Submaximal endurance capabilities of men and women

Edward Walkwitz

The University of Montana

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SUBMAXIMAL ENDURANCE CAPABILITIES OF MEN AND WOMEN

By

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B.S., Springfield College, 1972

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1974

Approved by:

[Signatures]

Chairman, Board of Examiners

Dean, Graduate School

Date Aug 28, 1974
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Female participation in long distance running is growing at a tremendous pace throughout the world. Several recent developments provide evidence of this phenomenon. Prior to the 1972 Olympiad at Munich, Germany, the longest Olympic track event for women was the 800 meter run. At Munich, the 1500 meter run was added to the program. By 1980, the women's 3000 meter run will be an Olympic event.

The Boston Athletic Association, sponsor of the world-famous Boston Marathon (26 miles-385 yards), allowed female entrants to officially run in this classic event for the first time in April 1972. Several weeks later, the Amateur Athletic Union (AAU) let women run in the Men's National Amateur Athletic Union Marathon Championship at Syracuse, New York. At its Kansas City convention in November 1972, the AAU ruled that women were allowed to start with men in races longer than two miles. An announcement made at the 1973 AAU National Convention further stimulated interest in women's marathoning when the Union officially recognized the marathon as a women's championship event. The first Women's National Amateur Athletic Union Marathon Championship was run at San Mateo, California on February 10, 1974. A thirty-one-year-old mother of three from Crestline, California led seventy-three other starters to the finish line in this 26 mile-385 yard race. A ten-year-old San Francisco girl finished fourth in this same event.
Women's cross-country running has also increased in popularity. Over 800 females competed in the Road Runners Club of America Age-Group Cross-Country Championships held in New York in early November 1972. In the same month, 900 entrants, aged seven to fifty-four, participated in the Women's National AAU Open and Age-Group Cross-Country Championships at Long Beach, California.

Several authors have attempted to compare men and women with regard to the physiological differences related to athletic performance. An examination of these differences should give a better insight into the capabilities of the female runner.

Aerobic capacity, or maximum oxygen intake, is the best single measure of endurance fitness and is closely related to the efficiency of the cardiovascular and respiratory systems. The maximum oxygen intake "......indicates the ability to take in, transport and utilize oxygen in the working muscle" (35). Astrand (3) reported that there was a close relationship between aerobic capacity, as measured in the laboratory, and performances in endurance events such as cross-country skiing and distance running. Men and women differ in physiological systems related to aerobic capacity. The differences include respiration, cardiac function, circulation and muscle available for oxygen utilization. A comparative review of these systems suggests that there might be performance differences of men and women in long distance running events.

Respiration Differences

Astrand et al. (3) found well-trained middle-aged women to have lung volumes ten percent smaller than trained men of the same age and
weight. The same author reported that untrained women had smaller lung volumes than untrained men.

Klafs et al. (25) noted that women have a smaller thoracic cavity, respire more rapidly and need less oxygen than men. Lower oxygen requirements for women might be attributed to their smaller body size and lower metabolic rate. The basal metabolic rate, however, is similar when evaluated in relationship to muscle mass (8).

Astrand (1) found similar maximal voluntary ventilation measurements in girls and boys thirteen years of age and younger. The same author cited considerable dissimilarity of maximal pulmonary ventilation in adult men and women; women averaged ninety-two liters/minute, while men averaged 122 liters/minute. He reported a twenty percent greater ventilation per liter of oxygen consumed in women than in men during submaximal work. Likewise, girls had a ten percent greater ventilation per liter of oxygen consumed in contrast to boys of the same age during maximal work.

Metheney et al. (29) compared ventilation in men and women (cc/min/kgm) while each subject walked on a treadmill (at three-and-one-half miles per hour on an 8.6 percent grade for fifteen minutes). No significant differences were found. The same study reported greater maximum ventilation measurements in men when compared to women (while running on a treadmill at seven miles per hour on an 8.6 percent grade).

Astrand et al. (3) found maximal voluntary ventilation to be lower in twenty-five-year-old women than in men of similar ages. Women average 100 liters, while men average 140 liters in this measurement (35). This difference in maximal voluntary ventilation might be attributed to body size.
Other studies have indicated that women have seventy percent of the vital and total lung capacities of men (1). However, the ratio of residual volume to total lung capacity was found to be the same in both sexes (1).

**Differences in the Blood**

It is well known that women have a lower hemoglobin content in the blood than men (1,5,8,15). DeVries (8) made the generalization that men in their twenties have fifteen percent more hemoglobin per 100 milliliters of blood and six percent more erythrocytes per cubic millimeter. This might suggest that men have a greater oxygen carrying capacity than women. Astrand (1) found an 11.9 percent difference in hemoglobin between the sexes, while another source (35) noted that men averaged sixteen grams per 100 milliliters of blood and adult females had approximately fourteen grams.

**Cardiac Function**

In general, the average man has a larger heart in relation to body weight in comparison to the female (20,25). Ulrich (20) suggested that the male needs a bigger heart because men have a larger portion of muscle tissue that must be supplied by the circulatory system.

In addition to a smaller heart, the heart rate of women is usually higher than of their male counterparts (1,29). Montoye et al. (31) stated, "the sex difference in heart rate is well known, and this is likely related to lower hemoglobin concentration and perhaps a smaller relative heart size, and oxygen A-V difference in females". Brouha (5) explained, "At a given level of oxygen consumption the heart rate is higher in women than in men and, conversely for a given heart rate, men
can transport more oxygen than women during submaximal and maximal work". He added, "in both sexes the maximum heart rate during exercise is linearly related with increasing work load, but exhaustion is reached at a lower level of performance in women".

Montoye et al. (31) used a modification of the Harvard Step Test to observe heart rate responses of men and women before, during and after submaximal exercise. The resting heart rates, exercise heart rates and post exercise heart rates were all higher in the women.

**Muscle-Fat Implications**

It is generally accepted that women have a greater percentage of adipose tissue than men. Researchers have found normally active college men to average 12.5 percent body fat (35). Healthy college women average 25.7 percent body fat with the range being 13.6 to 36.8 percent (35). On the other hand, the greater percentage of the total body weight in men is muscle tissue (20). This might suggest that men need more oxygen to supply their greater percentage of muscle. This muscle-fat difference also suggests that women have less strength per unit of body weight (35).

**Aerobic Capacity**

Men and women differ considerably in the physiological systems involved with taking in, transporting and utilizing oxygen. Because of this, it is not surprising to find that men have a higher maximal oxygen intake than women.

Astrand (2) found maximal oxygen intake per kilogram of body weight to be similar for girls and boys aged four to nine. After puberty, males have a higher maximum oxygen intake than females (1,5,15,19,26).
Von Dobeln (37) reported no differences in maximal oxygen intake in male and female physical education students and teachers when expressed per unit of fat-free weight. Macnab et al. (26) found males superior to females in this parameter when the maximum oxygen intake tests were expressed in liters per minute, milliliters per kilogram of body weight per minute, or milliliters per kilogram of fat-free body weight per minute. Macnab's subjects were college physical education students, while Metheney et al. (29) and Hermansen et al. (15) used university students in their maximum oxygen intake studies. The men had higher maximum oxygen intake values in the two later investigations.

Hermansen et al. (15) observed a forty percent greater maximum oxygen intake (liters per minute) in male students, or sixteen percent when body weight was considered. Data presented by the same author showed male athletes participating in endurance-type activities had maximum oxygen intake values averaging forty-five percent higher than female athletes, or thirty percent when body weight was accounted for. Hermansen concluded that maximum oxygen intake differences between men and women were greater among the athletes than among the non-athletic students.

Other authors have reported a twenty-five to thirty percent difference in maximum oxygen intake between the sexes (3,5). This average decreased to fifteen to twenty percent when adjustments were made for body weight (3). Despite these findings, Brouha (5) hypothesized that men and women can use anaerobic processes to the same extent. Although there is universal agreement with regard to the maximum oxygen intake differences, we have little knowledge of the physiological basis of these differences. Astrand (1,2) explained the lower maximum oxygen
intake in women by their higher adipose tissue percentage and lesser hemoglobin concentration in the blood. Macnab et al. (26) referred to differences in blood volume, cardiac output, lung capacity and maximal ventilation as possible causes of higher maximum oxygen intake in men.

Performance Differences

In a study by Astrand (1), male and female subjects pedalled on a bicycle ergometer at a work rate requiring 2.1 liters of oxygen per minute. The men reached average pulse rates of 128 beats per minute, while the women averaged 168 beats per minute. The results indicated that the women were probably under more stress for this type of exercise. It was estimated that the women used seventy-three percent of their aerobic capacity, while the men used fifty percent.

Macnab et al. (26) compared college physical education students on a modified Sjostrand Physical Work Capacity Test. The test measured physical work capacity at three submaximal work rates on a bicycle ergometer. He also administered a progressive step test whereby physical work capacity was evaluated by the ability to maintain a work rate equivalent to a steady state heart rate of 170 beats per minute. Men were superior to the women on both tests, whether results were interpreted using raw score units, units per body weight, or units per fat-free body weight. Holmgren, Cumming, and Bengtsson (26) found men to outperform women on the PWC$_{170}$ submaximal test.

Thirty years ago, Metheney et al. (29) investigated the physiological responses of men and women to moderate and exhaustive exercise. The moderate activity involved walking on a treadmill for fifteen minutes on an 8.6 percent grade, while the more exerting exercise required each
performer to run on a treadmill for five minutes at seven miles per hour. Ventilation, oxygen consumption, Respiratory Quotient, blood lactate, blood sugar, pulse rate and blood pressure measurements were recorded during and after each test. No significant differences were observed in the ventilation, oxygen consumption and Respiratory Quotient values during moderate walking exercise. Although blood sugar concentrations were similar, faster increases in the heart rates and greater lactate concentrations were noted among the female subjects. The recovery index and the work index, which measured fitness for exertion, seemed to indicate that the women were less fit for moderate physical activity.

During the running phase of the Metheney study, the women averaged half the running time of men, they had higher blood sugar levels after the run, and they had lower Respiratory Quotient, maximum ventilation and oxygen consumption values. It was concluded that the women were even less fit for running than they were for walking. The authors observed that the more fit women were similar to the less fit men. Despite the similarities, the blood lactate levels were slightly higher in the women and the female work index was slightly lower. It appeared that the females were less fit for long-duration, submaximal work.

DeVries (8) referred to the endurance experiments of Klaus and Noack involving the training of men and women over a period of eighteen weeks. The results indicated that the men's capacity for distance running was one-third more than for women. The investigators suggested discouragement of female participation in running competitions exceeding 1000 meters. It is interesting to note that eleven years after their study was published, the 1500 meter run for women was added to the Olympic Games. In 1971, over 100 women competed in marathons in the
United States (38). In February 1974, seventy-four females ran the 26 mile-385 yard marathon at San Mateo, California. At least 1700 females ran in national cross-country championships during the 1972 season.

Astrand (1,3) observed the physiological responses of two men and two women, aged 24-35, on a series of work tests on a bicycle ergometer and treadmill over an eight hour period. The subjects alternately cycled and walked fifty minutes and rested for ten minutes. Seven fifty-minute work periods were carried out throughout the day. A one-hour rest period was provided at mid-day. The workload of the submaximal tests corresponded to fifty percent of each individual's maximum oxygen intake. Each performer lost from .2 to 2.7 percent of his or her total body weight. In addition to dehydration, there were slight increases in body temperature and decreases in the Respiratory Quotient ratios. The Respiratory Quotient decreases may indicate a shift to fat combustion as a source of energy. The author concluded that work loads corresponding to fifty percent of the maximum oxygen intake should be the limit for eight-hour work periods for men and women.

A comparison of the actual competitive performances of men and women suggests that there are physiological differences related to long-distance running. The world record for the women's one mile run was established by Paola Cacchi of Italy in 1973. In 1967, Jim Ryun of the United States ran 3:51.1 for the men's record. Cacchi recorded a 4:29.5. In 1972, at least ten male collegians ran better than 3:59 in this same event. In fact, ten American schoolboy (high school) runners ran better than 4:13 during the same year.
Marathon performances also suggest that physiological capabilities differ in men and women. Twenty-eight year old Adrienne Beames of Australia is the fastest women's marathoner of all time with a time of 2 hours, 46 minutes, and 30 seconds. Miki Gorman, a Los Angeles housewife, ran the distance in 2 hours, 46 minutes, and 36 seconds. Gorman is recognized as the world record holder because Beames ran her marathon in an unsanctioned race. In 1969, Australian Derek Clayton ran 2 hours, 8 minutes and 33.6 seconds at Antwerp, Belgium for the men's record. As of January 1973, only ten women marathoners had ever run better than three hours in the marathon. Seven hundred American men ran faster than three hours in 1970, 1100 in 1972, and at least 1500 bettered this standard in 1973. In 1972, over 100 sub-2 hour-and-20-minute marathons were run by men throughout the world. The performances of women marathoners have also improved. Thirteen American women ran better than 3 hour-and-30-minute marathons in 1972. This figure represented a 100 percent increase from 1971. In 1972, fifty-three females ran four hours or better in the marathon. During the 1973 season, eighty females ran under four hours in marathons. When Miki Gorman established the women's marathon record, she finished forty-sixth in a field of nearly 600 men.

Environmental Adaptability

Women are less able to adapt to hot environments (8,13). Since the female's threshold for sweating is above that of the male's maintaining heat balance during hot weather is more difficult for the female. Forman (13) stated, "the fact that females perspire at a higher temperature threshold than males may mean that they would be adversely affected by heat relatively earlier than their male counterparts and thus require
markedly different rules pertaining to their participation in long distance races".

PROBLEM

Statement of the Problem

Despite the differences of males and females, women are not only competing with men, but many are also training under similar systems and workloads. This might suggest that coaches, physical educators and related professionals are prescribing training and jogging programs without a sound physiological understanding of the submaximal endurance capabilities of the female. Many studies have been conducted pertaining to the physiological responses of men to prolonged submaximal activity, but few have compared men and women during prolonged submaximal work. Past studies that have investigated the endurance capabilities of men and women have compared their performances at absolute workloads. Little research has been undertaken using relative loads. Little is known with regard to the relative endurance capabilities of men and women.

Purpose

The purpose of this study was to compare the submaximal endurance capabilities of men and women. Specifically, this investigation compared the ability of men and women to bicycle at ninety-five percent of their maximal oxygen intake capacities. Comparisons were made between trained men, trained women, untrained men and untrained women. An attempt was made to determine if women could perform as well as men while cycling at relative workloads eliciting ninety-five percent of their maximal oxygen intake capacities. The results of this study should add insight to
understanding the submaximal endurance capabilities of women when compared to their male counterparts.
CHAPTER II

THE PROCEDURE

THE SUBJECTS

Fourteen students, eighteen to twenty-one years of age, volunteered to participate in a series of maximal and submaximal bicycle endurance tests at the University of Montana Human Performance Laboratory. Subjects were categorized into one of the following groups:

- Group I - Trained Men (n=4)
- Group II - Untrained Men (n=3)
- Group III - Trained Women (n=4)
- Group IV - Untrained Women (n=3)

The members of the trained groups were long distance and middle distance runners from the Missoula, Montana area. The four trained women were athletes on the University of Montana Women's Track Team. Three of the trained men were varsity track candidates at the University of Montana, while the fourth was the Montana Interscholastic Champion at one mile (1973), two miles (1973) and cross-country running (1972, 1973).

The criteria used in the selection of the trained subjects were that the candidates must be:

1. eighteen to twenty-one years old
2. middle distance or long distance runners
3. interested in participating in the study
4. willing to participate in a series of maximal and
submaximal bicycle tests and follow the guidelines of rest and diet necessary for the success of the investigation.A description of each of the trained subjects appears in Table I.

The untrained volunteers were not athletes and were not participating in physical conditioning programs. None of the subjects had ever participated in physical activities such as distance running, cross-country skiing, swimming, distance bicycling or other activities where cardiovascular endurance was essential to the sport. The candidates were interviewed in order to assure that their experience in cardiovascular training was limited.

The criteria used in the selection of the untrained subjects were that the candidates must be:

1. eighteen to twenty-one years old
2. non-smokers
3. untrained in cardiovascular endurance type activities
4. interested in participating in the investigation
5. willing to participate in a series of maximal and submaximal bicycle tests and follow the guidelines of rest and diet necessary for the success of the study

A description of each of the untrained subjects appears in Table I.

The investigator explained the procedures, purposes and the expected time required of each subject. Each candidate was asked to report to the laboratory so that he or she could examine the equipment and get a better concept of the nature of the research program. The researcher informed each subject that the testing would require maximal efforts. Each volunteer was examined by a physician prior to partici-
<table>
<thead>
<tr>
<th>Subjects</th>
<th>Height (inches)</th>
<th>Weight (kilograms)</th>
<th>Age (years)</th>
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<tr>
<td><strong>Male Subjects (trained)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R.R.</td>
<td>70</td>
<td>68.18</td>
<td>18</td>
</tr>
<tr>
<td>D.E.</td>
<td>75</td>
<td>73.41</td>
<td>19</td>
</tr>
<tr>
<td>S.C.</td>
<td>68.5</td>
<td>55.45</td>
<td>21</td>
</tr>
<tr>
<td>I.C.</td>
<td>69</td>
<td>68.41</td>
<td>18</td>
</tr>
<tr>
<td><strong>Female Subjects (trained)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.B.</td>
<td>70</td>
<td>68.75</td>
<td>21</td>
</tr>
<tr>
<td>M.H.</td>
<td>67.5</td>
<td>52.72</td>
<td>21</td>
</tr>
<tr>
<td>B.M.</td>
<td>64</td>
<td>55.23</td>
<td>19</td>
</tr>
<tr>
<td>K.M.</td>
<td>62</td>
<td>46.59</td>
<td>19</td>
</tr>
<tr>
<td><strong>Male Subjects (untrained)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.A.</td>
<td>64</td>
<td>65.45</td>
<td>18</td>
</tr>
<tr>
<td>D.J.</td>
<td>70</td>
<td>71.25</td>
<td>19</td>
</tr>
<tr>
<td>J.H.</td>
<td>67</td>
<td>62.27</td>
<td>19</td>
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<tr>
<td><strong>Female Subjects (untrained)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.M.</td>
<td>68</td>
<td>56.36</td>
<td>19</td>
</tr>
<tr>
<td>K.M.</td>
<td>70</td>
<td>76.08</td>
<td>19</td>
</tr>
<tr>
<td>T.R.</td>
<td>67</td>
<td>62.39</td>
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pating in the tests.

**EQUIPMENT**

Equipment was needed to collect and analyze the expired respiratory gases from the bicycle performer. Instruments necessary in this study included the following:

**Bicycle Ergometer**

Each subject was tested for maximum oxygen intake and submaximal endurance capability on a Monark bicycle ergometer. By adjusting the knob located in front of the handlebars, belt tension was applied to the ergometer wheel. The workload, in kilopond or kilopond meter units, was dependent upon the degree of belt tension on the wheel as the performer pedalled. A gauge on the side of the bicycle recorded the force exerted in kiloponds. The load was converted to work rate (kilopond meters per minute) by multiplying the braking force in kiloponds by the distance pedalled (meters) in one minute. Figure 1 illustrates the bicycle ergometer used in this study.

**Gas Collection Apparatus**

Gas collection apparatus was needed in order to collect the expired respiratory air from the subject performing on the bicycle ergometer. These samples of air were later analyzed in order to determine the maximum oxygen intake. The gas collection equipment used in this study included the following:

**Breathing valve and mouthpiece.** A Collins Triple "J" breathing valve and flexible rubber mouthpiece allowed the subject to inhale atmospheric air, and expire respiratory air into the Douglas
Figure 1: Side view of bicycle ergometer
bags. A foam rubber, wired nosepiece was clamped to the performer's nose during the gas collection procedures to prevent air flow through the nostrils.

**Gas collection bags.** Two, 200 liter, vacuum-sealed, canvas Douglas bags were used to collect one minute samples of expired air during the maximum oxygen intake testing.

**Four-way valve.** A Hans-Rudolph four-way valve regulated the flow of expired air from the Collins Triple "J" breathing valve to the Douglas bags. The four-way valve also controlled the flow of air from the Douglas bags to the gasometer, where the volume of expired air was measured. One-and-one-half inch plastic corrugated tubing connected the breathing valve to the four-way valve, the four-way valve to the Douglas bags, and the Douglas bags to the gasometer. The gasometer is described under the next section on gas analysis instruments.

**Pendulum metronome.** A Wittner Precision pendulum metronome assisted the performer in maintaining a pedal rate frequency of sixty revolutions per minute.

**Physiological monitor.** A Tektronix, Model 410 physiological monitor allowed the investigator to observe heart rates during the gas collection procedures.

**Clock timer.** A universal clock timer was used to time the bicycle performer during the maximum oxygen intake and submaximal endurance tests.

**Stopwatch.** A thirty-second stopwatch was used to time the one minute collections of expired air into the Douglas gas collection bags. Stopwatches were also used to time the submaximal endurance tests and the gas analysis in the gas partitioner. Figure 2 illustrates
bags. A foam rubber, wired nosepiece was clamped to the performer's nose during the gas collection procedures to prevent air flow through the nostrils.

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Figure 2: Front view of subject, gas collection apparatus and testing equipment
the gas collection apparatus.

Gas Analysis Instruments

After the expired air was collected in the Douglas bags, the next procedure was to determine the maximum oxygen intake expressed in milliliters of oxygen utilized per kilogram of body weight. The following instruments were necessary for gas analysis:

Gas partitioner. Samples of expired air were analyzed for the percentage composition of carbon dioxide and oxygen by a Fisher-Hamilton gas partitioner. One-liter air samples were drawn through the .5 milliliter sample loop of the partitioner from the Douglas bag. Upon pressing the knob of the sampling valve, a flow of helium carried the gases through two chromatographic columns where the oxygen and carbon dioxide components were separated. A heated thermal detector in the partitioner sensed the difference in the thermal conductivity of each of the component gases, and an electrical signal was relayed to the recorder.

Recorder. A one millivolt Texas Instrument recorder accepted electrical signals from the gas partitioner and registered chromatographic peaks on the recorder graph paper. The percentage content of the components in the sample air could be interpreted by plotting the appropriate points on the reference graph line.

Suppressor. A Fisher zero suppressor supplemented the operation of the recorder and partitioner by extending the range of the recorder. The suppressor allowed the use of a high level of instrument sensitivity.

Pressure vacuum pump. A 115 volt Neptune Dyna-Pump pulled
Figure 3: Gas analysis instruments
A. Carrier gas tank (helium)
B. Gas partitioner
C. Pressure vacuum air pump
D. Recorder
E. Reference tanks
F. Suppressor
one liter samples of air from the Douglas bag, through one-quarter inch tygon tubing, through a drying tube and into the sampling valve of the gas partitioner.

**Drying tube.** An elongated glass tube filled with granulated moisture absorbent Drierite particles dried samples of air before they entered the gas partitioner.

**Carrier gas.** Helium gas carried the sample to be analyzed through the chromatographic columns in the partitioner where the oxygen and carbon dioxide were separated from the remainder of the sample. Gas flow was maintained at forty milliliters per minute by use of a regulator and frequent reference to a bubble tower flow rate indicator.

**Reference tanks.** Two tanks filled with a mixture of carbon dioxide and oxygen were used as reference gases throughout the study. Tank #1 contained 15.207 percent oxygen and 4.963 percent carbon dioxide, while tank #2 was filled with a mixture of 18.454 percent oxygen and 2.367 carbon dioxide. By plotting a reference gas graph each day, the percentage composition of oxygen and carbon dioxide in the expired gas samples could be interpreted from the peaks on the recorder graph paper.

**Sample bag.** A two liter rubber sample bag was used to extract and hold a sample of air from the reference tanks prior to introducing it into the partitioner.

**Scholander gas analyzer.** A Scholander micrometer gas analyzer was used to determine the percent composition of carbon dioxide and oxygen in the reference tanks. In addition to calibrating the Fisher gas partitioner, this analyzer was used to check the accuracy of the gas partitioner.

**Bailey bottle.** A bi-tubular glass bottle with a mercury
balance allowed the investigator to extract air from the reference tanks and Douglas bags for analysis in the Scholander gas analyzer.

**Gasometer.** A Collins 600 liter chain-compensated wet gasometer measured the volume and temperature of the expired air.

**Barometer-thermometer.** A combination mercury barometer-thermometer measured the barometric pressure (milliliters of mercury) and the room temperature (degrees centigrade) in the laboratory.

**Scale.** Each subject was weighed on a Medico Equipment balance scale prior to each testing period. The weight in pounds was converted to kilograms by dividing the weight (pounds) by 2.2.

---

**MAXIMUM OXYGEN INTAKE TESTING**

**Pilot Study**

Prior to the actual maximum oxygen intake testing schedule, the subjects were familiarized with the procedures and equipment used in the study. It was essential that each participant learn the bicycle pedal rate (sixty revolutions per minute) and adjust to the breathing apparatus (Collins Triple "J" valve and nosepiece). The pilot study was conducted over a period of two weeks. Upon completion of these preliminary sessions, the volunteers were assigned testing times.

**Maximum Oxygen Intake Test**

Subjects reported to the laboratory dressed in gym shorts, socks, sneakers (or running shoes), and a cotton T shirt. The women wore swimsuit tops for ease of electrode placement. All subjects were requested to refrain from eating or drinking for the two hours prior to testing. Strenuous exercise was avoided the day preceding each session, and all
participants remained relatively inactive the morning of the testing period. The laboratory temperature ranged from nineteen to twenty-one degrees centigrade throughout the investigation.

Upon entering the laboratory, the subject removed his or her footwear and was weighed to the nearest half-pound. The subject sat on the bicycle ergometer and the seat height was adjusted so that the knee was only slightly flexed on the lower leg swing. The volunteer removed his shirt so that the investigator could place moleskin adhesive electrodes on the left and right fifth ribs just lateral to and below each nipple. The females, attired in bathing suit tops, had electrodes placed on the left lateral fifth rib and the sternum. Exercise heart rates were observed with a Tektronix, Model 410 physiological monitor. Figures 4 and 5 illustrate the physiological monitor with the proper electrode placement for males and females.

The maximal oxygen intake test administered was similar to that of McArdle, Katch and Pearch (27). Keeping cadence with the aid of a metronome, the subject pedalled at sixty revolutions per minute. Hermansen et al. (16) found this pedal rate to elicit higher maximum oxygen intake values when compared to fifty, seventy and eighty revolutions per minute.

The cyclist began pedalling at sixty revolutions per minute with no belt tension on the bicycle flywheel. The nose was clamped with a wired-foam rubber nosepiece and the subject breathed into a Collins Triple "J" breathing valve and flexible rubber mouthpiece. The breathing valve allowed the subject to take in atmospheric air and expire respiratory air into a Douglas bag. The flow of air into the Douglas bag was regulated by a Hans-Rudolph four-way valve. The work rate was increased
Figure 4: Electrode placement on female

Figure 5: Electrode placement on male
180 kilopond meters per minute every two minutes until the pulse rate reached 140 to 150 beats per minute. The workload (kilopond meters per minute) was dependent upon the amount of belt tension on the ergometer wheel, and was regulated by adjusting the knob in front of the handlebars. A one minute sample of expired air was diverted into Douglas air bag number one at the workload at which the 140 pulse rate was elicited. Astrand et al. (3) reported that the oxygen uptake at a given workload leveled off after two-and-one-half minutes of exercise. The one minute gas collection was made after two-and-one-half minutes at that particular work rate. The heart rate and the precise load at which the gas was collected were recorded. Thereafter, the bicycle belt tension was continually increased 180 kilopond meters per minute every two minutes until the heart rate was monitored at 180 beats per minute. A one minute sample was channeled into Douglas bag number two at the 180 pulse rate load, and the heart and work rates were recorded. The ergometer pedal resistance was decreased and the exercise was terminated. The subject was instructed to return to the laboratory in three days.

The weighing, electrode placement and bicycle seat adjustment procedures during the second session were identical to those of the previous testing. The workloads were increased in 180 kilopond meter increments every two minutes. One minute expired air samples were collected after two-and-one-half minutes of work at each load beyond the highest level attained on the first day. The work increments were continually increased until the oxygen uptake leveled off or the subject was no longer able to continue exercising at the prescribed workload and pedal rate frequency. The criterion for the levelling off of oxygen consumption was an increase of less than 100 milliliters. Strong verbal
encouragement was given to the performer to promote the highest work output possible. If the maximum oxygen intake was not determined at this session, the volunteer reported to the laboratory three days later for retesting. The procedures were similar to the second test period.

Gas Analyzer Calibration Procedures

Expired air was analyzed for the percentage of oxygen and carbon dioxide with a Fisher-Hamilton gas partitioner. The partitioner was calibrated before and during each experimental session by analyzing the two reference gases in each of the commercially prepared tanks. The reference gas mixtures were verified with a Scholander micrometer gas analyzer. Each tank mixture was drawn into the partitioner where the oxygen and carbon dioxide were analyzed and the corresponding chart unit values were registered on the recorder graph paper. A conversion line was constructed for each of the reference gases during each session by plotting the chart unit values against the known percentage of carbon dioxide and oxygen in the tanks. This line was later used to convert the chart values of the gases in the expired air sample to percent composition.

Gas Analysis

A 115 volt vacuum pump, connected to the outlet port of the system, pulled one liter samples of air from a 200 liter Douglas bag and into a Fisher-Hamilton gas partitioner. The pump was disconnected after sample introduction, the sampling knob was pressed, and a flow of helium gas swept the expired air into two chromatographic columns where the component gases were separated and eluted from the system at different times. A heated filament, sensing the thermal conductivity of each of
the component gases, relayed an electrical impulse to the recorder. Chromatographic peaks, corresponding to the amount of oxygen and carbon dioxide in the sample, were registered on the recorder graph paper. Duplicate samples were introduced into the system to insure consistency in gas analysis.

The remainder of the expired air in the Douglas bag was diverted into a 600 liter, Collins chain-compensated wet gasometer. This instrument measured the volume and temperature of the gases. Prior to introducing the expired air into the gasometer, the pre-test scale reading was recorded on the data sheet. Table VI in the Appendix illustrates a sample data form. The post-test scale reading was recorded after the Douglas bag sample was emptied into the gasometer. The gas temperature was read from the thermometer on the metal cylinder.

Calculating the Corrected Volume

The volume of the respiratory air was computed by subtracting the pre-test from the post-test value, multiplying this difference by the gasometer factor (5.158 cm per liter), and adding the volume of sample air pumped into the partitioner to this product.

Corrected Volume = Post - Pre = Difference X Gasometer Factor + Analyzed Volume

Computing the Ventilation Rate

The STPD conversion factor, derived from the barometric pressure (millimeters of mercury) and gas temperature (degrees centigrade), was multiplied by the expired air volume to determine the ventilation rate. The ventilation rate was expressed in liters per minute by dividing the
corrected volume by the number of minutes in the collection period (one). Darling's nomogram (6) was used to determine the correction factor from the barometric pressure and gas temperature.

Conversion Factor \( \times \) Corrected Volume = Ventilation Rate

**Calculating the Oxygen Intake**

The calibration lines (carbon dioxide, oxygen) were constructed from the reference tank gas mixture analysis. Duplicate samples of expired air were drawn into the gas partitioner, and the carbon dioxide and oxygen chart unit values were recorded on graph paper as peak heights. By applying the chart values to the calibration lines, the percentages of oxygen and carbon dioxide in the air were determined. Because the partitioner registered the argon and oxygen in the sample as one peak on the recorder graph paper, it was necessary to subtract .9 percent argon (34) to compute the actual percentage of oxygen.

\[
\text{Percent Oxygen} = \text{Uncorrected Oxygen Percent} - .9 \text{ Percent Argon}
\]

The percentage composition of carbon dioxide and oxygen was applied to a nomogram and true oxygen. The oxygen intake (liters per minute) was calculated by multiplying the ventilation rate by the true oxygen. The oxygen intake was expressed as milliliters of oxygen consumed per kilogram of body weight by dividing the oxygen intake (liters per minute) by the subject's weight in kilograms.

\[
\text{Oxygen Intake (liters/minute)} = \text{Ventilation Rate} \times \text{True Oxygen}
\]

and

\[
\text{Oxygen Intake (ml/kg/min)} = \frac{\text{Oxygen Intake (liters/minute)}}{\text{Body Weight (kilograms)}}
\]
SUBMAXIMAL ENDURANCE TEST

Eight to ten days after the maximum oxygen intake testing was completed, the subjects reported to the laboratory for a submaximal endurance test on a bicycle ergometer. Food and water consumption was avoided three hours prior to testing. High carbohydrate diets were avoided during the four days preceding the test period to minimize the possible effects of glycogen supercompensation. Each participant had sufficient sleep and rest on the two nights before the performance. None of the volunteers were experiencing health problems, ailments, general fatigue or menstrual discomforts. Each participant was instructed to refrain from vigorous physical activity during the forty-eight hours preceding the submaximal endurance performance.

Upon entering the laboratory, the subject was weighed, the room temperature was recorded and the bicycle seat was adjusted to the correct height. The temperature range was similar to that of the maximum oxygen intake sessions (nineteen to twenty-one degrees centigrade). The participant was instructed to sit quietly for ten minutes.

Several points were considered before determining the workloads at which the submaximal tests were conducted. Katch (21) found that maximal oxygen intake did not predict bicycle endurance performance unless the exercise was continued for at least eight minutes, but the prediction validity increased only slightly for work beyond twelve minutes. Saltin (32) reported that a work intensity requiring ninety-five percent of the maximum oxygen intake capacity could be sustained for fifteen to thirty minutes. A marathoner can run at eighty-five percent of his capacity, while ninety percent of the maximum oxygen intake can be maintained for
one hour (32). Astrand (3) noted that work intensities demanding 100 and ninety-five percent of the total aerobic capacity could be endured for ten and thirty minutes respectively. The same author reported that eighty-five percent could be continued for sixty minutes, while the eighty percent level could be endured for 120 minutes. A workload demanding ninety-five percent of the maximum oxygen intake was selected for this investigation. The literature suggests that this percentage should allow all performers to exercise at least eight minutes.

This study compared the ability of trained men, untrained men, trained women and untrained women to bicycle at ninety-five percent of the maximum oxygen intake capacity. Specifically, each subject pedalled at relative work intensities dependent upon each individual's measured aerobic capacity.

In order to determine the ninety-five percent workload, a graph was constructed with the oxygen consumption (milliliters per kilogram of body weight) along the ordinate axis, and the workload (kilopond meters per minute) on the abscissa. A graph was drawn for each subject. The graph used for subject D.J. is illustrated in Figure 6. The workloads and the oxygen intake measurements from the previous testing sessions were plotted and a straight line was drawn from the 140 pulse rate oxygen consumption value to the maximum oxygen intake point. It is accepted that there is a linear relationship between work intensity and oxygen consumption (33).

Ninety-five percent of the maximum oxygen intake was calculated for each of the subjects. The computation for subject D.J. is shown below:

\[ \frac{95}{100} \times 52.73 = 50.10 \text{ ml/kg/min} \]
Figure 6: Relationship of oxygen consumption and workload for subject D.J.; determining the ninety-five percent workload.
A horizontal line was extended from this value on the ordinate axis to the constructed workload-oxygen intake line. A perpendicular line was drawn to the abscissa from the intersection of the horizontal and graph lines. The workload value that the perpendicular line intersected on the abscissa was the workload at which the performer bicycled for the ninety-five percent value. Identical procedures were used to determine the belt tension loads corresponding to twenty-five, fifty and seventy-five percent of the maximum oxygen intake. The three latter submaximal loads were used as a warm-up prior to exercising at the ninety-five percent workload. The appropriate computations for subject D.J. are illustrated below:

\[
\frac{25}{100} \times 52.73 = 13.18 \text{ ml/kg/min}
\]

\[
\frac{50}{100} \times 52.73 = 26.37 \text{ ml/kg/min}
\]

\[
\frac{75}{100} \times 52.73 = 39.55 \text{ ml/kg/min}
\]

The bicycle pedal rate (sixty revolutions per minute) was identical to the rate used during the maximum oxygen intake testing. A pendulum metronome established the sixty revolutions per minute cadence necessary for the test.

Katch (21) reported that male college students experienced considerable leg pain when tested for twelve minutes at 1656 kgm minute on a bicycle ergometer. During the pilot study portion of this investigation, it was observed that the subjects experienced acute leg cramps when the work intensity was increased in large increments. During the actual testing, it was necessary to increase the ergometer pedal resistance in smaller increments before cycling at the ninety-five percent level.
The subject pedalled for two minutes with no belt tension and then progressed to one-and-one-half minutes at workloads representing twenty-five, fifty and seventy-five percent of the maximum oxygen intake.

Table II presents the submaximal and maximal workloads. Upon completion of the continuous exercise at these four loads, the bicycle pedal resistance was immediately increased to the ninety-five percent level. The subject pedalled at this workload for as long as he could maintain the sixty revolutions per minute pedal rate. If the rate slowed, the investigator offered strong verbal encouragement for maximum effort. The exercise was terminated when the subject could no longer maintain the sixty revolutions per minute frequency at the ninety-five percent workload. The times for the ninety-five percent and other submaximal loads were recorded to the nearest second.
<table>
<thead>
<tr>
<th>Subject</th>
<th>25% workload (KPM)</th>
<th>50% workload (KPM)</th>
<th>75% workload (KPM)</th>
<th>95% workload (KPM)</th>
<th>100% workload (KPM)</th>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>I.C.</td>
<td>365</td>
<td>785</td>
<td>1200</td>
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<td>S.C.</td>
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<td>1884</td>
<td>1980</td>
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<td>325</td>
<td>910</td>
<td>1480</td>
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<td>815</td>
<td>1050</td>
<td>1116</td>
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<td>765</td>
<td>1010</td>
<td>1080</td>
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<td>900</td>
<td>990</td>
</tr>
<tr>
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<td>1620</td>
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<td>930</td>
<td>1192</td>
<td>1260</td>
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<td>1440</td>
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<tr>
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<td>890</td>
<td>1015</td>
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<td>615</td>
<td>945</td>
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RESULTS, DISCUSSION AND SUGGESTIONS

RESULTS AND DISCUSSION OF THE MAXIMUM OXYGEN INTAKE TESTING

Table III illustrates the maximum oxygen intake measurements for each of the fourteen subjects. The values are expressed in liters of oxygen per minute, and milliliters per kilogram of body weight per minute. The ventilation rate, maximal heart rate and the workload at which each maximum oxygen intake was elicited is indicated in the same table. Oxygen intake data for the 140 pulse rate-submaximal workloads are presented in Table V in the Appendix.

The maximum oxygen intake capacities for the trained men ranged from 56.48 to 69.12 (ml/kg/min), and averaged 64.27. In 1968, Stagg (36) tested six University of Montana varsity distance and middle-distance track athletes and found the maximum oxygen intake to range from 49.42 to 64.09 ml/kg/min. The average was 59.5. The trackmen in the present investigation have a better capacity for taking in, transporting and utilizing oxygen on the bicycle ergometer. Costill et al. (7) found maximum oxygen intake in six nationally ranked American marathoners to average 71.4 ml/kg/min on a continuous treadmill test. Although the higher values in Costill's study can be partially explained by the instruments used in the investigation (treadmill instead of a bycycle), the success of these marathoners in national competitions suggests that the maximum oxygen intake differences can also be attributed to their
<table>
<thead>
<tr>
<th>Subject</th>
<th>Ventilation rate (liters/minute)</th>
<th>Maximum oxygen intake (liters/minute)</th>
<th>Maximum oxygen intake (ml/kg/min)</th>
<th>Maximum oxygen intake workload (kpm)</th>
<th>Maximum heart rate</th>
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superior cardiovascular fitness. This is also consistent with Wilt's (12) postulation that the importance of aerobic capacity in running performance increases as the competitive distance is of longer duration. The four trackmen in the present study competed in events from one to six miles.

The response of the trained women to the maximum oxygen intake testing averaged 45.02 ml/kg/min, and ranged from 39.05 to 54.18 ml/kg/min. Drinkwater et al. (11) reported that highly trained trackwomen averaged 51.1. Doris Brown, who dominated women's distance running in the United States during the late 1960's and early 1970's, scored 65 on a bicycle ergometer and 67 on a motor driven treadmill (13). McArdle et al. (27) concluded that leg force capacity, muscle blood flow, metabolic capacity of specific muscle groups, and the amount of active muscle mass should be considered in explaining the lower bicycle measurements.

A partial explanation for the lower maximum oxygen intake measurements among the trackwomen in the present study when compared to other investigations can be attributed to the event specialization of the subjects tested. Two of the four female runners (M.H. and A.B.) competed in short middle-distance or sprint events (220 to 880 yards), and rarely raced in events longer than one mile. According to Wilt's (37) training emphasis tables, anaerobic metabolism and speed are more important than aerobic capacity (the maximal oxygen intake) in racing distances of 220 to 880 yards. Anaerobic metabolism is the process that does not require oxygen for the production of energy in muscular work. Trackwomen K.M. and B.M. specialized in middle distance events. K.M.'s comparatively higher maximum oxygen intake (54.18 ml/kg/min) indicates that she has a more efficient oxygen transporting system than the other trackwomen, and a greater capacity to excel in running events of a longer duration.
The untrained men had maximum oxygen intake measurements of 40, 49.42, and 52.73 ml/kg/min, and the untrained women registered 33.62, 39.72, and 43.77. The average for these groups were 39.04 and 43.78 ml/kg/min respectively. McArdle et al. (27) tested fifteen college men on a bicycle ergometer (twelve untrained and three varsity cross-country runners) and found the maximum oxygen intake to average 50 ml/kg/min.
Although the average in McArdle's study was slightly higher than in the present investigation, the values are in agreement because the data from the three varsity cross-country runners raised the total group average. The maximal oxygen intake measurements for the untrained women in the present study were higher than the average measurements of inactive women found by other researchers (30,28). The relatively small sample size must be considered as a possible explanation for these differences. However, one of the three untrained women tested (K.M. with 33.82 ml/kg/min) was similar to the averages in other studies.

Other studies (23,28,24) have reported a wide variation in maximum oxygen intake among untrained individuals. Recent histo-chemical research (32) on skeletal muscle cells indicates that the differences in maximum oxygen intake and endurance capability among non-athletes may be due to the naturally endowed variability in relative muscle fiber composition. Fast contracting low oxidative (fast twitch) and slow contracting high oxidative (slow twitch) muscle fibers are the two types of motor units found in the human. Individuals with a predominate percentage of slow contracting fibers are believed to have a greater capacity for endurance performance, while subjects with a majority of fast contracting fibers are more apt to be successful in explosive, very intense exercise of short duration. The recruitment of the fast
or slow fibers depends on the intensity and duration of the performance. Fast twitch fibers are selectively recruited when the exercise involves a high rate of muscular contraction, and when anaerobic metabolism is the predominate source of energy. In contrast, the slow twitch units have a high oxidative potential and are recruited for long duration exercise when aerobic mechanisms furnish the bulk of the energy requirements. The above research indicates that the individuals with high maximum oxygen intake measurements correspondingly have a higher percentage of slow contracting fibers. Training can increase the oxidative potential of the fibers (14,32). More will be said regarding the improvement of the aerobic processes in the two types of contractile units later in this discussion.

The trained trackmen had higher maximum oxygen intake values than any of the untrained subjects of either sex. These results support other studies that have found successful endurance athletes to be superior to untrained subjects in this capacity (28,3). Training can enhance the aerobic capacity by increasing the size of the slow twitch fibers, and producing higher concentrations of oxidative enzymes in skeletal muscle (32,14). Other researchers (32) have reported that untrained men have a lesser percentage of slow contracting muscle fibers in comparison to trained endurance athletes. The non-athletes averaged forty percent slow twitch fibers, while the endurance performers had a majority of the slow contractile units.

A comparison of the competitive performances of the trained groups indicates that the trackmen are more capable of taking in, transporting and utilizing oxygen for distance running. Trackmen S.C., D.E. and R.R. (68.69, 62.79 and 69.12 ml/kg/min) have run better than 4:30
for the mile, and 9:30 for two miles. Trackman I.C. (56.48 ml/kg/min) has run 10:20 for two miles and 4:55 in the mile. I.C.'s lower maximum oxygen intake indicates that he is lower in cardiovascular fitness than the other trained men. The less superior track performances support this hypothesis. None of the trackwomen have bettered five minutes for the mile or twelve minutes for two miles. Their lower maximum oxygen consumption recordings (39.05, 40.64, 46.21 and 54.18 ml/kg/min) indicate that their endurance capacities are less efficient than the trained men.

In contrast to the superiority of the trackmen to the other groups, the maximum oxygen intake measurements for the trained women were not consistently higher than those of the untrained men and women. The cardiovascular fitness levels of the representatives of the three latter groups varied considerably.

Much intergroup variability was observed in the maximum oxygen intake values among the trained men and trained women. This is not uncommon because other studies (1,4,9,17) have reported substantial variation even among the most highly trained athletes. Natural selection in relative muscle fiber composition and methods of training may account for the wide range of maximum oxygen intake measurements within the trained groups.

RESULTS OF THE SUBMAXIMAL TEST

Comparisons were made between the trained and untrained subjects of each sex for the riding time endured (seconds), and the total work output performed (kilopond meters) at ninety-five percent of the maximum oxygen intake on the submaximal performance test. The relative work-rates (kilopond meters per minute) at which the participants cycled on the submaximal endurance test were also compared. Table IV presents the
work output, riding time and workload measurements for each of the fourteen subjects. The appropriate group means are indicated in the same table. Figures 7-9 illustrate the results in graphic form.

The relationships of maximal oxygen intake (ml/kg/min) with riding time, work output and the ninety-five percent workloads were also investigated. Figures 10-12 illustrate the values for each of the fourteen subjects.

Riding Time Comparisons

Table IV compares the riding times (seconds) that the performers were able to maintain the workloads corresponding to ninety-five percent of the maximum oxygen intake. The total riding times for the entire submaximal test (including the no resistance, twenty-five, fifty, and seventy-five percent progressive warm-up loads) are indicated in the same table. Statistical comparisons were made only for the ninety-five percent riding times.

The single classification analysis of variance (10) indicated that there were no statistically significant differences in the riding times between the four groups. The computed F value of 0.52 was far below the 8.78 needed for a statistically significant difference. Figure 7 illustrates the results.

Riding Time and Maximum Oxygen Intake

A Spearman rank-order correlation coefficient (10) was computed to determine the relationship of riding time (seconds) at ninety-five percent and maximum oxygen intake. The computed rho of .253 indicated a very low relationship. A graphic presentation is illustrated in Figure 10.
### TABLE IV

**TOTAL WORK OUTPUT, RIDING TIME AND WORKLOAD MEASUREMENTS FOR THE FOURTEEN SUBJECTS**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Total riding time for entire test (minutes:seconds)</th>
<th>Riding time at 95% of max. O₂ (minutes:seconds)</th>
<th>Work output at 95% (kilopond meters)</th>
<th>95% workload (kilopond meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.C.</td>
<td>22:06</td>
<td>15:36</td>
<td>23868</td>
<td>1530</td>
</tr>
<tr>
<td>S.C.</td>
<td>15:46</td>
<td>9:16</td>
<td>13436</td>
<td>1450</td>
</tr>
<tr>
<td>R.R.</td>
<td>13:03</td>
<td>6:33</td>
<td>12707</td>
<td>1940</td>
</tr>
<tr>
<td>D.E.</td>
<td>14:42</td>
<td>8:12[\overline{x}=9:56]</td>
<td>15449[\overline{x}=16315]</td>
<td>1884[\overline{x}=1701]</td>
</tr>
<tr>
<td></td>
<td>16:24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRAINED MEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.M.</td>
<td>12:16</td>
<td>5:46</td>
<td>6054</td>
<td>1050</td>
</tr>
<tr>
<td>M.H.</td>
<td>12:35</td>
<td>7:05</td>
<td>6375</td>
<td>900</td>
</tr>
<tr>
<td>B.M.</td>
<td>21:17</td>
<td>14:47</td>
<td>14931</td>
<td>1010</td>
</tr>
<tr>
<td>A.B.</td>
<td>14:03</td>
<td>7:33[\overline{x}=9:28]</td>
<td>11401[\overline{x}=9690]</td>
<td>1510[\overline{x}=1117.5]</td>
</tr>
<tr>
<td></td>
<td>15:03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRAINED WOMEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.H.</td>
<td>11:59</td>
<td>5:29</td>
<td>6536</td>
<td>1192</td>
</tr>
<tr>
<td>D.J.</td>
<td>17:07</td>
<td>10:37</td>
<td>16774</td>
<td>1580</td>
</tr>
<tr>
<td>J.A.</td>
<td>12:04</td>
<td>5:34[\overline{x}=7:13]</td>
<td>7497[\overline{x}=10269]</td>
<td>1347[\overline{x}=1373]</td>
</tr>
<tr>
<td></td>
<td>13:43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UNTRAINED MEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.M.</td>
<td>13:41</td>
<td>7:11</td>
<td>7291</td>
<td>1015</td>
</tr>
<tr>
<td>T.R.</td>
<td>12:30</td>
<td>6:00</td>
<td>5910</td>
<td>985</td>
</tr>
<tr>
<td>S.M.</td>
<td>14:52</td>
<td>8:22[\overline{x}=7:11]</td>
<td>7906[\overline{x}=7035]</td>
<td>945[\overline{x}=981.66]</td>
</tr>
<tr>
<td></td>
<td>13:41</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7: A comparison of riding times at ninety-five percent of the maximum oxygen intake.
Figure 8: Work output (in kilopond meters) at ninety-five percent of the maximum oxygen intake capacity.
Figure 9: Workload comparisons on the ninety-five percent performance test.
Figure 10: The relationships of ninety-five percent riding time and maximum oxygen intake.

Key
Trained Men = x
Trained Women = o
Untrained Men = #
Untrained Women = *

Correlations
All subjects (rho = .253)
Men (rho = .357)
Women (rho = .035)
Figure 11: The relationship of ninety-five percent work output and maximum oxygen intake.
Figure 12: The relationship of ninety-five percent workload and maximum oxygen intake
The correlation between riding time and maximum oxygen intake for
the male subjects (rho = .357) indicated that there was a low relationship
for these two measurements. In contrast, a slightly negative relationship
(rho = -0.035) was found between the times and the maximum oxygen intake
capacities among the women.

Work Output Comparisons

Table IV presents the work output values (kilopond meters) for
the fourteen subjects on the ninety-five percent endurance test. Figure 8
illustrates the results in graphic form.

A single classification analysis of variance showed no statistically
significant differences in the group means. The computed value of 2.84
was below the 3.71 needed for significance at the .05 level. The
relatively small sample sizes and the inter-group variability might
account for the low value.

Work Output and Maximum Oxygen Intake

The computed Spearman rank-order correlation between these two
variables (rho = .592) indicates a moderate relationship between work
output and maximum oxygen intake. Figure 11 shows the results graphically.

A relatively high relationship (rho = .679) was found between work
output and maximal oxygen intake among the men. In contrast, a low cor-
relation was computed (rho = .142) between the same measurements for the
women.

Ninety-Five Percent Workload Comparisons

Each subject pedalled at relative work loads dependent on ninety-
five percent of his or her maximum oxygen intake capacity. The work
intensities were determined by the method explained in the previous chapter.

A single classification analysis of variance yielded an F value of 7.61, indicating a significant difference at the .01 level. Figure 9 illustrates the results graphically. The Scheffe' test (10) allowed group comparisons to determine where the dissimilarities were. The results indicated that the trained men performed at higher work loads than the trained and untrained women. The significance was at the .05 level. An F value of at least 11.13 suggests that there is a statistically significant difference. No statistically significant differences were found between the trained and untrained men. The other comparisons showed that the other groups were similar in the workloads.

The results:

- Trained Men ≠ Trained Women \( F=14.21 \)
- Trained Men = Untrained Men \( F=3.85 \)
- Trained men ≠ Untrained Women \( F=18.52 \)
- Trained Women = Untrained Men \( F=2.35 \)
- Trained Women = Untrained Women \( F=.66 \)
- Untrained Men = Untrained Women \( F=4.79 \)

**Maximal Oxygen Intake and Ninety-Five Percent Workloads**

A Spearman rank-order correlation coefficient was computed to determine the relationship of maximum oxygen intake (ml/kg/min) and the relative workloads used on the ninety-five percent performance test. The Spearman rho of .792 indicated a high relationship. Figure 12 illustrates the results graphically.

A high relationship (rho= .750) was found between the workloads
and maximum oxygen intake among the male subjects. The relationship between the same two variables was modest (rho = .50) for the women.

Summary

The results indicated that the women could perform as well as the men at relative workloads eliciting ninety-five percent of the maximal oxygen intake. The work output and riding time measurements were similar for the male and female groups. The exercise appeared to be equally stressful for both sexes. The inconsistent relationships between aerobic capacity and the results of the performance (i.e. riding time, work output) suggested that the maximal oxygen intake was only a partial determiner of successful performance. The higher correlations between maximal oxygen intake and the riding time and work output values among the men when compared to the women, may suggest that aerobic capacity was more highly related to performance for the males than for the females.

DISCUSSION RELATED TO SUBMAXIMAL ENDURANCE PERFORMANCES

The ninety-five percent riding times ranged from 5:29 to 15:36 (\(\bar{x} = 8:26\)), while the total riding times (including the four pre-ninety-five percent loads) extended from 11:59 to 22:06 (\(\bar{x} = 14:51\)). These values are considerably lower than those cited in the literature. Saltin (32) reported that work intensities eliciting ninety-five percent of the maximum oxygen intake capacity could be maintained for fifteen to thirty minutes, while Astrand (3) noted that this same percentage could be endured for thirty minutes. However, these authors based their generalizations in relation to prolonged running performance capacity (i.e. 5000 to 10,000 meter track races), and made no reference to sub-
maximal endurance capacity on a bicycle ergometer. The lower ninety-five percent riding times on a bicycle in comparison to track and treadmill running might be attributed to the localized thigh muscle tension and fatigue experienced during the performance test. The majority of the participants felt that these discomforts were the major limiting factors in their endurance times.

The total riding times suggested that the duration of the performance tests were sufficient for aerobic metabolism to provide the bulk of the energy requirements. This is consistent with Katch's finding (21) that maximum oxygen intake did not predict endurance performance effectively unless the exercise was continued for at least eight minutes. In contrast, supramaximal efforts of shorter duration (one to eight minutes) and higher intensity require more energy than can be supplied by the maximum oxygen intake capacity (32). Anaerobic metabolism is the predominate energy source during these short term, very intense exercises. Wilt's (12) oxygen requirement table for track events of varying distances indicates that there is considerable overlapping of the anaerobic and aerobic processes depending on the cardiovascular fitness of the individual, and the length and intensity of the event. Sharkey (35) notes that the shift from one energy source to another is not abrupt, but is a subtle transition in exercise of increasing intensity.

During the early stages of the ninety-five percent performance test, the circulatory and respiratory systems adjust to the demands of the exercise and adenosine triphosphate (ATP) is furnished by anaerobic metabolism. ATP is a high energy compound derived from the carbohydrate, fat and protein foodstuffs we consume, and is the major source of energy for muscle contraction. Anaerobic metabolism, consisting of the phospagen
and glycolytic phases, provides ATP without a dependence on oxygen consumption. During the initial phase, creatine phosphate combines with adenosine diphosphate (ATP) to produce ATP, while glycolysis involves the breakdown of glucose and glycogen to pyruvate and ATP in the muscle sarcoplasm. When the circulatory and respiratory systems adjust to the exercise demands, a steady state is reached whereby the ATP produced is equal to the ATP used and the energy for the muscular contractions is derived through aerobic metabolism. Aerobic pathways are dependent on the consumption of oxygen in order to provide energy for exercise from the oxidation of fats and carbohydrates. Pyruvate, an end product of glycolysis, is channeled to the aerobic mechanisms in the muscle cell mitochondria where it is converted to acetyl CoA and enters the Krebs cycle where energy bound in the chemical bonds is released. The entering compounds are degraded to carbon dioxide and hydrogen atoms. The electrons from the hydrogen atoms pass through the electron transport system where energy is produced and hydrogen is released as a by-product. Oxygen is necessary in aerobic metabolism in order to combine with the hydrogen of the electron transport system to yield water. The exercise intensity determines whether free fatty acids, glucose or glycogen are oxidized in the aerobic process. During greater intensities glycogen is used, while fat is the primary foodstuff oxidized during lower work rates. Intensity, however, is dependent on the cardiovascular fitness of the individual. During the later stages of the performance, the oxygen consumption is inadequate to supply the energy needs and the body calls upon less efficient anaerobic pathways for ATP production. Anaerobic metabolism is extremely limited because it can only endure at peak outputs for forty to fifty seconds. Upon depletion of the glycogen and phosphagen
reserves available for muscular activity, exhaustion occurs because the aerobic and anaerobic mechanisms can no longer keep up with the exercise demands for ATP. The subject must reduce his work rate to an intensity whereby metabolic processes can provide sufficient ATP.

Although the average ninety-five percent riding times were slightly higher for the trained groups (men = 9:56, women = 9:28) than for the untrained subjects (men = 7:13, women = 7:11), no significant group differences were found using the analysis of variance. The similarities in the endurance times might be expected because each subject pedalled at relative workloads equivalent to a percentage (ninety-five percent) of his or her maximal oxygen intake capacity. It is interesting to note that the trained men, trained women, untrained men and untrained women had similar exhaustion times, suggesting no superiority with regard to sex in bicycle riding time performance at ninety-five percent oxygen consumption at relative workloads. This may suggest that men and women may have equal capabilities to endure at submaximal percentages of their individual maximal oxygen intake capacities. Future research comparing the ability of men and women to exercise at relative friction loads at other percentages of the aerobic capacities should add insight into the endurance capabilities of the two sexes, and the role of the maximal oxygen intake in these performances.

The low relationship between maximum oxygen intake and riding time, as indicated by the Spearman rank-order correlation coefficient, (rho= .253) suggests that higher aerobic capacities did not necessarily produce longer bicycle riding times. The results in the present investigation are in agreement with Saltin's (32) finding that trained and untrained subjects, with markedly different maximum oxygen intake
capacities, had similar exhaustion times when performing at relative work intensities (kpm) on a bicycle ergometer. The workloads in Saltin's investigation required a steady-state oxygen uptake of only sixty-eight percent of the total maximum oxygen intake capacity, and the riding times averaged 283 minutes. The exercise intensities in the present investigation were considerably higher than those used in the Saltin study. The average riding time in the present investigation (14:54) indicated that the ninety-five percent work intensities were considerably higher than the loads used in his study. The performers in the present study exercised at a higher oxygen consumption per unit time, and had to dip into the phosphagen and glycolytic supplies (anaerobic metabolism) earlier in the performance.

A low relationship (rho = .357) was noted between maximum oxygen intake capacity and the riding times for the men on the performance test. In contrast, a slightly negative relationship (rho = -.036) was observed among the women. However, both relationships were very low, indicating that higher maximum oxygen intake was not associated with longer exhaustion times for either sex.

Subjects I.C., B.M., and D.J. performed considerably longer than the other eleven participants on the submaximal endurance test (15:36, 14:47 and 10:37 respectively). An examination of the oxygen consumption-workload graphs, from which the ninety-five percent loads were determined, reveals a possible cause for their more superior riding times. The oxygen consumption lines for these three performers flattened considerably at the peak crests. Because of this levelling phenomenon, the ninety-five percent workloads may not have corresponded exactly to ninety-five percent of the maximal oxygen intake capacity. The loads at which I.C.,
B.M. and D.J. exercised may have been underestimates of the exact pedal resistance required to tax ninety-five percent of the total aerobic capacity. The limitations of the gas collection and analysis instruments used in this investigation did not allow for the continuous monitoring of oxygen consumption in order to set the workload at the precise level to elicit ninety-five percent oxygen consumption. Because I.C., B.M., and D.J. may have been exercising at a lower percentage of their maximum oxygen intake capacities, they may have been able to perform aerobically longer, and stall the depletion of the phosphagen and glycolytic reserves. Since the other subjects may have operated at a greater percentage of their maximum oxygen intake capacities, they may have depended on anaerobic metabolism earlier in the performance, which may have led to earlier exhaustion.

Despite the differences in the group averages for work output on the ninety-five percent bicycle endurance test (trained men = 16315 kpm, trained women = 9690 kpm, untrained men = 10269 kpm, untrained women = 7035 kpm), the single classification analysis of variance indicated that these dissimilarities were not statistically significant. The results conflict with Saltin's (32) finding that a trained subject with a higher maximal oxygen intake capacity could perform considerably more work than an untrained individual with a lower maximal oxygen intake while exercising on a bicycle ergometer at relative work loads. Although most of the energy requirements in both studies were probably provided through aerobic metabolism and the selective recruitment of the high oxidative slow twitch muscle fiber types, the greater exercise intensities in the present investigation required an increased activation of anaerobic metabolism and the fast contracting fibers. The fast twitch contractile
units are recruited when the work intensity increases to a level when energy needs can no longer be provided strictly by the maximum oxygen intake. Anaerobic capacity may have played a more prevalent role in exercise of the intensity and duration used in this study than might be expected. None of the subjects had ever ridden on an ergometer prior to this investigation, thus there is a possibility that the subjects were inefficient at the task.

The correlation between maximal oxygen intake capacity and work output (rho = .592) on the ninety-five percent bicycle test suggests that there was a modest relationship between high aerobic capacity and more superior work output. Other factors may interrelate to determine work output at this intensity and duration. In addition to the increased anaerobic metabolism resulting from the activation of the fast contracting fiber types in response to higher workloads and rates of contraction, muscle strength, body composition measurements and motivational factors must also be considered as possible determiners of successful performance on ninety-five percent submaximal bicycle tests. Katch et al. (22) noted that bicycle work tests at high rates of contraction may involve a strength test and the termination of the exercise may occur because the friction load becomes too demanding for the subject's strength. He added that these tests are very sensitive to psychological (motivational) factors. Body composition measurements were not taken in this investigation, thus there is no way of knowing if a specific body frame or size is more advantageous for more superior bicycle performances at this work intensity.

While a low correlation (rho = .142) was found between maximum oxygen intake capacity and work output on the ninety-five percent performance test among the women, a rather modest relationship (rho = .679)
was noted for the men. Aerobic capacity was more highly related to work output among the men than the women. The results may suggest that the males may have used aerobic metabolism as a source of energy during the performance to a greater degree than the females. If this was true, the men might be expected to outperform the women because they could operate longer aerobically, while the women would have to depend more on anaerobic metabolism as a source of ATP. However, the analysis of variance indicated that the male and female groups had similar work output values while exercising at relative workloads eliciting ninety-five percent oxygen consumption. Muscular fatigue may have terminated the performances of the men prior to the depletion of the ATP that they could provide aerobic-ally. However, the riding time and work output data suggests that both sexes were under equal stress for this type of exercise.

A comparison of the work output values between the untrained men and women with similar maximal oxygen intake capacities supports the hypothesis that the males and females had similar capacities to work at the ninety-five percent level. Untrained women T.R. and S.M. (39.72 and 43.77 ml/kg/min) and untrained man J.H. (40 ml/kg/min) performed equally with regard to work output (5910, 7906 and 6536 kiloponds). However, untrained man J.A. (49.42 ml/kg/min) and untrained woman K.M. (33.62 ml/kg/min) had similar work values (7497 and 7291 kiloponds) despite the maximum oxygen intake difference. The inconsistent relationships between maximal oxygen intake and work output for both sexes again suggests that other variables (cited previously) may interrelate with aerobic capacity during bicycle exercise at the ninety-five percent level. Despite the similar work and riding time performances for the two sexes, the physiological basis of these similarities could not be determined
from the data in this investigation.

The relatively small group sizes and the intergroup variability may account for the lack of significance with regard to the work output measurements. Closer inspection reveals that the flattening of the oxygen consumption-workload lines from which the ninety-five percent intensities were determined may be related to this within group variability. The subjects (I.C., B.M. and D.J.) whose graphs demonstrated this exaggerated flattening, measure considerably higher work output values than the other members of their groups. As discussed earlier, these three individuals rode considerably longer than the eleven other subjects because the work rates at which they performed may have been underestimates of ninety-five percent oxygen consumption. Work output may have been greater because of the longer riding times. When the four groups are compared without the data from these four subjects, the trained men average nearly twice the work output (13864 kpm) of the other three groups (7943 kpm, 7017 kpm, 7035 kpm). The trained women and the untrained men and women are similar in this measurement. The untrained men and women appear to have similar capabilities for this type of exercise.

The lack of superiority of the trackmen and trackwomen over the non-athletes in work output might suggest that long distance and middle distance track training is not sufficiently specific to carry-over for successful performances on the bicycle. The specific muscle groups used in the event should be trained (35). If success in bicycle competition is desired, optimal improvement can only be gained through practice and conditioning on a bicycle. The specific metabolic processes used in the sport must be emphasized in the training program (32). Training can increase the oxidative and glycolytic potential of the muscle fibers (14, 32).
Long endurance exercise improves the aerobic functions, while sprint and very intense interval training conditions the anaerobic metabolic processes. The improvement in anaerobic efficiency takes place in the fast twitch muscle fibers, while the oxidative mechanisms improve in the fast and slow contractile fibers (32). Training can increase the glycogen storage capacity of skeletal muscle (32). Glycogen is an essential substrate increasingly used for the production of energy as the work intensity increases. Distance training enhances the activity of fat enzymes for fat degradation, thus the athlete can use fat as a substrate for moderate exercise.

There was a high relationship (rho = .792) between maximal oxygen intake capacity and the relative ninety-five percent work-rates at which each individual exercised on the submaximal test. The results indicate that the subjects with higher aerobic capacities performed more work per unit time (kpm/min) than the individuals with lower maximal oxygen intake capacities when exercising at relative friction loads eliciting ninety-five percent of the maximal oxygen intake. Work intensity is a relative measurement, and is dependent on the cardiovascular fitness of the individual. However, the relationship between maximal oxygen intake and the ninety-five percent workloads was considerably higher for the men (rho = .750) than for the women (rho = .50). The analysis of variance indicated that the trackmen exercised at higher workloads than the trained and untrained women. This might be attributed to the higher aerobic capacities among the trained men. This may be the causation for the higher relationship between aerobic capacity and the ninety-five percent workloads among the men.

The submaximal test results indicated that the women could perform
as well as the men at relative workloads eliciting ninety-five percent of the maximal oxygen intake capacity on the bicycle. Both sexes may have similar capabilities to exercise at a percentage of their maximal oxygen intake capacities, in a relative sense. The ability to provide energy through the anaerobic and aerobic metabolic mechanisms within the muscle fibers may be equally efficient in men and women for bicycle exercise of the intensity, duration and relative workloads used in the present investigation. The oxidative and glycolytic potential of the slow and fast contracting muscle fibers may be similar for both sexes during bicycle performances at relative ninety-five percent workloads. The relative concentrations of the aerobic enzymes within the muscle cell mitochondria may be similar in men and women. The mitochondria may have equal capabilities to provide the ATP required for exercise requiring ninety-five percent of the maximal oxygen intake. The glycolytic and phosphagen apparatus within the fast twitch fibers may have been equally efficient in the males and females in this investigation.

Histochemical measurements were not made in this investigation, thus there is no way of knowing if the similar exhaustion times and work output values among the men and women were attributed to relatively equal percentages of slow and fast twitch fibers within the muscles involved in the bicycle performance. Future studies must investigate this possibility.

The physiological systems involved with taking in, transporting and utilizing oxygen for the production of ATP energy appeared to be equally efficient for both sexes, as evidenced by the similar exhaustion times and work output measurements. This may suggest that the systems involved with respiration, circulation, cardiac function and the meta-
bolism of foodstuffs may not be superior in men as reported by the studies cited in Chapter I. However, past investigations have compared the function of these systems in response to absolute work loads, rather than relative work intensities.

Other researchers (1,29) that have reported a superiority of men over women in endurance capacity have used absolute workloads in their studies. The similar performances of the males and females suggests that both sexes may be able to perform similarly in relative terms at ninety-five percent of the maximal oxygen intake capacity. Future investigations must compare men and women at other percentages of the maximal oxygen intake in order to determine if both sexes have similar capabilities at other workloads.
CHAPTER IV

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

FINDINGS

The findings of this study are summarized in the following statements:

1. The trained men were superior to the trained women, untrained men and untrained women with regard to maximal oxygen intake capacity.

2. No definite group superiority in maximum oxygen intake could be found between the trackwomen and the untrained men and women.

3. A relatively large range in aerobic capacity was found within each of the four groups (trackmen, trackwomen, untrained men, untrained women).

4. There was a modest relationship (rho = .592) between maximal oxygen intake capacity (ml/kg/min) and work output on the ninety-five percent performance test. There was a modest relationship between these two measurements among the men (rho = .679) but a low correlation was noted (rho = .142) for the women.

5. There was a low relationship (rho = .253) between maximal oxygen intake capacity and riding time on the ninety-five percent performance test. A low relationship (rho = .357)
was found between these two variables among the men, while a slightly negative relationship (rho = -0.035) was observed among the women.

6. There was a high relationship (rho = 0.792) between maximal oxygen intake capacity (ml/kg/min) and the workloads at which the subjects performed on the ninety-five percent test. However, the relationship for the men (rho = 0.750) was higher than for the women (rho = 0.50).

7. The riding times on the ninety-five percent performance test were similar for the trackmen, trackwomen, untrained men and untrained women.

8. No statistically significant group differences were found with regard to work output between the trackmen, trackwomen, untrained men and untrained women.

9. The trained men exercised at higher workloads (representing ninety-five percent of the aerobic capacity) than the trained and untrained women on the submaximal performance test.

10. Localized thigh muscle fatigue and discomforts appeared to play an important role in the termination of the performances on the submaximal test.

CONCLUSIONS

1. The results suggest that the two sexes had relatively similar capabilities for steady-state bicycle exercise when each subject performed at relative workloads eliciting ninety-five percent of the maximal oxygen intake capacity.

2. The inconsistent relationships between maximal oxygen intake
capacity and bicycle performance at ninety-five percent of the total aerobic capacity suggests that other factors may play an important role in determining success for this type of exercise (i.e. motivational, leg strength, anaerobic capacity, body composition, specificity of training, pain tolerance, etc.).

3. The lack of superiority of the trained groups over the untrained groups may suggest that track training was not sufficiently specific to condition the body for successful bicycle exercise at the intensity and duration used in this study.

RECOMMENDATIONS

1. Similar studies with larger group sizes, comparing trained and untrained men and women exercising at ninety-five percent of the maximal oxygen intake per fat-free body weight should add insight to the endurance capabilities of the two sexes. Treadmill testing should be undertaken in order to relate the findings to long distance running.

2. Histochemical measurements preceding the submaximal test may shed light on the role of muscle fiber types and the aerobic and anaerobic capabilities in this type of performance.

3. Studies comparing men and women bicycling at relative friction loads eliciting different percentages of the maximal oxygen intake would be valuable in elucidating the endurance capabilities of men and women.

4. Because of the many variables influencing successful bicycle
performances, a similar study with larger group sizes and using a partial correlation method to remove the effects of strength and anaerobic capacity would shed light on the contribution of the maximal oxygen intake in this type of exercise.

SUMMARY

The similarities in the exhaustion times and work output measurements among the men and women suggests that the two sexes had equal capabilities to perform at ninety-five percent of the maximal oxygen intake capacity when relative workloads were used. The physiological basis of these similarities remains unanswered, as evidenced by the inconsistent relationships between aerobic capacity and the measurements of performance (i.e. work output, riding time, workload). It appears that the success of the bicycle exercise depends on a complex combination of factors (i.e. psychological, metabolic, strength). Future investigations must attempt to isolate the individual mechanisms contributing to the performance in order to understand the proportionate role of the anaerobic and aerobic processes in the production of the energy requirements for this type of exercise. When researchers are able to isolate the variables of the bicycle exercise, they will be better able to understand the physiological implications of the performance similarities of men and women at relative workloads.

The similar abilities of men and women cycling at relative friction loads eliciting a percentage (ninety-five percent) of the maximal oxygen intake may suggest that the physiological response of both sexes to endurance exercise may be similar when relative workloads are used.
This may suggest that similar cardiovascular training programs may be prescribed for males and females if the workloads are relative to the cardiovascular fitness of the male or female. More emphasis must be placed on comparing men and women at relative workloads, rather than absolute loads. This may suggest that training programs must be based on relative work intensities eliciting a percentage of the maximal oxygen intake capacity.
SELECTED BIBLIOGRAPHY


27. McArdle, W. D., Katch, F. I., and Pechar, G. S. "Comparison of Continuous and Discontinuous Treadmill and Bicycle Tests for


34. Sharkey, B. J. University of Montana. Personal communication.


APPENDIX
TABLE V

OXYGEN INTAKE MEASUREMENTS AT 140 HEART RATE (beats/minute)

<table>
<thead>
<tr>
<th>Subject</th>
<th>140 pulse rate oxygen intake (ml/kg/min)</th>
<th>140 pulse rate workload (kpm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRAINED MEN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.G</td>
<td>46.24</td>
<td>1080</td>
</tr>
<tr>
<td>D.E.</td>
<td>30.68</td>
<td>990</td>
</tr>
<tr>
<td>R.R.</td>
<td>39.41</td>
<td>1080</td>
</tr>
<tr>
<td>I.C.</td>
<td>44.09</td>
<td>1260</td>
</tr>
<tr>
<td></td>
<td>( \bar{x} = 40.11 )</td>
<td>( \bar{x} = 1102.5 )</td>
</tr>
<tr>
<td><strong>TRAINED WOMEN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.B.</td>
<td>22.01</td>
<td>540</td>
</tr>
<tr>
<td>K.M.</td>
<td>28.20</td>
<td>540</td>
</tr>
<tr>
<td>M.H.</td>
<td>25.16</td>
<td>630</td>
</tr>
<tr>
<td>B.M.</td>
<td>23.20</td>
<td>540</td>
</tr>
<tr>
<td></td>
<td>( \bar{x} = 24.64 )</td>
<td>( \bar{x} = 562.5 )</td>
</tr>
<tr>
<td><strong>UNTRAINED MEN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.H.</td>
<td>23.89</td>
<td>720</td>
</tr>
<tr>
<td>D.J.</td>
<td>15.64</td>
<td>540</td>
</tr>
<tr>
<td>J.A.</td>
<td>32.01</td>
<td>810</td>
</tr>
<tr>
<td></td>
<td>( \bar{x} = 23.85 )</td>
<td>( \bar{x} = 690 )</td>
</tr>
<tr>
<td><strong>UNTRAINED WOMEN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.R.</td>
<td>20.63</td>
<td>540</td>
</tr>
<tr>
<td>K.M.</td>
<td>21.61</td>
<td>810</td>
</tr>
<tr>
<td>S.M.</td>
<td>30.90</td>
<td>540</td>
</tr>
<tr>
<td></td>
<td>( \bar{x} = 24.38 )</td>
<td>( \bar{x} = 630 )</td>
</tr>
</tbody>
</table>
TABLE VI
HUMAN PERFORMANCE LABORATORY SAMPLE DATA SHEET

Subject _______________________________________ Date _________________ Treatment_____________________

Control Data: Rm Temp____ Bar Pr____ Rel Hum____ Oral Temp____________________

Body Wt____ Ht____ Resting Pulse ________________________________________________

Last Food____ Drink (not H2O)_______ Hrs Slp_______ Last Ex________________________

Other ______________________________________________________

Test Protocol:


Gas Analysis (Fisher):

<table>
<thead>
<tr>
<th>T1 (lines)</th>
<th>T2</th>
<th>(\bar{x})</th>
<th>Argon(-.9)</th>
<th>True (O_2)</th>
<th>(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CO_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(O_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(CO_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(O_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ventilation (GF = Gasometer Factor) Anal

<table>
<thead>
<tr>
<th>Post</th>
<th>Pre</th>
<th>Dif</th>
<th>GF</th>
<th>Vol</th>
<th>Vol</th>
<th>STIP</th>
<th>Temp+Pres</th>
<th>Vol</th>
<th>Min</th>
<th>(\dot{V})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results:

<table>
<thead>
<tr>
<th>(\dot{V})</th>
<th>True (O_2)</th>
<th>(\dot{V}O_2)</th>
<th>(\dot{V}O_2)</th>
<th>WT(kg)</th>
<th>(\dot{V}O_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STATISTICAL ANALYSIS USED IN THIS STUDY

1. SPEARMAN RANK-ORDER CORRELATION COEFFICIENT (Rho)

\[ p = - \frac{6 \sum d^2}{N (N^2 - 1)} \]

2. SINGLE CLASSIFICATION ANALYSIS OF VARIANCE

\[ F = \frac{\text{mean square for "between" groups}}{\text{mean square for "within" groups}} \]