A COMPARISON OF MAXIMAL OXYGEN UPTAKE VALUES DETERMINED BY THE ASTRAND-RHYMING INDIRECT TEST, THE CONTINUOUS BICYCLE TEST AND THE CONTINUOUS TREADMILL TEST IN MALE AND FEMALE SUBJECTS

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A comparison of maximal oxygen uptake values determined by the Åstrand-Ryhming indirect test, the continuous bicycle test and the continuous treadmill test in male and female subjects

by

© Michael Francis Greene, B.P.E., B.Ed.

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Abstract

This study was undertaken to compare the maximum oxygen uptake obtained by three standard maximal oxygen uptake tests. One indirect and two direct tests of maximum oxygen consumption were chosen. The direct tests chosen were the continuous bicycle test and the continuous treadmill test. The indirect test was the Åstrand-Ryhming test employing heart rate response to submaximal work.

The sample (N=20) which consisted of 10 male and 10 female volunteer students from Memorial University of Newfoundland was divided into two groups on the basis of sex. Each subject was required to perform each of the three maximum oxygen consumption tests.

The scores obtained from the maximum oxygen consumption tests were compared using the *t* test for paired samples. The scores obtained from all three maximum oxygen consumption tests were found to be significantly different at the .05 level in all cases except for the Åstrand Indirect test and the continuous cycling test in female subjects.

The mean difference between the scores on the cycling test and the treadmill test was 9% for males and

11% for females. The treadmill test resulted in values approximately 7% higher than those for both groups. A difference of approximately 3% was found between the Åstrand Indirect and the cycling test with the former yielding the higher scores in both male and female subjects.

Spearman's coefficient of rank correlation was used to find the correlation coefficients between the three tests. All correlation coefficients were found to be significant at the .05 level.

It was concluded that,

i the treadmill test results in values which are approximately 10% higher than those obtained during the cycling test,

ii the Åstrand indirect test underestimates the treadmill score by about 7%;

iii the Åstrand indirect and cycling test give scores which are similiar.

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Chapter I

Introduction

Need for the Study:

It has been established that the measurement of aerobic power provides an objective measure of the physical fitness of an individual as reflected by his cardio-respiratory system. (26) The best indicator of aerobic power in man is generally considered to be the maximum oxygen consumption test. Many methods and techniques have been developed for assessing an individuals maximum oxygen consumption or max. VO_2. (2,3,4,6,7,9,21,26,33) These methods range from indirect tests (3,21) in which maximal oxygen uptake is estimated from heart rate response to submaximal work to direct tests (2,4,6,9,26,33) in which the subject must work to near exhaustion.

If, however, max. VO_2 is to be measured, then the result reported should ideally be the most an individual can achieve with any form of exercise. All these methods are judged to elict a max. VO_2 although they vary from the procedure employed to the type of ergometer used.

In the measurement of max. VO_2 by direct techniques it is essential to use large muscle groups in order to fully stress the cardio-respiratory system and it is for this reason that cycling and running are frequently used. (2,4,6,7,9,22,26) Recent studies (15,17,29,13,27,19,22, 23,30) have shown that max. VO_2 is significantly higher (6 - 15%) during maximal uphill running as compared to cycling. However nearly all these studies have used healthy young males as subjects and the question remains whether this difference exists using other groups.

The excess physical demands made upon the subject during these direct techniques have led to the development of several indirect techniques. (3,21) These indirect techniques involve the use of a bicycle ergometer and have been developed using healthy young individuals. (4) Studies comparing max. VO_2 values obtained from indirect tests to direct tests have been reported. (4,7,29,34) These have generally been characterized by small sample size (4,29,7,34), lack of statistical data (29) and the use of only one direct test. (34) Whether these indirect techniques are applicable to a population unaccustomed to cycling remains in doubt. This is especially true in the case of female subjects.

The present study then is an attempt to compare two direct techniques of maximum oxygen consumption and one indirect technique in young male and female subjects.

The direct tests chosen were the continuous bicycle (23) and the continuous treadmill (23) tests. These direct tests were chosen because they were typical of both cycling and running tests and could be carried out in one laboratory session. The indirect test used was the Åstrand-Ryhming indirect test which is typical of the indirect tests.

Purpose:

The purpose of the present investigation was to compare the maximum oxygen consumption obtained from the Åstrand-Ryhming indirect test, the continuous bicycle test and the continuous treadmill test in male and female subjects.

Hypothesis:

It was hypothesized:

(1) that there is no significant difference between maximum oxygen consumption as measured by the Åstrand-Ryhming indirect test, the continuous bicycle test and the continuous treadmill test in males.

(2) that there is no significant difference between maximum oxygen consumption as measured by the Åstrand-Ryhming indirect test, the continuous bicycle test and the continuous treadmill test in females.

Limitations of the study:

(1) Anxiety prior to the Åstrand indirect test could have created an increase in resting heart rate. If this state of anxiety was also present during the Åstrand indirect test then an underestimate of the maximum oxygen uptake may have occurred since the max. VO_2 is estimated from heart rate response to submaximal work.

It has been found (32) that anxiety increases the pulse rate during submaximum work.

(2) Some subjects may not have yielded a maximum effort due to a lack of incentive or willingness to perform.

(3) Due to scheduling difficulties the subjects were not tested at the same time each day.

(4) The laboratory was neither temperature nor humidity controlled. This may have effected the results of either the direct tests or indirect test. (32)

Definitions

Maximum oxygen consumption (max. $\dot{V}O_2$) - the highest oxygen uptake that a person can attain during exhaustive muscular exercise of approximately 6 minutes duration. This exercise should be performed on either a bicycle or treadmill and at approximately sea level. The max. $\dot{V}O_2$ is also termed aerobic capacity.

Continuous treadmill test - a maximum oxygen consumption test performed on the treadmill in which the subject works continuously at increasing workloads until exhaustion.

Continuous bicycle test - a maximum oxygen consumption test performed on the bicycle ergometer in which the subject works continuously at increasing workloads until exhaustion.

Indirect maximum $\dot{V}O_2$ test - a test in which max. $\dot{V}O_2$ is estimated from heart rate response to a submaximal work load.

STPD - dry gas volume converted to standard atmospheric conditions of barometric pressure of 760 mm. Hg. and temperature of 0^0C.

BTPS - gas volume at body temperature (37^0C.), ambient barometric pressure, and air saturated with water vapor.

KGM/min - Kilogram metre per minute.

Chapter II

Review of Literature

In measuring maximum oxygen uptake it is important that large muscle groups be employed in order to maximally stress the cardio-respiratory system. (1,4,33) For this reason the treadmill and the bicycle ergometer are the two most frequently used laboratory devices for direct measurement of maximal aerobic power. (4,7,26,33) Many studies (15,17,29,13,27,19,22,23,30) have compared the maximum oxygen intake during maximal treadmill and bicycle exercise. The two main problems with these studies have been that the testing procedures used varied from one laboratory to another and that the subjects to which these methods have been applied are generally healthy young men. (15,17,29,13,27,23,24)

Glassford (15) using young male subjects compared the maximum oxygen uptake as measured by the Mitchell, Sproule and Chapman treadmill test, Taylor, Buskirk and Henschell treadmill test and the Åstrand bicycle ergometer test. He found that the two treadmill tests yielded significantly higher mean values than did the direct bicycle test. He concluded that the results indicate that the direct treadmill tests, employing a greater muscle mass yielded higher maximal oxygen uptake values (8%) than did the direct bicycle ergometer test.

Hermansen and Saltin (17) using male subjects compared the procedure suggested by Astrand and Saltin (5) for the bicycle ergometer test with a modified procedure originally described by Taylor at al. (33) for the treadmill. They found that .28 liters/min. or 7% higher oxygen uptakes were obtained during maximal uphill running as compared to cycling. This difference was significant at the 0.001 level. They found no significant differences in the maximal values for the work time, heart rate and pulmonary ventilation.

Newton (29) using male subjects compared a treadmill test with the rate and grade adjusted to the capacity of the individual and a bicycle ergometer test with the brakeload adjusted to the capacity of the individual. He reported that higher oxygen intake values were achieved on the treadmill than on the bicycle ergometer. There was however no statistical analysis of the results. Newton concludes that individuals unaccustomed to cycling were unable to reach as high a maximal oxygen intake on the bicycle ergometer as when running on the treadmill at a speed and grade suited to them. His subjects pedaled at a rate of 50 rpm although Hermansen and Saltin (17) have found 60 rpm to elict the highest max.VO_2 values.

Faulker at al. (13) compared the cardio-vascular responses to submaximum and maximum effort in cycling and running. In this study he used adult males nearly all of whom were accustomed to performing exhaustive tests on both the bicycle ergometer and the treadmill. He found that the maximum oxygen intake was 11% less cycling than running. He concluded that since the arterial-venous oxygen difference and the maximum heart rate are the same in both cycling and running then the lower maximum oxygen consumption in cycling is completely due to a smaller cardiac output and a smaller stroke volume.

Miyamura (27) again used young male university students when hecompared maximal oxygen uptake during maximal treadmill and bicycle ergometer exercise with stepwise incremental loading and constant loading. He found that the maximum oxygen intake was 15% higher during the treadmill exercise than the bicycle ergometer exercise regardless of which type of loading was used. These differences were found to be statistically significant.

Kamon and Pandolf (19) tested the maximal aerobic capacity of twelve female and eleven male subjects during uphill treadmill running and cycling at 60 rpm. They found a lower maximum oxygen consumption for cycling as compared to uphill running. The difference in the maximum oxygen uptake in cycling as compared to running was 10% in the male subjects and 7% in the female subjects. It is important to note that all subjects in this study were active in physical activities with the exception of two females and one male.

McArdle and Magel (24) studied the maximum oxygen consumption, heart rate and ventilatory patterns in male college students during bicycle and treadmill exercise. They found an average reduction in maximum oxygen consumption of .324 l/min or 10% was observed during bicycle work as compared to the treadmill. This difference was significant at the .01 level. They also found that the heart rate was significantly lower in the bicycle test but observed no significant difference in the ventilatory minute volume between the two tests.

McArdle et al. (23) compared two bicycle tests with four treadmill tests in male college students. He found that the mean values for the maximum oxygen consumption on the bicycle tests averaged from 10 - 11% below the treadmill test. This difference was significant at the .01 level.

Maximum heart rate was significantly lower on the bicycle tests in comparision to the treadmill test.

Rowell and co-workers (30) found on the average .60 litre/min higher values on the treadmill than on the bicycle ergometer. This large difference may be accounted for by the fact that leveling off was used as the criteron to establish the maximal oxygen uptake on the treadmill while the procedure used on the bicycle consisted of only one continuous exercise period.

Åstrand and Saltin (5) when comparing oxygen untake during different types of muscular exercise found that there was a 5% higher oxygen intake during maximal uphill running (>5.25%) than during maximal cycling at 50 rpm.

Earlier, Åstrand(2) was unable to demonstrate any significant difference in maximal oxygen untake between maximal treadmill and bicycle exercise. In this study there was only a slight incline of 1° (1.25%) on the treadmill. This may be the reason why no difference was found.

A review of the literature indicated that the maximum oxygen uptake is approximately 8 - 10% higher during uphill treadmill running as compared to cycling in healthy young male subjects.

Besides these direct tests of maximum oxygen consumption there have also been several indirect tests reported. (3,21,7) The Åstrand-Ryhming indirect test was used in this study. Studies have been undertaken in an attempt to evaluate the validity of this indirect test.

Glassford (15) using young male subjects compared the Åstrand-Ryhming indirect test with three direct tests of maximum oxygen consumption. He found that the indirect test yielded significantly higher mean values than did the direct bicycle test and values similiar to those obtained on the direct treadmill test. He concluded that the Åstrand indirect test appeared to produce a good estimation of maximal oxygen uptake in a population unaccustomed to cycling. He also observed that standard deviations obtained from the Åstrand indirect were of greater magnitude than those calculated from the three direct tests.

Hettinger (18) used policemen as subjects to compare the Åstrand indirect test with the Åstrand direct test. He found a significantly higher mean for the Åstrand indirect test.

Rowell et al. (30) compared the indirect test with the Taylor treadmill test. Again healthy young men served as subjects. The results showed that the indirect test of Åstrand and Ryhming underestimated the actual maximum by 27% in a sedentary group and by about 6% in a group of athletes. They also found that nonspecific stresses increased the predictive errors in all groups. They concluded that the indirect test provided a reasonably accurate prediction of maximum oxygen intake in endurance athletes. Indeed this is a similiar group with which Åstrand developed his indirect test.

Wyndham (34) found that prediction of maximum oxygen consumption by the Åstrand Ryhming indirect test will underestimate the true maximum by approximately .32 liters/min. He attributed this underestimation to the asymptotic approach of $\dot{V}O_2$ and the maximal values for pulse rate.

Davies (11) also observed that the nomogram underestimated the maximum oxygen consumption by about 20 - 25%. He concluded that the method remains of limited value and provides only a crude guide to an individuals ability to perform at maximum effort and that for accurate analysis of the maximum aerobic power there appears to be no alternative but to measure max. $\dot{V}O_2$ directly.

The literature then seems to be divided on whether the Åstrand-Ryhming indirect test is of use in predicting maximum oxygen consumption.

Chapter III

Methodology

Subjects

Ten male and ten female undergraduate students at Memorial University of Newfoundland volunteered as subjects for the study. The subjects ranged in age from 18 - 23 years with a mean age of 19.5 years. The twenty volunteers participated in normal college activities and recreational sports but were not involved in any strenuous physical conditioning programs. Table I, page 15, summarizes the physical characteristics of the subjects.

Research design

The subjects were divided into 2 groups according to sex. Two direct techniques of measuring maximum oxygen consumption and one indirect technique were administered to the subjects. The two direct methods were the continuous treadmill test (23, 32) and the continuous bicycle test. (23, 32) The indirect technique which was investigated was the Åstrand Ryhming indirect test. (3)

Table I - Some characteristics of test subjects

Males

Characteristic	Mean	SD	Range
Age, years	19.9	1.91	18 - 23
Height, cm.	178.2	6.01	170 - 189
Weight, kg.	70.95	6.90	62 - 82

Females

Characteristic	Mean	SD	Range
Age, years	19.1	1.37	18 - 22
Height, cm.	165	5.19	159 - 172
Weight, kg.	53.65	4.08	48 - 62

Methods

The running test was performed on a motor driven treadmill. The speed of the treadmill was calculated by counting the number of belt revolutions during a one minute period. Fifty three r.p.m. was equal to 11.2 km/hr. while 45 r.p.m. equaled 9.6 km/hr.

The bicycle exercise was performed on a mechanically braked bicycle ergometer as described by Dobeln. (12) Prior to testing the bicycle ergometer was calibrated according to the manufacturers instructions. A pedaling rate of 60 r.p.m. in all bicycle tests was established by having the subject keep a speed of 21.6 km/hr. In addition a counter was attached to the cycle's frame to provide an accurate measure of the pedaling rate. The seat height of the bicycle ergometer was adjusted individually to allow for an almost completely extended leg at the lowest pedal position. See Figure I, page 17.

An electro-cardiogram provided an accurate measure of the heart rate. In order to avoid the inconvenience of a trailing cable a telemeter was used to transmit the pulse signal to a physiograph in another part of the room. (16) Heart rate was recorded during the last 10 seconds of each minute of exercise. The electrodes were


Revolution
counter
Collins Triple J
respiratory valve
Cardic telemeter
Physiograph

Figure I

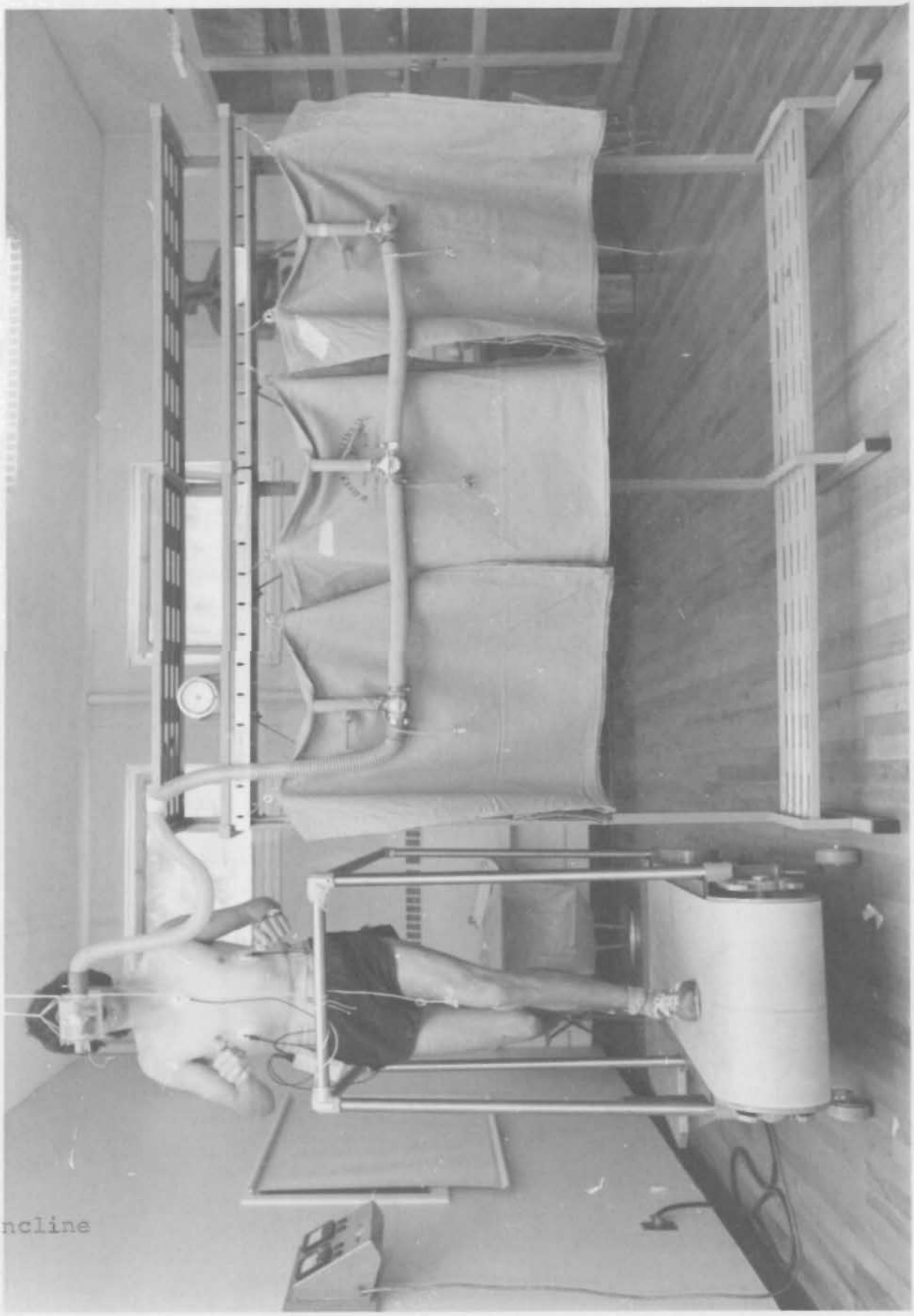
placed in the CV5 position as recommended by Blackburn. (8) One electrode was fitted over the manubrium sterni and the other was placed in the space tetween the fifth and sixth ribs where the apex beat of the heart is most readily palpated. The right chest electrode provided a good ground location. This electrode placement yielded a high R wave amplitude. See Figure II page 19.

The oxygen uptake was determined by the Douglas bag method. The subjects breathed through a low resistance Collins triple - J respiratory valve and the expired air was collected in rubberized Douglas bags. See Figure II page 19.

The volume of the expired air collected in the Douglas bags was measured in a dry gas meter which could be read with an accuracy of 0.2 liter. Oxygen analysis was performed using a RAPOX oxygen analyser and standard 11.35% oxygen was used in calibrating the gas analyser. This type of paramagnetic analyser can yield results that are accurate to about 0.04%. (32) See Figure III page20.

Oxygen consumption was converted to STPD using the formula in Table II page 21.

Pulmonary ventilation was converted to BTPS using the formula in Table III page 22.



Douglas Bag arrangement

Electrode placement

Speed and Incline controls

Figure II

Dry
Gas
Meter

RAPOX
Oxygen
Analyser

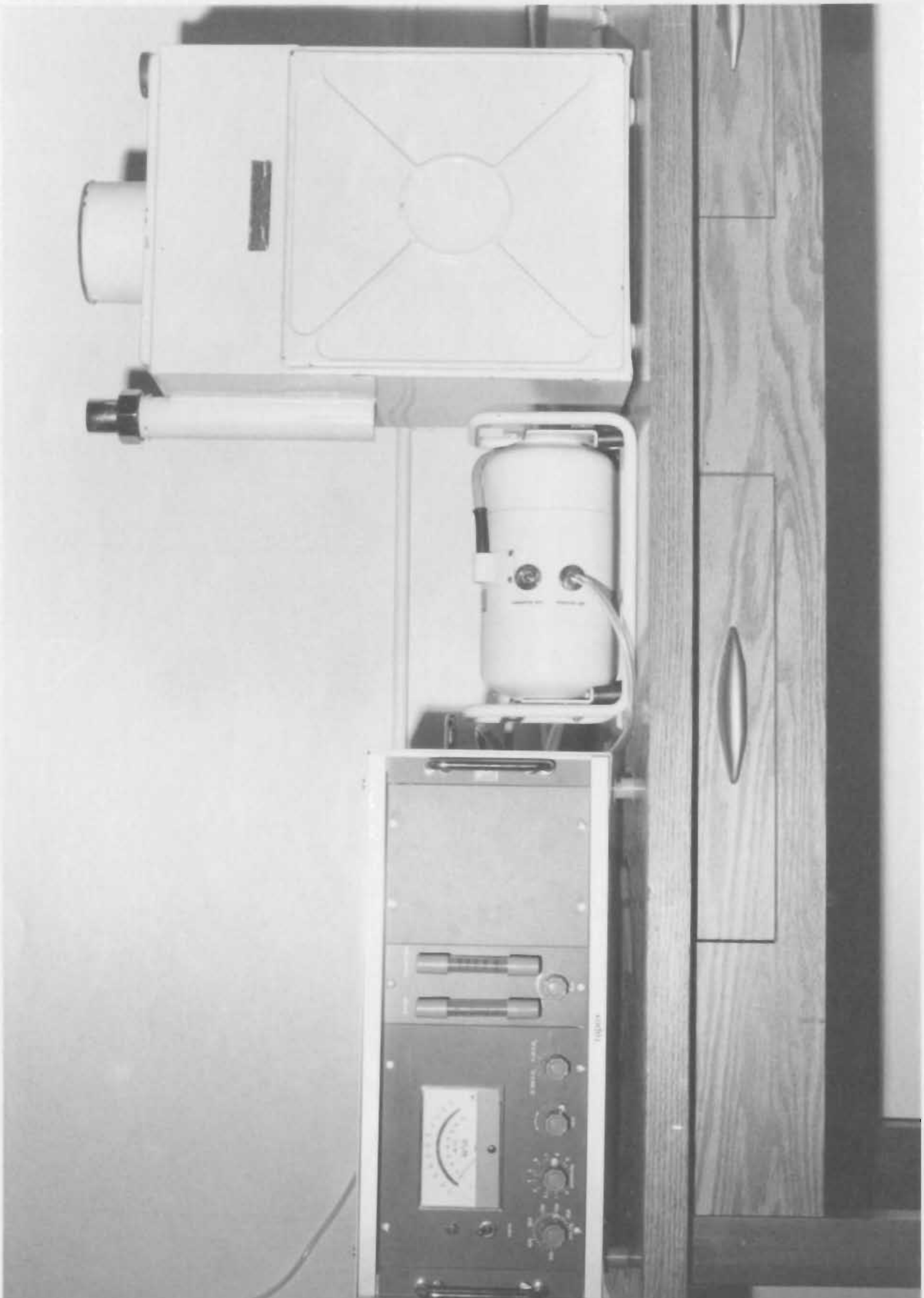


Figure III

Table II

Formula for Conversion of
Maximum Oxygen Uptake Values
to STPD

$$STPD_{corr.} = \frac{P_B \text{ (mm. Hg)} - P_{H2O} \text{ (mm. Hg)}}{760} \times \frac{273^0K}{273^0K + t^0C}$$

where

760	=	barometric pressure at sea level
273^0K	=	freezing point of water on Kelvin scale
P_B	=	ambient barometric pressure
P_{H2O}	=	water vapor tension. See Appendix B page 59
t^0C	=	temperature of collected gas sample

Table III

Formula for Conversion of

Pulmonary Ventilation Values

to BTPS

$$BTPS_{corr.} = \frac{273^0K + 37^0C}{273^0K + t^0C} \times \frac{P_B\ (mm.\ Hg) - P_{H2O}\ (mm.\ Hg)}{P_B\ (mm.\ Hg) - 47.1\ (mm.\ Hg)}$$

where

273^0K	=	freezing point of water on Kelvin scale
37^0C	=	body temperature
47.1	=	water vapor tension at 37^0C
t^0C	=	temperature of collected gas sample
P_B	=	ambient barometric pressure
P_{H2O}	=	water vapor tension. See Appendix B page 59

Procedures

Each subject reported to the laboratory a total of three times within a seven day period. The first session was designed to acquaint the subject with the laboratory, the investigator and the procedure to be used in the subsequent tests. During this visit the subjects became accustomed to pedaling the bicycle ergometer and running on the treadmill. In addition height was recorded to the nearest centimeter and body weight to the nearest 0.5 kilogram.

The subjects were instructed not to drink any stimulants such as coffee or tea and not to eat a large meal at least three hours prior to their next two visits. The four subjects who smoked were asked to refrain from smoking on the day of the experiment.

Due to scheduling difficulties the subjects could not be tested at the same time each day.

On the second day the Åstrand Ryhming indirect test was administered and followed by the continuous bicycle test. On the final day the subject again performed the Åstrand indirect test which served as a warm-up for the continuous treadmill test which followed. There was a minimum period of one day between the two maximum performance tests.

Although the laboratory was neither temperature or humidity controlled, the temperature never exceeded 24°C. and the relative humidity never went above 60%.

Åstrand Indirect Test

After adjusting the seat height the subject began pedaling at a rate of 60 r.p.m. The female subjects began the indirect test at a workload of 360 kgm/min. while the males began the test at 720 kgm/min. The subject pedaled at this work level until a steady state was attained between 125 - 170 beats/min. Two consecutive heart rate recordings seperated by one minute which differed by no more than 5 beats after the fifth minute of exercise was the criterion used to define steady state. If the heart rate had not reached 125 by the fifth minute the work load was increased by 360 kgm. and the subject continued to ride until a steady state within the required range was attained. The two heart rate values were then averaged and this value along with the corresponding work load was applied to the Åstrand Ryhming formula. In order to avoid any unnecessary errors the formula on which the nomogram is based was used instead of the nomogram itself. The maximal oxygen intake is given by (3):

(1) For men

$$\dot{V}O_2 \max = \frac{195 - 61}{P - 61} \times \dot{V}O_2 \text{ (observed)}$$

(2) For women

$$\dot{V}O_2 \max = \frac{198 - 72}{P - 72} \times \dot{V}O_2 \text{ (observed)}$$

where

P = corresponding pulse rate

$\dot{V}O_2$ (obs) = observed oxygen consumption

The observed oxygen consumption is given by the formula. (2)

$$\dot{V}O_2 \text{ (obs)} = 0.00229 . X + 0.081$$

where

X = Work load in Kgm/min.

Direct Oxygen Consumption Tests

Both the continuous bicycle and the continuous treadmill test followed the procedure recommended by

Shephard. (32) Both maximal tests were preceded by the Åstrand indirect test which represented a work load approximately 50 - 70% of the individuals maximum oxygen consumption. This test served as a warm-up for both maximal work bouts.

On the bicycle ergometer maximal oxygen intake was first predicted from the heart rate response to a sub-maximal work load on the bicycle ergometer according to the method of Åstrand. (3) With the aid of the equation of Åstrand

$$\text{Kgm/min.} = \frac{(y - 0.031)}{.00229}$$

where,

y = 100% of the predicted max $\dot{V}O_2$

The work load was then chosen so as to be just high enough to reach the predicted maximal oxygen untake. The subject pedaled the ergometer at a rate of 60 r.p.m. This pedaling frequency has been shown to elict the highest max VO_2 when compared with rates of 50, 70 and 80 r.p.m. (17) The work was increased 180 kgm/min. every 2 min. until the subject was unable to continue or the pedal rate dropped below 50 r.p.m. Expired air was collected during the last minute of each work period. See Figure IV, page 28.

On the treadmill test the maximal oxygen uptake was first predicted from the Åstrand indirect test (3) and expressed in $ml/kg \cdot min^{-1}$. With the aid of Figure IV page 28 the starting grade for the maximal run was chosen according to the same principles as described for the bicycle ergometer. The speed was 11.2 km/hr. for males and 9.6 km/hr. for females. The treadmill grade was increased by 2½% every 2 minutes until the subject was unable to continue. Expired air was collected during the last minute of each work period.

The work time for the maximal exercise periods varied between 4 and 6 minutes in both maximal bicycle and treadmill exercise.

It was accepted that the maximum oxygen intake had been reached when the oxygen consumption increased by less than 3% for a 180 kgm/min. increase on the bicycle ergometer and for a 2½% increase in grade on the treadmill. If an individual failed to meet this criteria a new test following the same procedures but starting at 110% the predicted VO_2 max was administered. Subsidiary criteria of a true maximum included obvious exhaustion of the subject and a pulse rate close to expected maximum.

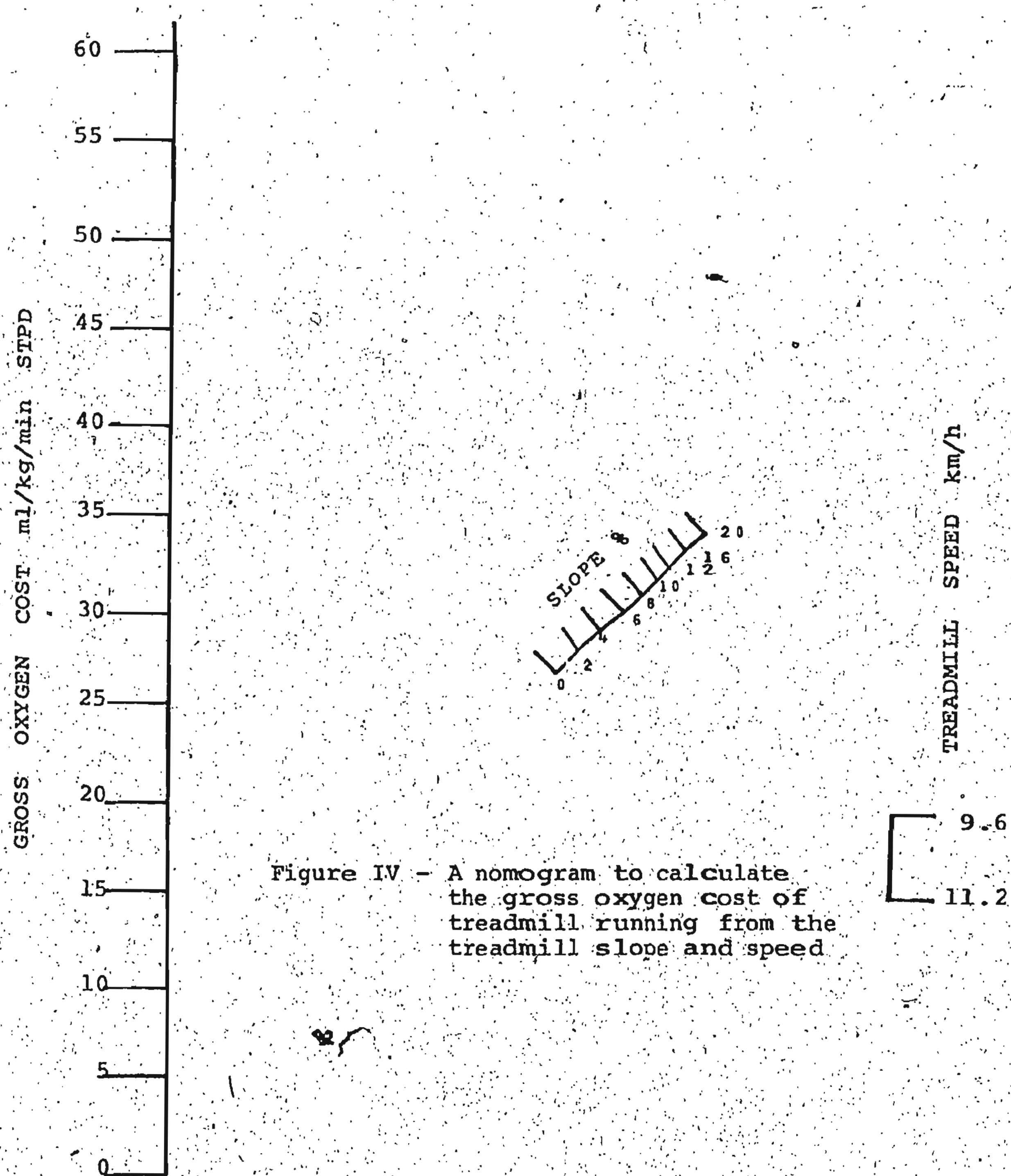


Figure IV - A nomogram to calculate the gross oxygen cost of treadmill running from the treadmill slope and speed

Treatment of Data

The data were collected on data collection sheets as shown on pages 57 and 58, Appendix A. All oxygen volumes were corrected to STPD and recorded on page 30, Table IV. The data collected from the three tests were compared on the basis of means and correlation coefficients. T tests for paired samples and Spearman's rank correlation were employed.

Table IV

Individual and average values for oxygen uptake (liters/min) during maximal bicycle exercise, maximal treadmill exercise and the Åstrand - Ryhming indirect test

Males

	Åstrand Indirect	Cycling	Running
1	2.39	2.50	2.74
2	2.97	2.83	3.12
3	3.29	3.22	3.51
4	3.36	3.18	3.55
5	3.39	3.17	3.45
6	3.42	3.39	3.73
7	3.50	3.51	3.66
8	3.72	3.50	3.83
9	3.73	3.46	3.80
10	3.85	3.76	4.12
mean	3.36	3.25	3.55
SD	.43	.37	.39

Females

	Åstrand Indirect	Cycling	Running
1	1.63	1.59	1.74
2	1.69	1.58	1.77
3	1.82	1.80	2.14
4	2.02	1.98	2.11
5	2.16	2.27	2.55
6	2.24	2.29	2.48
7	2.37	2.26	2.53
8	2.54	2.48	2.75
9	2.66	2.43	2.83
10	2.83	2.73	2.80
mean	2.20	2.14	2.37
SD	.41	.39	.41

Chapter IV

Results

Individual and mean values for oxygen uptake as measured by the continuous bicycle test, the continuous treadmill test and the Åstrand indirect test are presented for both male and female groups in Table IV, page 30.

During maximal treadmill exercise the mean maximal oxygen uptake was 9% higher for males and 11% higher for females as compared to maximal cycling exercise. This represented a difference of .30 l/min. in the men and .23 l/min. in the women. These differences were both significant at the .01 level. The smallest improvement was 3% while the largest was 17%. The results of the determination of oxygen uptake during maximal exercise on the bicycle and on the treadmill are shown in Figure V for the males and Figure VI for the females.

The mean maximal oxygen uptake during the maximal treadmill test was .18 l/min. and .19 l/min. higher than on the Åstrand Indirect test for females and males respectively. This difference was significant at the .01 level for both groups. The mean values for maximum oxygen consumption during uphill running were 3.55 l/min.

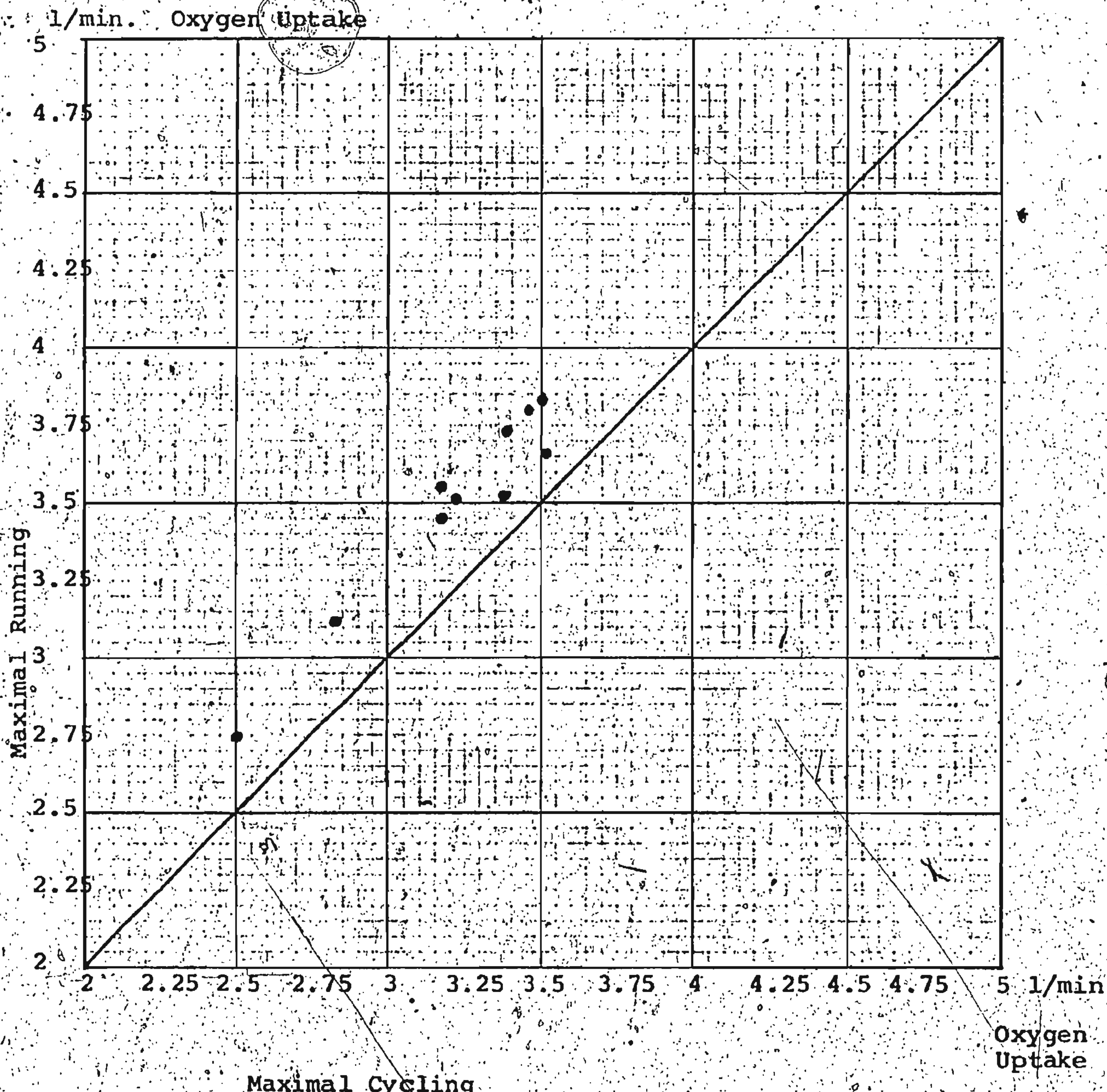


Figure V - Individual values for oxygen uptake during maximal treadmill exercise compared with corresponding values during maximal bicycling exercise in male subjects

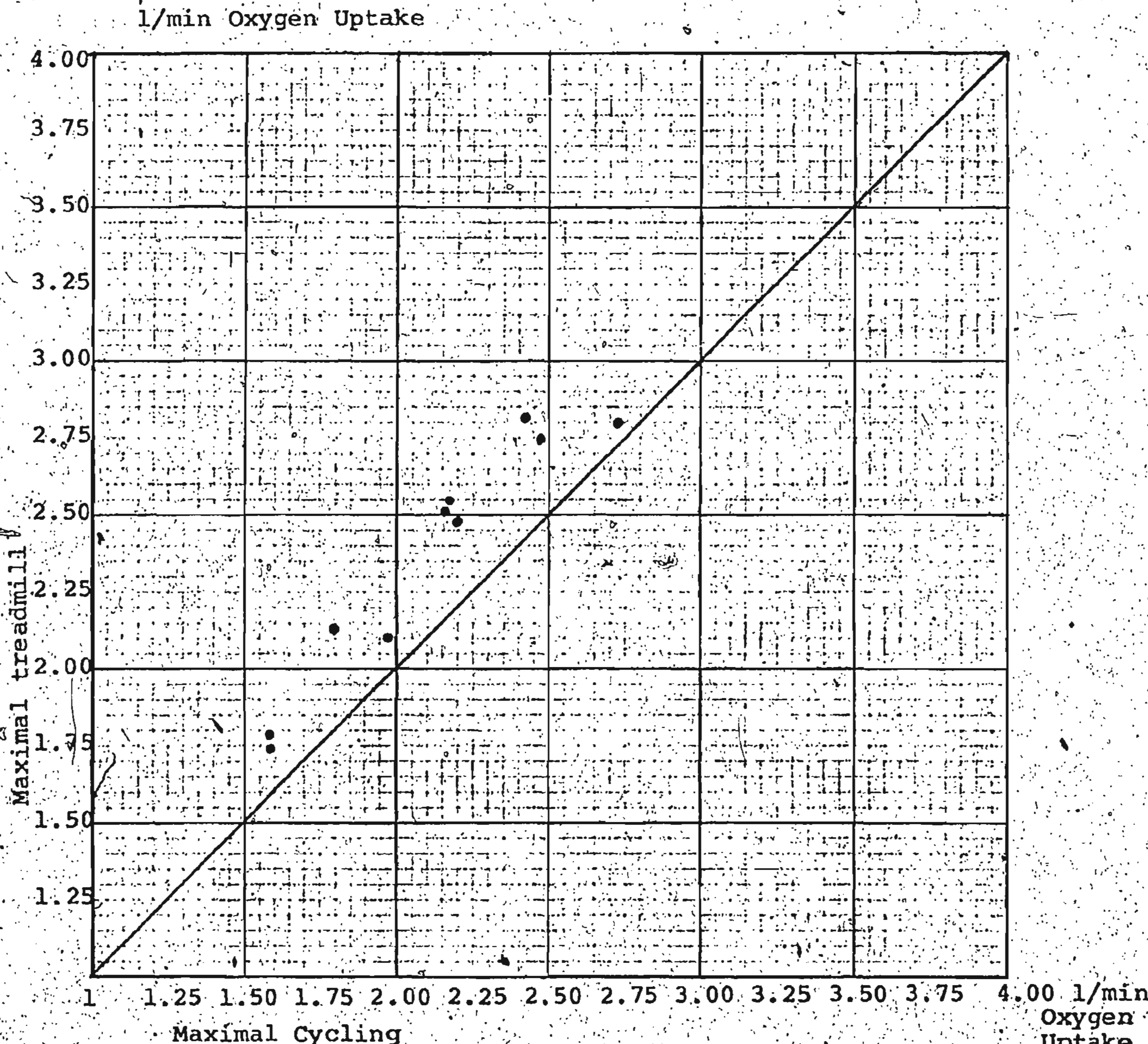


Figure VI - Individual values for oxygen uptake during maximal treadmill exercise compared with corresponding values during maximal bicycling exercise in female subjects for the men and 2.37 l/min for the women. This compared to 3.36 l/min. for the males and 2.20 l/min. for the females on the Åstrand Indirect test. This represented a difference of 6% in the males and 8% in the females with the treadmill test yielding higher maximum oxygen consumptions in both groups. The results of the determination of oxygen uptake during maximal exercise on the treadmill and on the Åstrand indirect are shown in Figure VII for the men and figure VIII for the women.

The maximal oxygen consumption was .11 l/min. and .05 l/min. lower on the continuous bicycle test as compared with the Åstrand indirect test in male and female subjects. In the case of the male subjects this difference proved to be significant at only the .05 level but was significant at only the .10 level for the female subjects. In both cases the percentage increase was approximately 3% with the males being slightly over and the females slightly below. The results of the determination of oxygen uptake during maximal exercise on the bicycle and on the Åstrand indirect test are shown in Figure IX for the men and Figure X for the women.

Individual and mean values for maximal pulmonary ventilation and maximum heart rate during the bicycle test

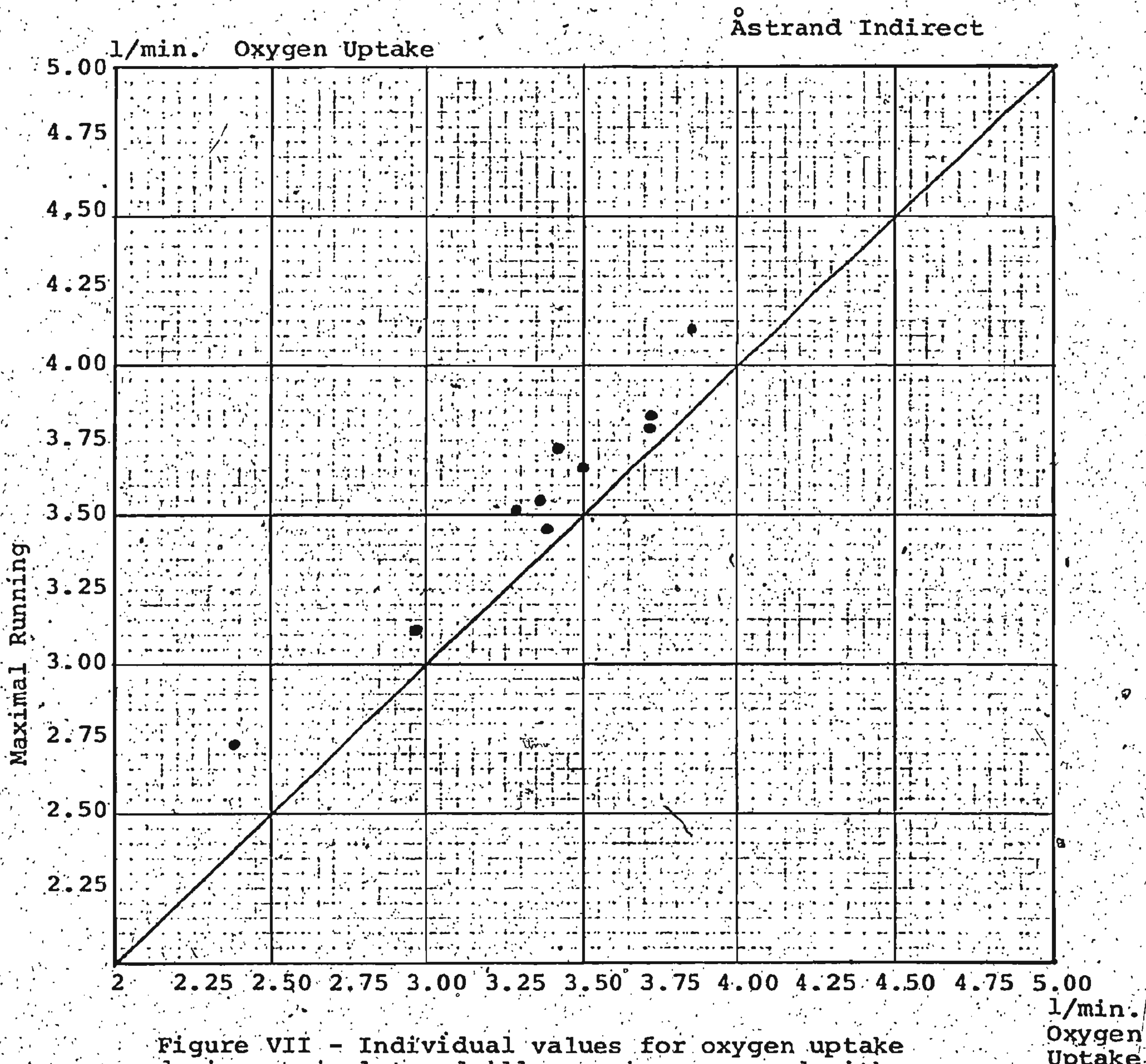


Figure VII - Individual values for oxygen uptake during maximal treadmill exercise compared with corresponding values obtained from Åstrand Indirect test in male subjects

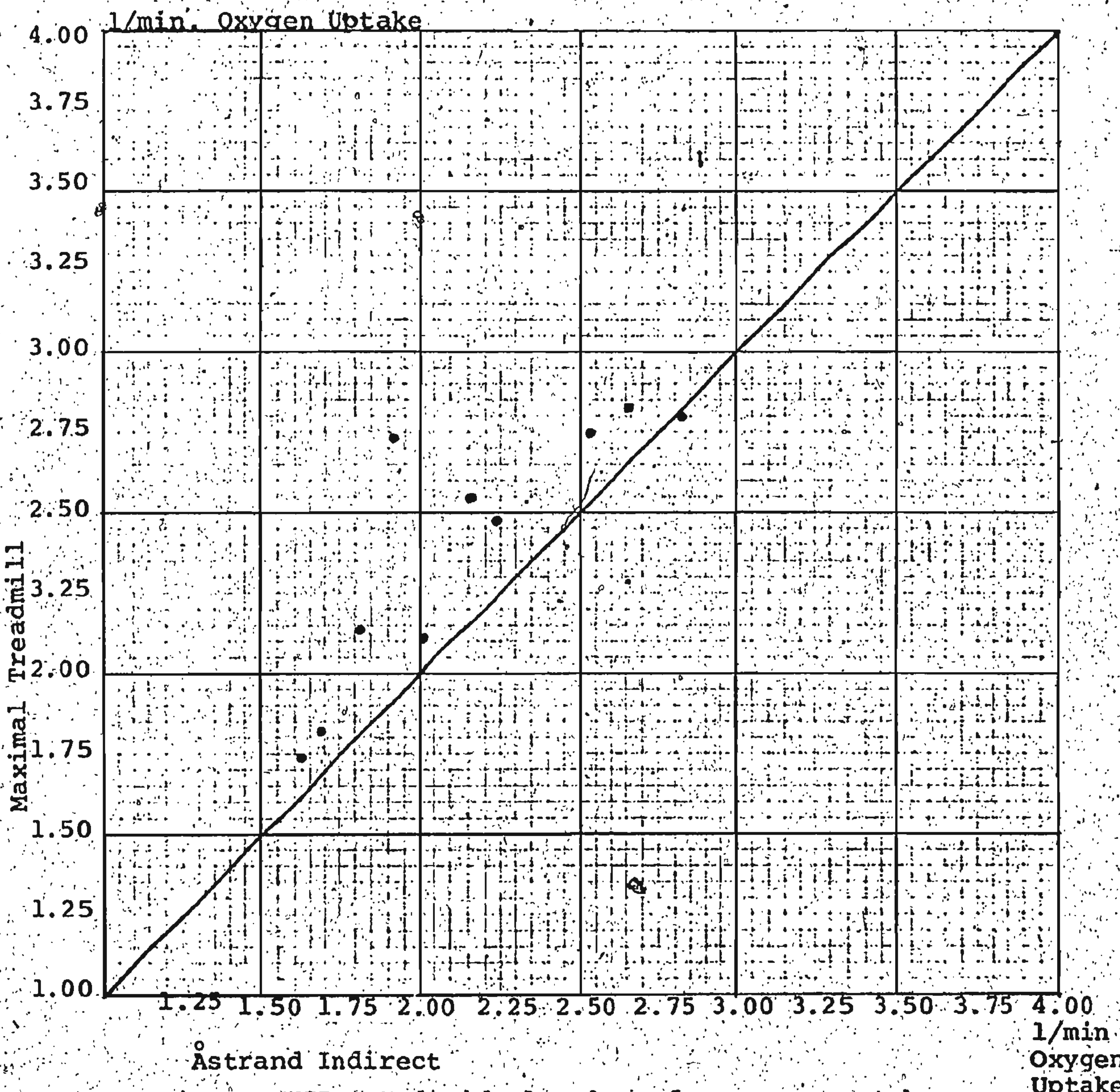


Figure VIII - Individual values for oxygen uptake during maximal treadmill exercise compared with corresponding values obtained from the Åstrand Indirect test in female subjects.

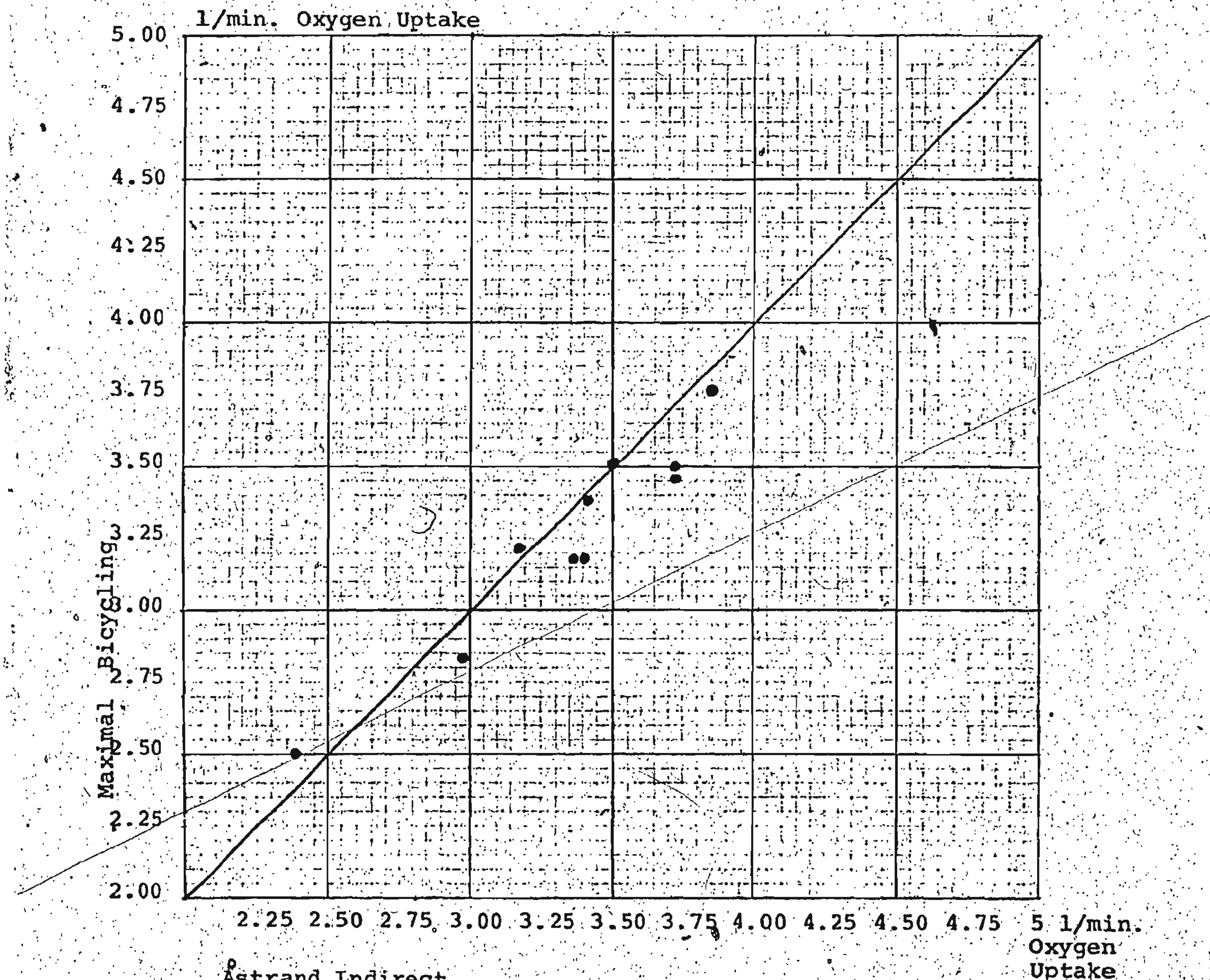


Figure IX - Individual values for oxygen uptake during maximal bicycle exercise compared with corresponding values obtained from the Åstrand indirect test in male subjects

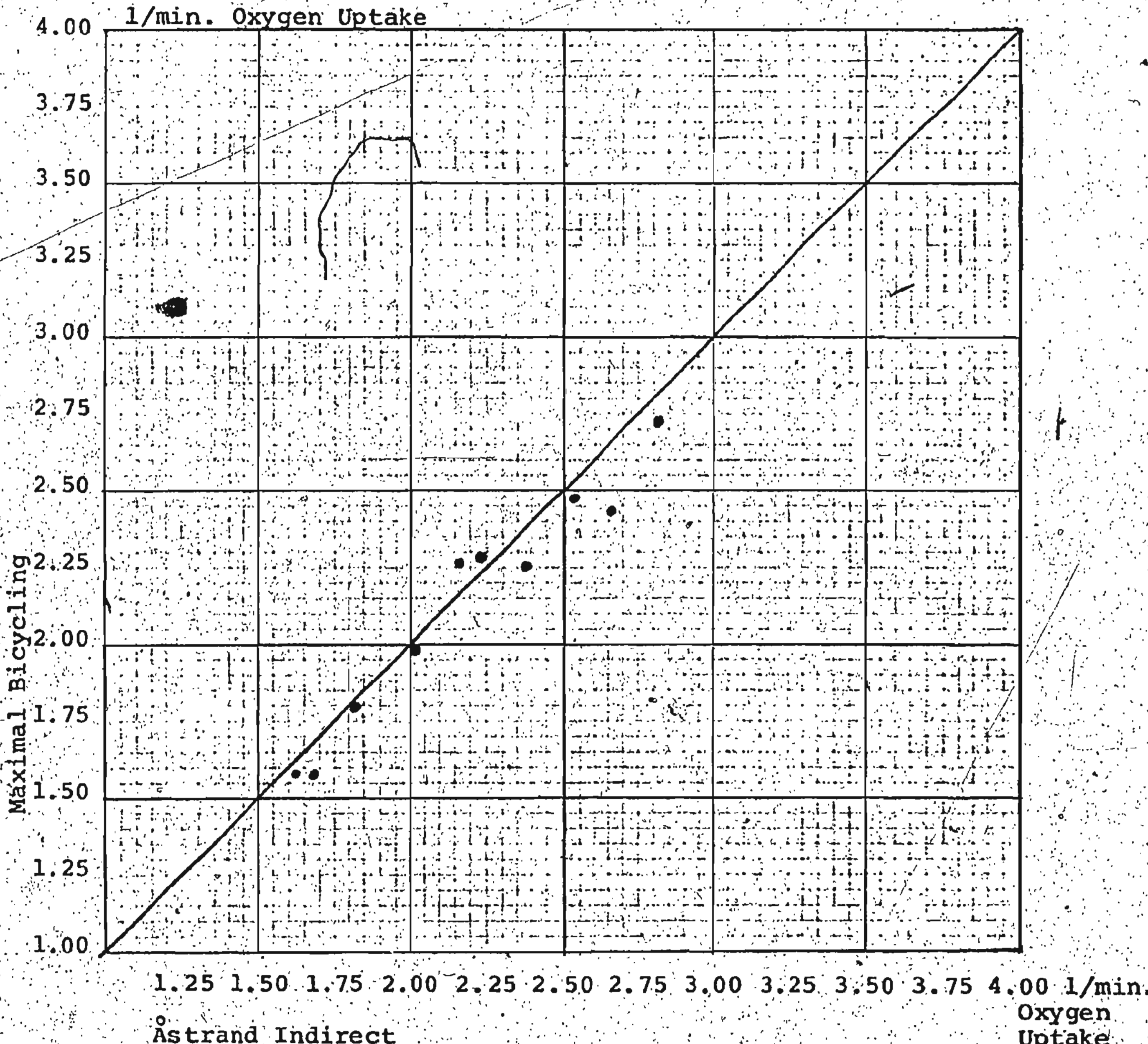


Figure X - Individual values for oxygen uptake during maximal bicycling exercise compared with corresponding values obtained from the Åstrand indirect test in female subjects and the treadmill test are presented for both male and female groups in Table V.

The pulmonary ventilation was higher in the treadmill test than in the bicycle test for both groups. The difference was 2.9 l/min. for the males and 3.8 l/min. for the females. These differences were both significant at the .o5 level.

No significant difference was found between the maximum heart rate during bicycle or treadmill exercise in either the male or female groups.

The interrelationships between maximum oxygen consumption as measured on the three tests are presented as a correlation matrix in Table VI, page 41. All correlation coefficients were statistically significant at the .01 level and ranged from .90 to .94.

The interrelationships between the maximum oxygen uptake as measured on the continuous bicycle test and the treadmill test and the physiological response of heart rate and pulmonary ventilation are presented as a correlation matrix in Table VII, page 42. The correlation coefficients between max VO_2 and max pulmonary ventilation were all significant at .05 level. There was however no statistical significance between VO_2 max and heart rate.

Table V

Individual and average values for pulmonary ventilation (BTPS) and maximum heart rate during bicycle and treadmill exercise

	Pulmonary Ventilation* BTPS liters/minute		Heart Rate* beats/minute	
	Bicycle	Treadmill	Bicycle	Treadmill
Males				
1	117.2	119.2	202	206
2	124.3	127.9	197	196
3	122.2	128.2	195	198
4	127.3	127.0	197	195
5	130.5	135.1	200	203
6	134.1	135.0	191	195
7	133.7	136.4	195	193
8	129.0	137.5	205	201
9	131.2	130.3	194	197
10	139.5	141.6	192	197
mean	128.9	131.8	197	198
Females				
1	75.2	77.3	197	199
2	77.4	76.1	205	195
3	81.6	84.0	195	201
4	85.6	88.9	187	193
5	81.9	85.0	190	191
6	96.7	99.4	196	190
7	94.1	100.3	189	207
8	84.1	96.6	203	205
9	89.7	92.5	191	196
10	101.0	104.7	189	188
mean	86.7	90.5	194.2	194.7

* This data not used in this study.

Table VI

Correlation matrix for max. VO_2 values on Åstrand indirect test, continuous treadmill test and the continuous bicycle test

Males

	Test	2	3
1.	Åstrand indirect	.90	.94
2.	Continuous bicycle		.92
3.	Continuous treadmill		

Females

	Test	2	3
1.	Åstrand indirect	.94	.94
2.	Continuous bicycle		.90
3.	Continuous treadmill		

p = .746 is significant at .01 level

Table VII

Correlation matrix for max. $\dot{V}O_2$ scores, pulmonary ventilation and maximum heart rate

Males

	Pulmonary Ventilation	Max. Heart Rate
Cycling test	.76	-.27
Treadmill test	.77	-.48

Females

	Pulmonary Ventilation	Max. Heart Rate
Cycling test	.76	-.28
Treadmill test	.68	-.12

p = .746 is significant at .01 level

p = .564 is significant at .05 level

Discussion

The major question in the present study was whether or not the same values for oxygen uptake could be obtained from the Åstrand indirect test, maximal bicycle test and maximal treadmill test in male and female subjects. The significantly lower values for max. VO_2 on the bicycle ergometer in comparison to the treadmill ~~are~~ in close agreement with the results of previous investigations. (15,17,19,23,24,27,29,30) Hermansen and Saltin (17) reported mean values which were 7% higher in treadmill running as compared to cycling at 50 r.p.m. They also found that sedentary students had a 120% higher value on the treadmill as compared to the bicycle. This study showed a difference of 9% for the males and 11% for the females.

Glassford (15) using procedures similiar to those in the present study reported that direct treadmill tests yeilded higher oxygen uptake values by 8% than the direct bicycle test. The study by Rowell (30) however showed values .60 liter/minute higher on the treadmill than on the bicycle ergometer. These values are considerably higher than the .30 liter and .23 liter which were observed in this study. However in the study by Rowell leveling off was used as the criterion to establish the maximal oxygen uptake on the treadmill while only one continuous exercise period was used on the bicycle. This may account for such a large difference between the studies.

In comparing the improvement in men and women this study found an improvement of 9 and 11% respectively. This result seems to be similiar to that reported by Kamon and Pandolf (19) who found improvements of 13% in men and 8% in females. McArdle and Magel (24) found an average reduction of .32 l/min. or 10% reduction in VO_2 max. during cycling as compared to running using male college students. Our study showed a reduction of .30 l/min. which is very close to that of McArdle and Magel.

A common complaint of subjects on the continuous bicycle test was a feeling of intense local discomfort in the thigh muscles during their maximum work levels. Many of the subjects stated that this was a major factor in limiting their ability to perform more work on the ergometer test. This was not a general complaint with the treadmill running. It is likely that the development of local muscular fatigue may set the limit for oxygen uptake in cycling. It seems that the results of this study agree with previous research in that there is an approximately

10% higher VO_2 max. during uphill running as compared to cycling. This difference seems to exist regardless of the sex of the subject.

The results showed that the Åstrand indirect test yeilded maximal oxygen uptake values which were approximately 3% greater than those measured during the cycling test and approximately 6 - 8% smaller than those measured during the treadmill test.

Glassford (15) found that the indirect test yielded significantly higher means than did the direct bicycle test. However he found the difference to be approximately 7%. This may be explained by the fact that he used a discontinuous bicycle test whereas this study used a continuous bicycle test. Hettinger (18) also found a significantly higher mean for the Åstrand indirect test as compared to the Åstrand direct bicycle test.

In comparing the indirect test to the treadmill direct test it was found that the Åstrand indirect significantly underestimated the treadmill max. VO_2. This was in general agreement with Rowell et al. (30), Wyndham (34) and Davies (11). All these studies agree with these findings but both Davies and Rowell suggest differences as great as 20% and 27% respectively.

Wyndham however suggested an underestimation of approximately .32 liters or 10%. This is similiar to the value of from 6 - 8% obtained from this study.

Glassford (15) however found no significant difference between VO_2 max. on the treadmill test and as predicted by the Åstrand indirect test. He used a series of discontinuous threadmill tests to determine the VO_2 max. while this study used one continuous treadmill test. This may account for the difference in the results.

Pulmonary Ventilation and heart rate during maximal treadmill and bicycle exercise were compared. The results showed no significant difference between maximum heart rate during both tests. There was, however, a significant difference in pulmonary ventilation. Pulmonary ventilation was higher during the treadmill test in both male and female subjects.

Correlation coefficients between max. VO_2 and pulmonary ventilation were significant at the .05 level. However there was no significant correlation between max. VO_2 and max. heart rate. These two correlations are in agreement with previous studies. (32)

Analysis of the correlation coefficients between the three tests indicated that all three oxygen consumption tests were highly correlated. McArdle reported a correlation of .93 between the continuous treadmill test and the continuous bicycle test. Correlation coefficients of .92 for males and .90 for females were obtained in this study. Glassford (15) also reproted significant correlation coefficients between both cycling and running max. VO_2 tests as well as the Åstrand indirect. The correlations obtained between the indirect test and the two direct tests were equivalent to the intercorrelations between the latter tests. Since this was the case it would seem that the indirect test and any one set of values determined by a direct technique is as good as the relationship between the values of the two direct measures.

Chapter V

Conclusions

The purpose of this study was to compare the maximum oxygen consumptions obtained from the Åstrand-Rhyming indirect test, the continuous bicycle test and the continuous treadmill test. Many previous studies had compared the maximum oxygen consumption obtained in these tests but most had used young male subjects.

The sample of 10 males and 10 females consisted of volunteer students from Memorial University of Newfoundland. Each subject was required to perform each of the three maximum oxygen consumption tests.

The statistical analysis employed in this study were the t test for paired samples and the Spearman's coefficient of Rank correlation. The t test enabled the researcher to determine if there was a significant difference between the means of the three tests. The Spearman's correlation enabled the researcher to examine the relationship between each of the three tests.

The means of the three tests were found to be significantly different at the .05 level in all cases except for the Åstrand indirect test and the continuous cycling test in female subjects. The latter was significant at the .10 level. The correlation coefficients between the three tests were all significant at the .05 level.

The differences between the means of the cycling test and the running test were 9% for males and 11% for females. The Åstrand indirect test gave a mean approximately 3% higher than the cycling test in both groups. The treadmill test gave values of approximately 7% higher than the Åstrand indirect test.

The results obtained from the t tests led to the rejections of the null hypothesis.

(i) that there is no significant difference between max. $\dot{V}O_2$ as measured by the Åstrand indirect test, the continuous bicycle test and the continuous treadmill test in males

(ii) that there is no significant difference between max. $\dot{V}O_2$ as measured by the Åstrand indirect test, the continuous bicycle test and the continuous treadmill test in female subjects.

The results obtained led to the following conclusions:

(i) the treadmill running test (incline 7.5%) results in maximum oxygen consumption values which are approximately 10% higher than those obtained during the cycling test (60 r.p.m.) in male and female subjects.

(ii) the Åstrand indirect test underestimates the true maximum oxygen consumption as measured during treadmill running by about 7% in male and female subjects.

(iii) the Åstrand indirect test gives values of maximum oxygen consumption which are similar to those obtained on the continuous cycling test in male and female subjects.

BIBLIOGRAPHY

1 Asmussen, E. and I. Hemmingsen, "Determination of maximum working capacity at different ages in work with legs or with the arms," Scandavian Journal of Clinical Laboratory Investment. 10. 67-71, 1958.

2 Åstrand, P.O. "Experimental Studies of Physical Working Capacity in Relation to Sex and Age," Copenhagen: Munksgaard, 1952

3 Åstrand, P.O. and I. Ryhming, "A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work", Journal of Applied Physiology, 7: 218-221, 1954.

4 Åstrand, P.O. and B Saltin, "Oxygen uptake during the first minutes of heavy muscular exercise", Journal of Applied Physiology, 16: 971-976, 1961

5 Åstrand, P.O. and B. Saltin, "Maximal oxygen uptake and heart rate in various types of muscular activity", Journal of Applied Physiology, 16: 977-981, 1961.

6 Balke, B. and R. Ware, "An experiemental study of physical fitness of air force personnel," U.S.A.F. Medical Journal 10: 675-688, 1959.

7 Binkhorst, R.A. and P. Van Leuween, "A rapid method of the determination of aerobic capacity," International Z. Angew Physiology 19: 459-467, 1963.

8 Blackburn, H. et al., "Standardization of the exercise electrocardiogram. A systematic comparision of chest lead configurations employed for monitoring during exercise", in Physical Activity and the Heart, ed. Karvonen M. J. and Barry, A.J., Springfield, Ill., 1967

9 Buskirk, E. and H.L. Taylor, "Maximal oxygen intake and its relation to body composition with special reference to chronic physical activity and obesity", Journal of Applied Physiology 11: 72-78, 1957.

10 Consolazio, C., R. Johnson and L. Pecora, "Physiological Measurements of metabolic functions in man", New York: McGraw-Hill Book Company, 1963.

11 Davies, D.J. "Limitations to the prediction of maximum oxygen intake from cardiac frequency measurements", Journal of Applied Physiology 24: 700-706, 1968.

12 Dobéln, W, v "A simple bicycle ergometer", Journal of Applied Physiology 7: 222-224, 1954.

13 Faulkner, J.A., D.E. Roberts, R.L. Elk and J. Conway, "Cardiovascular responses to submaximum and maximum effort cycling and running", Journal of Applied Physiology 30: 457-461, 1971.

14 Ferguson, G.A. "Statistical Analysis in Psychology and Education", New York: McGraw, 1959.

15 Glassford, R.G., et al. "Comparision of maximal oxygen uptake values determined by predicted and actual methods", Journal of Applied Physiology 20: 509-513, 1965.

16 Goodwin, J.E. and P. Levill, "Telemetering heart rate during exercise", Proc. Can. Fed. Biol. Soc, 5: 45-49, 1962.

17 Hermansen, L. and B Saltin, "Oxygen uptake during maximal treadmill and bicycle exercise", Journal of Applied Physiology 16: 153-156, 1961.

18 Hettinger, T. et al. "Assessment of physical work capacity", Journal of Applied Physiology 26: 31-37, 1969.

19 Kamon, E and K.B. Pandolf, "Maximal aerobic power during laddermill climbing, uphill running and cycling", Journal of Applied Physiology 32 467-473, 1972.

20 Maksud, M.G. and K.D. Coutts, "Comparision of a continuous and discontinuous graded treadmill test for maximal oxygen uptake", Medicine Science in Sports 4: 182-186, 1972.

21 Margaria, R., P. Aghemo, and E. Rovelli, "Indirect determination of maximum O_2 consumption in man", Journal of Applied Physiology 20: 1070-1073, 1965.

22 McArdle, W.D. et al. "Reliability and interrelationships between maximal oxygen intake, physical work capacity and step test scores in college women". Medicine Science in Sports 4: 182-186, 1972.

23 McArdle, W.D., F Katch and G. Pechar, "Comparision of continuous and discontinuous treadmill and bicycle tests for max. VO_2", Medicine and Science in Sports 5: 156-160, 1973

24 McArdle, W.D. and J.R. Magel, "Physical work capacity and maximum oxygen uptake in treadmill and bicycle exercise", Medicine and Science in Sports 2: 118-126, 1971.

25 Michael, E.D. and S. Howath, "Physical work capacity of college women", Journal of Applied Physiology 20: 263-270, 1965.

26 Mitchell, J.B., B Sproule and C. Chapman, "The physiological meaning of the maximal oxygen intake test", Journal of Clinical Investigation 37: 538-546, 1958.

27 Miyamura, M and Y Honda, "Oxygen uptake and cardiac output during maximal treadmill and bicycle exercise", Journal of Applied Physiology 32: 185-188, 1972.

28 Morehouse, L. "Laboratory Manual for physiology of exercise", St. Louis: C.V. Mosby Company, 1972.

29 Newton, J.L. "The assessment of maximal oxygen intake", Journal of Sports Medicine Physical Fitness 3: 164-169, 1963.

30 Rowell, L.B. H.L. Taylor and W. Wang, "Limitations to prediction of maximal oxygen uptake", Journal of Applied Physiology 19: 919-927, 1964.

31 Sinning, W.E. "Experiments and demonstrations in exercise physiology", Philadelphia, W.B. Saunders Company, 1975.

32 Shephard, R. "Endurance Fitness", Toronto, University of Toronto Press, 1969.

33 Taylor, H., E. Buskirk and A. Henschel, "Maximal oxygen intake as an objective measure of cardio-respiratory performance", Journal of Applied Physiology 8: 73-80, 1955.

34 Wyndham, C.H. "Submaximal tests for estimating maximum oxygen intake", Canadian Medical Association Journal 96: 736-742, 1967.

Appendices

Appendix A

Table VIII

Data Sheet

Subject Age Sex

Height cm. Weight kg.

Estimation of $\dot{V}O_2$ max. from Astrand indirect test

Workload kgm./min.

Heart rate beats/min.

$\dot{V}O_2$ max. liters/min. ml/kg./min.

Direct Bicycle Ergometer Test

Barometric Pressure

Room Temperature

Humidity

	Workload kgm./min.	Heart Rate max./min.	Collection Time	V_E (ATPS) liters/min.
1				
2				
3				

	t^0 of collected gas	V_E (BTPS) Liters/min	V_E (STPD) liters/min	F_{EO_2} %	VO_2 (STPD) ml/min
1					
2					
3					

Direct Treadmill Test

Barometric Pressure

Room Temperature

Humidity

	Workload		Heart Rate	Collection Time	V_E (ATPS)
	Speed km/hr	Grade %	max./min.		liters/min.
1					
2					
3					

	t^0C of gas	V_E (BTPS) liters/min.	V_E (STPD) liters/min	F_{EO_2} %	VO_2 (STPD) ml/min.
1					
2					
3					

Appendix B

Table IX

Vapor pressure of water at various temperature (31)

Temperature °C.	Vapor Pressure of Water
15	12.8
16	13.6
17	14.6
18	15.5
19	16.6
20	17.5
21	18.7
22	19.8
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.3
29	30.0
30	31.8

Appendix C

Table X

To show t test values of differences between means of three max. VO_2 tests in males and females

Males	Åstrand Ryhming	Treadmill	Bicycle
Åstrand Ryhming	1.00	6.03	2.88
Treadmill	6.03	1.00	14.35
Bicycle	2.88	14.35	1.00

Females	Åstrand Ryhming	Treadmill	Bicycle
Åstrand Ryhming		4.49	1.88
Treadmill	4.49		7.19
Bicycle	1.88	7.19	

$t > 3.250$ required for significance of 0.01 level
$t > 2.663$ required for significance of 0.05 level
$t > 1.833$ required for significance of 0.10 level

Appendix D

Table XI

To show t test values of difference between means of Pulmonary Ventilation of male and female subjects during maximal exercise on a treadmill and bicycle ergometer

	t value
Males	3.16
Females	3.31

t > 3.250 required for significance at 0.01 level

t > 2.663 required for significance at 0.05 level

t > 1.833 required for significance at 0.10 level

Table XII

To show t test values of difference between means of maximal heart rates of male and female subjects on maximal treadmill and bicycle exercise

	t value
Males	1.29
Females	.73

t > 3.250 required for significance at 0.01 level

t > 2.663 required for significance at 0.05 level

t > 1.833 required for significance at 0.10 level

Appendix E

Table XIII

A Matrix to show Spearman Coefficients of rank correlation for max. $\dot{V}O_2$ scores on 3 tests of maximum oxygen uptake

Males

	Åstrand Ryhming	Treadmill	Bicycle
Åstrand Ryhming	1.00	.94	.90
Treadmill	.94	1.00	.92
Bicycle	.90	.92	1.00

Females

	Åstrand Ryhming	Treadmill	Bicycle
Åstrand Ryhming	1.00	.94	.94
Treadmill	.94	1.00	.90
Bicycle	.94	.90	1.00

A critical value of P > .60 is required for significance at the 0.05 level.
A critical value of P > . 783 is required for significance at the 0.01 level.

Appendix F

Table XIV

To show Spearman Rank Order Correlation Coefficients between maximum Pulmonary Ventilation and max. VO_2 of Male and Female Subjects on treadmill and cycling tests

	Pulmonary Ventilation Males	Pulmonary Ventilation Females
Treadmill	.77	.68
Bicycle	.76	.76

Appendix G

Table XV

To show Spearman Rank Order Correlation Coefficients between maximum heart rate and max. VO_2 of male and female subjects on treadmill and cycling tests

	Maximum Heart Rate Males	Maximum Heart Rate Females
Treadmill	-.48	-.28
Bicycle	-.27	-.12