UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

CROSS VALIDATION OF ROCKPORT II

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Clinical Exercise Physiology

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PREDICTION OF VENTILATORY THRESHOLD FROM A SUBMAXIMAL ONE-MILE WALK TEST
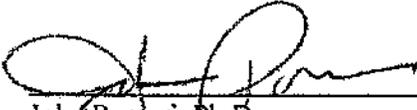
By Samantha Sonnek

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology
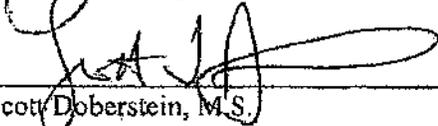
The candidate has completed the oral defense of the thesis.

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ABSTRACT

Fry, S.L. <u>Cross validation of Rockport II.</u> MS in Clinical Exercise Physiology, December 2015, 43pp. (C. Foster)

Introduction: The purpose of this study is to cross validate two new equations for the Rockport 1-mile walking test to more accurately predicted VO_2max and VO_2 at the Ventilatory Threshold (VT). Methods: Eighty-nine subjects performed a treadmill-based VO_2max test and a brisk 1-mile walk test. Equations were formulated from 71 of the subjects. The data from the remaining 18 subjects was used to cross-validate the new equations. Results: The two equations were: Predicted VO_2max $= 31.142 - ((1.13 -$ (Walk time)) $- (.305$(final RPE); $R^2 = 0.4859$; SEE $= 6.76$ ml·kg^{-1}·min^{-1} and Predicted VO_2 at VT $= [28.169 - (1.117$ X Walk Time) $- (0.295$ X Final RPE)] X 3.5; $R^2 = 0.51$; SEE $= 6.3$ ml·kg^{-1}·min^{-1}. Cross-validation showed that the R^2 values are not significantly different from the validation group. Discussion: A reasonably accurate predictor of VO_2max and VO_2 at VT can be formulated using only the variables of 1-mile walking time and RPE from the Rockport 1-mile walk test.

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INTRODUCTION

The maximal oxygen uptake (VO_2max) has been referred to as the gold standard for measuring fitness and aerobic capacity and is historically the primary basis for exercise prescription (Pescatello, 2014). The problem with directly measuring VO_2max is that it is costly, presents at least the potential for risk, and is highly dependent on equipment and qualified personnel. This creates a need for simple submaximal tests that are able to accurately predict VO_{2max}.

Another valuable marker of fitness and sustainable exercise capacity is ventilatory threshold (VT). Mezzani et al. (2012) have suggested that VT is a better criterion for the evaluation of aerobic function and, consequently, for aerobic exercise intensity assessment and prescription. VT is effective in stratifying exercise intensity between light, moderate, high, and severe intensities and has been shown to relate to the ability to speak comfortably (Foster et al. 2008).

There are a variety of submaximal tests that are used as predictors of VO_2max. Grant et al. (1995) compared four different submaximal tests in order to find out what type of test was most accurate. The different tests were the Cooper walk-run test, a multistage shuttle run test, and a submaximal cycle test. VO_2max was measured directly on a treadmill in order to provide the reference standard for the submaximal tests. It was found that the best predictor was the Cooper walk-run test with a correlation coefficient of r=0.92. The other tests systematically underestimated VO_{2max}. This study shows that

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VO_{2max} can be accurately predicted without measuring heart rate (HR) or respiratory gas exchange.

Condello et al. (2014) demonstrated that VT can be predicted as a percentage of maximal running speed. It was found that steady state treadmill running at 64% and 86% of maximum velocity predicted speeds at VT and RCT. It has also been studied that VT is similarly useful in measuring gross efficiency (GE) while exercising at high intensities. This is because aerobic power production is measured using a VO_2 below VT in submaximal exercise, assuming that submaximal GE is representative of GE and aerobic-power production during high-intensity exercise (de Koning et al., 2013). Foster et al. (2008) observed a strong correlation between the ability to speak comfortably during exercise and VT. Porcari et al. (2015) has recently shown that the 6 minute walk test (6MWT) time and terminal Rating of Perceived Exertion (RPE) can also predict VT.

The larger aim of this study was to design a more accurate equation for predicting VO_2max and VT from the Rockport 1-mile walk test. The original Rockport is valid for most individuals, but since it is based primarily on the relationship between HR and workload (Astrand & Ryhming, 1954), this leaves room for error. Estimating VO_{2max} from HR is based on assumptions such as: uniformity of HR_{max} for a given age, no medications that alter HR, and that a steady state is obtained for each exercise work rate (Sartor et al., 2013).

In order to account for variability in these assumptions, the RPE was incorporated into a new regression equation. This information was used to see if both the Metabolic Equivalent of Task (MET) level and VO_2max at VT could be predicted. The specific

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purpose of this study was to cross-validate these new equations for predicting VO_2max and VT.

METHODS

Subjects

The larger study included 89 male and female subjects that represented a wide range of age and physical fitness. A cross validation group of 18 subjects was randomly selected from the total group and used for this portion of the study. A physical activity questionnaire was administered on the informed consent form to see if the participants were active or sedentary including how many hours per week were spent exercising. All subjects provided written informed consent. The protocol had been approved by the International Review Board for the Protection of Human Subjects at the University of Wisconsin – La Crosse. Table 1 shows the subject demographics from the cross validation group.

Table 1. Subject Demographics – Cross-validation Group

	Males (n=11)	Females (n=7)
Age (years)	34.7 ± 14.88	32.0 ± 11.44
Height (cm)	183.3 ± 9.73	168.4 ± 82.07
Weight (kg)	90.9 ± 11.54	71.6 ± 8.56
VO_2max (ml/kg/min)	42.4 ± 6.28	41.8 ± 8.06
HR Max (bpm)	171 ± 13.4	181 ± 11.4
VO_2 at VT (ml/kg/min)	29.9 ± 8.13	33.2 ± 8.85
Walk Time (min)	14.1 ± 1.31	13.2 ± 1.61
Final RPE	12.2 ± 0.83	12.9 ± 1.47
Walk HR (bpm)	119 ± 17.46	139 ± 21.5

The most important exclusion criterion was if the subject were classified as high

risk based on ACSM guidelines (Pescatello. 2014). High risk was defined as having more

than two risk factors and/or being symptomatic in any way. Only those that were of low

or moderate risk were included because high-risk subjects would need to have a

physician present for both the maximal and submaximal tests. Subjects were also

excluded if they had any orthopedic issues that would have prevented them from being

able to complete a 1-mile walk test or the VO_{2max} test.

Procedures

Each subject performed two exercise tests. The first test was a 1-mile walk test

performed on an indoor 200m track (8 laps = 1 mile). The subjects were told to walk as

"briskly" as possible and were instructed regarding how to use the RPE chart. RPE was

recorded every 200m. Palpation was used to measure HR when the 1-mile walk test was

completed to obtain the terminal HR.

The second test was a VO_2max test done on a motor driven treadmill using a

modified Balke protocol (Balke & Ware, 1959). The walking speed was self-selected

during the first stage of the treadmill test. Increments in workload were achieved by

increasing the treadmill grade 2.5% every 2 minutes RPE and HR were measured every 2

minutes and respiratory gas exchange was monitored continuously using open circuit

spirometry (AEI Metabolic Cart, Pittsburgh, PA). After all the data were collected,

equations for predicting VO_2max and VT that used the variables RPE and total walk time

were formulated based on the results from the 71 subjects in the validation group. These

equations were then used on the remaining 18 subjects from the cross-validation group in

order to determine if the predictive ability was similar when predicting max METs and METs at VT.

RESULTS

The primary equations for predicting VO$_2$max and VT from 1-mile walking time and terminal RPE in the validation group were:

Predicted max METs = 31.142 − (1.13 × Walk time) − (.305 × final RPE)

$r = 0.697$

The SEE = 1.93 METs

Predicted METs at VT = 28.169 − (1.117 × Walk Time) − (0.295 × Final RPE)

$r = 0.716$

The SEE = 1.8 METs

Figure 1 shows the average measured max METs and METs at VT in the cross

validation group compared against the average values predicted from the new equation.

There was no significant difference between predicted and measured max METs (p =

0.546). This figure also shows the measured METs at VT compared to the predicted

value at VT. There was no significant difference between measured and predicted values

(p = 0.692).
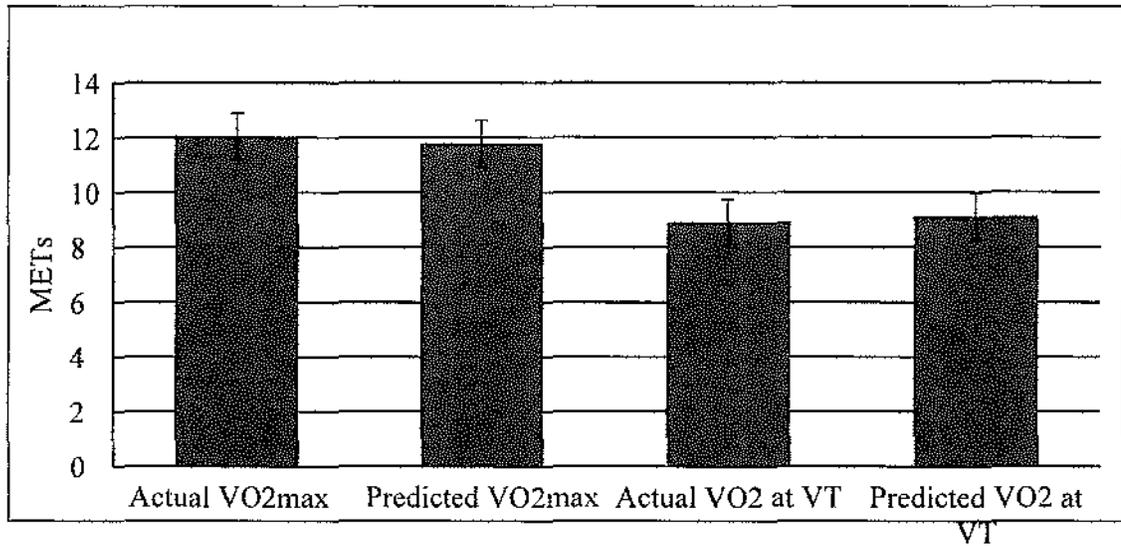
Figure 1. Actual vs.Predicted Average VO_2max and VO_2 at VT

Figure 2 shows VO_2max, expressed as METs, compared to the actual measured

values. This shows how well the new equation was able to predict max METs in the

cross-validation group. The closest fit is among those of moderate fitness, with the

equation having less predictive quality in those of very high and very low VO_2max

values. Thus, even though there was no significant difference between predicted and

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measured max MET value (Figure 1), there was an overall weak to moderate relationship

between predicted and measured based on r value.
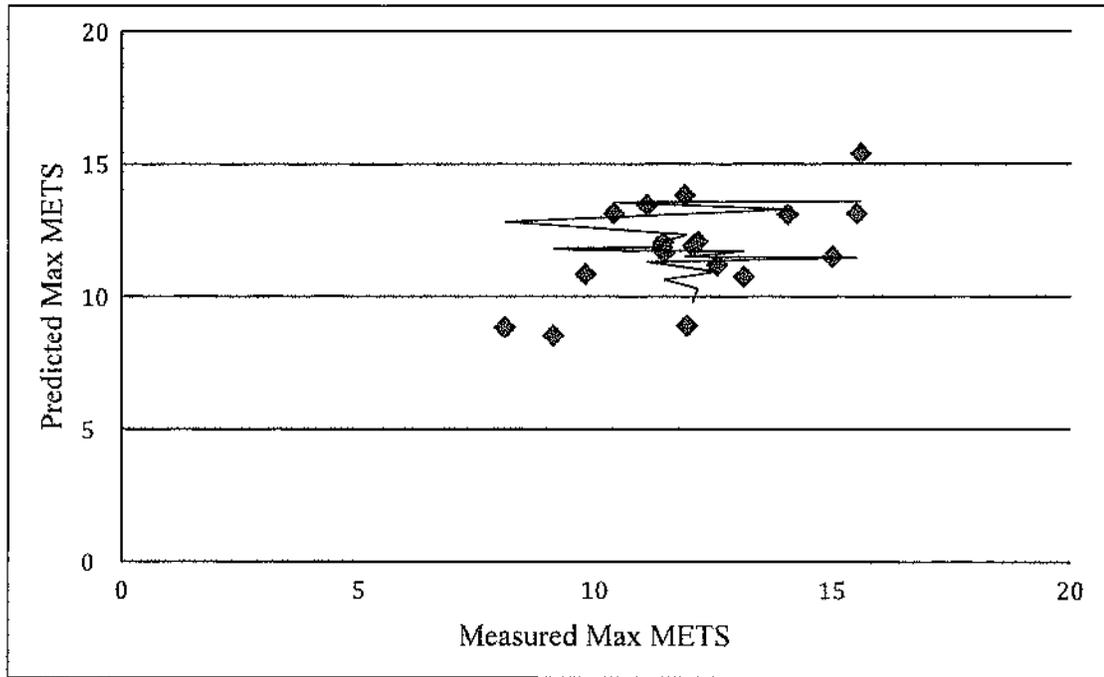
Figure 2. Measured vs. Predicted Max METs

Figure 3 shows the residual error at predicted maximal METs minus observed

max METs which displays how different the predicted values are from the measured

values. Subjects with a maximal exercise capacity in the range of 10-12 METs had small

residual errors. Subjects with lower or higher exercise capacities had larger residual

errors. The average standardized residual error was 4.659 METs.

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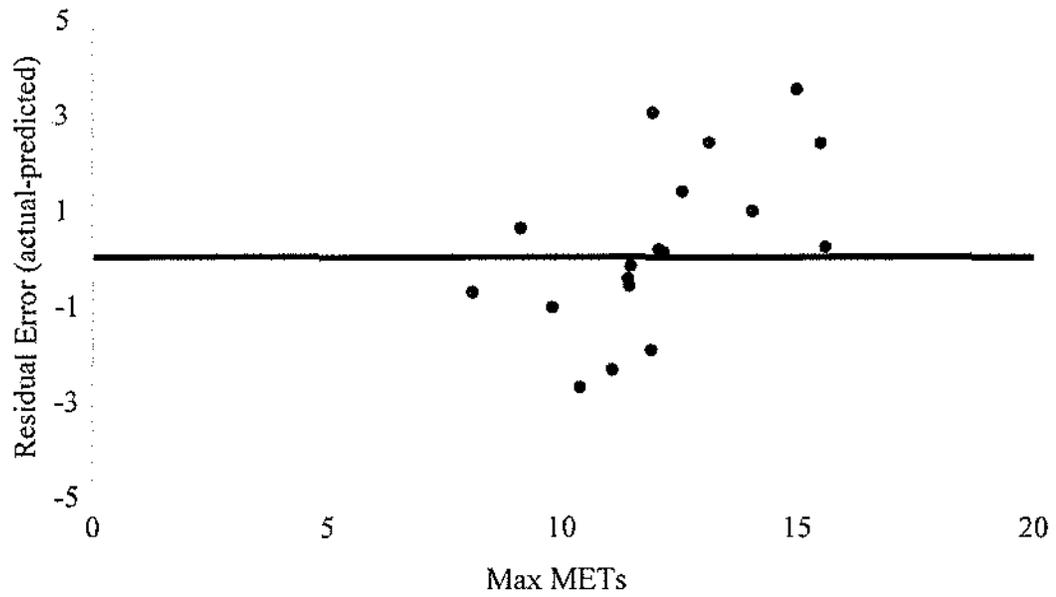
Figure 3. Residual Errors in Actual vs. Predicted Max METs

Figure 4 demonstrates the measured METs at VT compared to predicted METs at

VT for the cross validation group. The closest fit was with those of moderate fitness, and

had less predictive value among those who took longer or did not reach VT. Thus, even

though there was no significant difference between predicted and measured mean values

for METs at VT, the overall correlation between predicted and measured values was

weak.
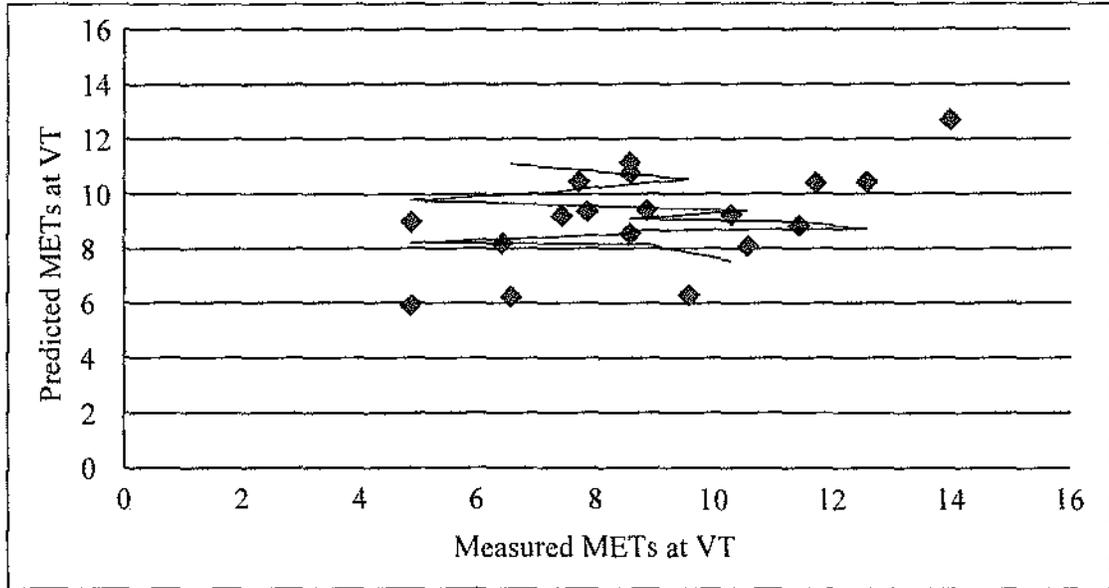
Figure 4. Measured vs. Predicted METs at VT

Figure 5 shows the residual error of predicted METs minus observed METs at VT

for the cross validation group. Subjects that reached VT around 7-11 METs had relatively

small residual errors. Those who reached VT at low MET levels (5-7) and subjects that

reached VT at higher MET levels (11-13) had large residual errors. The average

standardized residual error was 0.203 METs.
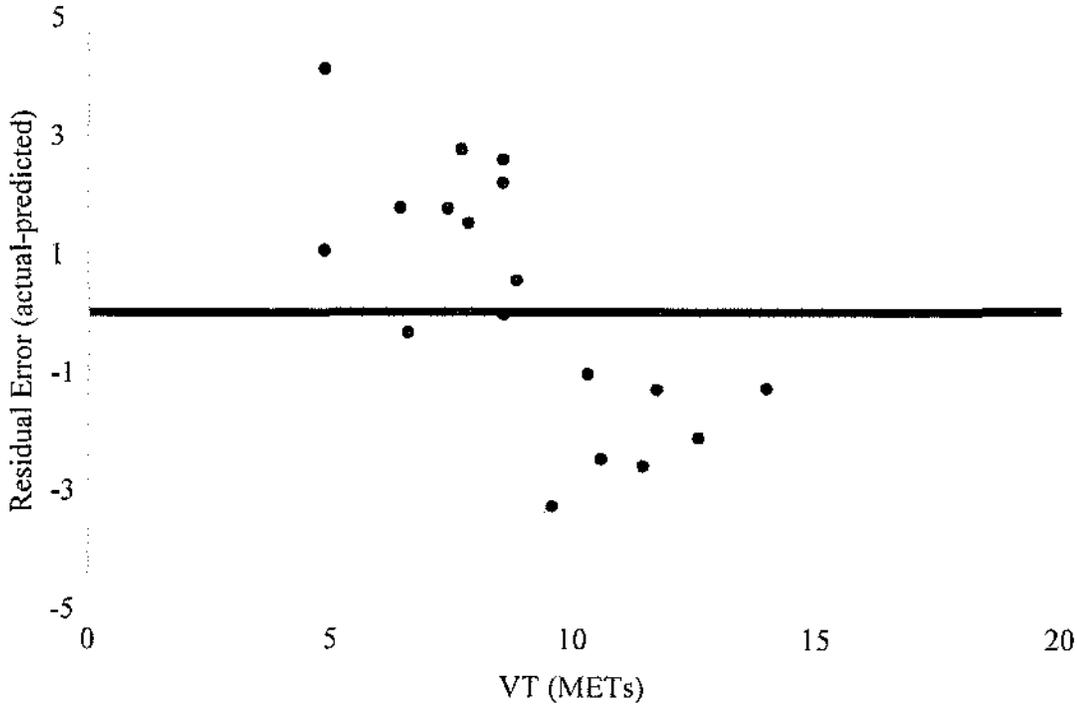
Figure 5. Residual Error in Actual vs. Predicted METs at VT

DISCUSSION

The main goal of the larger study was to design a more accurate equation for predicting max METs and METs at VT from the Rockport 1-mile walk test by incorporating RPE as a predicting variable. Submaximal tests are important because maximal tests that directly measure VO_2max and VT are often much more complicated and costly whereas submaximal tests provide a simpler and more cost-efficient prediction of VO_2max. The original Rockport 1-mile walk test is widely considered to be one of the best submaximal predictor tests.

The original Rockport equation is highly dependent on the HR response at the end of the 1-mile walk. This is a variable that is difficult to depend on for several different populations such as those on medications (beta-blockers or calcium-channel blockers) that blunt HR response. This creates a need for a submaximal equation that does not depend on HR and uses another variable, such as RPE, which is more subjective.

The generalized equations were developed on 89 subjects and cross-validated on 18 subjects with similar characteristics. The validity coefficients for predicted max METs and METs at VT in the cross-validation group ($r = 0.583$ and $r = 0.550$ respectively) show no significant differences from the main group of subjects from which the equations were developed, although the r values suggest relatively weak relationships.

The results of this study demonstrate that the Rockport 1-mile walk test can be simplified by two variables, walk time and terminal RPE, and still be a relatively accurate predictor of max METs and METs at VT. As shown in Figures 2 and 4, the predictive value of the newly developed equation is highest at MET values that represent moderate fitness. It appears that this test may not be appropriate for the extremely fit and athletic populations whose VO_2max values are above 50 ml/kg/min. It also may not be effective

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in populations who are extremely deconditioned as the predictive value of the equation was low in VO$_2$max values under 30 ml/kg/min. When the generalized equation for predicting max METs was applied to the cross-validation group, the standard error of estimate (SEE) for predicting VO$_2$max was 1.73, which is comparable to the main group with a SEE of 1.93. The equation for predicting METs at VT had an SEE of 1.8, which is also somewhat comparable to the SEE from the cross validation group of 2.17.

The original Rockport equation had a higher predictive value compared to the new developed equation, although the SEE values are fairly similar. The better fit from the original equation could be attributable to a greater variability of subjects, despite the design of the study, as the new equation was developed from a disproportionate number of younger and more athletic subjects. Another potential reason for the increased accuracy in the original Rockport 1-mile walk test was that the original subjects completed the 1-mile walk test more than once which allowed the subjects to become familiarized with the test and find an appropriate speed for their bodies' mechanics (Kline et al., 1989).

Some potential causes of the lower r values and the higher SEE values would be a lack of familiarity with the use of RPE. We found that most younger, fitter subjects did not feel comfortable giving a higher RPE, even when they appeared breathless. Perhaps more extensive pre-test education on the use of the scale would provide more accurate results.

In summary, there is a great need for submaximal exercise tests that are independent of HR when predicting VO$_2$max. This study demonstrates that the original

Rockport 1-mile walk equation could use RPE as a reasonable surrogate for populations of moderate fitness to predict VO_2max and VO_2 at VT.

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APPENDIX A

INFORMED CONSENT AND RISK STRATIFICATION

Informed Consent

Purpose and Procedure

The purpose of this study is to determine whether incorporating RPE and Talk Test data into the original Rockport one-mile walk test equation will provide a more accurate prediction of VO_{2max}. A maximal treadmill test will be done using the Balke protocol in order to measure VO_{2max}. A Rockport one-mile walking test will also be performed. My participation will involve two separate tests including a maximal treadmill in the Exercise Physiology Lab in Mitchell Hall where I will walk on an increasing incline until exhaustion while heart rate, oxygen consumption and rating of perceived exertion will be measured. Heart rate will be monitored continuously through the use of a chest strap. Oxygen consumption will be measured through a mouth piece that will monitor inspired and expired air throughout the whole test. The second test will be performed on the indoor track at Mitchell Hall. For this test, I will walk one mile as quickly as possible. Heart rate, rating of perceived exertion and the Talk Test will all be measured. The Talk Test will be measured through recitation of the "Pledge of Allegiance". Heart rate will be monitored continuously with a chest strap and palpated at the end of the test.

Potential Risks

I have been informed that there are no risks associated with this study other than fatigue, leg tiredness, and shortness of breath, all of which are similar to intense training. The risk of serious complication is very low in the apparently healthy population. If an emergency should occur, CPR trained individuals will be in the lab at all times. Additionally, the laboratory has a standard emergency plan and an Automated External Defibrillator readily available.

Rights and Confidentiality

My participation in this study is entirely voluntary and I can withdraw from the study at any time, for any reason, without penalty.

In the event that the results of this study are published in the scientific literature, my name and personal information will not be identified.

My results will remain confidential. Only the investigator and appropriate laboratory personnel will have access to my data.

Possible Benefits

The general public may benefit from a more accurate equation to predict VO_{2max} from the Rockport walking test. This may allow for fewer costly maximal tests and more submaximal tests.

Questions

I have read the information provided on this consent form. I have been informed of the purpose of this test, the procedures, and expectations of myself as well as the testers, and of the potential risks and benefits that may be associated with volunteering in this study.

I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

If I have any further questions I will not hesitate to ask the people that I am doing the study for.

_____   _____
Subject Name (printed)   Subject Signature
Date

_____   _____
Witness Name (printed)   Witness Signature
Date

Activity Questionnaire:

1.) Within the last 3 months, how many hours per week do you exercise?

2.) What types of exercise do you participate in?

AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire
Assess your health needs by marking all true statements.

History
You have had:
____ a heart attack
____ heart surgery
____ cardiac catheterization
____ coronary angioplasty (PTCA)
____ pacemaker/implantable cardiac defibrillator/rhythm disturbance
____ heart valve disease
____ heart failure
____ heart transplantation
____ congenital heart disease

*If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a **medically qualified staff**.*

Symptoms Other Health Issues:
___You experience chest discomfort with exertion
___You have musculoskeletal problems
___You experience unreasonable breathlessness
___You have concerns about the safety of exercise
___You experience dizziness, fainting, blackouts
___You take prescription medications
___You take heart medications
___You are pregnant

Cardiovascular Risk Factors:
___You are a man older than 45 years
___You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal
___You smoke
___Your blood pressure is greater than 140/90
___You don't know your blood pressure
___You take blood pressure medication
___Your blood cholesterol level is >240mg/dL

*If you marked two or more of the statements in this section, you should consult your healthcare provider before engaging in exercise. You might benefit by using a facility with the **professionally qualified exercise staff** to guide your exercise program.*

___You don't know your cholesterol level.
___You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister).
___You are diabetic or take medicine to control your blood sugar.
___You are physically inactive (i.e., you get less than 30 minutes of physical activity on at least 3 days per week).
___You are more than 20 pounds overweight.
___None of the above is true.

You should be able to exercise safely without consulting your healthcare provider in almost any facility that meets your exercise program needs.
AHA/ACSM indicates American Heart Association/American College of Sports Medicine.
Health appraisal questionnaires should preferably be interpreted by qualified staff (see next section for criteria) who can limit the number of unnecessary referrals for preparticipation medical evaluation, avoiding undue expense and barriers to participation.

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

It has been shown time and time again that aerobic capacity is an accurate measure of overall health and fitness. The American College of Sports Medicine (ACSM) refers to a maximal oxygen uptake (VO_{2max}) test as the criterion measure, or gold standard, in looking at one's cardiorespiratory fitness (CRF) (Pescatello, 2014). VO_2max has been defined as the point in which oxygen intake per unit of time has attained its maximum and remains constant owing to the limitation of the circulatory and respiratory systems (Mitchell, Sproule, & Chapman, 1958). This means a person will maintain a plateaued oxygen intake when the workload continues to increase when the body has reached its physiologic limits. Maximal aerobic capacity is a value that can be used in a prognostic, diagnostic, or prescriptive manner.

Maximal Testing

In a study done by Mitchell et al. (1958), the physiological meaning of VO_2 was examined and it found that cardiac output and arterial/venous blood oxygen difference were both the main determinants of the body's response to exercise and increased O_2 demand. Through the maximal testing of 65 apparently healthy men on a motorized treadmill, it was found that at VO_{2max}, cardiac output was increased by 4.3 times and through widening of the AV O_2 difference by 2.2 times, VO_2 exceeded 3 liters on average. In other words, VO_2 is dependent on both the heart's ability to pump blood

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through the body and the ability of the tissues and vasculature to extract oxygen from the blood. This shows that performing VO_{2max} tests therefore provides clinically useful information about the functioning of a person's cardiovascular system.

The ACSM goes into depth about the variables and procedures involved with maximal testing. When performing a VO_{2max} test, open circuit spirometry is used to measure pulmonary ventilation. This information demonstrates the cardiorespiratory system's ability to keep up with the work being demanded of it. (Pescatello, 2014). These tests are costly and require a lot of equipment, space, and personnel to complete. This has led to the development of many different types of submaximal tests that are used to predict a person's VO_{2max} value without having to perform a full-out maximal test. These tests are often based on HR response to exercise, as this is a linear relationship in those populations whose HR are not affected through medications, stress, illness, or other various factors. The ASCM (Pescatello, 2014) also states that the decision to use a maximal or submaximal test depends largely on the reason for the test, risk level of the patient, and availability of appropriate equipment/personnel. These are all reasons that make submaximal tests more appealing as they require less equipment, personnel, effort from the participant, and are much less costly.

<u>Submaximal Tests</u>

Grant et al. (1995) conducted a study that sought out to compare different submaximal methods of predicting VO_2max. The different tests that were examined were the Cooper walk run test, a multistage shuttle run test, and a submaximal cycle test. VO_2max was measured directly on a treadmill in order to test the accuracy of the predictive, submaximal tests. Twenty-two active, healthy, college-aged males performed

one trial of each test along with the VO₂max test. The Cooper test's primary focus was looking at how far the participants could run (or walk) in 12 minutes on an indoor track. The cycle ergometer test followed a modified YMCA protocol and collected data on the subjects' HR and ventilatory gas exchange at the ends of various stages in the test. The shuttle run test had the subjects running back and forth between two lines 20 meters apart with an increasing frequency of sound signals. The VO_{2max} was predicted from the number of shuttles completed before failure to reach the line on three consecutive occasions. It was found that the best predictor was the Cooper walk/run test with a correlation coefficient of 0.92, as the other tests underestimated VO_{2max}. This study shows that VO_{2max} can be accurately predicted without measuring HR or ventilatory gas exchange.

Non-Exercise Predictors

This brings forth the question, what is necessary to measure CRF? In a study done by Mailey et al. (2010), research was done in order to determine if aerobic capacity could be predicted through non-exercise measures. One hundred and seventy-two subjects ages 60-80 that were of low to moderate risk according to ACSM guidelines completed a maximal graded exercise test (GXT) and a submaximal one-mile walk test. Data was collected on each subject on his or her age, sex, BMI, resting HR, and physical activity based on self-report. This particular study was testing whether the original non-exercise equation developed by Jurca et al. (2005) was valid in an older population. Hierarchal regression analysis was used to determine which of the variables of subject data was most relevant in predicting VO_{2max}. The strongest contributors to variance in metabolic equivalent (MET) level reached were the subjects' sex, age, and BMI with resting HR having almost no contribution. It was found that not only were the results similarly valid

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to the original equation, but there was almost an identical correlation (r=0.66) between the non-exercise equation to GXT vs. submaximal test to GXT.

This study was then cross-validated by Sloan et al. (2013) in a study that sought to determine whether the non-exercise fitness assessment (NEFA) was valid in an Asian population, which is physiologically different from a Caucasian population. Singaporean adults (n=100) were recruited; only those adults with low or moderate risk were allowed to participate. These subjects also completed a VO_{2max} test using the Bruce protocol (Bruce et al., 1980). It was found that the original prediction equation was able to accurately estimate CRF in a Singaporean population. The researchers also created an additional equation that does not include resting HR as a variable and it was found that this equation was also valid. NEFAs are useful for populations that are unable to exercise due to physical, time, and/or financial limitations.

Field Testing

When exercise is used to predict VO_{2max}, it is not always possible to use a treadmill or other ergometer, making field tests a better option. The ACSM (Pescatello, 2014) defines a field test as a test consisting of walking or running a predetermined time or distance. These types of tests allow for a more specified design and oftentimes provide a more relevant exercise prescription over other VO_2 predictors because there are fewer methodological limitations They also allow for less equipment and can be conducted on many people at one time. Possible disadvantages involved with field tests include variations in individuals pacing strategies, motivations, and the appropriateness for those with musculoskeletal/cardiovascular complications.

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In a study done by Flouris et al. (2010), the validity and reliability of a new 15m square shuttle run test (SST) was compared against the traditional 20m square shuttle run test (MST) in predicting VO_{2max}. The 15m test was developed in order to make it easier to administer in limited space settings. Forty-five healthy males without history of smoking or musculoskeletal injuries were recruited to complete the two separate tests along with a treadmill max test. Workload during the shuttle tests was controlled using an audio CD that gave prompts at appropriate intervals to maintain a specified velocity. Tests were terminated once the subjects were unable to complete two consecutive rounds following the prompts of the CD. Ventilatory gas exchange was monitored throughout the shuttle tests using a portable metabolic cart and HR was monitored continuously through use of a chest strap. The researchers found that SST was in fact an accurate predictor of VO_{2max} and that there was little to no difference between the predictive value of the SST and MST. This shows that field tests, such as shuttle run tests, can be successfully utilized instead of cost-intensive, laboratory treadmill-based max tests.

Occupational Applications

The clinical world is not the only place where measuring aerobic capacity becomes necessary. There are many occupations that depend on an individual's ability to maintain a certain level of physical fitness in order to remain productive, efficient, and most importantly, safe. This creates a need for a way to measure employee fitness and readiness to work.

In a study done by Klaren, Horn, Fernhall, Motl (2014), the accuracy of the VO_{2peak} equation that is currently used to predict firefighters fitness was tested. The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) was established to

confirm that firefighters were fit enough to perform their jobs safely. This was defined as having a minimal estimated VO_{2peak} of 42ml/kg/min. The current protocol to test fitness was a treadmill-based submaximal test using the Gerkin protocol (Gerkin, Kelley, Perry, 1997) which involves increasing speed and grade in stages until the participant reaches 85% of estimated HR based on the Tanaka formula (Tanaka, Monahan & Seals, 2001). This study had 22 firefighters complete the traditional WFI submaximal test and then had them follow the exact same protocol until he or she reached complete exhaustion. It was found that although the difference between predicted and measured VO_{2peak} was small, the SD was ± 9ml/kg/min. This means that there is a high variability in accuracy where VO_{2peak} was frequently overestimated in older firefighters and underestimated in younger firefighters. This is particularly dangerous because that translates into the fact that the population who is at the highest risk of sudden cardiac events is being incorrectly evaluated as being fit enough to complete a very physically demanding job. The study concluded by stating that the prediction equation needs reevaluation to improve duty assignments, employment status, and overall safety of the firefighter.

Another occupational area that requires a standard level of physical fitness is the military. A study was done in 2013 that sought to validate a one-mile walk equation in estimating the aerobic capacity of British military personnel under the age of 40 (Lunt, Roiz de Sa, Roiz de Sa, & Allsopp, 2013). According to the study, lower intensity walk-based tests are usually reserved only for those above the age of 40 and those in a medical category where high-impact/maximal testing is contraindicated because in healthy, fit populations, VO_{2peak} is often overestimated using these tests. For this study, 200 military personnel completed a treadmill-based VO_2max test and two separate one-mile walk

tests. It was found that when using the traditional Rockport equation (Kline et al., 1987), VO_{2peak} values were consistently overestimated. This again is particularly dangerous because this could mean sending people out to do a task that he or she is not aerobically fit enough to complete safely. The researchers developed 3 additional equations and found that the equation that was cross-validated against a separate group to be most accurate. This equation incorporated gender, speed, terminal HR, body mass, and age. The difference between measured and predicted VO_{2peak} using this equation was -0.5%. This shows the importance of selecting a submaximal test that is appropriate for the age group and fitness level of those being tested. It also demonstrates that equations can be manipulated to account for a wide range of inter-subject variability.

Cardiac Rehabilitation Applications

One of the most clinically relevant form of exercise testing is when it is used in relation to a cardiac rehabilitation population. In a study by Mezzani et al. (2012), the ability to prescribe exercise and assess aerobic exercise intensity for this group was tested. It has been said that there is a great need for direct evaluation of functional capacity prior to patients entering an outpatient cardiac rehabilitation program. This would provide information on risk stratification, amount of supervision required, and appropriate exercise prescriptions. There are many methods of estimating aerobic capacity for this population, most centering on the relationship between VO_2, HR, HR reserve, and rating of perceived exertion (RPE).

Despite the plethora of valuable information that a GXT provides, there has been a trend for patients to not have one done prior to entering a phase II or III program of cardiac rehabilitation. Reasons for this include: shorter hospital stays, more aggressive

interventions, increased sophistication of diagnostic tools, extreme deconditioning, orthopedic limitations, etc. This is unfortunate because when prescribing exercise without a GXT, the beneficial effects of training are potentially reduced and this could therefore impede the progress of these patients. It is important that this population takes part in some sort of exercise test, preferably a maximal aerobic capacity test as that is the gold standard on which to base exercise intensity. This would also provide a safer and more personalized exercise prescription for each individual.

Perceptually-Regulated Tests

There are many variables that can be included when predicting a person's VO_{2max} from a submaximal test. One variable that has become more prominent recently is RPE. The use of RPE in exercise testing has shown that there are biological markers such as HR, blood lactate, and VO_2 that are anchored to different RPE values. In a study done by Faulkner, Parfitt, and Eston (2007), the accuracy of using a perceptually-regulated submaximal test in predicting the VO_2max in both active and sedentary adults was put to the test. Perceptual regulation is when the subject selects the workload that he of she feels correlates with a designated RPE value on Borg's Scale of 6-20 (Borg, 1998). For this particular study, 45 total subjects completed two GXTs and three perceptually-regulated GXTs incremented by RPE values of 9, 11, 12, 15, and 17 all done on cycle ergometers. While completing the submaximal tests, the participants instructed the researcher to adjust the resistance on the cycle until they felt they were cycling at an intensity that matched a "9" on the RPE scale. The stages continued with increasing RPE values (11, 13, 15, and 17) every three minutes. Rating of perceived exertion and HR collected during the perceptually-regulated tests were then regressed against VO_2 to predict

VO$_2$max. It was found that the extrapolation of submaximal VO$_2$ from the perceptual range of RPE 9-17 to an RPE value of 19 while incorporating age-predicted maximal HR was an accurate predictor of the subjects' VO$_2$max. Another finding of the study was that the subsequent submaximal tests were more accurate predictors than the first perceptually-regulated test. This is most likely due to the subjects' increasing familiarity with the use of Borg's scale (Borg, 1998).

Eston et al. (2012) conducted a similar study that utilized motorized treadmills instead of cycle ergometers as the mode of exercise. The set up was very similar to the study done by Faulkner et al. (2007) in that subjects completed a maximal GXT and also perceptually-regulated submaximal tests at RPE values of 9, 11, 13, and 15. The display screen on the treadmill was hidden from the subject with speed and grade being adjusted by the subject to the corresponding RPE value of each stage. HR was monitored continuously through the use of a chest strap. The order of testing was also manipulated according to the subject's status as either active or sedentary. The sedentary individuals completed the submaximal tests during the first and second sessions with the maximal GXT being the last test. The opposite was true for active individuals. The researchers feel this was an important design decision due to convenience and avoiding having sedentary individuals start off with an exhausting and uncomfortable maximal test.

Similar to the previous study, the RPE values were extrapolated to an endpoint of RPE$_{19}$ to predict VO$_2$max. The results showed that HRs produced by both active and sedentary adults during the RPE range of 9-15 can be used when the HR: oxygen uptake relationship is extrapolated to the age-predicted maximal HR. These studies both

demonstrate that perceptually-regulated tests that utilize RPE as a foundation for a protocol may be used to accurately predict VO₂max.

Rockport One-Mile Walk Test

One of the most common and widely utilized submaximal exercise tests is the Rockport One-Mile test developed by Kline et al. (1987). This test was developed out of a need for a submaximal test that would accurately estimate VO₂max without a protocol that is inappropriate or potentially dangerous for sedentary and older populations. The variables that the researchers chose to incorporate to produce an accurate equation were gender, age, body weight, and time to complete the walk. The methods used in this study were tested on 343 healthy adults ages 30-69 years. A maximal treadmill-based test was used to measure VO₂max, and each subject performed at least two, one-mile walking tests on a track. During the track walk, the subjects were instructed to walk as fast as possible and if the finishing times of the two tests were not within 30 sec of each other, an additional test was completed. Heart rate was monitored and recorded every minute and each quarter mile during the walk.

The researchers developed six different equations for predicting VO₂max with the most accurate being: $VO_2max = 6.9652 + (0.0091 \times Weight) - (0.0257 \times Age) + (0.5955 \times Sex) - (0.2240 \times T_1) - (0.0115 \times HR_{final})$. This equation was developed from 174 subjects and then cross validated against 169 subjects and was found to be an accurate predictor of VO₂max. It was also found that it would be sufficient to perform only a single walking test and use the generalized equation because any variation in walk time on the track was accompanied by an equal and inverse variation in HR.

Additional tests have been conducted to test the validity of the Rockport test when it is performed on a treadmill instead of a track. Pober et al. (2002) carried out a study looking to see if the Rockport equation was appropriate in predicting VO₂max in healthy adults ages 40-79 years when the test is done on a treadmill. Three hundred and four healthy volunteers who were not taking any medications or supplements that would affect HR response completed a VO₂max test and a one-mile treadmill walk. The speed on the treadmill was chosen by the subject per instruction that it be at an intensity he or she would be able to maintain for 15-20 minutes. It was found that the current model did not translate well onto treadmill walking. This is most likely due to the fact that over-ground locomotion generally has a greater oxygen requirement at a given speed than treadmill walking. The researchers were able to formulate a new equation that is specifically designed for a one-mile treadmill walk. This protocol may be advantageous over track walking with higher risk participants as it allows for closer monitoring.

Another study done by Seneli, Ebersole, O'Connor, and Snyder (2013) tested whether or not the Rockport test was valid on a non-motorized curved treadmill. This is different from a motorized treadmill because the individual on the treadmill has the ability to accelerate and decelerate at his or her own pace rather than being dependent on the motorized belt. Healthy adults (n=23) participated in this study by performing a traditional Rockport test on an indoor track, another on a curved treadmill, and a GXT for criterion measure of VO₂max. Heart rate and completion time were recorded. There was no difference in completion times between the track and treadmill tests, but HR was significantly higher from the curved treadmill tests which in turn lead to a consistent underestimation of VO₂max when using the curved treadmill. A more accurate equation

was not developed, but the researcher states that with a more appropriate equation, the curved treadmill would provide an alternate form of submaximal testing.

The Rockport test is a popular and simple test that requires minimal equipment. As stated by Kline et al., the r-value of the generalized equation in the prediction of VO_2peak (ml/kg/min) was 0.88 with a SEE value of 5.0 (Kline et al., 1987). This leaves some room for improvement in the accuracy of predicting maximal aerobic capacity. One way to potentially improve the SEE and r-value would be to incorporate other variables such as RPE and data on subjects' ventilatory thresholds.

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