ABSTRACT

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Maximal graded exercise testing was performed on 31 active males between the ages of 18-39 using the Bruce protocol. Maximal VO₂ values (ml/kg/min) were used to examine the validity of the Tarskij VO₂ max prediction equation (TAR). Tarskij predicted values were compared with three other prediction methods: ACSM Running equation (ASCMR), Bruce Active Male equation (BAM), and Foster et al. Generalized Cubic equation (FGC). One-way ANOVA with repeated measures found a significant difference ($p < 0.05$) between cell means across the five methods. Tukey's post hoc comparison indicated significance ($p < 0.05$) existed between measured VO₂ max and predicted VO₂ max values of the three comparison methods. There was no significant difference ($p > 0.05$) found between measured and TAR. The TAR had the best CE and TE with values of 0.28 and 1.55, respectively. However, TAR had the highest SEE (4.19) accounting for the lowest r value (0.810). The ACSMR, BAM, and FGC equations respectively had SEE values of 3.82, 3.94, and 3.81 and r-values of 0.815, 0.880, and 0.872. The results indicated that the TAR and the three comparison methods are accurate means of predicting VO₂ max when instrumentation is unavailable for direct measurements of oxygen consumption.

EXAMINATION OF THE VALIDITY OF THE TARSKIJ VO_2 MAX
PREDICTION EQUATION IN AN ACTIVE MALE POPULATION

A MANUSCRIPT STYLE THESIS PRESENTED

TO

THE GRADUATE FACULTY

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THESIS FINAL ORAL DEFENSE FORM

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We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Masters of Science-Adult Fitness/Cardiac Rehabilitation

The candidate has successfully completed the thesis final oral defense.

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TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF APPENDICES	vii
INTRODUCTION	1
METHODS	7
Subjects	7
Protocol	7
Statistical Treatment of Data	10
RESULTS	10
DISCUSSION	18
REFERENCES	22
APPENDICES	24

LIST OF TABLES

TABLE	PAGE
1. Descriptive Characteristics of Subjects	11
2. Comparison of VO_2 max Values Between Methods	11
3. One-way ANOVA with Repeated Measures Between Actual and Predicted Methods	13
4. Error Analysis of Prediction Methods	13

LIST OF FIGURES

FIGURE	PAGE
1. Mean and standard deviation for the five methods used to determine VO_2 max.....	12
2. Scattergram of Tarskij VO_2 prediction versus measured VO_2	14
3. Scattergram of ACSM Running VO_2 prediction versus measured VO_2	15
4. Scattergram of Foster et al. Generalized Cubic VO_2 prediction versus measured VO_2	16
5. Scattergram of Bruce Active Male VO_2 versus measured VO_2	17

LIST OF APPENDICES

APPENDIX	PAGE
A. Informed Consent	24
B. Health History Form	28
C. Expired Air Analysis	32
D. Review of Literature	35

INTRODUCTION

Often taken for granted yet so very complex, the human body has intrigued people over the centuries. The extraordinary ability of a newborn to adapt to life outside the womb in a matter of seconds and to continue to grow physically and psychologically is amazing. Just as a high priced sports car is capable of going 0 to 60 mph in a matter of seconds, the human body has the ability to go from rest to maximal exertion, while maintaining essential bodily functions necessary to support life.

People have studied the human body for centuries. Michelangelo marveled at the artistic characteristics of the human physique and Hippocrates introduced many theories found in modern medicine. More recently, researchers have begun to examine the capacity of the human body to perform work. Just as an automotive engineer wants to know the capacitance of a sports car's engine (horsepower), a physiologist likewise wants to know the capacity or ability of the human body to perform work over long and short periods of time. With an understanding of this concept, clinicians can then help refine and/or train individuals to

perform more efficiently and effectively both at work and play.

Fundamental to any performance is the ability of a system to provide sufficient energy to working components. The human body is comprised of two basic energy-transport systems, aerobic and anaerobic, both distinguished by their respective properties. In order to examine the capacity of any system one must be able to quantify the needs of such a system. For humans, this means attempting to analyze physical limits at the cellular level. Unfortunately, this is not a very realistic approach when considering the various requirements for each cell type within the body. Rendering precise limits to a system at any given time is difficult if not impossible. While directly measuring a system's capacity or limitation to perform work is not practical, examining the power output of the system allows one to estimate its potential.

Power is defined as the energy transferred to do work per unit of time. Thus, researchers use measures of aerobic and anaerobic power output to characterize the capacity or limitations of both energy systems within the body.

The aerobic or oxidative energy system has been well researched in relation to work and exercise (9,10,13). By

far the most complex of the two systems, the oxidative system generates energy by converting fuels with the aid of oxygen, producing very high-energy yields (18).

Measurements of maximal aerobic power (VO_2 max) therefore evaluate the body's ability to use oxygen. Hill, Long, and Lupton (9) reported that VO_2 max was important to prolonged exercise. They found that athletes who had a higher VO_2 max were able to perform better during endurance events. Other research has examined not only the fundamental role of VO_2 max testing and human performance, but also its capacity as a diagnostic tool in certain cardiorespiratory disease processes (3,6,14).

Subjecting patients to such a time consuming and complex test, not to mention the possible harmful complication within populations unaware of disease progression, has led researchers to examine other methods of VO_2 max determination.

It has been demonstrated that maximal VO_2 can be predicted based on a linear relationship of heart rate and oxygen consumption during a period where mechanical efficiency is constant (2,5). Prediction equations generally estimate VO_2 max using a submaximal effort (4,8). The use of prediction equations is economical, time saving,

requires little if any technical instrumentation, and can be applied to large groups, or organizations like the military (4,7). Prediction of VO_2 max can be done using exercise and nonexercise equations. Mode of exercise, age, heredity, body composition, size, fitness level, and gender can influence VO_2 max prediction. Like maximal testing, submaximal testing too has certain drawbacks.

First, many prediction equations are population specific (2,17). Therefore, calculated values are only valid when applied to a small percentage of people. Second, pulse rate can vary independently of VO_2 under a number of physiological conditions such as emotional state, body hydration, and physical conditioning (18). The relationship between mechanical efficiency and heart rate response during physical fitness testing allows the prediction of VO_2 max by extrapolating the slope of work (Watts or kpm) or time to completion (seconds or minutes) to a predicted maximal pulse rate ($220 - \text{age}$) (8). It has been demonstrated that physically active persons will have a lower heart rate during any submaximal workload compared to inactive persons (18). Therefore, if one were to extrapolate the slope of submaximal VO_2 to a predicted maximal pulse rate, the equation may underestimate a physically active person's VO_2

max. When applied appropriately, submaximal testing has been shown to be valid and reliable for assessing exercise capacity for a majority of the population (7,12,13). Those persons affected by cardiorespiratory diseases may not benefit from submaximal testing.

Maximal oxygen consumption is the product of maximal cardiac output (Q max) and maximal arterial-mixed venous oxygen difference ($a-VO_2$ max) (14). According to Bruce, Kusumi, and Hosmer (3), a reduction of $a-VO_2$ max does not signify heart disease, but a reduction of VO_2 max does signify a decrease in functional cardiac output. Therefore, formal exercise testing is invaluable in the evaluation, treatment, and rehabilitation of patients with cardiorespiratory disease (15). Squires outlined five purposes for formal exercise testing:

1. Accurate diagnosis of exercise capacity, disability, and severity of symptoms
2. Patient listing for cardiac transplantation
3. Exercise prescription
4. Prognosis following treatment
5. Assessment of myocardial ischemia

To accurately measure functional capacity, a facility must have access to expensive instrumentation and equipment. To eliminate the need for such equipment, researchers have examined possible predictive measures to assess aerobic

impairment. Unlike other methods of VO_2 max prediction, maximal exertion values are essential to these equations. While various equations have been validated, to date no predictive measure has been proposed to gauge a patient's performance between testing methods and protocols.

Dr. N.A. Tarskij, a cardiologist from Dubna, Russia, has proposed such an equation. The theoretical equation was formulated not so much to decrease previously mentioned disadvantages of VO_2 max testing, but as an effort to gauge the performance of a workload that consequently leads to the determination of VO_2 max. The equation gauges a workload by calculating the maximal power output of a performance which is then used to predict VO_2 max. This method may prove to be better at predicting a person's maximal oxygen consumption because of the maximal exertion values used.

The purpose of this investigation was to examine the validity of the Tarskij VO_2 max prediction equation. The results were compared to other prediction equations: ACSM's Running equation, Bruce Active Male Population equation, and Foster's Generalized Cubic equation.

METHODS

Subjects

Thirty-one apparently healthy, physically active males aged 18-39 years, volunteered to participate in the present investigation. The purpose of the investigation and the potential risks and benefits associated with it were provided both verbally and in written format. Each potential participant signed an informed consent form prior to testing (see Appendix A). Subjects were also asked to fill out a health history questionnaire for screening purposes (see Appendix B). The Institutional Review Board at the University of Wisconsin-La Crosse previously approved all methods.

Protocol

All testing was performed in the Human Performance Laboratory on the campus of the University of Wisconsin-La Crosse. Subjects were asked to refrain from vigorous exercise 24 hours before testing, and to abstain from food, caffeine, and tobacco use 4 hours prior to testing. Subjects were measured for both height and weight while dressed in shorts without wearing shoes. A 5-minute warm-up/treadmill orientation period at 3 mph at a 0% grade was

given to each subject before testing began.

Cardiorespiratory testing was performed using the Bruce treadmill protocol. Expired air was continuously analyzed by open circuit spirometry using a QMC metabolic cart by Quinton Instruments Co. (Bothell, WA) with software version 2.10 (see Appendix C). Ventilation values were recorded every 15 seconds and averaged every minute throughout the test. Before each test, calibration of the metabolic cart was done using known gas concentration values previously determined by the micro-Scholander technique. Volume calibrations were made using a 3.002-liter syringe at various flow rates. Heart rates were recorded every 15 seconds using a Polar Advantage[®] heart rate monitor (Woodbury, NY). Ratings of perceived exertion were obtained during the last minute of each stage. The highest full minute VO_2 value observed was recorded as the participant's maximal oxygen consumption. Characterization of VO_2 max included a plateau in oxygen uptake, rating of perceived exertion (RPE) of 17-20 using the traditional Borg scale, and/or a respiratory exchange ratio (RER) value greater than 1.15 (1).

Maximal ventilatory oxygen uptake was predicted for each subject using the Tarskij equation:

$$VO_2 \text{ (ml/kg/min)} = [1290 * \sqrt{(P/HR_{\max} - 60)} * (e^{-0.00884 * \text{Age}}) / Wt \text{ (kg)}]$$

$$\text{Power (m*kg/min)} = V \text{ (km/hr)} * 1000\text{m}/60 \text{ min} * (\sin \theta) * Wt \text{ (kg)}$$

For comparison, three other predictive methods were also utilized:

1. The ACSM Running equation:

$$VO_2 \text{ (ml/kg/min)} = 3.5 \text{ ml/kg/min} + m/\text{min} * 0.2 + \text{grade (frac)} * m/\text{min} * 0.9$$

2. Foster et al. Generalized Cubic equation:

$$VO_2 \text{ (ml/kg/min)} = 14.8 - 1.379 \text{ (time)} + 0.451 \text{ (time}^2\text{)} - 0.012 \text{ (time}^3\text{)}$$

3. Bruce Active Male equation:

$$VO_2 \text{ (ml/kg/min)} = 3.778 \text{ (time)} + 0.19$$

Statistical Treatment of Data

Standard descriptive statistics were used to summarize subject characteristics. A one-way ANOVA with repeated measures was used to establish whether differences existed among the five methods used to determine VO_2 max. A Tukey's post-hoc test was used to isolate pairwise differences between cell means. To evaluate the relationship between the methods and measured VO_2 max, Pearson correlations, constant error (CE), standard error of estimate (SEE), and total error (TE) were calculated. An alpha level of 0.05 was used to calculate significance. All data were analyzed with the statistical package SPSS 7.5 for Windows 95.

RESULTS

The descriptive characteristics of the subjects are presented in Table 1. The mean VO_2 max for the population was 48.0 ± 7.4 ml/kg/min which corresponds to an excellent rating of cardiorespiratory fitness according to the ACSM. Comparisons of mean VO_2 max values are displayed in Table 2, and graphed in Figure 1.

Table 1. Descriptive characteristics of subjects (N = 31)

Variable	Mean $\pm$ SD	Range
Age (yr)	29.0 $\pm$ 5.0	19-39
Height (cm)	176.9 $\pm$ 5.9	165-188
Weight (kg)	78.6 $\pm$ 9.8	60.8-100.7
Measured VO ₂ (ml/kg/min)	48.0 $\pm$ 7.4	35.1-60.7
HR max (bpm)	190.9 $\pm$ 8.6	175-209
RER	1.27 $\pm$ 0.06	1.15-1.39

Table 2. Comparison of VO₂ max values between methods

Variable	Mean $\pm$ SD	Range
Measured	47.99 $\pm$ 7.38	35.10-60.70
Tarskij	47.71 $\pm$ 7.14	36.73-63.11
ACSM Running	50.38 $\pm$ 6.60*	42.22-67.50
Bruce Active	51.78 $\pm$ 7.78*	41.78-72.02
Foster Cubic	49.25 $\pm$ 8.29*	38.23-69.10

* Significantly different from measured method ($p < 0.05$).

Figure 1. Mean and standard deviation for the five methods used to determine VO_2 max

The one-way ANOVA with repeated measures found a significant difference ($p < 0.05$) between cell means across the five methods (see Table 3). Tukey's post-hoc test indicated significance difference ($p < 0.05$) existed between the measured VO_2 max and predicted VO_2 max as calculated using the ACSM Running, Foster et al. Generalized Cubic, and Bruce Active Male equations. There was no significant difference ($p > 0.05$) found between measured and Tarskij's predictive equation.

Table 3. One-way ANOVA with repeated measures between actual and predicted methods

Source	SS	df	MS	F	Sig.
VO ₂	356.614	4	89.153	13.313	0.000
Error (VO ₂)	803.589	120	6.6697		

Figures 2-5 display scattergrams and identity lines for the relationship between measured VO₂ max and the four predictive equations. Table 4 displays the CE, SEE, TE, and Pearson correlation values for the four predictive VO₂ measures in comparison to measured VO₂ max. The Tarskij equation had the best constant error, underpredicting by only 0.28%. However, it had the highest SEE (4.19) accounting for the lowest correlation (0.810).

Table 4. Error analysis of prediction methods

Comparison	CE	SEE	TE	R
M vs. TAJ	-0.28	4.19	1.55	0.810
M vs. ACSMR	2.40	3.82	13.35	0.815
M vs. BAM	3.79	3.81	21.11	0.872
M vs. FGC	1.26	3.94	7.00	0.880

Figure 2. Scattergram of Tarskij VO_2 prediction versus measured VO_2

Figure 3. Scattergram of ACSM Running VO_2 prediction versus measured VO_2

Figure 4. Scattergram of Foster et al. Generalized Cubic VO_2 prediction versus measured VO_2

Figure 5. Scattergram of Bruce Active Male VO_2 versus measured VO_2

DISCUSSION

The purpose of the present investigation was to examine the validity of the Tarskij VO_2 max prediction equation and compare the results to three other popular methods (1,3,6). It was found that there was no significant difference between TAR and measured VO_2 max. Tarskij's predictive equation underestimated measured VO_2 max by only 0.28% while ACSMR, BAM, and FGC significantly overpredicted measured VO_2 max by 2.40%, 3.79%, and 1.26%, respectively.

The basic concept behind VO_2 max prediction is to provide a means by which variances in predicting VO_2 max are minimized. Bruce et al. (3) found that gender, age, physical activity, and body weight account for 65% of the variance of VO_2 max. A study by Jackson et al. (11) examined the prediction of VO_2 max using a nonexercise (N-Ex) model. They found that adding measured submaximal VO_2 , HR, and treadmill time to their N-Ex equation was the only way to produce an SEE below 4 ml/kg/min.

Use of maximal values, such as in the present study, should increase the accuracy (minimize the variance) of the prediction even more. Tarskij's prediction equation though produced a SEE of only 4.19, meaning there was a variance

of 4.19 ml/kg/min from measured VO_2 max. The ACSM Running, BAM, and FGC had SEE's of 3.82, 3.81, and 3.94, respectively; establishing an even lower variance from measured VO_2 max. Standard error of estimates reported by Bruce et al. and Foster et al., were 4.8 and 3.35 ml/kg/min. In addition, TAR had an r of 0.810, which was lower than ACSMR, BAM, and FGC.

Of the three methods used for comparison in the present study, only the ACSMR is considered a generalized equation applicable for both genders and varying clinical statuses. The ACSMR did have the second lowest mean difference of the three. This could be due to the fact that the ACSMR typically is used to predict steady-state VO_2 and is not generally used to predict VO_2 max. Only five of the subjects in the present study attained a steady state VO_2 just before voluntarily terminating their test. Typically, a steady state is attained when heart rate or VO_2 does not change between two consecutive stages within a protocol. A study by Fairbairn et al. (5) used the ACSM walking and running equations to estimate steady state VO_2 that was then used along with steady state HR to predict VO_2 max using the Astrand and Rhyning nomogram. No values of mean differences between prediction and measured VO_2 max were given.

The FGC is a generalized equation for prediction of VO_2 max in men, regardless of health status. It was based on a sample size of 230 men and therefore is only valid when used on a male population (6). Much of the differences found between TAR and FGC are probably based on sample size.

The BAM equation was the only one designed specifically to predict VO_2 max for active males. Yet, it had the largest mean difference, CE, and TEE of the three comparison methods. According to Foster et al. (6), the Bruce equation was constructed based on a linear relationship between treadmill performance and VO_2 . This relationship does not hold true at the higher end of treadmill performance where a curvilinear appearance is seen (6).

The TAR equation, unlike the comparison equations, does not have a time component. When power output is calculated there is no difference between the power output for the first and last minutes of a protocol. This may account for the lower SEE of the prediction methods.

In conclusion, the Tarskiy VO_2 max prediction equation appears to be valid for males between the ages of 18-39 using the Bruce protocol. The ACSM Running, Bruce Active

Male, and Foster et al. Generalized equations have been previously validated. In the present study the three comparison equations overpredicted VO_2 max by a minimum of 1.26%, while the Tarskij underpredicted by only 0.28%. Addition of a time factor to the Tarskij equation may increase its accuracy. Further examination of the Tarskij prediction equation is recommended for other age groups and clinical status.

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APPENDIX A
INFORMED CONSENT

Consent to Act as a Subject in an Experimental Study

TITLE: Examination of the validity of the Tarskij VO_2
max prediction equation in an active male population

INVESTIGATOR: Christian M. Westby (608) 787-6556
3150 S 34th St. #104 La Crosse, WI 54601

THESIS ADVISOR - Dr. Rick Mikat (608) 785-8182

ELIGIBILITY: The following criteria must be met to be eligible for this study. Subjects must be male between the ages of 18-39 years, who presently live a physically active life style. Subjects must be healthy and available for at least an hour.

DESCRIPTION: I, (the participant) am being asked to participate in a study designed to validate the Tarskij VO_2 max equation. I understand the information gathered in this study is expected to be used in the fields of exercise science, and will provide information into the nature of accurately predicting maximal oxygen consumption. The values obtained from such a test can then be used to prescribe specific exercise levels to either enhance sport performance or promote general health.

Males between the ages of 18-39 will participate in this study. The study will consist of a one time experimental session where each subject will undergo a maximal treadmill test to obtain maximal heart rate, maximal oxygen consumption values, and maximal power output. I will be fully briefed by the investigator as to my role and benefits to volunteering as a participant. At the beginning of the experimental session, the investigator will measure my height and weight prior to testing. I understand that I will be asked to perform a maximal treadmill test using the Bruce protocol, a stepwise protocol with 3-minute stages and between each stage the speed and grade will increase until the point of volition.

RISKS AND BENEFITS: I have been fully informed that injuries will be kept to a minimum by my participation in a routine warm-up and cool-down session prior to and following the testing session. However, risks are inherent

to this study. These risks include: muscle fatigue and soreness, muscle and or joint injury, abnormal heart rate, dizziness, shortness of breath, abnormal blood pressure responses, stroke, heart attack, and even death. To minimize risk even further a person certified in CPR will be present during each test. I will also be asked to fill out a health questionnaire and agree to disclose any health information that may contraindicate my participation in the present study.

COSTS AND PAYMENTS: There will be no costs to me for my voluntary participation in this study and I will not be compensated for my participation.

RIGHT TO CONFIDENTIALITY AND INQUIRY: My medical profile and all data obtained will be protected and any data that may become published will be done so that no one will be able to identify me. Anonymity will be kept unless a written release form is given to the investigator. I have the right to inquire about any part of the testing and/or procedures that I do not fully understand. The investigator will be happy to answer any question I have during the experimental session.

RIGHT TO REFUSE OR END PARTICIPATION: I have the right to voluntarily withdraw from the test and/or terminate the test at any stage for any reason.

VOLUNTARY CONSENT: I have read this form and the research investigator has fully explained the study to me and answered my questions regarding the study. I have been informed as to what I am being asked to do and agree to participate in this study. Further questions concerning the study or my rights as a research participant will be answered promptly by the investigator. A copy of the consent form will be given to me.

If I have any questions regarding the protection and use of Human Subjects, I can contact:

IRB Chairperson - Dr. Garth Tymeson (608) 785-8155

My signature below means that I freely agree to participate in this study.

Subject's Signature

Date

INVESTIGATOR CERTIFICATION: I, (the investigator) certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with the participating study and have answered all questions.

Investigator's Signature

Date

APPENDIX B

HEALTH HISTORY FORM

HEALTH HISTORY FORM

29

Identification # _____

Date: _____

Last Name

First Name

Middle

Address

Apt. #

City

State

Zip

Home Telephone

Work Telephone

Ext.#

Birthdate

Age

Gender

M

F

Ethnic Background

1. White

2. African American

3. Hispanic

4. Asian

5. Native American

6. Pacific Islander

7. Eskimo

8. Other

Education

1. High School

2. High School Graduate

3. Some College

4. College Graduate

5. Graduate School

Marital Status

1. Single

2. Married

3. Separated

4. Divorced

5. Widowed

Occupation

Emergency Contact

Last Name

First Name

Relationship

Home Telephone

Work Telephone

Ext.#

HEALTH HISTORY FORM

30

Medical Information

Doctor

Clinic Phone

Date of last examination

Are you allergic to any medications, foods, or other substances (please list them)

Please give the following information concerning the last three times you were hospitalized.

Type of condition and/or operation and year of hospitalization

Physical or Psychological Disabilities

Are you currently under a doctor's care?

Yes

No

If yes please explain

HEALTH HISTORY FORM

31

During the last year

- Has your physician prescribed any medication for you?
 Has your body weight fluctuated more than a few pounds?
 If yes, as this weight loss due to exercise and dieting
 Have you experienced bouts of dizziness, light-headedness, and/or blackouts?
 Have you had reoccurring sleeping problems?
 Have you experienced blurred vision?
 Have you had and severe headaches?
 Have you experienced and temporary speech problems?
 Have you experienced and unusual heartbeats or palpitations?
 Have you experienced periods where your heart was racing for no apparent reason?

Yes	No
Yes	No
Yes	No
Yes	No
Yes	No
Yes	No
Yes	No
Yes	No
Yes	No

Presently

- Do you feel shortness of breath while exercising?
 Do you experience any tingling or numbness in your extremities?
 Do you experience swelling in your feet or ankles?
 Do you get pains or cramps in your legs?
 Have you been experiencing and tightness in your chest?
 Do you have diabetes?

Yes	No
Yes	No
Yes	No
Yes	No
Yes	No
Yes	No

If yes, how is it controlled?

☐ By Diet
☐ Oral Medication

☐ Insulin Injections
☐ Uncontrolled

Daily Stress and Tension

- At work your average stress level is? Low High
 1 2 3 4 5 6 7 8 9 10
 At home your average stress level is?
 1 2 3 4 5 6 7 8 9 10

- Have you ever been diagnosed for ☐ Myocardial Infarction ☐ Coronary Occlusion
☐ Arteriosclerosis ☐ Heart Disease
☐ Angina ☐ Heart Murmur
☐ Rheumatic Fever ☐

To the best of my knowledge the above testament is true.

Signature of Subject

Date

APPENDIX C

EXPIRED AIR ANALYSIS

APPENDIX D
REVIEW OF LITERATURE

REVIEW OF LITERATURE

Often taken for granted yet so very complex, the human body has intrigued people over the centuries. The extraordinary ability of a newborn to adapt to life outside the womb in a matter of seconds and to continue to grow physically and psychologically is amazing. Just as a high priced sports car is capable of going 0 to 60 mph in a matter of seconds, the human body has the ability to go from rest to maximal exertion while maintaining essential bodily functions necessary to support life.

People have studied the human body for centuries. Michelangelo marveled at the artistic characteristics of the human physique and Hippocrates introduced many theories found in modern medicine. More recently, researchers have begun to examine the capacity of the human body to perform work. Just as an automotive engineer wants to know the capacitance of a sports car's engine (horsepower), a physiologist likewise wants to know the capacity or ability of the human body to perform work over long and short periods of time. With an understanding of this concept clinicians can help to refine and/or train individuals to perform more efficiently and effectively both at work and

play. The purpose of this review is to provide a background on maximal oxygen uptake testing and its role in estimating the human bodies capacity for work and play, the different means of measuring and predicting it, and the physiological factors that influence it.

Maximal Oxygen Consumption Testing

Fundamental to any performance is the ability of a system to provide sufficient energy to working components. The human body is comprised of two basic energy-transport systems, aerobic and anaerobic, both distinguished by their respective properties. In order to examine the capacity of any system one must be able to quantify the needs of such a system. For humans, this means attempting to analyze physical limits at the cellular level. Unfortunately, this is not a very realistic approach when considering the various requirements for each cell type within the body. Rendering precise limits to a system at any given time is difficult if not impossible. While directly measuring a system's capacity or limitation to perform work is not practical, examining the power output of the system allows one to estimate its potential.

Power is defined as the energy transferred to do work per unit of time. Thus, researchers use measures of aerobic and anaerobic power output to characterize the capacity or limitations of both energy systems within the body.

The aerobic or oxidative energy system has been well researched in relation to work and exercise (15,16,23). By far the most complex of the two systems, the oxidative system generates energy by converting fuels with the aid of oxygen, producing very high-energy yields (31).

Measurements of maximal aerobic power (VO_2 max) therefore evaluate the body's ability to use oxygen. Hill, Long, and Lupton (15) reported that VO_2 max was important to prolonged exercise. They found that athletes who had a higher VO_2 max were able to perform better during endurance events.

Previously Hill and Lupton (16) had already established that VO_2 max was variable among individuals. During World War II Taylor, Buskirk, and Henschell (29) studied the relationships between performance and biological stress. Taylor et al. agreed with Hill, Long, and Lupton that VO_2 max appeared to offer the best possibility for characterizing limiting factors in endurance performance. The only criticism was that the measurement of VO_2 max had limitations such as the skill level needed to perform the

task or exercise and the motivation of the subject during testing. Besides examining the relationship of performance and stress, Taylor et al. (29) developed testing procedures to help eliminate inconsistencies or problems that may hamper testing. Although not inclusive, they include:

1. Using a treadmill at a constant speed and increasing the grade until VO_2 max is obtained.
2. Oxygen consumption should be measured during the final minute of a three-minute stage protocol to allow for a steady state to be obtained.
3. Maximal oxygen consumption is attained when the increase in grade of the treadmill elicits an oxygen consumption value no greater than 150 ml/min.
4. Room temperature can have a significant effect on VO_2 max.

A couple of years later Mitchell, Sproule, and Chapman (23) examined the physiological meaning of VO_2 max testing and its relationship to cardiovascular functioning in normal and abnormal subjects. The meaning of VO_2 max testing up until this time they believed was insufficiently understood. Their findings disproved the theory, as presented by Bainbridge (3), that cardiac capacity was the main determinant of VO_2 max. It was found that this assumption ignored the widening of the arterial-venous oxygen difference (AV- O_2 difference). If not for this widening gap, cardiac output would have to increase nearly

ten times that of resting (as compared to the 4.3 measured during testing) to supply the working tissues. They concluded by saying that according to their investigation VO_2 max was the product of maximal cardiac output (Q max) and maximal arterial-mixed venous oxygen difference (a-VO_2 max), but was not a measure of the ability of vascular beds to accommodate cardiac output. While the previously mentioned studies established techniques for VO_2 max testing their procedures had a major drawback. Taylor et al. (29) took three days to establish true VO_2 max values using 24 hour rest intervals between workloads. Considerably shorter, Mitchell et al. still used an hour and a half to obtain such values. Such discontinuous protocols limit the practicality of VO_2 max testing in the clinical setting. Consequently, simple and valid continuous exercise treadmill protocols were established (1,4,5).

Predictions of Maximal Oxygen Consumption

Maximal Regression Equations

The use of a maximal test for predicting VO_2 max is the most accurate means for assessing limitations to human performance to diagnosing certain cardiorespiratory diseases (5,23). Maximal regression equations incorporate

time to fatigue or power output measures with other physiological characteristics to predict VO_2 when facilities do not have access to the expensive equipment needed for actual measurements of VO_2 (5,10,14,25).

Bruce, Kusumi, and Hosmer (5) examined the correlation between the duration of exertion with VO_2 max. Maximal exercise tests were performed on 151 men and 144 women, 29-73 years of age. A stepwise linear regression was performed and found that maximal performance time was the most important determining factor for predicting VO_2 max (r 0.91). From this conclusion three different equations were developed and depended on clinical and activity status of each individual (healthy, cardiac, and hypertensives).

Controversy surrounded the concept of maximal performance time as the most important determining factor for predicting VO_2 max. A study by Froelicher and Lancaster (11) examined the prediction of VO_2 from a continuous exercise treadmill protocol. Using 1800 male soldiers Froelicher and Lancaster found that performance time in a progressive treadmill protocol, such as that devised by Bruce et al., only grossly predicts VO_2 max and that factors other than VO_2 max determines treadmill time.

Foster et al. (10) also noted this nonlinear relationship between treadmill time and performance. Foster et al. also thought that the use of three different equations could be confusing due to the need to classify the clinical status of a patient or subject according to the Bruce et al. equations. Using variables such as health status (known cardiovascular disease/healthy), activity status (sedentary/active), the interaction between health and activity status, age, and time, a multifactorial regression analysis was performed. Foster et al. found the relationship between treadmill time and performance was best represented in a cubic model instead of a linear relationship. A cross-validation of the Foster et al. results produced a higher correlation coefficient ($r = .97$) and lower SEE of 3.7 ml/kg/min when compared to the population specific equations of Bruce, Kusumi and Hosmer ($r = .96$) and SEE was 4.8 ml/kg/min.

In an attempt to make VO_2 max testing still easier and pleasant for subjects, while reducing the cost and technical skill needed in administering a test, a variety of prediction equations evolved.

Maximal Regression Equations

During the early 1950's Åstrand and Rhyming (2) demonstrated that maximal VO_2 could be predicted based on a linear relationship of heart rate and oxygen consumption during a period where mechanical efficiency is constant. The nomogram they constructed to predict VO_2 max was based on this assumption. Using submaximal HR and steady state VO_2 values previously calculated for the bicycle ergometer, step test, or treadmill running, the estimation of VO_2 max could be extrapolated. This method proved to be economical, time saving, required little if any technical instrumentation, and could be administered to large groups, or organizations like the military or schools (6,11). However as noted by Davies (7) the Åstrand and Rhyming nomogram consistently underpredicted VO_2 max due to the deviation of linearity of HR response as one approaches actual VO_2 max.

Kline et al. (18) developed another well-known method of VO_2 max prediction. This study monitored HR during two separate one-mile walk tests on a quarter mile track using 343 volunteers, 30-69 years of age. Using time to complete the one-mile walk, HR, weight, age, and gender, a regression analysis was performed to predict VO_2 max. It was

found that no significant differences existed between measured VO_2 max and the estimated values. A cross-validation was performed and again there were no significant differences between the means ($r = .92$ and the $\text{SEE} = .335 \text{ L/min}$). This investigation demonstrated that a one-mile walk test could accurately predict VO_2 max.

Other predictive protocols such as the YMCA bicycle ergometer test (12) use HR response to progressive workloads to estimate VO_2 max. Another popular method for large group testing is the 12-minute run (6) in which total distance covered is used as an estimate of one's VO_2 max.

Like maximal testing, submaximal prediction testing has certain drawbacks also. Prediction equations tend to be population specific (2,30). Therefore, calculated values are only valid when applied to a small percentage of the population. Secondly, pulse rate can vary independently of VO_2 under a number of physiological conditions such as emotional state, body hydration, and physical conditioning (1,31). Thirdly the relationship between mechanical efficiency and heart rate response has been used to estimate VO_2 max by extrapolating the slope of work (Watts or kpm) or time to completion (seconds or minutes) to a predicted maximal pulse rate ($220 - \text{age}$) (12). It has been

demonstrated that physically active persons will have a lower heart rate during any submaximal workload compared to inactive persons (31). Therefore, if one were to extrapolate the slope of submaximal VO_2 to a predicted maximal pulse rate, the equation may underestimate a physically active person's VO_2 max.

When applied appropriately though, submaximal prediction testing has been shown to be valid and reliable for assessing exercise capacity for a majority of the population. It is best used, however, for longitudinal studies of fitness due to the inconstancies between mode of exercise, age, heredity, body composition/size, fitness level, and gender, which can influence VO_2 max prediction.

Physiological Factors that Influence VO_2 max

Values for VO_2 max are not only determined by the type of protocol employed but are also heavily influenced by the mode of exercise. The most commonly used pieces of exercise equipment include treadmills and cycle ergometers. Both pieces of equipment obtain similar maximal HR although the treadmill yields a 10-15% higher VO_2 max (1,25,32).

However, VO_2 max testing can also be done with arm ergometers, bench stepping, and swimming protocols.

Treadmill testing is commonly used because it elicits the

highest VO_2 max. First, the tester has better control over the workload, improving the accuracy of the incremented workloads. Secondly, subjects are more familiar with walking and running. Lastly, it has been found that VO_2 max measures are higher when large muscle masses are tested (1,5,10,23,29). However, specificity must be considered. Studies have demonstrated that individuals who train and compete in a particular sport may reach or exceed standard treadmill or bicycle tests especially if they are swimmers or rowers (1,22).

A study by Londeree et al. (22) compared values of VO_2 max between six modes of exercise, the treadmill, cycle, skier, shuffle, stepper, and rower. It was found that VO_2 max was highest on the treadmill, with cycle, stair stepping, and rower following in decreasing order, respectively.

It is generally excepted that women have a 15-30% lower VO_2 max than men. This is due in part to a number of gender differences. Such differences include body composition and size, hemoglobin concentrations, and cardiac output (31). Women generally have about 6-10% more body fat than men. This means that they also have less lean muscle mass to generate aerobic power (31). Women also have

a 10-14% lower hemoglobin concentration (31). Since the main determining factor to prolonged exercise is the delivery of oxygen, lower hemoglobin concentrations result in lower oxygen content in the circulating blood supply.

When predicting VO_2 max, multiple investigations indicate that age strongly influences VO_2 max (8,13,24). Maximal oxygen consumption peaks between the ages of 17-21 for males and 12-15 for females. It then decreases linearly with time at a rate of approximately 10% per decade (8,13). It has been generally hypothesized that the early decrease of VO_2 max in females is due to the assumption of a earlier sedentary lifestyle. Ogawa et al. (24) studied the influence of age, gender, and physical training on VO_2 max and found age was associated with a 40-41% lower VO_2 max in sedentary subjects as compared to a 25-32% lower VO_2 max in trained subjects with a three to four decade difference in age. Age related differences were due mainly to a smaller stroke volume, but are also affected by lower max HR, decreased ability of tissues to extract oxygen, and a decrease in muscle mass.

The specific contribution that genetic make-up has on VO_2 max is controversial. Estimates of 10-90% in variation

have been published (19). Results from data on 436 identical and 622 fraternal male twins indicated that more than half of the variance in VO_2 max values was due to genetic make-up (27,28). The remaining variance may be due to environmental factors and/or measurement error. The exact contribution of genetic make-up on VO_2 max may never be solidly established.

Lastly, VO_2 max differs between trained and sedentary individuals. Studies have established that trained individuals have a VO_2 max two to three times greater than their sedentary counterpart (28). Physiological adaptations responsible for differences in fitness levels include local musculature adaptations that improve oxygen transport and utilization, and increases in cardiac output.

Conclusion

Maximal oxygen consumption allows researchers and clinicians to estimate one's capacity to perform work. It is also an important determinate of health and physical fitness. Many modes of establishing VO_2 have been reviewed. Their application is specific to time, expense, subject comfort, and need of accuracy. Research will continue to progress in this area as technology permits researchers to better define the physiological make-up of the human body, differences between genders, the effects of heredity, and the aging process.

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