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A COMPARISON AMONG THREE TESTS FOR MEASURING
MAXIMAL OXYGEN CONSUMPTION

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

by

David Norman Camaione, B.S., M.A.

The Ohio State University

Approved by

D. K. Mathews
Adviser
School of Physical Education
To my wife and daughters

Judi, Caron, and Crisi
ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. Donald K. Mathews, my adviser, for his assistance during my professional program, to Dr. Edward L. Fox, Dr. Richard W. Bowers, and Dr. Robert L. Bartels for their generous aid in this study.

I wish to thank the wrestlers who served as subjects, Jim Humphrey, Frank Romano, John Groves, Dan Young, Jerry Hanley, Dave Shaffle, and Ron Heath for their excellent cooperation throughout the study.

Special appreciation is directed to my friends Duane O. Eddy, L. Tony Whitney, and Bruce Hollering whose assistance during the many test runs was invaluable.
VITA

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<td>Born - Watertown, New York</td>
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<tr>
<td>1960</td>
<td>B.S., The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1961</td>
<td>M.A., The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1961-1968</td>
<td>Assistant Professor, MacMurray College, Jacksonville, Illinois</td>
</tr>
<tr>
<td>1968-1969</td>
<td>Research Associate, The Ohio State University</td>
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PUBLICATIONS


FIELDS OF STUDY

Major Field: Physical Education, Professor Donald K. Mathews

Minor Field: Anatomy, Professor Margaret Hines
TABLE OF CONTENTS

ACKNOWLEDGMENTS .......................................................... iii
VITA ........................................................................ iv
TABLES ................................................................... vii

CHAPTER

I. INTRODUCTION ..................................................... 1
   Related Literature
   Criteria for Construction of a $V_0^2$ Max. Test

II. METHODS AND PROCEDURES ............................................ 13
   Subjects
   Apparatus
   Procedures
   Protocol for Mitchell, Sproule and Chapman Method
   Protocol for Saltin and Astrand Method
   Protocol for The Ohio State University Method

III. ANALYSIS OF DATA ................................................... 21
   Statistical Procedures
   Discussion

IV. SUMMARY AND CONCLUSIONS ............................................ 28
   Summary
   Conclusions

APPENDIXES

A. Raw Data for Trials One and Two for Mitchell, Sproule
   and Chapman Method ................................................... 32

B. Raw Data for Trials One and Two for The Ohio State
   University Method ....................................................... 33
<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Raw Data for Trials One and Two for Saltin and Astrand Method</td>
</tr>
<tr>
<td>D. Analysis of Variance for Three Methods of Maximal Oxygen Consumption</td>
</tr>
<tr>
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# LIST OF TABLES

<table>
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1. Characteristics of the Three Treadmill Tests
2. Age, Height and Weight of Subjects
3. Comparisons of Variables Among Three Maximal Oxygen Intake Tests
4. "t" Test for Trial One Against Trial Two for All Tests
5. Correlation Between Trial One and Two for All Tests
6. Correlation Among the Test Results
CHAPTER I

INTRODUCTION

Falls et al.\textsuperscript{18} cite the studies of Astrand,\textsuperscript{2} Balke and Ware,\textsuperscript{8} Dill,\textsuperscript{16} Taylor and Brozek,\textsuperscript{41} and Strydom\textsuperscript{40} as having endorsed maximum oxygen uptake as the ultimate criterion of physical fitness. According to Shephard et al.\textsuperscript{36} maximal oxygen consumption ($V_{O_2}$ max.) has been accepted as the primary criterion against which other methods of physical fitness are to be compared. The utilization of $V_{O_2}$ max. is thus the single most important criterion relative to the measurement of one's cardiovascular condition.\textsuperscript{28}

With $V_{O_2}$ max. universally accepted as the ultimate criterion for cardiovascular fitness, a search into the literature was undertaken in order to study and evaluate the various methods used in its measurement. The goal was to determine basic similarities and differences among the many methods with the express purpose of delineating major criteria for measuring maximal oxygen consumption. As a consequence of the search, an ideal $V_{O_2}$ max. test was constructed and compared to two known tests.

RELATED LITERATURE

There are three commonly used laboratory methods of exercise for assessing maximal oxygen consumption: treadmill (running and walking), stepping, and cycling.\textsuperscript{36}
Treadmill (Running and Walking)

Robinson in his classical study of 1938 described a treadmill method intended to exhaust the subject in 5 minutes. There was a preliminary exercise lasting 15 minutes, followed by a 10-minute rest interval. Before the subject ran, he sat for at least 3 minutes to "flush out" the collection system. The subject then ran to exhaustion and no experiments went beyond 5 minutes. During the first 3 minutes of the test run, expired air was collected from a mixing chamber and for the final two minutes directed into two Douglas bags.

Balke in 1952 constructed a test of maximal aerobic capacity based on cardiovascular and respiratory responses to gradually increased work. The test began with the subject walking at 5.6 km/hr. (3.5 m.p.h.) on a motor-driven treadmill on a zero per cent grade. After the first minute, the treadmill was elevated to 2 per cent grade and then raised 1 per cent grade each subsequent minute. The subject walked until his heart rate reached 180 beats/min. Balke established that when an individual reaches a heart rate of 180 beats/minute, certain physiologic responses exhibit themselves in such a way as to suggest this level to be a maximal effort for that individual. The various physiologic variables are: (1) a drop in alveolar CO₂ tension, (2) a rapid rise in respiratory frequency and minute volume, (3) a respiratory quotient which exceeds unity, (4) a pulse pressure of maximal value, and (5) blood lactate rapidly elevating.

Åstrand developed a VO₂ max. method in 1952. There are two starting treadmill elevations; for those subjects under 20 years of age, the treadmill was horizontal and for those over 20, the treadmill was set at an angle of 1° (1.75 per cent grade). The first test runs were done at
low speed, 7-8 km/hr. (4-5 m.p.h.), for school children and 10-12 km/hr. (6.5-7.5 m.p.h.) for adult subjects. After a few days the subject returned to the laboratory and the experiment was repeated at a higher speed of 1-2 km/hr. until the workload was sufficient to exhaust the subject in 4 to 6 minutes. These determinations, however, were over a period of 3 weeks or more.

Taylor, Buskirk and Henschel in 1955 designed a maximal oxygen consumption method for male subjects between the ages of 18 and 35. Subjects reported to the laboratory to perform the treadmill version of the Harvard Fitness Test designed by Johnson, Brouha and Darling. This preliminary treadmill test made it possible to reasonably estimate the correct grade that yields a maximal oxygen intake. On the next visit, the subject walked at 5.6 km/hr. (3.5 m.p.h.) on a 10 per cent grade. There was a brief period of rest lasting 5 minutes or less before the subject started running at 11.3 km/hr. (7 m.p.h.) on a grade previously selected. The test run lasted 3 minutes. The gas collection was taken from 1 minute 45 seconds to 2 minutes 45 seconds. On subsequent visits to the laboratory, the procedure was repeated with the treadmill elevated at a 2.5 per cent grade higher than the previous run until a $V_{O2\ max}$ value was found.

In 1957 Slonim, Gillespie and Harold developed a $V_{O2\ max}$ test for healthy young men while walking on a treadmill. The subject walked for 10 minutes at 5.6 km/hr. (3.5 m.p.h.) on a 10 per cent grade. The treadmill was then elevated to a 20 per cent grade and the subject walked at the same speed for a period of 6 minutes. After a brief rest, the subject repeated the procedure but at a 24 per cent grade. This concluded
the first test session. On the second test day the subject repeated his walk on a 26 per cent grade, and on the third test day on a 28 per cent grade. If any of the six-minute walks were not completed, a 1 per cent decrease in elevation was undertaken until the subject could complete six full minutes. Some of the limiting factors of this method cited by Consolazio and others\textsuperscript{12} were weakness of the lower extremities, muscle tightness, nausea, blackout, and premature ventricular systole.

Another \( V_{02} \) max. test was established in 1957 by Mitchell, Sproule and Chapman.\textsuperscript{29} The subject walked for 10 minutes at 4.5 km/hr. (3.0 m.p.h.) on a 10 per cent grade, followed by a 10-minute rest interval. The first run began at 9.7 km/hr. (6 m.p.h.) and on a zero per cent grade. The run lasted 2.5 minutes and the subject's expired air was collected from 1 minute and 30 seconds to 2 minutes and 30 seconds. Again, a 10-minute rest period was allowed. For the second run, the workload was increased by raising the treadmill to a 2.5 per cent grade, maintaining the same speed. It was necessary for the workload to be increased to 14.5 km/hr. (9 m.p.h.) and 14.75 per cent grade to elicit a maximal value for some of their 65 subjects.

Saltin and Astrand\textsuperscript{35} in 1967 constructed a maximal oxygen uptake method when they tested the 95 male and 38 female members of the Swedish National teams. All subjects initially performed at a submaximal workload for 6 to 7 minutes on a Krogh bicycle ergometer. Data collected from these rides were used to predict maximal oxygen values according to the Astrand-Ryhming\textsuperscript{6} Nomogram. These data were used to set the speed and inclination of the treadmill for each of the subjects. The subject then walked on the treadmill for a 10-minute preliminary exercise at a
workload approximating 50 per cent of his predetermined starting load. Immediately following this exercise period, and without rest, the treadmill was elevated and the speed increased. Every third minute the inclination of the treadmill was elevated 1.5° (2.67 per cent). The subject ran to exhaustion. No subject ran longer than 7 minutes.

Stepping

Fletcher in 1960 studied the ability of 12 well-motivated men who underwent a step test to exhaustion. They stepped on and off a 22-inch bench at a constant rate of 30 complete cycles/minute with the preferred leg leading throughout. A preliminary test lasting 15 to 30 seconds was undertaken by all subjects to become familiar with the stepping procedure. The subjects continued to step onto the bench and were timed from the beginning of the first step until they either could not maintain the pace of the metronome or could not step any longer.

Kasch et al. in 1965 designed a step test for measuring maximal oxygen consumption while the subject performed barefoot on a 12-inch bench. An initial submaximal test was undertaken two days prior to the full test. On the day of the test, a 5 to 7 minute preliminary exercise period was administered to obtain a heart rate between 150 to 180 BPM. A 10-minute rest period was then allowed. The maximal test lasts from 6 to 12 minutes. The starting pace was set at 24 steps/min. and is increased 3 to 6 steps/min. each minute until exhaustion takes place. The criteria for maximal effort included the inability to increase the stepping rate, high heart rate, signs of fatigue, and drop in oxyhemoglobin saturation. Continuous gas collection in Douglas bags began when the subject approached his maximal stepping rate.
Bicycle Ergometer

It should be mentioned that there are many VO₂ max. tests involving the bicycle ergometer but there is also considerable variability when using this technique in various exercise physiology laboratories. Moreover, there is much similarity to the treadmill method. One of the more popular methods has been designed by Astrand for both male and female subjects. The pedal frequency for all test rides was set at 50 r.p.m. The subject rode for 10 minutes at approximately 50 per cent of his (her) maximal predicted value. The working intensities for the male subjects were 900, 1200, 1500, 1800, and 1950 kgm/min. For the female subjects the working intensities were 600, 900, 1200, and 1350 kgm/min. The maximal duration of heavy exercise was fixed at 8 minutes. Repeated visits to the laboratory were necessary to properly "load" the bicycle in order to elicit a maximal value.

It is important to point out that Shephard et al. mentioned that performance on a bicycle ergometer is limited largely to exhaustion of the lower extremities rather than general cardiorespiratory exhaustion. They further stated that the Fleisch Ergostat is not adequately designed for maximum work though they failed to elaborate as to the reasons why.

In 1966 a proposal was made to standardize bicycle ergometry. This effort attempted to assure comparability of the results of ergometric measurements by standardizing the methods of procedures.

Comparison of the Three Methods

The literature is contradictory on studies in which VO₂ max. values were compared by the above three methods. In 1961, Astrand and Saltin
found no difference in $V_{O_2}^{max.}$ values when comparing the treadmill to the bicycle ergometer. Newton in 1963 compared four methods of measuring $V_{O_2}^{max.}$, three treadmill tests and a bicycle ergometer test. He found that the highest values were obtained with either the standard treadmill run or Balke treadmill test with a lower value being recorded on the bicycle ergometer in most subjects. In 1965, Glassford et al. found a 5 per cent higher $V_{O_2}^{max.}$ value on the treadmill as compared to the bicycle ergometer. Kasch et al. in 1966 showed a correlation coefficient of 0.95 and a difference of means of 0.24 ml/kg/min. when comparing the treadmill to the step test and concluded that because of its reliability, economy, safety and versatility, the step test is preferred. Wyndham and associates in a series of articles published in 1966 reported that the mean $V_{O_2}^{max.}$ obtained on the bicycle ergometer was significantly lower than those obtained on the treadmill. They also found that the step test method resulted in a higher $V_{O_2}^{max.}$ than the bicycle ergometer method and pointed out that the step test can be validly applied to actual working conditions. In support of Wyndham, Shephard et al. in 1968 found that $V_{O_2}^{max.}$ was greatest on the treadmill, 3.4 per cent smaller in a step test, and 6.6 per cent smaller on the bicycle ergometer method.

The most marked difference in oxygen uptake when comparing the treadmill to the bicycle ergometer was cited by Rowell in 1967. He reported an average 0.6 liters/min. (15.4%) higher value with the treadmill method. Hermansen and Saltin in 1969 attempted to clarify the crucial question as to whether the treadmill and bicycle methods gave identical results and found a 7 per cent higher $V_{O_2}^{max.}$ on the treadmill as compared to
It has been pointed out that the non-bicycling American population will not elicit as high a value as their European counterparts, which must give rise to many of the discrepancies found in the literature when attempts were made to compare these two modes of exercise.  

It can be concluded that a greater amount of muscle mass is involved during maximal running than in either maximal cycling or stepping. For this reason it can be assumed that maximal running would elicit a greater maximal oxygen value.

**Predictive Methods**

The above discussion dealt with the direct measurement of maximal oxygen consumption; however, there is an indirect method as well. Many investigators have constructed indirect methods to estimate $V_{O_{2}}$ max.$^1, 4, 6, 8, 9, 14, 22, 26, 37, 43, 45$ Their purpose was to avoid using cumbersome apparatus and to ensure the safety of the subject, especially those with medical disorders. In almost every situation the indirect method was an underestimate of the directly measured value.$13, 20, 34, 44$

**Preliminary Exercise**

A preliminary exercise period has been widely used in many of the methods found in the literature.$29, 30, 35, 36, 38, 42$ It is characteristic of almost all the $V_{O_{2}}$ max. methods. However, only Binkhorst and vanLeeuven$^9$ tested the "warm-up" variable and found no significant difference when evaluating three methods of measuring $V_{O_{2}}$ max. Thus, this preliminary exercise appears to serve mostly as a psychological factor while allowing the subject to become adjusted to the equipment.
Equipment for Maximal Test Runs

Both Shephard et al.\textsuperscript{36} and Saltin and Astrand\textsuperscript{35} in describing their apparatus emphasized the need for respiratory equipment having low-resistance at high-flow rates so that the subject would feel minimal discomfort when ventilating at maximal work capacity. Dill\textsuperscript{15} discussed the advantages and disadvantages of various equipment and concluded that the bicycle ergometer and gas meter system is better than the treadmill and spirometer system.

Criteria for Estimation of Maximal Values

It has been difficult to determine when a subject has reached VO\textsubscript{2} max. Astrand\textsuperscript{3} states that VO\textsubscript{2} max. has been reached when the oxygen consumption "levels-off." Taylor et al.\textsuperscript{42} reported that if two oxygen intake values were different by less than 150 ml/min. or 2.1 ml/kg/min., the higher value is selected as the VO\textsubscript{2} max. Mitchell et al.\textsuperscript{29} stated that if the difference in oxygen intakes for two consecutive test runs were less than 54 ml/min., the higher value was accepted as the maximal value. Wyndham and others\textsuperscript{45} emphasized that there is no simple criterion to determine when a subject has reached VO\textsubscript{2} max. because of the slow approach to the asymptote of the true curve of O\textsubscript{2} intake plotted against work load.

Continuous vs. Discontinuous Loading

Continuous loading refers to the technique of increasing the work-load while the subject exercises to exhaustion. Discontinuous loading involves starting the subject at a given workload, then allowing for a brief rest period if the evaluation is to be completed in one session,
or 24 to 48 hours if the evaluation is to involve multiple-day sessions. Shephard et al. concluded that continuous loading at two-minute intervals was preferred. This supported the findings of Binkhorst and van Leeuven who stated that continuous loading yielded reliable aerobic capacity values. Saltin and Astrand used a continuous loading technique with a 3-minute time interval between progressive workloads. It has been concluded that the single-day session can replace the multiple-day session procedure with continuously increasing load.

**Duration of Maximal Effort**

Robinson stated that a 5-minute test run is sufficient to elicit $V_{O_2}^{\text{max}}$. Astrand and Saltin concluded that the workload must be of sufficient intensity to terminate the exhaustive run within a period of 3 to 8 minutes. Bonjer stated that the measurement of aerobic capacity is only feasible when there is a high demand from the oxygen-consuming tissues and this condition exists if the working muscles are active during 4 minutes or more. Margaria suggested a work intensity from 6 to 10 minutes.

**Motivation of the Subjects**

One of the primary prerequisites for obtaining a valid $V_{O_2}^{\text{max}}$ is the attitude of the subject. Motivation of the subject is essential.

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**CRITERIA FOR CONSTRUCTION OF A $V_{O_2}^{\text{max}}$ TEST**

Review of the literature on the various methods of measuring oxygen consumption resulted in the following conclusions:
Equipment. Of the three direct methods used for measuring $V_O^2_{2\text{max.}}$, treadmill running elicits the highest value. Respiratory apparatus with low-resistance at high flow rates is required.

Time. The length of the maximal run should last from 3 to 10 minutes.

Testing Procedure. Continuous loading during a single session is best for the subjects and investigators, since it avoids multiple visits to the laboratory.

Treadmill Speed. It is important to have some estimate of the speed of the treadmill for each subject which will elicit a maximal oxygen value in the time noted above.

Preliminary Exercise. A "warm-up" bout is used in almost all methods as a psychological benefit to the subject as well as allowing time to adjust to the equipment.

Statement of the Problem

The purpose of this study was to construct a test of maximal oxygen consumption while the subject ran on a motor-driven treadmill and to compare it with two similar methods.

Sub-Problems

1. To determine whether it is better to compare $V_O^2_{2\text{max.}}$ tests on the basis of $V_O^2$ ml/kg/min. or $V_O^2$ liters/min.

2. To examine the possibility of using maximal heart rates as a means of comparing $V_O^2_{2\text{max.}}$ methods.

3. To ascertain whether continuous loading yields higher maximal $O_2$ values than discontinuous loading.
4. To discover whether it is better to predict treadmill speeds by using a bicycle ergometer or the treadmill itself.

5. To see if the subjects prefer any one of the three tests under investigation.
CHAPTER II

METHODS AND PROCEDURES

The preceding chapter makes reference to several different methods by which maximal oxygen consumption can be measured. The purpose of this study was to compare three \( V_O_2 \) \( \text{max} \) tests while the subject ran on a motor-driven treadmill. The Mitchell, Sproule and Chapman Test, the Saltin and Astrand Test, and The Ohio State University Maximal Treadmill Test were chosen for this study. Each method meets most of the criteria established for measuring \( V_O_2 \) \( \text{max} \) noted in Chapter I.

Detailed discussion of the first two methods were presented in the section on related literature in the previous chapter. The Mitchell method was modified in this study. Each subject started his run at 12.9 km/hr. (8 m.p.h.) and on a 5 per cent grade rather than 9.7 km/hr. (6 m.p.h.) on the horizontal. The criteria established by Taylor et al. were adhered to unless the subject was unable to undertake another test run due to exhaustion. For the Saltin and Astrand method, the subjects performed on a Jacquet Universal Ergostat instead of a Krogh bicycle ergometer. The length of the rides varied from 6 to 7 minutes and the bicycle was "loaded" to elicit a heart rate of approximately 140 to 150. In this study these rides, however, took place a few days prior to any maximal runs on the treadmill.
The Ohio State University Maximal Treadmill Test is similar to the Saltin and Astrand method, but with a few modifications. A 5-minute preliminary exercise walking at 5.6 km/hr. (3.5 m.p.h.) on a 10 per cent grade was utilized. During the period from 3.5 to 4.5 minutes, expired air and heart rate data were collected. This submaximal \( V_{O2} \) (l/min.) and heart rate were plotted against the Astrand-Ryhming Nomogram to obtain a predicted maximal oxygen uptake value. These data were used to determine the speed of the treadmill according to Saltin and Astrand. For example, if the subject's predicted \( V_{O2} \) max. was 48 ml/kg/min., then he ran at 12.5 km/hr. (7.8 m.p.h.). This entire procedure took from 5 to 5.5 minutes, thus constituting a rest period for the subject. The subject then began his run at the set speed and on a 2 per cent grade. The speed remained constant throughout the run and the treadmill was elevated 2 per cent every two minutes. The subject ran to exhaustion.

Prior to any of the three methods, a period of 5 minutes of rest was allowed to obtain a resting heart rate. For the Saltin and Astrand method and The Ohio State University method, expired air collections began when the subject's heart rate reached 176 beats/minute.

The information listed in Table 1 shows the major variables of each of the three methods that were investigated.

Subjects

The seven well-conditioned and well-motivated subjects selected for the study were members of The Ohio State University Wrestling Team. They had just completed training for the wrestling season. Vital data appear in Table 2. The subjects were rotated among the three methods by the Latin
### TABLE 1
CHARACTERISTICS OF THE THREE TREADMILL TESTS

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<th>OSU</th>
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<td>Preliminary Exercise</td>
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<td>Treadmill Speed</td>
<td>9.7 to 14.5 km/hr. (6 to 9 mph)</td>
<td>10 to 20 km/hr. (6.2 to 12.5 mph)</td>
<td>10 to 20 km/hr. (6.2 to 12.5 mph)</td>
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<tr>
<td>Technique</td>
<td>Discontinuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Elevation</td>
<td>2.5% after each run</td>
<td>2.0% every 2 minutes</td>
<td>1.5° every 3 minutes</td>
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<tr>
<td>Start of Gas Collection</td>
<td>1.5 minutes to 2.5 minutes</td>
<td>H.R. at 176</td>
<td>H.R. at 176</td>
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<tr>
<td>Duration of Run</td>
<td>2.5 minutes</td>
<td>All-out run</td>
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### TABLE 2
AGE, HEIGHT, AND WEIGHT OF SUBJECTS

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<td>J. Hu.</td>
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<td>F. R.</td>
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<td>J. G.</td>
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<td>D. Y.</td>
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<tr>
<td>J. Ha.</td>
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<td>59</td>
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<tr>
<td>D. S.</td>
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<td>77</td>
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<tr>
<td>R. H.</td>
<td>18</td>
<td>172</td>
<td>81</td>
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<tr>
<td>M</td>
<td>19.23</td>
<td>169.43</td>
<td>69.0</td>
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<tr>
<td>S.D.</td>
<td>1.15</td>
<td>6.09</td>
<td>8.48</td>
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<tr>
<td>Range</td>
<td>18 to 21</td>
<td>162 to 178</td>
<td>57 to 81</td>
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Square design. For replication each subject ran each method twice, yielding a total of 42 runs. They were asked not to eat any food for five hours prior to their scheduled runs, not to take part in any physical activity on the days of their runs, and not to smoke or imbibe in alcoholic beverages for 24 hours prior to their runs. Each subject made a preliminary visit to the laboratory to become oriented to the overall testing procedure.

Apparatus

Each subject was first weighed in the nude on an Exact Weight scale Model 1250. The scale has a capacity of 105 kilograms and measures to the nearest gram.* Heart rates were monitored with the Hewlett-Packard Electrocardiograph Model 1500A. All heart rates were taken during the third 15-second segment of each minute and multiplied by 4 to obtain a rate for a full minute.

Open-circuit spirometry was utilized for measuring oxygen consumption. The subject inspired room air through a Parkinson-Cowen CD-4 Gas Meter which has an accuracy of ± 1 per cent of the whole range and a capacity of 11,000 liters/hour or 183 liters/minute. It was calibrated against a Collins Chain-compensated spirometer at a flow rate of 180 liters/minute resulting in a 0.2 per cent error. While under actual testing conditions with a subject on the treadmill, per cent errors for ventilation were 0.35, 0.12, and 2.02. Situated at the outlet of the gas meter was a Collins low turbulence Three Way "Y" valve, Model P-319.

A Collins low-resistance Triple-J Valve having a dead space of 180 cc. was used. From the mouthpiece to the mixing chamber there was a
34-inch Collins transparent, non-kinking plastic tube Model P550-527 with an I.D. of 38 mm. The expired air entered a glass jar mixing chamber which had a volume of 4,200 ml. When comparing the concentrations of O2 and CO2 in the mixing chamber with those collected in a Tissot spirometer, the range in per cent errors was from -0.03 to +0.006 in 5 consecutive gas collections. A microcatheter pump pulled a steady supply of expired air from the mixing chamber through a plastic tube, with an I.D. of 5 mm., connected to a system of four three-liter anesthesia bags, each being separated by 13 centimeters and a three-way stopcock. The total dead space in the collection system was 5,500 ml. Oxygen concentration was analyzed with a Beckman E-2 Oxygen Analyzer and carbon dioxide concentration with a Beckman Medical Gas Analyzer Model LB-1.

Procedures

All runs took place in the Exercise Physiology Laboratory of The Ohio State University. The temperatures varied from 18.8°C to 26.1°C and the relative humidity from 37.3 per cent to 67.9 per cent.

When the subject commenced his run on the treadmill, the microcatheter pump was turned on to wash out the collection system. The first gas collection always started at the beginning of a full minute, i.e., 2 to 3 minutes or 3 to 4 minutes. The individual stationed at the gas meter simultaneously turned the small stopcock into the sample bag and the Collins "Y" valve into the gas meter, so that room air was now being drawn through the gas meter with a sample of expired air being pumped into the anesthesia bag. At the end of the full minute both valves were turned off. The next full minute collection did not begin until a period
of 15 seconds had elapsed allowing time to record the gas meter reading, e.g., gas collection times would be: (1) 2:00 to 3:00 minutes, (2) 3:15 to 4:15 minutes, (3) 4:30 to 5:30 minutes, and (4) 5:45 to 6:45 minutes. The duration of the run in this example would be 6 minutes and 45 seconds.

Collections less than 30 seconds were not used. In the 42 test runs completed in this study, only four 30-second collections, one 45-second collection, and one 57-second collection were used for the calculation of \( \text{VO}_2 \) max.

**Protocol for Mitchell, Sproule and Chapman Method**

1. The subject sat for 5 minutes to obtain a resting heart rate.
2. The subject walked for 10 minutes at 4.8 km/hr. (3.0 m.p.h.) on a 10 per cent grade.
3. A 10-minute rest period was allowed.
4. The subject ran at 12.9 km/hr. (8 m.p.h.) on a 5 per cent grade for 2 and a half minutes.
5. Gas collection and heart rates were taken the last minute of the run.
6. Step 3 was repeated.
7. The subject ran at the same speed but on a 7.5 per cent grade.
8. This procedure was repeated elevating the treadmill 2.5 per cent grade for each test run until exhaustion.

**Protocol for Saltin and Astrand Method**

1. Submaximal workloads were obtained on a bicycle ergometer. These rides were completed a few days prior to any maximal
treadmill runs. Their purpose was to predict the inclination and speed of the treadmill.

2. On the day of the maximal run the subject first sat for 5 minutes to obtain a resting heart rate.

3. The subject walked for 10 minutes at approximately 50 per cent of the "initial" run.

4. At the end of the 10th minute of walking, the treadmill speed and inclination were set at the pre-determined values. Thus, the subject went from walking to running.

5. The treadmill was elevated 1.5° every third minute.

6. Gas collection began when the subject's heart rate reached 176 beats/minute.

7. The subject ran to exhaustion.

Protocol for The Ohio State University Treadmill Method

1. The subject sat for 5 minutes to obtain a resting heart rate.

2. The subject walked for 5 minutes at 5.6 km/hr. (3.5 m.p.h.) on a 10 per cent grade.

3. Gas collection and heart rates were taken from minutes 3:30 to 4:30.

4. Approximately 5 minutes were taken to analyze the sample of gas and predict the speed of the treadmill (this constituted a rest interval).

5. The subject began his test run on a 2 per cent grade.

6. The treadmill was elevated 2 per cent every 2nd minute.
7. Gas collection began when the subject's heart rate reached 176 beats/minute.

8. The subject ran to exhaustion.
CHAPTER III

ANALYSIS OF DATA

It was the purpose of this investigation to compare three methods of assessing maximal oxygen consumption while the subject ran on a motor-driven treadmill. The tests evaluated were those of Mitchell, Sproule and Chapman, Saltin and Astrand, and The Ohio State University Maximal Treadmill Test. The four variables tested in each method were: (1) \( V_{O_2} \) ml/kg/min., (2) \( V_{O_2} \) 1/min., (3) pulmonary ventilation (\( V_{E_{BTPS}} \)), and (4) maximal heart rate. Although this study was concerned primarily with oxygen consumption, both maximal ventilation and heart rate were investigated to determine whether these variables yielded any pertinent information.

TABLE 3

COMPARISONS OF VARIABLES AMONG THREE MAXIMAL OXYGEN INTAKE TESTS (N = 7)

<table>
<thead>
<tr>
<th>Test</th>
<th>( V_{O_2} ) ml/kg/min.</th>
<th>( V_{O_2} ) 1/min.</th>
<th>( V_{E_{BTPS}} )</th>
<th>H.R./min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell et al.</td>
<td>57.09 (53.4 to 62.4)</td>
<td>3.94 (3.18 to 4.66)</td>
<td>158.2 (137.6 to 191.9)</td>
<td>188.6 (180 to 196)</td>
</tr>
<tr>
<td>OSU</td>
<td>57.63 (51.6 to 62.5)</td>
<td>3.96 (3.27 to 4.92)</td>
<td>153.5 (119.6 to 196.2)</td>
<td>192.3 (184 to 200)</td>
</tr>
<tr>
<td>Saltin-Astrand</td>
<td>56.57 (52.2 to 61.4)</td>
<td>3.91 (3.20 to 4.72)</td>
<td>154.2 (123.1 to 182.7)</td>
<td>191.3 (184 to 200)</td>
</tr>
</tbody>
</table>
Statistical Procedures

The data collected from the three methods were compared on the basis of means, correlation coefficients and variance. Statistical analysis of the data revealed no significant differences among the three methods of measuring maximal oxygen consumption, maximal $V_{E\text{BTPS}}$, and maximal heart rate. The null hypothesis is therefore accepted.

Reliability (Between Trials). To determine whether a significant difference occurred between trials one and two for each of the three methods, the "t" test for means was applied to the four variables mentioned above. Table 4 shows that no significant differences were found for any of the variables tested.

<table>
<thead>
<tr>
<th>Test</th>
<th>$V_{O2}$ ml/kg/min.</th>
<th>$V_{O2}$ l/min.</th>
<th>$V_{E\text{BTPS}}$</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell et al.</td>
<td>1.329</td>
<td>1.564</td>
<td>0.476</td>
<td>0.654</td>
</tr>
<tr>
<td>OSU</td>
<td>0.980</td>
<td>1.037</td>
<td>1.360</td>
<td>0.296</td>
</tr>
<tr>
<td>Saltin-Astrand</td>
<td>0.829</td>
<td>0.571</td>
<td>0.151</td>
<td>0.411</td>
</tr>
</tbody>
</table>

To measure the reliability of the three methods, the test-retest technique using Pearson product-moment correlation coefficients, calculated between trial one and two were undertaken. The results are contained in Table 5. Of the three methods measured for their reproducibility by the test-retest technique for $V_{O2}$ ml/kg/min., only The Ohio
State University method resulted in a statistically significant correlation coefficient \( r = 0.880; p < .01 \). When \( \dot{V}_O_2 \) \( \text{ml/kg/min.} \) was tested, all three methods yielded statistically significant correlation coefficients. When \( V_{EBTPS} \) was tested, only the OSU method did not yield a statistically significant correlation. No significance was found for maximal heart rate in any of the three tests.

**TABLE 5**
CORRELATION BETWEEN TRIAL ONE AND TWO FOR ALL TESTS

<table>
<thead>
<tr>
<th>Test</th>
<th>( \dot{V}_O_2 ) ( \text{ml/kg/min.} )</th>
<th>( \dot{V}_O_2 ) ( \text{1/min.} )</th>
<th>( V_{EBTPS} )</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell et al.</td>
<td>0.633</td>
<td>0.964(^a)</td>
<td>0.848(^b)</td>
<td>0.050</td>
</tr>
<tr>
<td>OSU</td>
<td>0.880(^a)</td>
<td>0.967(^a)</td>
<td>0.752</td>
<td>0.490</td>
</tr>
<tr>
<td>Saltin-Astrand</td>
<td>0.669</td>
<td>0.954(^a)</td>
<td>0.804(^b)</td>
<td>0.355</td>
</tr>
</tbody>
</table>

\( a = P < .01 \)
\( b = P < .05 \)

Mean Differences Among Methods. Since the data between trials showed no significant differences, they were combined and treated as one group of data under each of the conditions. These data appear in Appendixes A, B and C. The "F" test was applied to each of the four variables mentioned above and no significance was found for any of the means tested. The results of the "F" test are contained in Appendix D.

Relationship Among Three Methods. Further correlation coefficients were tested in order to determine the relationship among the methods for each of the four variables. The data appear in Table 6. When correlating
\( V_{O2_{\text{max.}}} \) in \( \text{ml/kg/min.} \), statistically significant correlation coefficients resulted with the comparison between Mitchell \textit{et al.} and OSU, and with the comparison between Mitchell \textit{et al.} and Saltin and Astrand, but not between OSU and Saltin and Astrand. However, when correlating \( V_{O2_{\text{max.}}} \) in \( 1/\text{min.} \) and \( V_{EBTPS} \), all comparisons were significant. Again, no significance was found for maximal heart rate in all three comparisons.

\textbf{TABLE 6}

\textbf{CORRELATION AMONG THE TEST RESULTS}

<table>
<thead>
<tr>
<th>Tests</th>
<th>( V_{O2_{\text{max.}}} ) ml/kg/min.</th>
<th>( V_{O2} ) 1/min.</th>
<th>( V_{EBTPS} )</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell vs. OSU</td>
<td>.779(^b)</td>
<td>.945(^a)</td>
<td>.902(^a)</td>
<td>.314</td>
</tr>
<tr>
<td>Mitchell vs. Saltin-Astrand</td>
<td>.878(^a)</td>
<td>.991(^a)</td>
<td>.877(^a)</td>
<td>.220</td>
</tr>
<tr>
<td>OSU vs. Saltin-Astrand</td>
<td>.643</td>
<td>.943(^a)</td>
<td>.934(^a)</td>
<td>.698</td>
</tr>
</tbody>
</table>

\(^a\) \( P < .01 \)

\(^b\) \( P < .05 \)

\textbf{Discussion}

The mean \( V_{O2_{\text{max.}}} \) values noted in Table 3 are comparable to those found in the literature. Saltin and Astrand\(^{35}\) recorded a mean value of approximately 57.0 ml/kg/min. for 10 wrestlers. For 17 male athletes they reported a maximal heart rate of 186.6 and 156.0 maximal \( V_{EBTPS} \) for 11 male athletes. Buskirk and Taylor\(^{35}\) found a mean value of 58 ml/kg/min. for a group of nine wrestlers, gymnasts and football players. Slonim and others\(^{38}\) reported a mean expiratory minute volume (BTPS) of 147 liters for a group of trained men ranging in age from 18 to 25 years old.
Reliability (Between Trials). It is interesting to note that the lower correlation coefficients for $V_0^2$ ml/kg/min. were attributed to weight variations, a characteristic of wrestlers, in Mitchell, Sproule and Chapman, and Saltin and Astrand methods, but not in The Ohio State University method. In fact, subject R.H. weighed 80 kg. one test day and 82.56 on another which represented a 3.2 per cent difference. With only 7 subjects the significant correlation coefficient for the OSU test is unexplainable. However, the reliability (reproducibility) of all tests was significant when testing $V_0^2$ l/min. Significant correlation coefficients were found for $V_{EBTPS}$ in Mitchell, Sproule and Chapman, and Saltin and Astrand, but not in The Ohio State University method. Correlation coefficients for maximal heart rate were very low which indicates that heart rate is an unreliable index for yielding much information concerning maximal aerobic work.

Relationship Among Three Methods. Comparisons of the methods are best made with $V_0^2$ l/min. rather than with ml/kg/min. This supported the findings of Glassford and others. Comparisons using $V_{EBTPS}$ all yielded significant correlation coefficients, but those with maximal heart rate did not. Once again, heart rate is not a reliable index for $V_0^2$ max., since it can be elevated above that heart rate when the $V_0^2$ max. was reached, because a subject may continue the test run due to motivation.

Continuous vs. Discontinuous Loading. Shephard et al. and Binkhorst and vanLeeuven demonstrated a preference toward continuous rather than discontinuous loading because it gave higher $V_0^2$ max. values. However, this study did not substantiate their findings.
Two-minute vs. Three-minute Interval. There is no difference in \( V_O_2 \) max. values when loading the treadmill in two-minute intervals as compared to three-minute intervals which is contrary to the conclusion by Shephard et al.36

Criteria for Estimation of Maximal Values. This investigator was confident that the subjects ran to exhaustion in all test runs. Of the 42 runs 8 elicited a "leveling-off phenomena" as defined by Astrand3 for \( V_O_2 \) 1/min. In 17 test runs the \( V_O_2 \) 1/min. was within 150 ml. difference for two consecutive gas collections with the second collection having a greater \( V_O_2 \) 1/min. The remaining 17 test runs yielded differences for the last two gas collections greater than 150 ml/min. Thus, 34 of the 42 test runs were terminated with a higher \( V_O_2 \) max. value for the last gas collection which might suggest that an all-out exhaustive run is the best criteria for determining a \( V_O_2 \) max. value.

Respiratory Exchange Ratio. The R for the Mitchell et al., the Saltin and Astrand, and OSU tests were 1.07, 1.13, and 1.14 respectively. These data met the requirement stated by Binkhorst and vanLeeuven9 and Balke7 that an R should exceed unity under maximal testing conditions. Issekutz and others22 have suggested an R of 1.15 as a reliable indice that \( V_O_2 \) max. has been achieved.

Under the limitations of this study, any of the three methods of measuring maximal oxygen consumption studied can be used since they resulted in almost identical values. The Mitchell, Sproule and Chapman Method was validated against the Taylor, Buskirk and Henschel Method by a team of investigators.20 As a result of the findings of that study, both the Saltin and Astrand and The Ohio State University Maximal methods
can be accepted as highly reliable tests. The latter method, however, takes less time to complete and thus from an administrative standpoint is better than the other two methods. One disadvantage to the Saltin and Astrand Method is the necessity for a bicycle ergometer in addition to a treadmill for the purpose of predicting the speed and inclination of the treadmill. However, since comparable $V_{O_2 \text{ max}}$ values were obtained for both the Saltin and Astrand and OSU tests, it appears the bicycle ergometer can be eliminated for the submaximal workload.

The subjects were asked to indicate their preference and in six out of seven cases, their choice was the Mitchell et al. method. The reason given for this choice was that they knew they had to run only $2\frac{1}{2}$ minutes for any one time.
CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to compare three methods of assessing maximal oxygen consumption ($V_O_2$ max.) while the subject ran on a motor-driven treadmill. Seven well-conditioned, well-motivated wrestlers served as subjects. The methods investigated were the Mitchell, Sproule and Chapman test, the Saltin and Astrand test, and The Ohio State University Maximal Treadmill Run. All subjects ran each of the methods twice according to the Latin Square design. There was a total of 42 maximal test runs.

Open-circuit spirometry was utilized and the subjects inspired room air through a gas meter which recorded $V_{IATPS}$. Air was expired into a mixing chamber and a microcatheter pump pulled aliquots of air into anesthesia sample bags which were analyzed on a Beckman Oxygen Analyzer, Model E-2 and a Carbon Dioxide Beckman Medical Analyzer. Calculations included correction of $V_{IATPS}$ to $V_{ESTPD}$ and $V_{EBTPS}$. A Hewlett-Packard Electrocardiograph was used to monitor the heart rate. Recordings were done the third 15-second segment of each minute of exercise extrapolated to a minute rate.

The "t" test for means was employed to determine whether any real differences existed between trials one and two. The test-retest method was used to measure reliability. Analysis of variance was employed to
test mean differences among the methods. Four variables were tested:

(1) \( V_{O_2} \) ml/kg/min., (2) \( V_{O_2} \) l/min., (3) \( V_E \) BTPS, and (4) maximal heart rate/min.

Conclusions

Based on the findings of this study the following conclusions are stated:

1. The Mitchell, Sproule and Chapman test, the Saltin and Astrand test, and The Ohio State University Maximal Treadmill Run did not elicit statistically significant differences in oxygen consumption, \( V_E \) BTPS, and maximal heart rate/min.

2. Under the conditions of this study, the newly constructed Ohio State Maximal Treadmill Run can be regarded as a reliable and valid test.

3. When comparing methods of assessing maximal oxygen consumption, it is suggested that the \( V_{O_2} \) l/min. be used over ml/kg/min. because of weight fluctuations.

4. Of the four variables tested, maximal heart rate in all cases is a poor indicator of reliability and a poor index for comparison among methods.

5. Based upon the administrative time necessary for a subject to reach \( V_{O_2} \) max., The Ohio State University Maximal Treadmill Run is most brief, with Saltin and Astrand test next, and the Mitchell, Sproule and Chapman test last.

6. There is no preference as to a continuous or discontinuous technique. Two-minute interval loading is comparable to three-minute interval loading.
7. The best criterion for estimation of the maximal aerobic value appears to be an exhausted effort by a highly-motivated subject.

8. An R greater than unity should be considered as another indice as to when \( V_0_{2, \text{max}} \) has been reached.

9. Predicting a suitable treadmill speed by the use of a bicycle ergostat is comparable to having a submaximal load on the treadmill.

10. The subjects preferred the Mitchell, Sproule and Chapman test because they knew how long they were to run.
APPENDIX A

Raw Data for Trials One and Two for Mitchell, Sproule, Chapman Method

<table>
<thead>
<tr>
<th>Subjects</th>
<th>V0₂ ml/kg/min.</th>
<th>V0₂ l/min.</th>
<th>VₑBTPS</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J. Hu.</td>
<td>55.6</td>
<td>58.4</td>
<td>3.612</td>
<td>3.799</td>
</tr>
<tr>
<td>F. R.</td>
<td>58.2</td>
<td>56.0</td>
<td>3.326</td>
<td>3.177</td>
</tr>
<tr>
<td>J. G.</td>
<td>58.7</td>
<td>59.3</td>
<td>4.418</td>
<td>4.484</td>
</tr>
<tr>
<td>D. Y.</td>
<td>56.0</td>
<td>56.3</td>
<td>3.872</td>
<td>3.898</td>
</tr>
<tr>
<td>J. Ha.</td>
<td>58.3</td>
<td>62.4</td>
<td>3.491</td>
<td>3.655</td>
</tr>
<tr>
<td>D. S.</td>
<td>53.8</td>
<td>53.4</td>
<td>4.144</td>
<td>4.154</td>
</tr>
<tr>
<td>R. H.</td>
<td>54.8</td>
<td>57.7</td>
<td>4.432</td>
<td>4.657</td>
</tr>
</tbody>
</table>

Mean | 56.5| 57.6| 3.899| 3.975| 157.214| 159.143| 189.7| 187.4 |
S.D.  | 1.92| 2.84| .412 | .464 | 16.36   | 18.78  | 3.61 | 5.42  |

Combined
Mean | 57.09| 3.937| 158.185| 188.6 |
S.D.  | 2.00 | .438 | 17.22   | 3.33  |
APPENDIX B

Raw Data for Trials One and Two for
The Ohio State University Method

<table>
<thead>
<tr>
<th>Subjects</th>
<th>V₀₂ ml/kg/min.</th>
<th>V₀₂/min.</th>
<th>VₑBTPS</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J. Hu.</td>
<td>56.9</td>
<td>60.8</td>
<td>3.697</td>
<td>3.970</td>
</tr>
<tr>
<td>F. R.</td>
<td>57.8</td>
<td>57.5</td>
<td>3.287</td>
<td>3.272</td>
</tr>
<tr>
<td>J. G.</td>
<td>58.9</td>
<td>60.1</td>
<td>4.416</td>
<td>4.508</td>
</tr>
<tr>
<td>D. Y.</td>
<td>51.7</td>
<td>52.6</td>
<td>3.542</td>
<td>3.637</td>
</tr>
<tr>
<td>J. Ha.</td>
<td>61.8</td>
<td>62.5</td>
<td>3.654</td>
<td>3.738</td>
</tr>
<tr>
<td>D. S.</td>
<td>51.6</td>
<td>54.0</td>
<td>4.014</td>
<td>4.146</td>
</tr>
<tr>
<td>R. H.</td>
<td>61.5</td>
<td>58.5</td>
<td>4.919</td>
<td>4.684</td>
</tr>
</tbody>
</table>

| Mean     | 57.2 | 58.0 | 3.933 | 3.993 | 149.071 | 157.900 | 192.6 | 192.0 |
| S.D.     | 4.15 | 3.60 | .523  | .459  | 17.70   | 24.31   | 5.42  | 4.27  |

Combined

| Mean     | 57.6 | 3.963 | 153.488 | 192.3 |
| S.D.     | 3.45 | .484  | 19.56    | 4.20  |
## APPENDIX C

Raw Data for Trials One and Two for the Saltin and Astrand Method

<table>
<thead>
<tr>
<th>Subjects</th>
<th>$V_O^2$ ml/kg/min.</th>
<th>$V_O^2$ 1/min.</th>
<th>$V_{ESTPD}$</th>
<th>H.R./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J. Hu.</td>
<td>56.9</td>
<td>53.2</td>
<td>3.719</td>
<td>3.444</td>
</tr>
<tr>
<td>F. R.</td>
<td>57.1</td>
<td>56.7</td>
<td>3.293</td>
<td>3.198</td>
</tr>
<tr>
<td>J. G.</td>
<td>61.4</td>
<td>58.9</td>
<td>4.599</td>
<td>4.430</td>
</tr>
<tr>
<td>D. Y.</td>
<td>55.7</td>
<td>55.3</td>
<td>3.838</td>
<td>3.812</td>
</tr>
<tr>
<td>J. Ha.</td>
<td>59.7</td>
<td>57.7</td>
<td>3.564</td>
<td>3.419</td>
</tr>
<tr>
<td>D. S.</td>
<td>52.2</td>
<td>54.6</td>
<td>4.023</td>
<td>4.184</td>
</tr>
<tr>
<td>R. H.</td>
<td>55.4</td>
<td>57.2</td>
<td>4.462</td>
<td>4.724</td>
</tr>
</tbody>
</table>

| Mean S.D. Combined | 56.9 3.00 | 56.2 .96 | 3.928 .436 | 3.887 .531 | 154.614 19.96 | 153.814 19.01 | 191.7 4.33 | 190.9 4.11 |
| Mean S.D. Combined | 56.6 2.12 | 3.907 .485 | 154.227 18.42 | 191.3 3.49 |
APPENDIX D

Analysis of Variance for Three Methods of Maximal Oxygen Uptake

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>df</th>
<th>Sum of Square</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V0₂ ml/kg/min.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>147.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between methods</td>
<td>2</td>
<td>3.913</td>
<td>1.957</td>
<td>.2461</td>
</tr>
<tr>
<td>Within methods</td>
<td>18</td>
<td>143.117</td>
<td>7.951</td>
<td></td>
</tr>
<tr>
<td><strong>V0₂ ml/min.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>4.679</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between methods</td>
<td>2</td>
<td>.0109</td>
<td>0.0054</td>
<td>.0207</td>
</tr>
<tr>
<td>Within methods</td>
<td>18</td>
<td>4.6581</td>
<td>0.2600</td>
<td></td>
</tr>
<tr>
<td><strong>VEBTTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>7217.763</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between methods</td>
<td>2</td>
<td>87.640</td>
<td>43.820</td>
<td>1.1061</td>
</tr>
<tr>
<td>Within methods</td>
<td>18</td>
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BIBLIOGRAPHY


