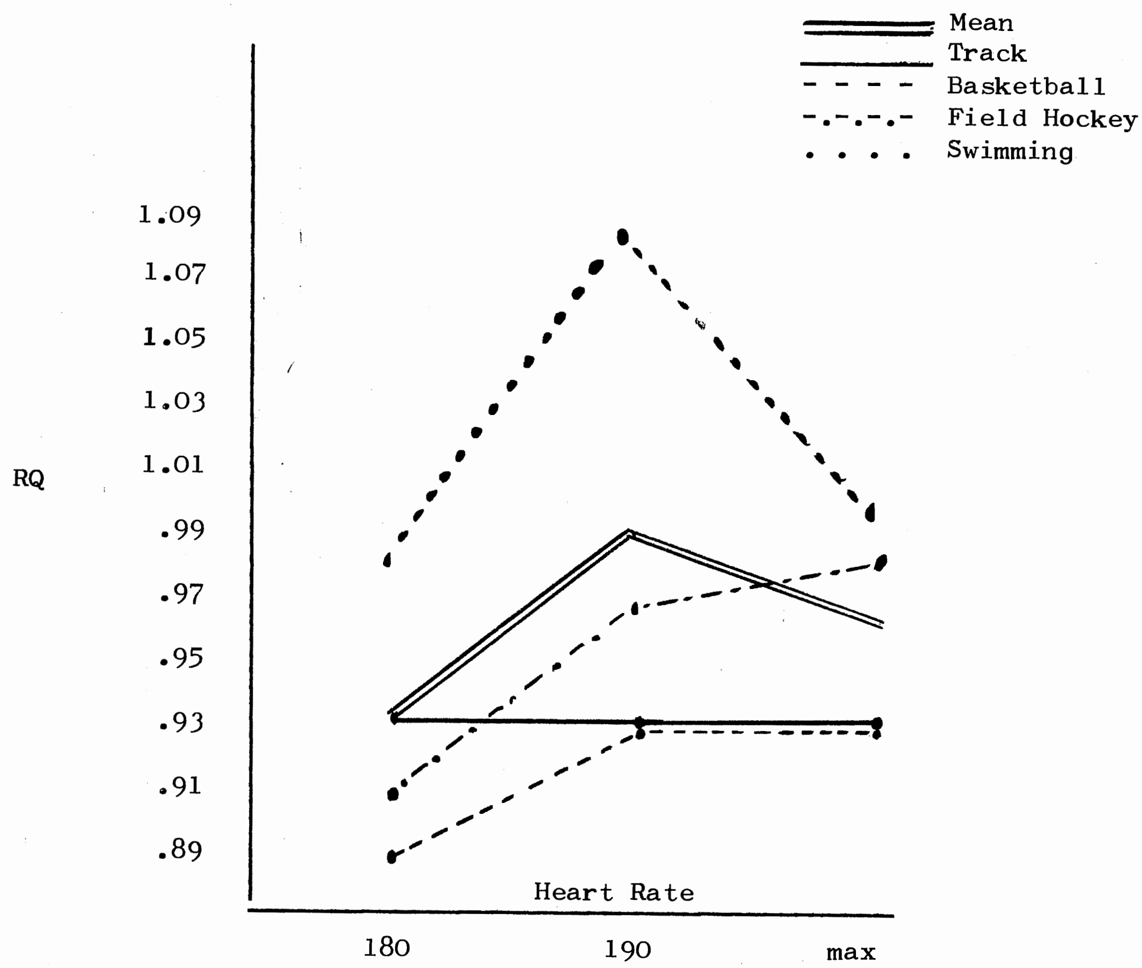

Figure 5. Respiratory Quotients During Maximal Exercise

Mean O_2 and CO_2 percentages in the expired air for the four groups are shown in Figures 6 and 7. Figure 6 shows a slight increase in per cent of O_2 in the expired air at heart rates of 180, 190 and maximum. The decline in per cent of CO_2 in the expired air shown in Figure 7 was not what is usually expected during exercise. It is interesting to note that the largest per cent of CO_2 and largest decrease in the per cent of CO_2 in the expired air samples was for the group of swimmers. It may be speculated that this unusual trend in the per cent of CO_2 during exercise could be due to the type of training in which swimmers engage. Work done by swimmers is in a different element, i.e., water, than that done by runners or other athletes. The amount of anaerobic work done by a swimmer as compared to other endurance trained athletes could also be a factor to remember when interpreting these results.

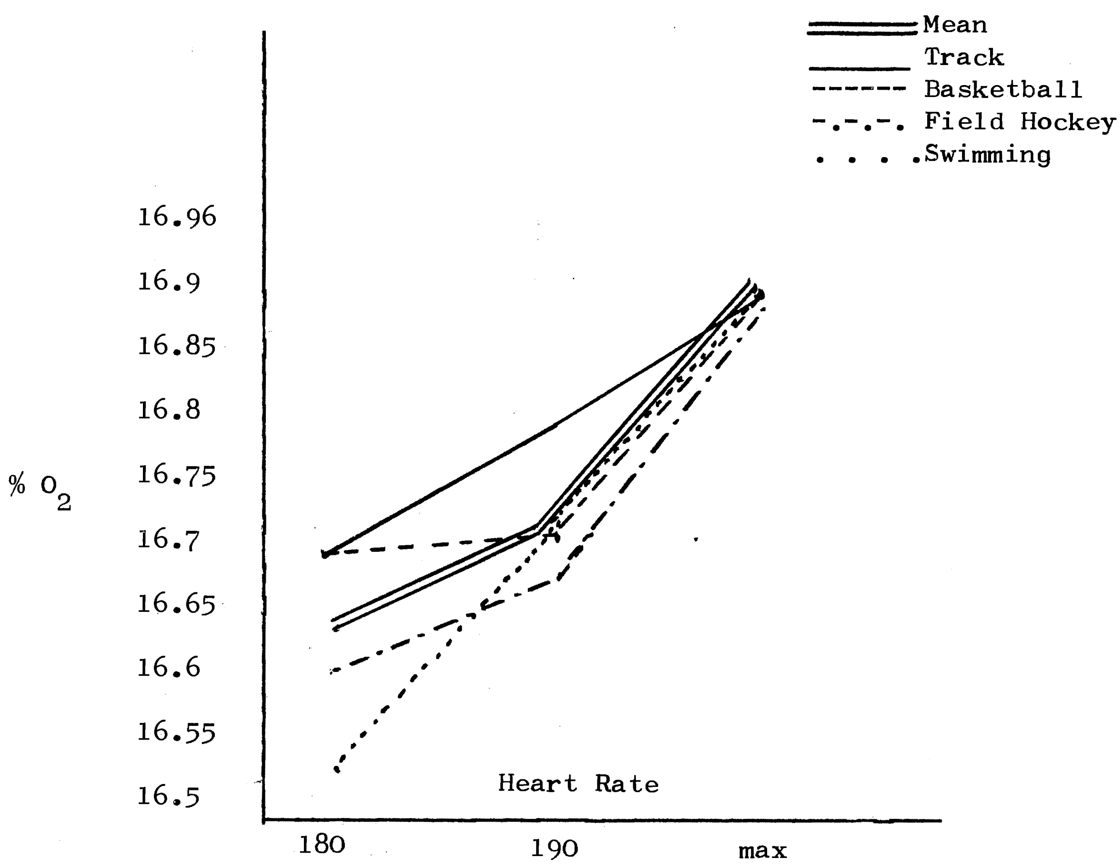

Figure 6. Mean O_2 Per Cent in Expired Air

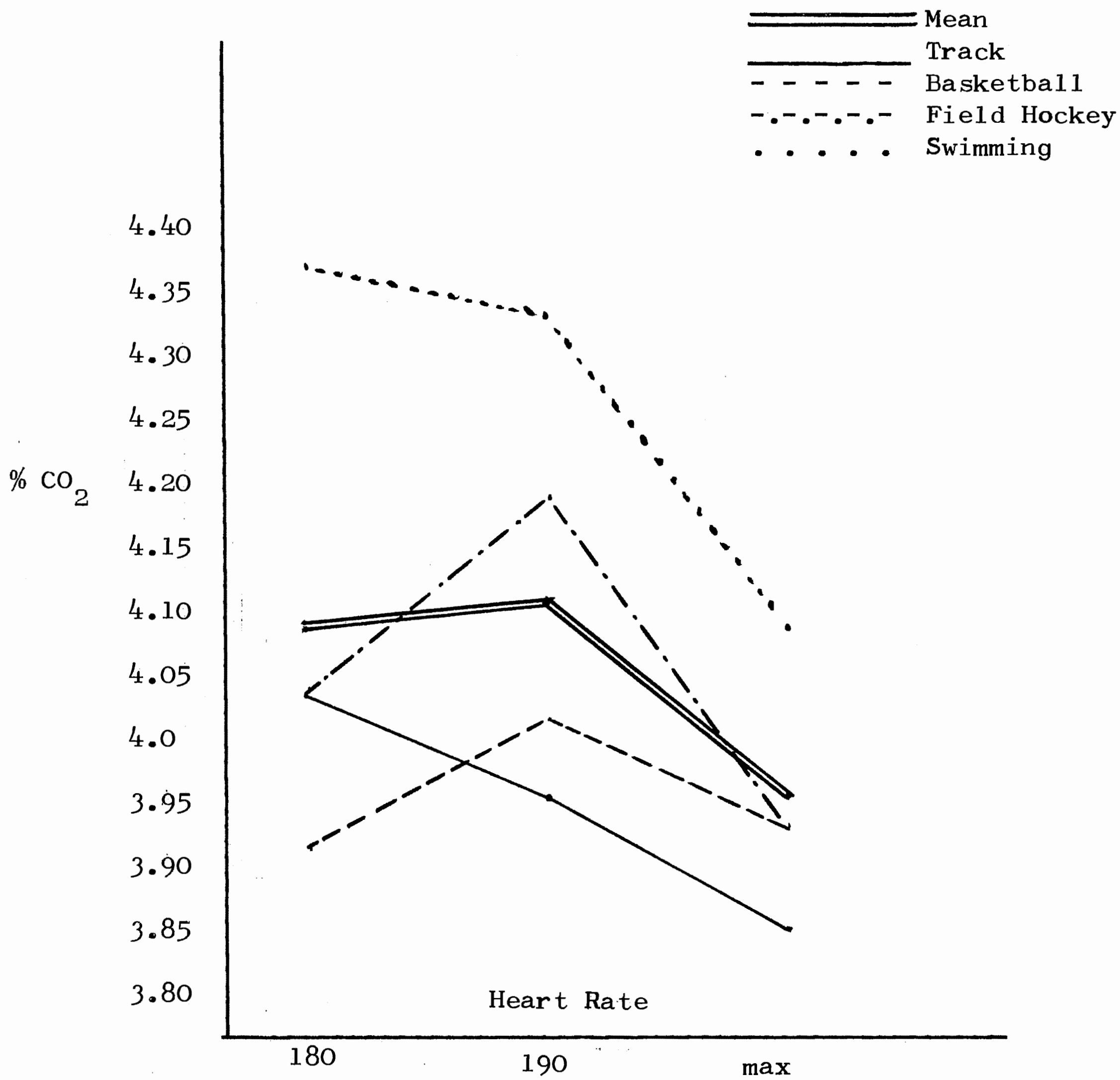

Figure 7. Mean CO_2 Per Cent in Expired Air

The recovery rates of the four groups are shown in Figures 8 and 9.

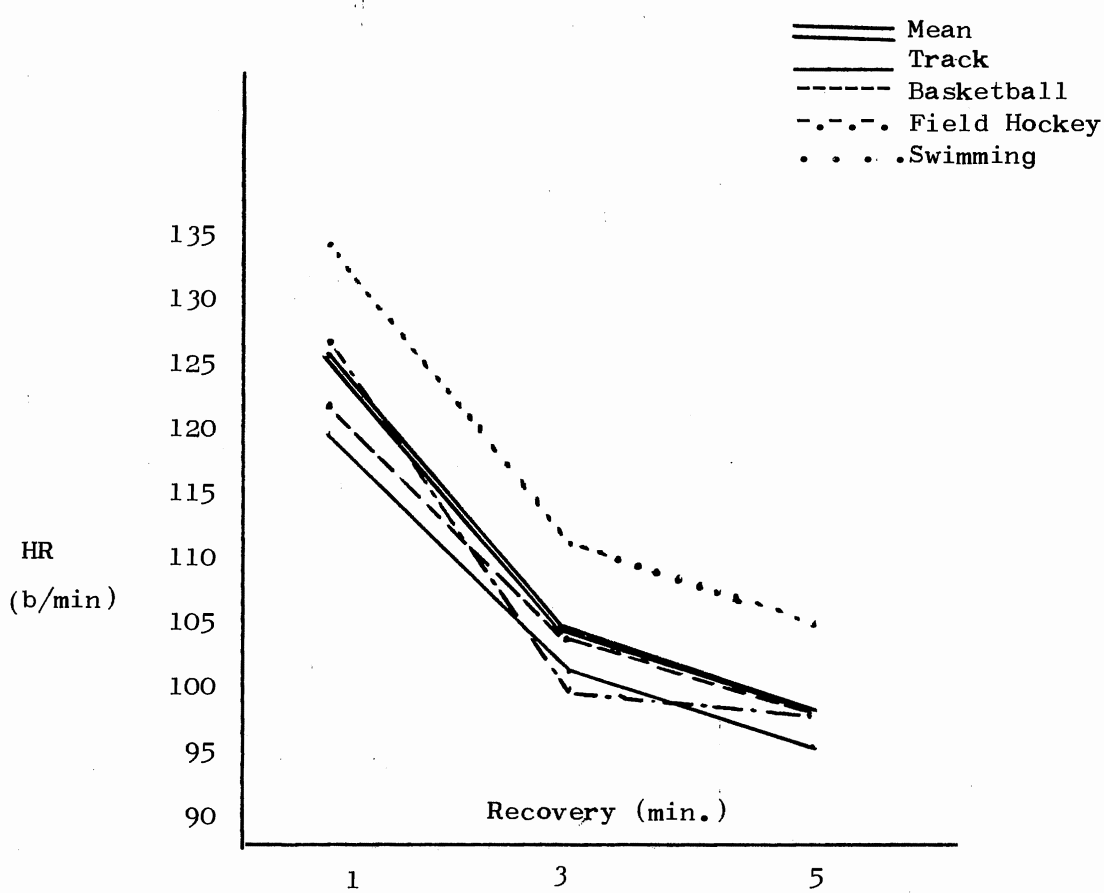

Figure 8. HR During Recovery

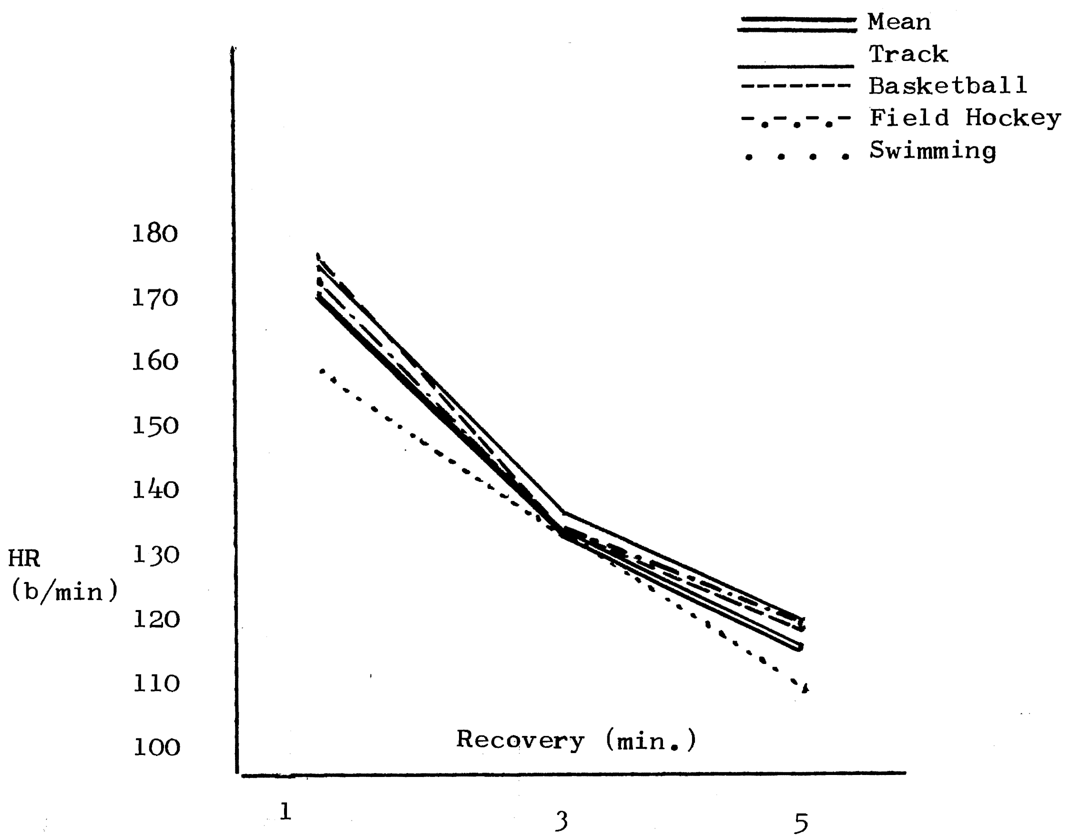

Figure 9. Systolic Blood Pressure During Recovery

The recovery heart rate and blood pressure responded as expected after exercise. The heart rates of the swimmers were continuously higher than the other athletes during recovery. This was probably due to the maximal heart rates reached by the swimmers.

Correlations Between Variables

A Pearson product moment correlation was performed between the following sets of variables:

1. time to reach 180 HR and VO_2max
2. time to reach 190 HR and VO_2max
3. VO_2 (180) and pred VO_2max
4. VO_2 (190) and pred VO_2max
5. VO_2(180) and predict VO_2max + 25 per cent

The basketball players reached an average VO_2max of 47.14 ml/kg/min. The VO_2max of the basketball players of the present study exceeded other reported values. McArdle, et al. (28), reported 35.75 ml/kg/min, and Sinning and Adrian (23) reported 38.7 ml/kg/min for college female basketball players. The results tend to indicate that the conditioning program of the female basketball player has lagged behind the program of the track athlete or the swimmer. However, it will later be shown that the differences found, though evident, were not statistically significant.

When reviewing the literature, the author found a scarcity of material involving female field hockey players. With the rising popularity of this sport, one would expect to have found studies being performed on this particular group of athletes. The VO_2max of the field hockey players was 45.84 ml/kg/min. This compared favorably with other groups of American female athletes (23, 28, 35, 37), but it is lower than the highly endurance trained female athlete, such as the cross-country skier (36) or the distance runner (30).

In summary, the athletes in this sampling exhibited a higher VO_2max than other American female athletes. When viewed in total perspective, it can be seen that the scarcity of information involving women athletes, particularly American athletes, may provoke some rather crude interpretations of data. More research on the woman athlete in different sports is needed before conclusions may be drawn.

The swimmers seemed to have a higher VO_2max than the other groups; however, the difference was not significant. The ANOVA showed an F value of .183, or very little significance. The significance was greater (1.76) when groups were compared with respect to their oxygen consumptions at 180 HR. The value would have needed to be 3.01 to be acceptable at the .5 level of confidence.

The ANOVA was also calculated for the maximum HR and for the maximum elevation reached. There was no significance between groups (F=1.13) when considering the elevation reached. There was significance between groups (F=3.02) with respect to maximum heart rate achieved. A t-test was subsequently run within the four groups showing a significant difference (t=2.84) between heart rates of the track athletes and the swimmers. The difference was significant at the .05 level of confidence. This was to be expected since the swimmer is capable of longer periods of anaerobic work, and the long distance runner engages in basically aerobic types of work. The higher heart rate of the female swimmer was also shown in the literature. Holmer, et al. (21), reported values of 201 beats/minute as an average heart rate for Swedish national champion female swimmers.

The results showed low correlations (.46 and .34) between time to reach HR = 180 and HR = 190, respectively, and VO_2max. The low correlation obtained could be expected due to the limitations of this study. If more subjects had been used from each sport, perhaps a higher correlation could have been reached between the time to 180 HR and 190 HR and VO_2max.

Satisfactory correlations (r=.81) were achieved between the actual VO_2max for females measured at both HR = 180 and HR = 190 and the Balke predictions for men. Although the correlation was not as high as previously reported values for men (8) it was high enough to be a valid predictor for women athletes.

The correlation between VO_2(180) + 25 per cent and VO_2max yielded a value of .521, indicating that adding 25 per cent to the Balke prediction was a poor method of establishing maximal oxygen consumption for endurance trained female athletes.

The present study showed values of VO_2max that compared favorably with other American female athletes. Mean maximal oxygen intakes of this group of athletes exceeded values reported by other researchers for college female athletes (23, 28, 35, 31). One finds that the VO_2max of national female champions (20, 33, 21) exceeded the VO_2max of the athletes in the present study by approximately 10 ml/kg/min. This was to be expected. Olympic caliber athletes are usually on a more vigorous training program than the usual college athlete.

The athletes in this study exhibited higher values for VO_2max than either female physical education majors or conditioned women that have been reported for American or foreign female athletes (16, 32, 48, 27, 49, 28, 15, 37). It can be stated, therefore, that the participants in this study exhibited high enough values of VO_2max to be segregated from the normal population of college female women and could be classified as trained athletes.

The first two hypotheses which were previously state (p. 5) were rejected as a result of the low correlations found between the time to reach 180 HR and 190 HR and VO_2max. There was no significant difference between maximum oxygen consumptions of the participants of the different sports, therefore, the third hypothesis was accepted.

The subproblems of the study were related to the acceptance of the Balke regression line for prediction of VO_2max for women athletes. The same correlation (r=.81) was found for predictions of VO_2max at heart rates of 180 and 190. It would seem, although the predictability of the Balke regression line is not as high as for men, that it is a valid predictor for women athletes at either 180 HR or 190 HR. These results agreed with conclusions reached by previous researchers (13,35). McArdle, et al. (35) found a high validity of the Balke test for women; however, Humphrey and Falls (50) have been among others to question the validity of 180 heart rate as a cut-off point for females. It would be valuable to investigate the possibility that 190 heart rate would be a more valid predictor than 180 heart rate of VO_2max of the female non-athletes. The addition of 25 per cent to the Balke prediction resulted in an overestimation of VO_2max for the athletes in this study, and was found to have a poor correlation (r=.52) to actual VO_2max. This would tend to indicate that, when testing endurance trained women athletes, the Balke regression line would be a valid means of predicting VO_2max from either the heart rate of 180 or 190.

Reliability

The test - re-test correlation coefficient was .86, indicating satisfactory reliability for the procedures used during this study. The apparent ill condition of one of the subjects during the re-test may have influenced the results of the test - re-test correlation.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Recently, there has been a growing concern over the validity and reliability of research involving the physical work capacity of women. Women are increasingly being used as subjects for the measurement of physiological variables which might influence their success in athletic competition. The effects of different training methods, conditioning programs and participation in athletics are now being considered with respect to the women as well as the men.

The purpose of this study was to complement information that has been recorded for female athletes. The author recognizes that the present sample was not sufficient to draw general conclusions about the work capacity of all female athletes; however, a look into the work capacities of various groups of female athletes will begin fostering more research in this area on a greater diversity of subjects.

The main problem of the present study was to determine the validity of workloads at 180 and 190 heart rate as predictors of maximal oxygen consumption of endurance trained female college athletes. Actual measures of oxygen consumption were taken for workloads at 180, 190 and maximum heart rates. The results were analyzed and comparisons were made between groups and between different target heart rates. Total group figures were obtained and compared to data previously reported. In addition, the actual maximum oxygen intakes recorded were related to the predicted value on the Balke regression line, and finally, 25 per cent was added to the actual value and related to the Balke prediction.

Conclusions

The results of this study warranted the following conclusions:

1. This testing procedure was found to have satisfactory reliability (.86).
2. Maximal oxygen intakes of this group of athletes were slightly higher than those reported for other American female intercollegiate athletes.
3. There was a low correlation (r=.46) between the time to reach 180 HR and the actual VO_2max.
4. There was a low correlation (r=.34) between the time to reach 190 HR and the actual VO_2max.
5. There was a high correlation (r=.81) between oxygen intake at both HR = 180 and HR = 190 and the predicted value from Balke's regression line.
6. There was a low correlation (r=.52) between oxygen intake at HR = 180 plus 25 per cent and the predicted VO_2max from Balke's regression line.
7. There was no significant difference between the groups with respect to VO_2180 (F = 1.76), VO_2190 (F = .69), or VO_2max (F = .183).

8. There was a significant difference between groups with respect to the heart rate (F = 3.02). The difference between heart rates of the track participants and the swimmers was significant (t=2.84).

9. There was no significant difference between the groups with respect to the per cent grade achieved on the treadmill.

10. The Balke regression line is a valid predictor of VO_2max for endurance trained women athletes.

Recommendations

The Balke regression line appeared to be a valid predictor for women athletes. More research needs to be completed on the American woman with respect to different sports and to different types of conditioning. A regression line, similar to Balke and Ware's regression line, needs to be constructed for women using a large group of women subjects who represent a range of fitness, from completely sedentary to highly trained.

The procedure used in the present study, though reliable, may need modification for use on lowly motivated individuals. It is also recommended in future studies that more attention be paid to the motivation of the individual. Though motivation did not seem to be a limiting factor in this study, the nature of maximal stress testing indicated the problems of motivation in all-out work.

A cross sectional sampling from many different schools would be of value to one researching the capabilities of women athletes. It is also suggested that, even though many sports are not endurance sports (i.e., gymnastics), there would be value in the acquisition of data for women athletes participating in those sports. Such data would have added much to the present study; however, adequate testing of the proper number of subjects from each sport was beyond the scope of this study.

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APPENDIXES

APPENDIX A

LABORATORY METABOLIC CALCULATION SHEET

LABORATORY METABOLIC CALCULATION SHEET

Subject________________ Date________ Age______ Surface Area______________ Sq.M.

Temp.__________ degrees C. Barometric Pressure________ mm Hg. Corr. Factor________

SITTING (Non basal)

1. Oxygen %______ CO_2%_______ True O_2_______ R.Q._______ (from nomogram)
2. Ventilation/min.= $\frac{\_\_\_\_\_\_}{10}$ Kym mm.=__________ x 1.332 = ________ l/Min
3. Corr. Vent. = Vent. x Corr. Factor = ________ x ________ = __________ L/Min
4. Oxygen Intake = $\frac{\text{Corr. Vent. x True } O_2}{100}$ = $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{100}$ = ________ L/Min
5. S.M.R. = $\frac{\_\_\_ \text{x5} \quad \text{x60} \_\_\_}{\text{sq. M. S.A.}}$ = ________________ Cal/Hr. Sq. M.

EXERCISE:

SPEED______________ HEIGHT______________ TIME________________

1. Oxygen %_______ CO_2% ________ True O_2_________ RQ__________ (from nomogram)
2. Ventilation/min. = $\frac{\_\_\_\_\_\_}{10}$ KYM mm. = _________ x 1.332 = ___________ L/Min
3. Corr. Vent. = Vent. x Corr. Factor = ______________ x __________ = ________ L/Min
4. Oxygen Intake = $\frac{\text{Corr. Vent. x True } O_2}{100}$ = $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{100}$ = ___________ L/Min
5. EMR = $\frac{\_\_\_ \text{x5} \quad \text{x60} \_\_\_}{\text{Sq. M. SA}}$ = _____________ Cal. hr/Sq. M.

EXERCISE:

SPEED______________ HEIGHT________________ TIME__________________

1. Oxygen %________ CO_2%____________ True O_2____________ RQ__________ (from nomogram)
2. Ventilation/Min. = $\frac{\_\_\_\_\_\_}{10}$ kym mm. = __________ x 1.332 = __________ L/min
3. Corr. Vent. = Vent. x Corr. Factor = _____________ x _________ = _________ L/Min
4. Oxygen Intake = $\frac{\text{Corr. Vent. x True } O_2}{100}$ = $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{100}$ = _____________ L/min
5. EMR = $\frac{\_\_\_ \text{x5} \quad \text{x60} \_\_\_}{\text{Sq. M. SA}}$ = __________________ Cal./hr/Sq. M.

EXERCISE:

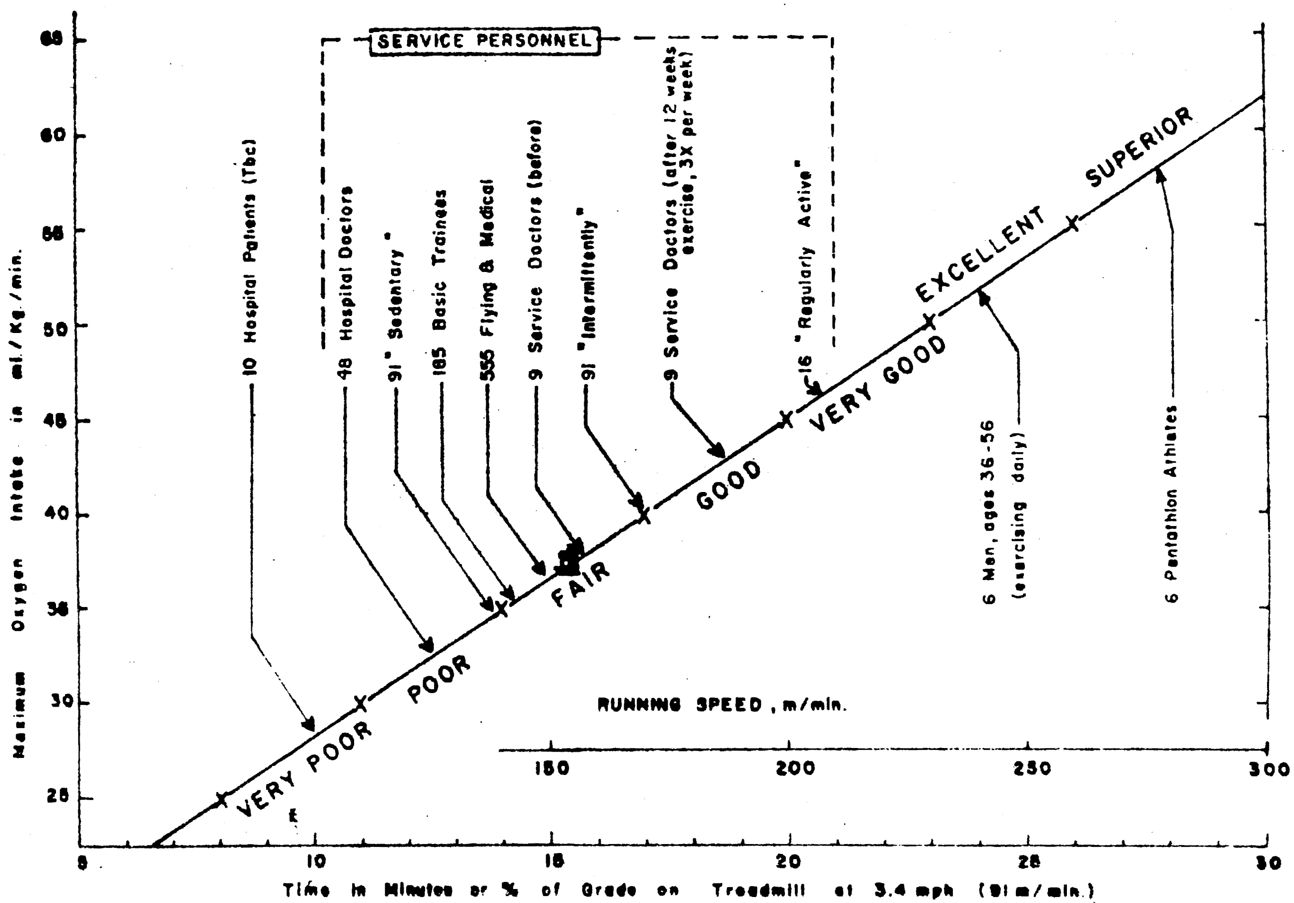
SPEED________________ HEIGHT______________ TIME_________________

1. Oxygen % ____________ CO_2%_________ True O_2____________ RQ__________ (from nomogram)
2. Ventilation/min. = $\frac{\_\_\_\_\_\_}{10}$ kym mm = __________ x 1.332 = __________ L/min.
3. Corr. Vent. = Vent. x Corr. Factor = _____________ x _________ = _________ L/min
4. Oxygen Intake = $\frac{\text{Corr. Vent. x True } O_2}{100}$ = $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{100}$ = ___________ L/min.
5. EMR = $\frac{\_\_\_ \text{x5} \quad \text{x60} \_\_\_}{\text{Sq. M. SA}}$ = ___________________ Cal/hr./Sq. M.

APPENDIX B

REGRESSION LINE FOR PREDICTION OF MAXIMAL OXYGEN INTAKE USING PER CENT ELEVATION TO REACH A HEART RATE OF 180

Maximum Oxygen Intake as Criterion of Functional Potential



Source: Balke, Bruno, and R. T. Clark, "Cardio-Pulmonary and Metabolic Effects of Physical Training," Health and Fitness in the Modern World, Athletic Institute (1961)

APPENDIX C

TOTAL GROUP WORK PERFORMANCE

RAW DATA

No.	Group	HR = 180					HR = 190					HR = max					HR_{max}
		VO_2 (ml/kg/min)	%grd	% O2	$\%CO_2$	Vent (L/min)	VO_2 (ml/kg/min)	%grd	% O2	$\%CO_2$	Vent (L/min)	VO_2 (ml/kg/min)	%grd	% O2	$\%CO_2$	Vent (L/min)	
1	FH	44.52	19	17.05	3.39	69.94						44.52	19	17.05	3.39	69.94	180
2	FH	31.93	15	16.5	4.37	48.80	39.31	17	16.8	4.07	64.42	43.68	20	16.9	4.00	73.33	198
3	FH	30.37	14	16.4	4.07	39.11	33.75	16	16.7	4.45	48.32	47.08	20	16.7	4.34	67.25	198
4	FH	43.40	20	16.75	4.30	59.46						47.51	23	17.0	3.85	68.38	186
5	FH	27.30	15	16.7	3.77	33.82	38.68	18	16.65	4.15	48.35	42.33	22	16.9	4.0	56.45	198
6	FH	45.69	19	16.1	4.68	54.06	50.57	23	16.2	4.75	61.88	52.59	24	16.5	4.52	69.23	192
7	FH	39.72	15	16.8	3.7	55.0	45.76	21	17.0	3.54	66.86	43.18	22	17.1	3.39	64.49	198
8	TR	36.45	12	16.9	3.58	53.58	41.15	14	17.1	3.32	63.07	44.81	15	17.3	3.09	72.31	194
9	TR	42.74	17	16.75	4.03	57.60	47.59	21	17.1	3.77	70.10	53.08	22	17.2	3.47	79.41	192
10	TR	38.55	19	16.9	3.92	48.31	43.05	21	16.75	4.15	52.28	46.30	23	16.8	4.15	56.49	192
11	TR	46.64	23	16.7	4.19	73.53						55.85	27	16.75	4.30	89.95	186
12	TR											42.80	22	17.0	3.62	65.64	174
13	TR											43.05	22	16.75	4.15	62.01	174
14	TR	37.28	15	16.2	4.49	57.61	41.30	17	16.15	4.56	63.30	44.60	19	16.4	4.15	71.60	198
15	BB	39.03	14	16.95	3.62	62.19	41.75	17	17.1	3.47	68.88	50.07	20	17.2	3.83	84.98	204
16	BB	48.55	19	17.0	3.70	83.74						48.55	19	17.0	3.70	83.74	180
17	BB	37.03	16	16.55	4.07	54.80	42.22	19	16.6	4.22	63.77	52.10	23	16.9	3.92	84.69	198
18	BB	43.58	19	16.5	4.15	53.27	45.71	21	16.7	4.00	58.47	51.94	23	16.9	3.92	70.36	204

No.	Group	HR = 180					HR = 190					HR = max					HR_{max}
		VO_2 (ml/kg/min)	% grd	% O2	$\%CO_2$	Vent (L/min)	VO_2 (ml/kg/min)	%grd	% O2	$\%CO_2$	Vent (L/min)	VO_2 (ml/kg/min)	%grd	% O2	$\%CO_2$	Vent (L/min)	
19	BB	32.24	14	16.7	3.77	48.06	40.40	16	16.5	4.07	57.97	43.74	19	16.6	4.15	64.91	192
20	BB	28.06	11	16.55	3.92	44.59	34.44	13	16.7	4.07	57.54	42.82	19	17.06	3.70	77.71	204
21	BB	32.52	13	16.60	4.15	56.29	36.78	15	16.6	4.30	64.26	40.79	16	16.6	4.30	71.24	198
22	SW	42.02	17	16.75	4.0	63.42	46.87	19	17.0	3.8	75.56	50.62	22	17.1	3.7	83.49	198
23	SW	37.24	15	16.75	4.52	63.58	40.77	17	16.9	4.52	72.81	40.77	17	16.9	4.52	72.81	190
24	SW	35.52	14	16.7	4.19	45.13	41.56	15	16.8	4.22	54.61	56.15	22	17.15	3.73	79.79	204
25	SW	31.50	11	16.5	4.22	41.39	33.90	12	16.6	4.22	45.88	49.83	18	16.9	3.85	72.06	216
26	SW	30.30	12	16.0	4.90	36.65	34.35	14	16.15	4.98	43.39	45.19	19	16.4	4.52	59.59	204
27	SW	30.13	15	16.4	4.30	38.65	41.35	18	16.6	4.52	56.74	48.27	20	16.75	4.34	68.63	192
28	SW	29.29	13	16.55	4.37	43.60	35.30	15	16.80	4.07	55.99	42.58	18	17.00	3.88	70.11	198

VITA

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Master of Science

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