PREDICTION OF MAXIMAL OXYGEN UPTAKE USING THE ROCKPORT ONE MILE WALK TEST AND RATING OF PERCEIVED EXERTION

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 MAXIMAL OXYGEN UPTAKE USING THE ROCKPORT ONE MILE WALK TEST AND RATING OF PERCEIVED EXERTION

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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

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ABSTRACT

Beauchene, A.L. Prediction of maximal oxygen uptake using the rockport one mile walk test and rating of perceived exertion. MS in Clinical Exercise Physiology, December 2015, 43pp. (C. Foster)

This study was designed to evaluate the effect of using the Rating of Perceived Exertion (RPE) on the accuracy of the Rockport 1-mile walk test. Eighty-eight subjects ranging in age and fitness levels performed a Rockport 1-mile walk test and a Balke maximal oxygen consumption (\(V_O\_max\)) test on the treadmill. During both tests the subject’s RPE was recorded each stage of the \(V_O\_max\) test and every 200 meters of the Rockport test. Maximal oxygen consumption was predicted by using linear regression. The accuracy of the equations was determined using multiple regression (\(R^2\)) and standard error of estimate (SEE). A moderate correlation was seen between \(V_O\_max\) predicted from 1 mile walk time and RPE with measured \(V_O\_max\). The Rockport II equation was slightly less accurate compared to the original Rockport, but is simpler as it only used 2 variables. The equation: Predicted \(V_O\_max\) = 31.142 - (1.13 - (Walk time) - (.305(final RPE)) x 3.5, \(R^2 = 0.4859\), and \(SEE = +/- 6.76\) ml/kg/min. In conclusion RPE added significant predictive power to the equation when compared to only using time to walk 1-mile and was not significantly different than the original Rockport equation.
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I would like to thank all of our subjects for the time and patience they showed during the testing process. I would especially like to thank my family for all of the motivation and support they have given me over the past year. It would never have been possible without the support of my parents. Dedicating time to come and participate in this study and convincing others to come as well helped to give us the data we needed.
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INTRODUCTION

The goal of this study was to design an equation for predicting maximal oxygen intake (VO$_{2\text{max}}$) from the Rockport 1-mile walk test. VO$_{2\text{max}}$ is the single best measurement that defines aerobic capacity and cardiorespiratory fitness (Pescatello, Arena, & Thompson 2015). VO$_{2\text{max}}$ measurements also provide prognostic information for clinical populations (Myers, et al. 2002). The importance of an accurate VO$_{2\text{max}}$ measurement is crucial in the clinical setting because of its power to predict mortality and functional capacity and its best measured during a maximal graded exercise test with respiratory gas analysis.

Although direct VO$_{2\text{max}}$ is considered to be the most accurate method of measuring aerobic capacity, it can be expensive, time-consuming, requires high patient motivation, and is not convenient for testing of large numbers (Kline, et al. 1987). Performing a submaximal test allows for a reduced risk and cost compared to maximal testing. Also, when using a submaximal test there is an inherent error in estimating VO$_{2\text{max}}$. One popular submaximal test is the Rockport 1-mile walk test. This test takes into account age, weight, heart rate (HR), and the time required to complete the 1-mile walk (Kline, et al 1987) and is a well-accepted submaximal test for predicting VO$_{2\text{max}}$ in most individuals. But since the Rockport uses HR as part of the prediction equation, it is subject to considerable error (Kline, et al. 1987). Estimating VO$_{2\text{max}}$ from HR is based on assumptions such as the uniformity of HRmax for a given age, the absence at medications that alter HR, and a steady state work rate (Sartor, et al 2013). Another test that uses HR
to help predict $VO_{2\text{max}}$ is the Astrand bike test (Astrand & Rhyming 1954). The Astrand test is a submaximal test where the $VO_{2\text{max}}$ is predicted based on extrapolating the HR vs. power output relationship to an assumed maximal HR. The Astrand test has the same room for error as the Rockport when it comes to using HR, being that some populations will have altered HR’s that will make the predicted $VO_{2\text{max}}$ less accurate. Even in normal healthy individuals, using predicted maximal HR ($220 - \text{age}$) leaves a large room for error.

Another measurement that can also be used to help estimate $VO_{2\text{max}}$ is rating of perceived exertion (RPE). RPE assesses how hard the subject feels they are working, incorporating fatigue, sweating, HR, soreness, and breathing (Borg, 1970). The RPE scale has verbal anchors associated with the physical experience such as light, very light, somewhat hard, hard, and very hard. When compared to actual $VO_{2\text{max}}$, predicting $VO_{2\text{max}}$ using RPE values 9-17 extrapolated to a terminal RPE of 19, there was no significant difference (Eston, Lamb, Parfitt & King 2005). RPE can also be more useful with patients in that HR may be abnormal because of drug effects, atrial fibrillation, autonomic dysfunction, and chronotropic incompetence (Mezzani, et al. 2012). This offers clinical value for estimating $VO_{2\text{max}}$ when direct measurement is not feasible. RPE has also been shown to be a valid tool for prescribing exercise and can be associated with relative physiological markers that can then be applied to certain exercise intensities (Faulkner & Eston 2007).

A recent study by Porcari, et al. (2015) showed that $VO_{2\text{max}}$ could be accurately predicted by the combination of RPE and 6 minute walk distance (6 MWD). The data showed that RPE added a significant amount of accuracy to a prediction equation based
on 6 MWD. Both 6 MWD (p= 0.002) and terminal RPE (p= 0.006) were significant contributors to the VO2max prediction equation. The Rockport 1-mile walk test is conceptually similar to the 6 MWD, although the 6 MWD is designed for clinical population with lower exercise capacity. With information showing that RPE is a valid adjunct to walking performance for estimating VO2max and prescribing exercise; therefore, the purpose of this study is to redesign the initial Rockport submaximal test equation using terminal RPE as a predictive variable in place of terminal HR. A more accurate equation would allow for a more accurate estimation of VO2max without requiring a maximal test. The intent of the study was to determine if a submaximal equation, based only on 1-mile walking time and terminal RPE would predict VO2max as accurately as the traditional Rockport 1-mile walk test.
METHODS

Subjects

During this study 88 subjects participated with a wide range of physical fitness and age (19-72 years old). Before testing, the protocol was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects. All subjects provided a written informed consent and were risk stratified (Pescatello, et al. 2013). Each subject was also given an activity questionnaire to assess activity levels prior to testing. The subject characteristics can be found in table 1.

Table 1. Subject Characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Males (n=21)</th>
<th>Females (n=50)</th>
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<tr>
<td>Age (years)</td>
<td>40.1 ± 15.90</td>
<td>36.2 ± 14.87</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>70.9 ± 2.81</td>
<td>65.4 ± 3.60</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>88.8 ± 12.11</td>
<td>70.1 ± 11.56</td>
</tr>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>45.2 ± 9.95</td>
<td>38.4 ± 8.09</td>
</tr>
<tr>
<td>HR Max</td>
<td>172 ± 20.1</td>
<td>178 ± 11.0</td>
</tr>
<tr>
<td>Walk Time (min)</td>
<td>13.8 ± 1.52</td>
<td>14.2 ± 1.31</td>
</tr>
<tr>
<td>Final walk RPE</td>
<td>12.2 ± 2.21</td>
<td>12.1 ± 1.90</td>
</tr>
<tr>
<td>Walk HR</td>
<td>121 ± 20.0</td>
<td>130 ± 18.0</td>
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</table>
Procedures

Each subject performed a VO$_{2\text{max}}$ test on a motor driven treadmill using the modified Balke & Ware (1959) protocol. The initial speed was set at a “comfortable walking pace” during the first stage with a 0% grade. Increments in workload were accomplished by adding 2.5% grade every 2 minute stage. HR was measured at the conclusion of each 2 minute stage. Respiratory gas exchange was monitored continuously using open circuit spirometry using a mixing chamber based metabolic cart (AEI, Pittsburgh, PA). The Borg 6-20 RPE scale was used to measure perceived exertion and the subject rated their effort 1.5 minutes into each stage (Borg, 1970). VO$_{2\text{max}}$ was accepted at the last 30 second value they were able to complete.

Each subject also performed a Rockport 1-mile walking test. The test was performed on the Mitchell Hall indoor track. During the walking test, RPE was measured every 200 meters. HR was palpated at the radial artery at the completion of the 1-mile walk test. The subjects were asked to walk at a “brisk” pace throughout the duration of the walk test. Potential predictors of VO$_{2\text{max}}$ were entered into a stepwise multiple regression equation.
RESULTS

The first comparison made was the max METs predicted from the original Rockport equation to that of the measured Mmx METs of the subjects used in our study. Figure 1 shows that when our subjects were entered into the original Rockport equation, there was an R value of 0.727. The original equation was divided by 3.5 to convert the value to METs, allowing for comparison to the new predictive equation. The original Rockport equation in METs is:

Max METs = \[ \frac{[132.853 - (0.0769 \times \text{Weight}) - (0.3877 \times \text{Age}) + (6.315 \times \text{Gender}) - (3.2649 \times \text{Time}) - (0.1565 \times \text{Heart rate})]}{3.5} \]

Figure 1. Measured vs Predicted VO\(_{2\max}\) (ml·kg\(^{-1}\)·min\(^{-1}\)) from Original Rockport equation
Figure 2 shows max METs predicted by the use of the equation derived from the RPE and one mile walk time. Adding RPE showed a significant improvement to the predictive power of the equation compared to using 1-mile walk performance alone.

The calculation of max (METs) = 31.142 (1.13 – Walk time) – (.305 x final RPE)

SEE = 1.93 METs and r value = 0.697

Figure 2. Measured vs. Predicted Max METs from Rockport II equation
Figure 3 shows the difference between predicted and measured max METs using the residual error (actual - predicted). The mean residuals error was +/- 1.53 METs from the measured max METs achieved. The most variation can be seen on the lower and higher end of max METs, particularly noticeable as max METs increased. For subjects with low values for max METs, actual METs were under-predicted, whereas for subjects with high values for maximal METs, actual METs were over predicted. The average standardized residual error was 1.44 METs.

Figure 3. Residual error vs. Max METs
DISCUSSION

The purpose of this study was to determine $V_O^{2\text{max}}$ by modifying the Rockport 1 mile walking test and incorporating terminal RPE. $V_O^{2\text{max}}$ has long been considered the standard for quantifying cardiorespiratory fitness. The $V_O^{2\text{max}}$ test in the clinical setting can provide important prognostic information in several clinical populations such as congestive heart failure and coronary artery disease (Myers, et al. 2002). Although direct $V_O^{2\text{max}}$ testing is considered to be the most accurate method of measuring aerobic capacity, it can be expensive, time-consuming, requires high patient motivation, and does not allow testing of large numbers (Kline, et al. 1987). Performing a submaximal test that can accurately predict $V_O^{2\text{max}}$ may be safer and less costly for patients. Some submaximal tests have been designed based on HR like the original Rockport (Kline, et al. 1987) and the Astrand Bike test (Astrand & Rhyming 1954) but using HR as a major variable creates room for error. Patients with atrial fibrillation, on beta blockers, who have autonomic dysfunction due to heart transplant, or have chronotropic incompetence (Mezzani, et al. 2012) are all pathologic conditions that will cause HR to become a much less reliable tool. Studies have brought about the idea that using RPE instead of HR can reduce the error with prediction when using 6 MWD (Porcari et al., 2015) and may translate when using the 1-mile Rockport walk test.

The main finding of this study was that using RPE contributes significantly to the predictive value when estimating max METs from the Rockport 1-mile walk test. In this
study a moderate correlation was seen between a predictive equation based on the time required to walk a mile at a “brisk” pace and terminal RPE achieved at the end of the one mile. For the predictive equation, it was shown that the only two variables had statistically significant relationships to VO$_{2\text{max}}$, terminal RPE and time required to walk 1 mile. Other variables that were evaluated included terminal HR at end of mile, height, weight, age, and gender. However the SEE was relatively high when using the new predictive equation. This may be attributed to the fact that a large portion of the subjects were in a superior fitness level, which means that our sample violated the assumption of normality of distribution. The most variation was seen above 14 METs and below 9 METs. The subjects that were in the lower and higher fitness categories had error margins of greater than 2.5 METs when comparing predicted versus measured max METs. Subjects in between these two ends seemed to have a much more linear relationship with predicted max METs.

When comparing the original Rockport equation to our new equation using the same subject population, the correlation was similar between to the two equations. This showed that even the original equation had a lower r value when our subject population was used. One explanation could be that Kline et al. (1987) allowed their subjects to perform the test multiple times until they had two tests within 30 s of each other. This gave the subjects more opportunities to find an appropriate speed and to familiarize themselves with the test.

One of the limitations of this study was that a large part of our subject population was far above average fitness, where the largest amount of error was seen. This led to an uneven distribution of fitness levels among our subjects. This reasonably means there
was reduced number at the lower end of the maximal METs. Another limitation seemed to be terminal RPE for the more fit subjects. According to Eston et al. (2005), to achieve the best predictive value RPE should be 17 or higher. In our subjects the average terminal RPE was 12. This could have led to a less accurate equation. In this study the subject population size was also a factor that could have contributed to some of the error. We were only able to acquire 89 subjects to perform the tests required for the study. When compared to the 343 subjects that were used in the original Rockport, our small sample size could have also reduced the accuracy of the equation.

More research is needed to improve on this equation. The study results may have improved with a much larger and more diverse population. Subjects that have a lower \( \text{VO}_2\text{max} \) may be needed to improve the accuracy of the equation.
REFERENCES


Porcari, J., Brown, H., Foster, C., Doberstein, S., Greany, J., French, K., & Schmidt, K.. Prediction of maximal METs and ventilator threshold using 6-minute walk test

APPENDIX A

INFORMED CONSENT
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 VO₂max. A maximal treadmill test will be done using the Balke protocol in order to measure VO₂max. A Rockport one-mile walking test will also be performed.

My participation will involve three 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$_{2\text{max}}$ 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.
APPENDIX B

ACTIVITY QUESTIONNAIRE
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?
APPENDIX C

AHA/ACSM HEALTH/FITNESS PRE-PARTICIPATION SCREENING QUESTIONNAIRE
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 D

REVIEW OF LITERATURE
REVIEW OF LITERATURE

INTRODUCTION

Maximal Oxygen Uptake (VO_{2max}) testing has long been considered the standard for quantifying the cardio respiratory fitness in a given individual. The VO_{2max} test in the clinical setting can provide important diagnostic and prognostic information in several clinical populations such as congestive heart failure and coronary artery disease (Sartor, et al. 2013). Many different forms of graded exercise tests have been designed to acquire an individual’s VO_{2max}. A true VO_{2max} ends when the subject reaches a point where they can no longer continue or when certain criteria are met, such as >90% of predicted heart rate max (HRmax), >1.1 respiratory exchange ratio, or plateauing VO_{2}. Although direct VO_{2max} testing is considered to be the most accurate method of acquiring an individual’s aerobic capacity, it can be expensive, time-consuming, requires high patient motivation, and does not allow testing of large numbers (Kline, et al 1987). Many different submaximal tests have been designed to help alleviate the errors that come with a VO_{2max} test. One of the most accepted ways of predicting VO_{2max} is by using HR or power output (PO) based equations. One factor that is beginning to receive recognition is the rating of perceived exertion (RPE) scale. This scale uses the patients understanding of how difficult the work is relative to them. The RPE scale has been shown to have a linear relationship to VO_{2max} that has been shown to be as accurate as HR at predicting a person’s VO_{2max} (Eston, et al 2005).
Maximal Oxygen Intake

In 1955 Taylor, Elsworth, and Henschel looked at VO$_{2\text{max}}$ as an objective measure of cardio-respiratory performance. During this study, they attempted to assess the validity of the VO$_{2\text{max}}$ testing protocols and its usefulness in a longitudinal study by comparing the subjects to themselves under differing conditions. The first group was twenty-seven soldiers who underwent acute caloric restriction. The other group was forty-six male volunteers in apparently good health with a wide range of physical fitness levels. Each subject had multiple visits with a different maximal test to help assure a proper VO$_{2\text{max}}$ test. For the first visit the participants performed a Harvard fitness treadmill test. The results were able to estimate a percent grade. The second test the subjects walked at 3.5 mph at a 10% grade as part of a warm up. After the warm up the subjects ran at 7 mph at the grade selected from the first test. The last test ran the subjects ran at 7 mph but at a grade 2.5% greater than the second test to look for any variation in results. After performing the test it was concluded that a test with an increasing grade, and constant speed, was the most satisfactory method of acquiring VO$_{2\text{max}}$. For this longitudinal study they looked that the effects of stressors on subjects VO$_{2\text{max}}$ that ranged in severity and time frames. The subject stressors ranged from malaria, acute starvation, bed rest, semi-starvation, and minimum calories. This study showed that the calorically restricted subjects were able to establish a new VO$_{2\text{max}}$ plateau, thus eliminating motivation as a factor for decreased VO$_{2\text{max}}$. The authors stated that a diminished VO$_{2\text{max}}$ over longitudinal study can be attributed to multiple factors such as bed rest leading to decreased cardiovascular function or changes in muscle mass.
In a study that was done by Mitchell, Sproule and Chapman 1957, the meaning of \(\text{VO}_{2\text{max}}\) was evaluated. The purpose of the study was to examine the relationship of the results of the \(\text{VO}_{2\text{max}}\) and the physiologic meaning behind it. The methods used were that 65 men performed a maximal motor driven treadmill test, in which the speed was attempted to be held at 6 mph while the grade increased by 2.5% per minute. They evaluated the response of when a subject achieved maximal exertion as being if the oxygen increase was less than 54 ml between stages. During the test they noticed that if the subjects continued past their oxygen intake either plateaued or declined. In the study they state that the term maximal oxygen intake is relative to a given set of conditions, which must be carefully defined, rather than in an absolute sense (Mitchell, et al. 1957). They acknowledged that appropriate criteria must be met to state if the subject had actually achieved maximal oxygen intake. They stated that arterial-venous (AV) oxygen difference and cardiac output are the main determinants for assessing \(\text{VO}_2\). They noticed that a change in oxygen concentration in the blood was due to two separate factors. The first being the extent at which \(O_2\) can be given to muscle, and the second is the shunting of blood away from inactive areas. This study was able to show the main factors of oxygen intake, venous tension does not really change regardless of desaturation, and arterial tension was not really changed regardless of rest and heavy work.

Balke, (1960) studied the effects of exercise on metabolic potential as a crucial measure of physical fitness. Physical fitness was first described as a person's biodynamic potential which is composed of his functional and of his metabolic potential. He attempted to test biodynamic potential by having subjects walk at a constant speed of 3.4 miles per hour and at an increasing grade. It was believed that as the difficulty increased
the subject's body would adapt to the increased energy demands. One measurable increase would be the subject's HR and pulse pressure, which would indicate an increase in cardiac output which is of primary importance for adequate oxygen and energy supply. During this study they had subjects perform a maximal VO$_2$ graded exercise test. It showed a linear increase in oxygen consumption with an increase in treadmill grade. At a HR around 180 beats per minute is when functional limitations become apparent. After assessing direct VO$_{2\text{max}}$ it was speculated that an estimated maximal oxygen intake can be estimated by a steady state run for 2.5 miles, with only submaximal breathing. With the time it required to complete the test they were able to estimate the subject's VO$_{2\text{max}}$.

When compared to the directly measured intake there was no significant difference. This assessed functional potential, not metabolic potential. Metabolic potential required a longer duration to make an accurate assessment. To determine this they had two subject groups. One group was considered "well trained" and the other group were considered "less trained". Before the trial the subject's blood glucose and plasma cholesterol baseline measurements were taken. Then the subjects exercised for 2 hours at 70-80% of VO$_{2\text{max}}$. The glucose and cholesterol measurements were retaken an hour into exercising, and at termination of exercise. What they noticed was the glucose in the "well-trained" decreased at a much slower rate than the "less-trained". The "less-trained" were performing less work but were having a more drastic blood glucose decrease. They also showed that "well-trained" subjects were much better at utilizing fat. This study was able to demonstrate not only a functional capacity improvement by physical activity but also in metabolic capacity.
VO_{2\text{max}} is the gold standard for understanding a person's cardiovascular function. Being able to quantify a person's VO_{2\text{max}} gives clinicians irreplaceable prognostic and diagnostic information about patients and their aerobic capacity. These tests have many different protocols but all share the common theme that with an increase in grade, speed, or a combination of both, a person's aerobic systems will be pushed as the work load increases.

**Submaximal Testing**

Sartor, et al. 2013 reviewed many of the submaximal testing protocols and reviewed the importance of selecting the right protocol for the given population. Seventy-six total protocols were examined during the review from articles published between 1963 and 2012. The review stated most of the protocols use the linear correlation between HR or PO and VO_2 to estimate VO_{2\text{max}}. Comparatively submax testing leaves room for error when compared to a direct VO_{2\text{max}}. In this review they looked at the fact that test like the Rockport one mile walk test, 6 minute walk test (MWT), step test, and 12 minute cooper run test are all valid tools for estimating VO_{2\text{max}}, but they also state that many HR-based submaximal tests are known to underestimate VO_{2\text{max}}. This review also discussed the importance of VO_{2\text{max}} estimation in the home setting. They showed that even though some protocols such as the step test can be used in the home setting, there is a large room for error due to the fact that accurate HR measurements are required. This is a concern because HR measurement can be difficult for people to do on their own. In conclusion this review looked at the need for a low-risk, low-cost, low-supervision test to help assess aerobic capacity.
In an article by Kline, et al (1987), the one mile walk test was designed as a submaximal test that is useable in a broad range of participants. The subjects included 183 males and 207 females ranging from 30-69 years old. Each participant was weighed and wore an ECG monitor prior to VO_{2max} testing. For the max test participants selected their own walking speed that increased by 2.5% every two minutes until they could no longer continue. For the one mile walk test the subjects performed a minimum of two tests on a measured track. HR was recorded every 30 seconds. When the equation was designed, it was cross validated with remaining subjects. It showed there was no difference between estimated and measured VO_{2} (Kline, et al. 1987). Six different equations were designed which incorporated age, gender, weight, HR, and Time.

Understanding an individual’s VO_{2max} gives us valuable clinical information on cardiovascular function. Although the best way to acquire this data is a maximal test, this may not be a possibility due to a person’s health status. Maximal tests also very costly and require more advanced equipment. Submaximal testing is a safer and more cost efficient way of quantifying a subject’s VO_{2max}. The need for an accurate test has been stated, and although the tests that are currently used have been proven to be relatively accurate, there is room to improve.

Equations for Predicting Functional Capacity

Others have attempted to develop a multifactorial regression equation for predicting VO_{2max} from treadmill performance, and determine if such an equation would simplify VO_{2max} prediction (Foster, et al 1984) and to improve on the prior equations designed by Balke (1960). For this study 230 male participants with a wide range of age and fitness underwent maximal GXT’s based on the Bruce protocol. The Subjects were
categorized on the basis of having or not having cardiovascular disease. The equation was designed using data from 200 subjects with the equation being cross validated on the remaining 30. These new generalized equations had smaller mean errors in predicting VO₂_{max} than the prior equations developed by Balke (1960).

Rating of Perceived Exertion

Using RPE (Borg, 1970) has shown to have a direct relationship with VO₂_{max}. Eston, Lamb, Parfitt, King (2005) performed a study to help assess the validity of predicting VO₂_{max} through the use of RPE. Subjects performed one maximal graded exercise test followed by three submaximal RPE self-guided tests, in which the subject were given the ability to establish intensities for each RPE. The perceptually regulated tests were performed at RPE’s of 9, 11, 13, 15, and 17. During these tests the participants were educated on the 6-20 Borg scale, then the subject pedaled at intensities starting with an RPE of 9, and then increasing by 2 on the RPE scale until they reached 17. The VO₂ values were associated to each RPE value measured and extrapolated to a terminal RPE of 20. This value was considered the predicted VO₂_{max} for the submaximal RPE regulated tests. The estimated VO₂_{max} and measured VO₂_{max} were not significantly different. It is noteworthy for the most accurate measurements an RPE of 17 was reached before termination. This study showed the value of RPE for estimating VO₂_{max}.

In an article written by Faulkner and Eston (2007) overall and peripheral RPE were combined with HR to see if there was a relationship with VO₂_{max}. This study also looked to see if there was a difference between RPE in different fitness levels, and within the different Genders. The participants performed two cycle ergometer GXT’s to find their VO₂_{max}, RPEo (overall), HR, and RPEp (peripheral). RPE of (9, 11, 13, 15, and 17)
were used in linear regression to determine sub-maximal VO\textsubscript{2max}. The results section revealed that RPE\textsubscript{o} was significantly more accurate than Rep in terms of comparison to actual VO\textsubscript{2max}. Compared to direct VO\textsubscript{2max} the RPE\textsubscript{o} extrapolated VO\textsubscript{2max} was not significantly different when extrapolated from RPE's of 13, 15, and 17. This study showed that RPE is as highly correlated as HR when it comes to linear relationships with VO\textsubscript{2max}. It was shown that RPE is a valid tool for estimating VO\textsubscript{2max} and can be used to help with exercise prescription in high and low fitness individuals regardless of gender.

Faulkner, Parfitt, and Eston 2007 studied the validity of predicting VO\textsubscript{2max} by using HR and RPE. They had 27 males and 18 females perform 2 GXT's and 3 perceptually guided exercises tests. The perceptually regulated tests allowed the subjects to designate workloads where the RPE's were 9, 11, 13, 15, and 17. The subjects then pedaled at each intensity for 3 minutes. Heart rate and VO\textsubscript{2max} were recorded in each stage as well. The RPE and corresponding values were extrapolated to terminal RPE\textsubscript{19}, HR\textsubscript{maxpred}, and RPE\textsubscript{30}. The estimated VO\textsubscript{2max} was acquired by extrapolating HR and VO\textsubscript{2max} from perceptual 9-17 RPE's and then compared to the measured VO\textsubscript{2max}. When extrapolating these values there was no significant difference between estimated VO\textsubscript{2max} and directly measure VO\textsubscript{2max}. This study also stated that extrapolating VO\textsubscript{2max} from RPE values of 9-13 and 9-15 to a terminal RPE of 20 showed no significant difference then measured VO\textsubscript{2max} which was a new development from previous study that stated that RPE 9-13 and 9-15 underestimated VO\textsubscript{2max}. As predicted the third perceptually rated test had the most accurate measurements. This was attributed to learning the test and understanding which workloads were appropriate for each RPE.
RPE has shown to have a direct relationship with VO$_{2\text{max}}$. Eston, Lamb, Parfitt, King (2005) performed a study to help assess the validity of predicting VO$_{2\text{max}}$ through the use of RPE. For this study Eston et al. performed one maximal graded exercise test followed by three sub maximal RPE self-guided tests, in which the subject was given the ability to decide an appropriate intensity for each RPE. These perceptually regulated tests were performed at RPE’s of 9, 11, 13, 15, and 17. During these tests the participants were educated on the 6-20 Borg scale, then the subject pedaled at intensities starting with an RPE of 9, and then increasing by 2 on the RPE scale until they reached 17. The VO$_2$ values were associated to each RPE value measured and extrapolated to a terminal RPE of 20. This value was considered the predicted VO$_{2\text{max}}$ for the submaximal RPE regulated tests. The estimated VO$_{2\text{max}}$ and measured VO$_{2\text{max}}$ were not significantly different. It is noteworthy for the most accurate measurements an RPE of 17 was reached before termination. This study showed the value of RPE for estimating VO$_{2\text{max}}$. With this information it allows for submaximal testing without relying only on equations where power out and heart rate were an important variable.

The importance of prescribing exercise intensities based on stress testing before cardiac rehabilitation was reviewed by Mezzani et al. 2012. During this review a basic physiologic explanation was given for prescribing intensities based off of certain physiological thresholds. They explain that first ventilatory threshold (1stVT) is when CO$_2$ production begins to be more than during aerobic metabolism. 1stVT marks the point between light to moderate and moderate to light intensity, or 50-60% peak VO$_2$. Second ventilatory threshold is the point when intracellular bicarbonates are unable to counteract exercise induced metabolic acidosis, this occurs around 70-80% peak VO$_2$. In
this review they discussed that each of the intensities had certain estimated durations that were tolerable due to certain physiologic demands of each intensity. The importance of exercise testing to help decide a more accurate prescription was also assessed. They state that performing an entry level test shows the chronotropic and inotropic response to exercise, severity of dysrhythmias, and is used to identify functional capacity of patients prior to starting the rehab. This allows for a more accurate and individualized exercise prescription. During this review percent of heart rate reserve (HRR) and percent of VO₂ reserve were also assessed for accuracy. It was stated that HRR is considered the gold standard by the American College of Sports Medicine for exercise intensity. The relationship between RPE and VO₂ was also addressed in this review as an acceptable tool for exercise intensity in certain patient populations such as; patients with atrial fibrillation, patients who are on beta blockers, autonomic dysfunction due to heart transplant, and chronotropic incompetence due to pacemaker. Most common scales used for measuring RPE is the Borg 6-20 scale and the 0-10 scale. They also stated that RPE had certain physiologic markers, such as RPE of 13 can be closely associated with 1stVT (Mezzani, et al. 2012). This review expresses the importance of prescribing exercise intensity and volume according to each individual’s physiological limitations. Certain intensities may be unattainable for specific individuals due to difficulties being outside of their capabilities and physical limitations. For prescribing exercise the review showed 3 different caveats should be taken into consideration: 1. Beyond 1stVT energy expenditure will be more inaccurate 2. Moderate to high intensity may be unattainable or not maintainable for certain populations. 3. Use small increments if doing incremental exercise to allow for VO₂ lag (Mezzani, et al. 2012). For prescribing light to moderate
intensity, patients should have a diminished exercise capacity. This range of intensities
can be as low as 40% VO\textsubscript{2} reserve, which for patients with reduced capacity can still
provide benefits.
References


