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SPEED DEPENDENCE OF THE ROCKPORT FITNESS WALKING TEST

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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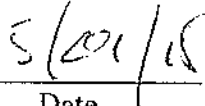
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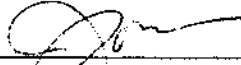
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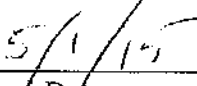
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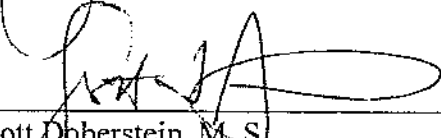
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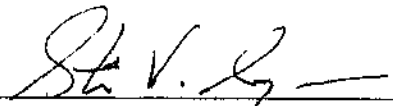
  
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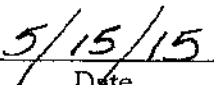
  
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## ABSTRACT

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**Introduction:** The Rockport Fitness Walking Test is a submaximal test that predicts  $VO_{2max}$  to be used in fitness assessment and exercise prescription. This test requires subjects to walk at a brisk pace. However the ability to predict  $VO_{2max}$  is unknown when walking at paces slower than a brisk walk. **Methods:** Healthy adults ( $N = 35$ ) performed a GXT following a modified Balke protocol to obtain  $VO_{2max}$  and VT. All subjects also completed two 1-mile walk tests. The first walk test followed the Rockport Fitness Walking Test protocol, completing the test at a brisk pace. Other than walking at a comfortable pace, the second walk test also followed the Rockport Fitness Walking Test protocol.  $VO_{2max}$  from the GXT was compared to the prediction of  $VO_{2max}$  from the brisk and comfortable walk tests. **Results:** Total walk time, lap time, and HR were all higher for the brisk pace in comparison to the comfortably paced walk, while RPE was lowest for the comfortable pace walk. The brisk walk was better able to predict  $VO_{2max}$  and VT. **Conclusion:** The Rockport Fitness Walking Test must be performed at a brisk pace or higher to accurately predict  $VO_{2max}$ .

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## INTRODUCTION

Despite the wide use of various submaximal methods to predict exercise capacity, the maximal oxygen uptake ( $VO_{2max}$ ), as determined during graded exercise testing (GXT), remains the gold standard assessment method.  $VO_{2max}$  is recognized as the most accurate and direct measure to assess functional capacity and prescribe exercise. The ventilatory threshold (VT) is also recognized as a gold standard method for assessing exercise capacity (Mezzani et al., 2012). However, the direct measurement of  $VO_{2max}$ , and/or VT is expensive: often requiring physician availability, sophisticated equipment, and maximal exertion from the subject. Consequently, submaximal tests have emerged to circumvent these limitations. Submaximal tests are simple, familiar, inexpensive, and can be completed anywhere, with virtually any population, to predict  $VO_{2max}$ . However, submaximal tests are not as accurate as the direct measurement of  $VO_{2max}$ . Increasing the accuracy of submaximal tests is necessary to increase the ease and utility of functional assessments and exercise prescription.

Balke's 15-minute test started the trend of using submaximal tests to predict  $VO_{2max}$  (Balke, 1963). Other submaximal tests evolved to simplify prediction, such as the 12-minute run test, Self-Pace Walking Test, 1-mile Rockport Test, and the six-minute walk test. (Cooper, 1968; Basey, Fentem, MacDonald, & Scriven, 1976; Kline et al., 1987, & ATS, 2002). Walking tests remain quite popular due to the familiarity of the activity and the lack of required equipment.

To accommodate the need for a simple, yet accurate prediction of  $VO_{2max}$ , Kline et al. (1987) created a walking test, known as the 1-mile Rockport Fitness Walking Test. Subjects walked one mile as fast as possible and their age, height, weight, terminal heart rate (HR), and total time for the 1-mile walk were inserted into a regression equation to predict  $VO_{2max}$ .

$$VO_{2max} \text{ (ml/kg/min)} = 132.853 - (0.0769 \cdot WT) - (0.3877 \cdot AGE) + (6.3150 \cdot SEX) - (3.2649 \cdot T_1) - (0.1565 \cdot HR_{1-4})$$
$$r = 0.88, R^2 = 0.7744, SEE = 5.0$$

This equation had a strong relationship to  $VO_{2max}$  ( $r = 0.88, R^2 = 0.77$ ) and thus represented a viable submaximal method to predict  $VO_{2max}$ . Other researchers have expanded the work by Kline et al. (1987) by attempting to generalize the Rockport test to younger and older populations (Fenstermaker, Plowman, & Looney, 1992; Dolgener, Hensley, Marsh, & Fjelstul, 1994). In addition, George, Fellingham, and Fisher (1998) changed the intensity and length of the 1-mile Rockport test by decreasing the pace to a brisk walk (nearly as fast as possible) and decreasing the distance to one-fourth of a mile. Both modifications proposed by George et al. (1998) predicted  $VO_{2max}$  accurately, which further simplifies the utility of the original Rockport test (Kline et al. 1987) for elderly and clinical populations.

While George et al. (1998) decreased the pace of the 1-mile Rockport test to a brisk walk, such a pace may still be too fast for certain populations. Individuals with physical limitations or disease commonly have difficulty performing at higher intensities. Thus, decreasing the walking pace intensity would allow more individuals to complete the 1-mile Rockport test.

Another weakness of the Kline et al. (1987) 1-mile Rockport test is the reliance of the regression equation on terminal HR. Terminal HR is a logical variable to include as an indicator of exercise intensity. However, it does not account for the substantial individual differences in maximal HR or the influence of medications on the HR response. An alternative variable that might be considered to replace terminal HR as an indicator of how hard the subject is working is the Rating of Perceived Exertion (RPE) (Borg, 1998).

RPE represents a better indicator of overall exertion, since it is comparatively unaffected by individual differences (Eston, Lamb, & Parfitt, 2005; Faulkner & Eston, 2007). The structure of the Rockport equation involves subtracting points from a population normative of  $VO_{2max}$ , which is based on the duration of a 1-mile walk time and terminal HR. Replacing terminal HR with RPE also allows the subtraction of points from a population baseline estimate of  $VO_{2max}$ . Using RPE presents the opportunity to change the pace of the test to a comfortable walk. While more points will be subtracted for increasing the walk time by using a comfortable walking pace, fewer points will be subtracted with a lower terminal RPE or HR (as it would seem easier). Ideally, responses to different walking efforts would be reciprocal and would match the predictive accuracy of the brisk walking pace.

Thus, our lab created a new regression equation for the 1-mile Rockport test using RPE as a surrogate of HR. This equation includes only two predictor variables: total walk time at the end of 1-mile ( $T_8$ ) and RPE at the end of 1-mile ( $RPE_8$ ). In addition, our lab also created a regression equation for the 1-mile Rockport test to predict ventilatory threshold (VT) using the same two-predictor variables.

$$\text{VO}_{2\text{max}} (\text{ml/kg/min}) = 31.42 - (1.13 \cdot T_8) - (0.305 \cdot \text{RPE}_8)$$
$$r = 0.6971, R^2 = 0.4859, \text{SEE} = 6.76$$

$$\text{VT} (\text{ml/kg/min}) = 28.169 - (1.117 \cdot T_8) - (0.295 \cdot \text{RPE}_8)$$

The purpose of this study was to determine if a comfortable walking pace can be substituted for the brisk walking pace commonly used in the 1-mile Rockport test to predict  $\text{VO}_{2\text{max}}$  with the original Rockport regression equation and the lab-developed regression equation. We hypothesized that the comfortable walking pace will predict  $\text{VO}_{2\text{max}}$  with similar accuracy compared to the traditional, brisk-to-maximal walking pace of the 1-mile Rockport test.

## **METHODS**

The University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects approved the protocol of this study. Prior to participation, each subject provided written informed consent. Subjects completed a two-question activity questionnaire, which asked, “Within the last 3 months, how many hours per week do you exercise?” and “What types of exercise do you participate in?” Subjects also completed the American Heart Association (AHA)/American College of Sports Medicine (ACSM) Health/Fitness Facility Pre-participation Screening Questionnaire. The AHA/ACSM Questionnaire assessed the risk of a subjects’ ability to exercise: classifying them as low, moderate or high risk. Subjects classified as moderate risk were screened further, whereas those subjects classified as high risk were automatically excluded.

### **Subjects**

Thirty-five healthy subjects (men=12, women=23) aged 18 to 67 years participated in this study. Table 1 illustrates mean age, height, weight,  $VO_{2max}$ ,  $VO_2$  at VT, brisk walking time, comfortable walking time, and training hours for men and women (mean  $\pm$  standard deviation). The subjects varied in exercise capacity ranging from sedentary to very active based on the American College of Sports Medicine (ACSM) guidelines (2014).

Table 1. Subject Demographics (mean  $\pm$  SD)

	Males (n=12)	Females (n=23)
Age (years)	27.8 $\pm$ 3.75	24.3 $\pm$ 1.02
Height (cm)	180.1 $\pm$ 1.11	168.5 $\pm$ 1.36
Weight (kg)	91.0 $\pm$ 5.09	65.9 $\pm$ 1.79
VO <sub>2max</sub> (ml/kg/min)	47.2 $\pm$ 3.39	43.8 $\pm$ 1.52
VO <sub>2max</sub> (L/min)	4.19 $\pm$ 0.277	2.84 $\pm$ 0.097
Max HR (bpm) at VO <sub>2max</sub>	174 $\pm$ 7.2	186 $\pm$ 1.6
VT (ml/kg/min)	28.8 $\pm$ 2.40	28.3 $\pm$ 1.47
Brisk Walk Time (min)	14.06 $\pm$ 0.497	12.73 $\pm$ 0.235
Brisk Walk HR (bpm)	132 $\pm$ 3.9	149 $\pm$ 3.8
Brisk Walk RPE	13.3 $\pm$ 0.51	13.3 $\pm$ 0.31
Comfortable Walk Time (min)	18.33 $\pm$ 0.513	16.99 $\pm$ 0.408
Comfortable Walk HR (bpm)	110 $\pm$ 4.9	107 $\pm$ 2.3
Comfortable Walk RPE	9.7 $\pm$ 0.42	10.1 $\pm$ 0.24
Training (hours/week)	5.8 $\pm$ 3.93	7.0 $\pm$ 4.57

### Procedures

Each subject completed a maximal GXT to obtain VO<sub>2max</sub> and VT. Each subject also completed two 1-mile Rockport tests: one walked at a “brisk” pace and the other at a “comfortable” pace. All tests were separated by at least 48 hours to prevent an impact of one test on the other. The order of test administration remained consistent throughout the study, with the maximal test completed first, and followed by the brisk 1-mile Rockport walking test and finally the comfortable 1-mile walking test.

The maximal GXT measured VO<sub>2max</sub> on a treadmill using open circuit spirometry (AEI metabolic cart, Pittsburgh, PA). The VO<sub>2max</sub> was defined as the highest VO<sub>2</sub> during the test, while the VT was established using the v-slope and ventilatory equivalent methods (Foster and Cotter, 2005). The GXT test employed the Balke protocol (Balke, 1960). The treadmill speed remained constant throughout the test. Treadmill grade started at 0% and increased by 2.5% every two minutes. The subjects chose their speed

at the start of the test and were allowed to change it within the first two stages until a comfortable pace was found. After stage two, no changes in speed were allowed. Heart rate and RPE were recorded at the end of each two-minute stage using an E600 Polar USA HR monitor (Polar Electro Inc., Woodbury, NY) and Borg's 6-20 scale (Borg, 1998), respectively. Termination of the test occurred when the subject indicated they could no longer continue.

The 1-mile Rockport test took place on a 200-meter indoor track. Subjects completed the "brisk" walking test first and  $\geq 48$  hours later they completed the "comfortable" paced walk. To complete the brisk mile, subjects were instructed to walk around the track as briskly (e.g. quickly) as possible. To complete the comfortable paced mile, subjects were instructed to walk at a pace they found "comfortable." Subjects wore an E600 Polar USA HR monitor (Polar Electro Inc., Woodbury, NY) to measure resting HR and exercise HR at the completion of each lap. RPE was also measured each lap using Borg's 6-20 scale (Borg, 1998). The time to complete each lap was also recorded as the subject crossed the "start" line and lastly when they crossed the "finish" line to represent their total time. The variables collected from the 1-mile Rockport test included: HR, RPE, and lap time.

### **Statistical Analysis**

Using a separate regression equation, created in our laboratory, the data from the brisk and comfortable 1-mile Rockport test was inserted to obtain predicted values for  $VO_{2max}$  value. These predicted values were compared to the measured  $VO_{2max}$  value to determine how well the equation predicted  $VO_{2max}$ . A similar analysis was made using

data from the brisk and comfortable walk fitted into the original Rockport equation  
(Kline et al., 1987).

## RESULTS

To determine how the comfortable walking pace compared to the brisk walking pace of the 1-mile Rockport test, the following variables were graphed for each of the eight laps of the walk test for both the brisk and comfortable paces: total walk time, lap time, HR, RPE, maximal METs, and VT METs.

Figure 1 depicts the mean and standard error (SE) for the total walk time for the subjects with both the brisk and comfortable walk. The subjects completed the 1-mile Rockport test faster with a brisk walking pace ( $13.18 \pm 1.480$  minutes) versus the comfortable walking pace ( $17.45 \pm 1.978$  minutes).

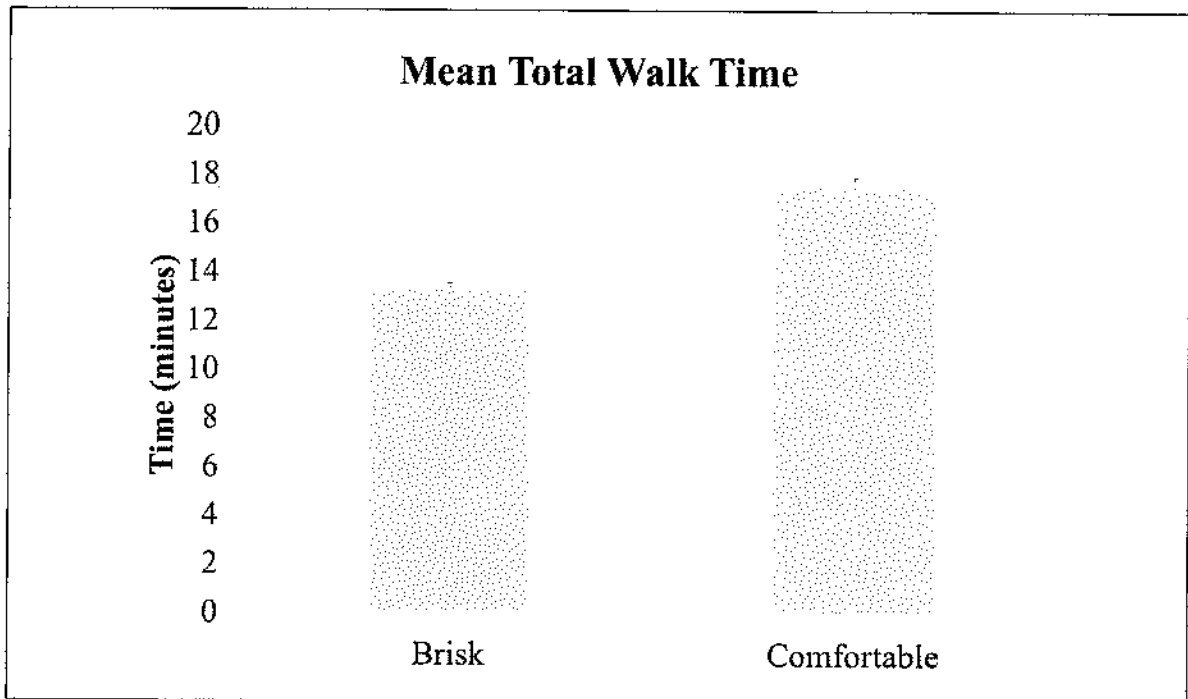


Figure 1. Mean total walk time (mean  $\pm$  SE) for the brisk and comfortable 1-mile walking tests.

Since the brisk walk time was shorter than the comfortable walk time, the mean lap time (Figure 2) was also shorter for the brisk walk (1.65 minutes) in comparison to the comfortable walk (1.87 minutes).

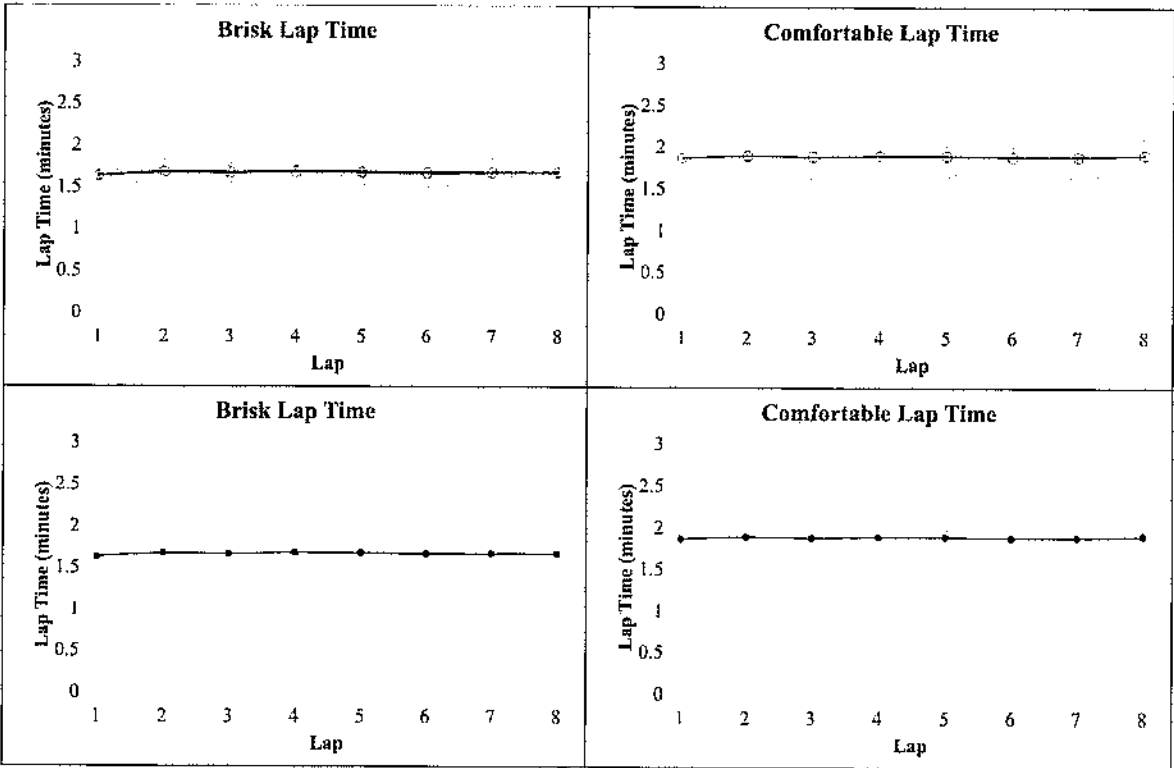


Figure 2. Mean lap time for the brisk (left) and comfortable (right) 1-mile walking tests. The upper graphs of the brisk and comfortable lap times depicts individual data as represented by a light grey line, while the thickened black line with open circle data points represents the mean. The two bottom graphs of the brisk and comfortable lap times depict the mean lap time data with standard error (SE) bars.

With a faster overall time and lap time for the brisk 1-mile walk, it was not surprising that the HR responses were higher as depicted in Figure 3. The HR responses of each subject responded predictably due to HR's relationship with workload: as workload increases, HR increases proportionately. Since the brisk walking test required increased exercise intensity, a higher HR was observed for the brisk 1-mile Rockport walking test ( $143 \pm 18.4$  bpm) compared to the comfortable walking test ( $108 \pm 13.2$  bpm). This increase in intensity during the brisk walk also caused more variability in HR with

each lap (Figure 3): starting at  $128 \pm 15.1$  bpm and ending at  $143 \pm 18.4$  bpm. The comfortable walking pace had less variability in HR with each lap due to a decrease in intensity (Figure 3): starting at  $103 \pm 11.1$  bpm and ending at  $108 \pm 13.2$  bpm.

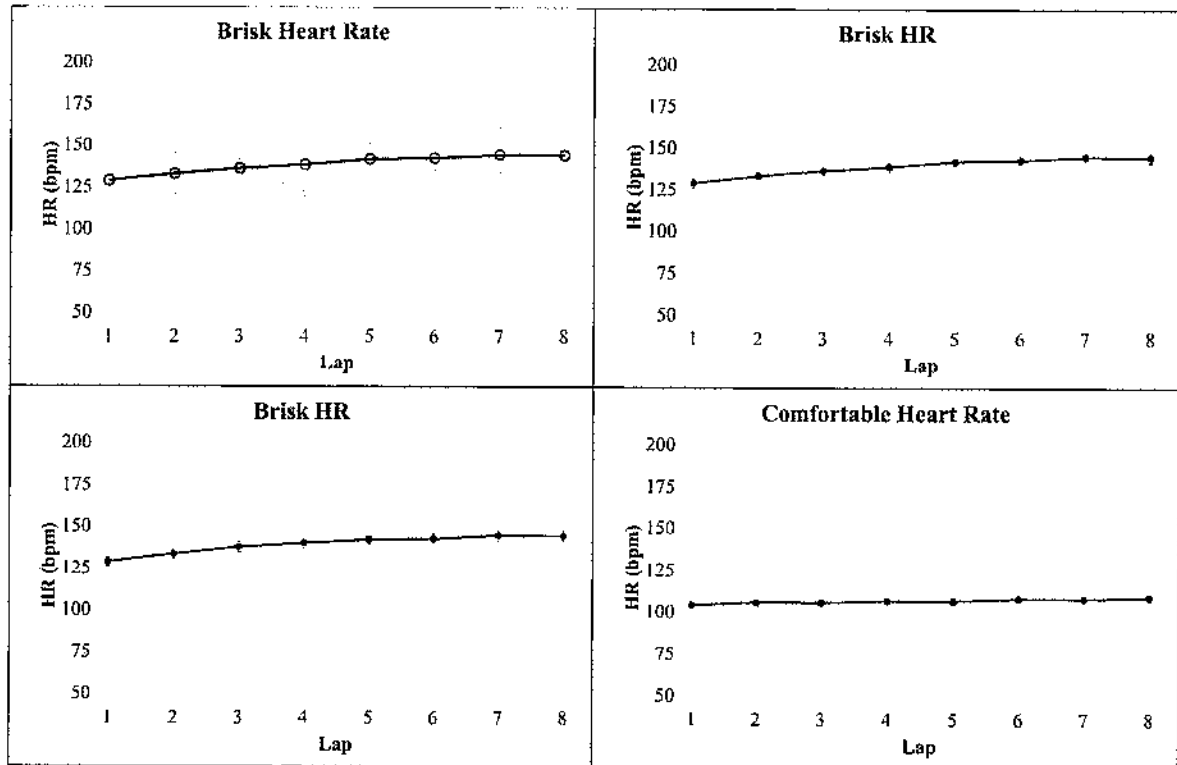


Figure 3. Mean HR per lap (bpm) for the brisk (left) and comfortable (right) walking tests. The upper graphs show the individual data with the light grey lines, while also representing the mean HR with the open circles on the bold, black line. The lower graphs also show the mean HR, but SE bars are also included (mean  $\pm$  SE).

Similar to the HR response, RPE was greater for the brisk walking pace ( $13.3 \pm 1.57$ ) and less for the comfortable walking pace ( $10.0 \pm 1.27$ ) due to the difference in workload requirement (Figure 4). RPE also varied more from start to finish for the brisk walking pace compared to the comfortable walking pace. The brisk walk started at a mean RPE of  $10.0 \pm 1.41$  and ended at  $13.3 \pm 1.57$ , while the comfortable walk started with a mean RPE of  $8.6 \pm 1.18$  and ended at  $10.0 \pm 1.27$ . Thus, subjects perceived the brisk

walking pace of the 1-mile Rockport test to be more difficult than the comfortable walking pace.

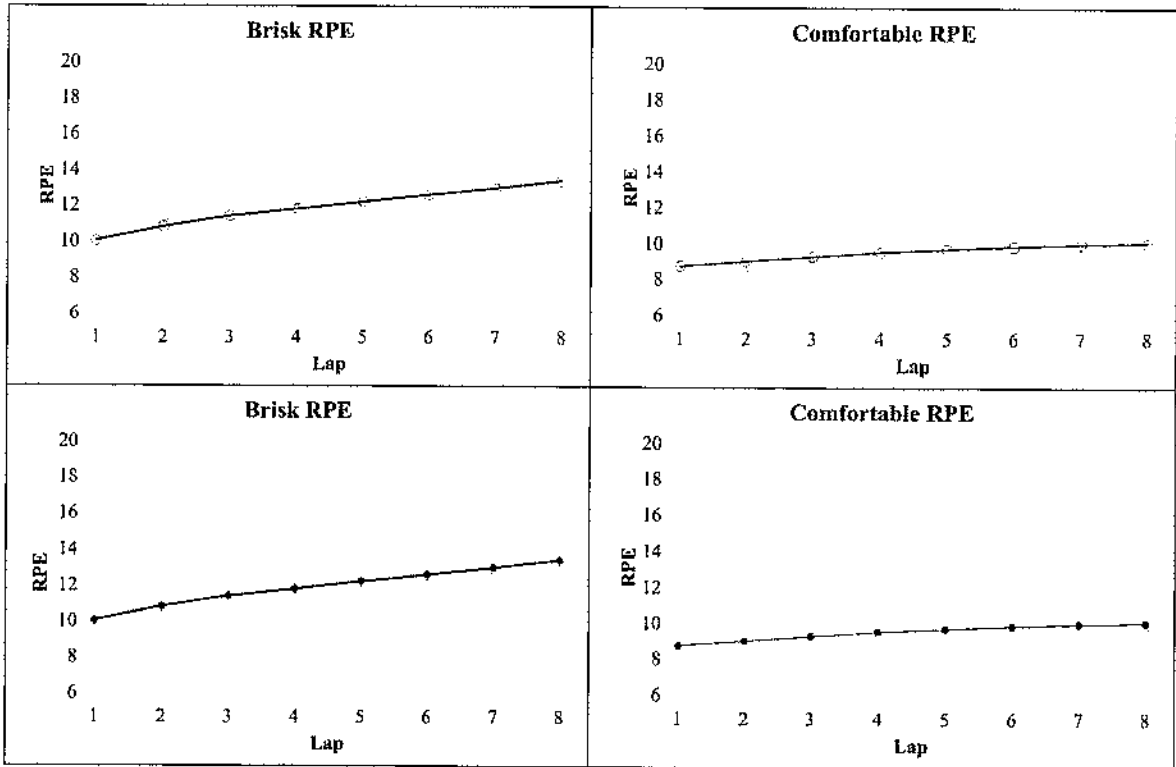


Figure 4. RPE for the brisk (left) and comfortable (right) walking tests using the Borg 6-20 scale. The upper graphs depict the individual RPE data using light grey lines, while the mean RPE is represented by the bold, black line with open circles for both the brisk and comfortable walk tests. The lower graphs show the mean RPE with SE for the brisk and comfortable walk tests.

Figure 5 depicts the relationship between measured maximal and VT METs in relation to the predicted values created by the laboratory-based Rockport equation from the brisk and comfortable 1-mile walks. The brisk walking pace predicted both maximal ( $r=0.501$  vs.  $0.1981$ ) and VT METs ( $r=0.465$  vs.  $0.034$ ) better than the comfortable walking pace. While these correlation coefficients from the brisk walking pace are not strong, they certainly indicate a better prediction of maximal and VT METs than with the comfortable walking pace. The correlation coefficients for the comfortable walking pace represent a weak relationship between the prediction of maximal METs and the measured

maximal METs ( $r = 0.1980$ ). The relationship between the predicted and measured values of VT METs for the comfortable walking pace is very weak ( $r = 0.034$ ) compared to the brisk walking pace ( $r=0.465$ ).

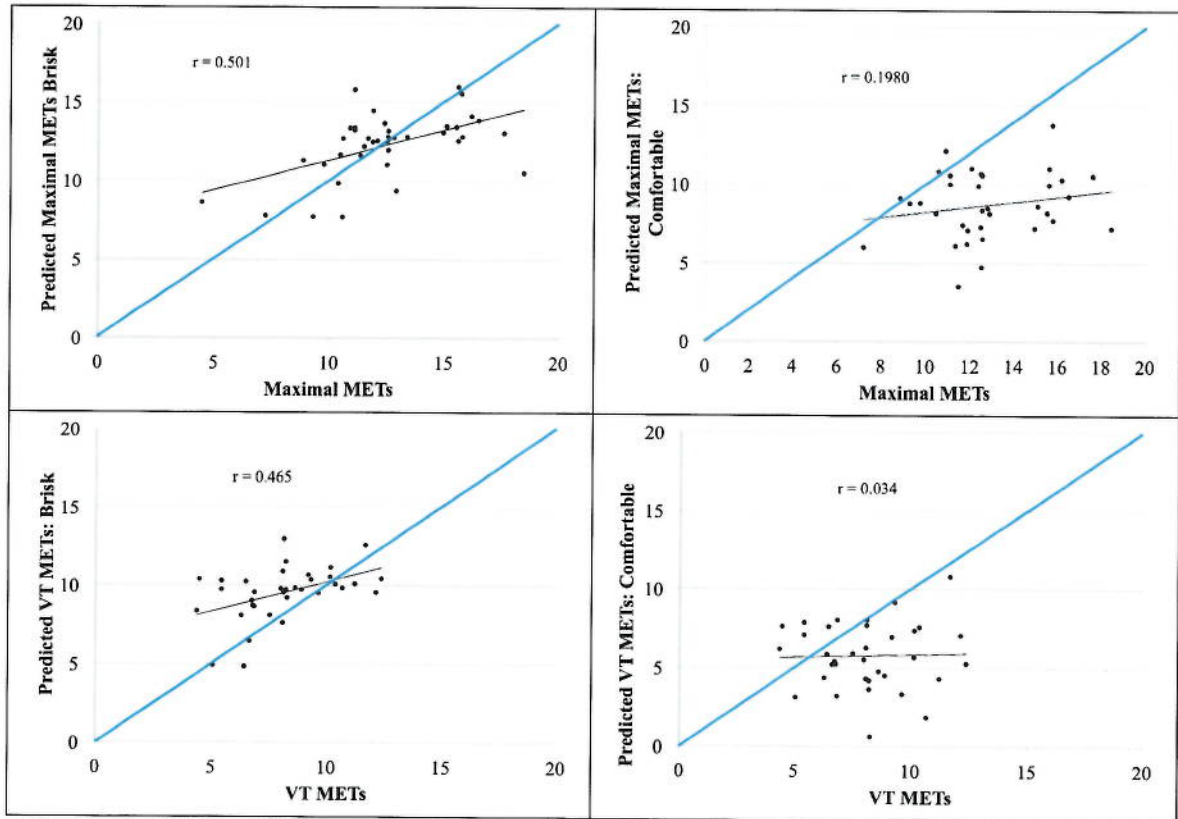


Figure 5. Predicted Max and VT METs for the brisk (left) and comfortable (right) walking tests using a lab developed equation. The upper graphs illustrate the predicted maximal METs, while the lower graphs illustrate the predicted VT METs for the brisk (left) and comfortable (right) walking tests. The correlation ( $r$ ) is also provided between measured and predicted maximal METs using the lab-developed equation.

Figure 6 illustrates the difference between the measured maximal METs from the GXT and the predicted maximal METs for the brisk and comfortable walking paces of the 1-mile Rockport walking tests from the laboratory created equation. The mean, maximal MET values for measured, predicted brisk, and predicted comfortable are as follows:  $12.84 \pm 2.58$  METs,  $12.46 \pm 1.74$  METs, and  $8.67 \pm 2.13$  METs, respectively.

There was no significant difference ( $p=0.323$ ) between the measured maximal METs and

the predicted from the brisk walk maximal METs. However, there was a significant difference ( $p < 0.01$ ) between the measured maximal METs and the maximal METs predicted from the comfortable walk.

In addition, Figure 6 also depicts the mean values of measured VT METs compared VT METs predicted from the brisk and comfortable walking tests. The mean, for the measured VT METs, predicted brisk VT METs, and predicted comfortable VT METs are as follows:  $8.13 \pm 2.11$  METs,  $9.51 \pm 1.71$  METs, and  $5.74 \pm 2.11$  METs, respectively. There was a significant difference between the measured VT (METs) and the VT (METs) predicted from both the brisk walking pace ( $p < 0.01$ ) and the predicted comfortable walking pace ( $p < 0.01$ ) VT.

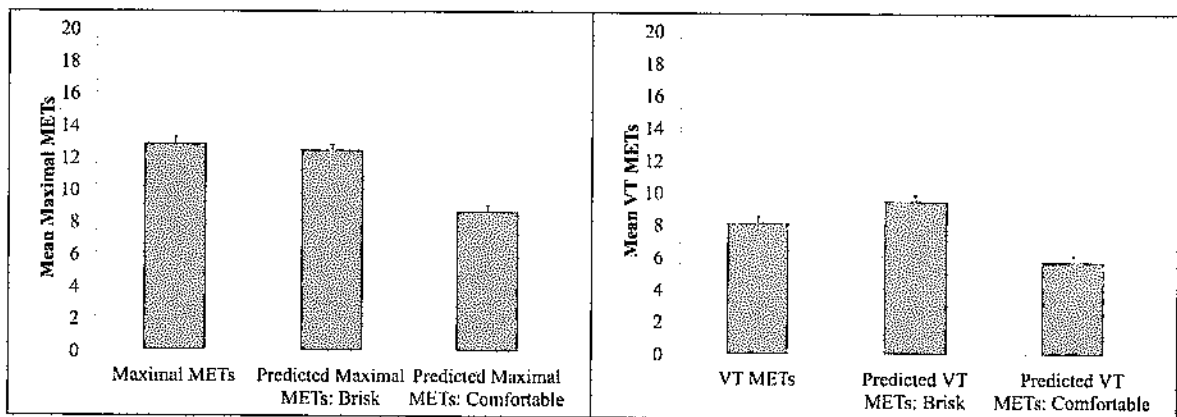


Figure 6. Comparison of measured maximal and VT METs to the predicted maximal and VT METs for the brisk (left) and comfortable (right) walking tests using the lab developed equation (mean  $\pm$  SE).

The predicted values of maximal METs from the brisk and comfortable walking pace tests were also correlated with the original Rockport equation (Figure 7). The predicted maximal METs for the brisk walking test were strongly correlated ( $r = 0.690$ ) with the measured maximal METs, while the predicted maximal METs from the comfortable walk test correlated only moderately ( $r = 0.424$ ) with the measured maximal

METs. Similar to the results of the lab-developed equation, the brisk walk was better able to predict exercise capacity in comparison to the comfortable walk.

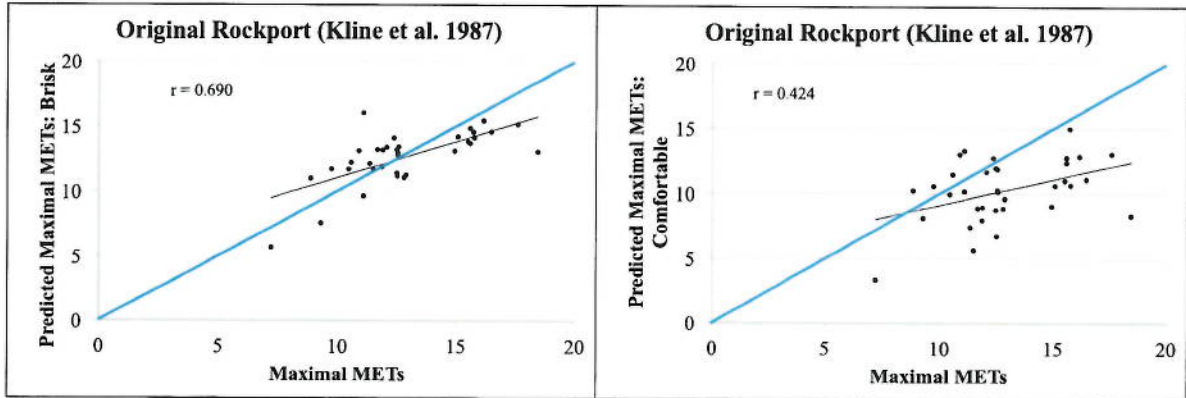


Figure 7. Predicted Max METs for the brisk (left) and comfortable (right) walking tests using the original Rockport equation.

To further demonstrate the relationship between measured and predicted METs, Figure 8 displays the differences of the mean, measured maximal METs and predicted maximal METs for the brisk and comfortable walks using the original Rockport equation. The measured maximal METs, predicted brisk maximal METs, and the predicted comfortable maximal METs are as follows:  $12.8 \pm 2.58$ ,  $12.6 \pm 2.09$ , and  $10.2 \pm 2.39$ . There was not a statistically significant difference between the measured maximal METs and the predicted brisk maximal METs ( $p = 0.454$ ). However, there is a statistically significant difference between the measured maximal METs and the predicted comfortable maximal METs ( $p < 0.01$ ).

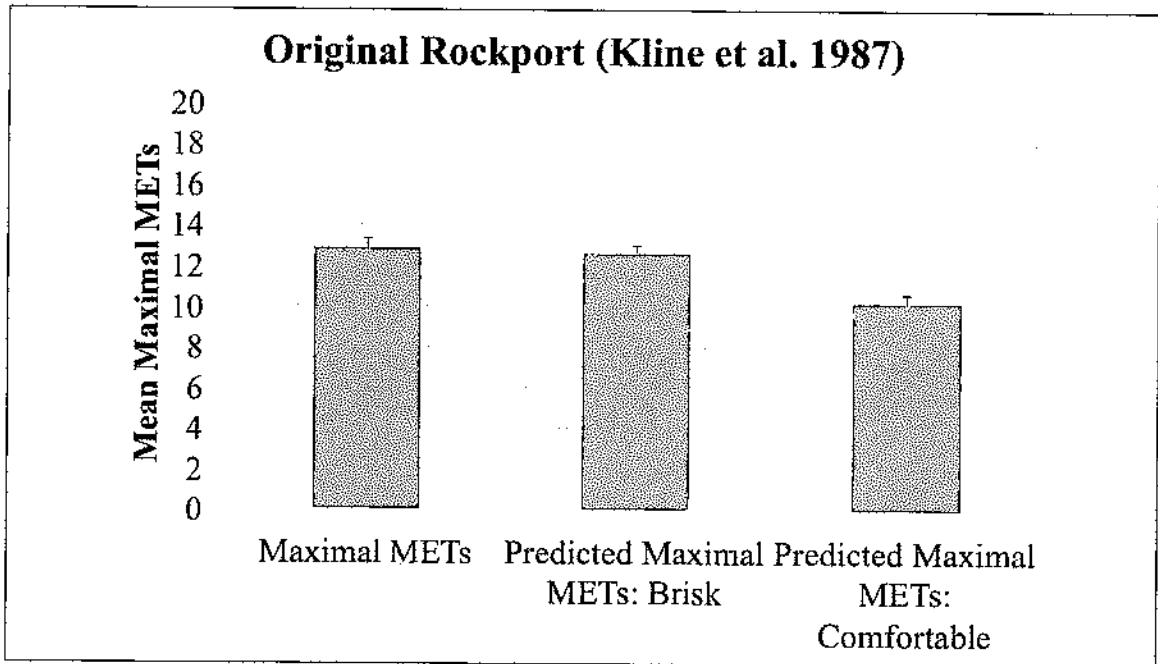


Figure 8. Comparison of measured max METs to the predicted max METs for the brisk and comfortable walking tests using the original Rockport equation.

## DISCUSSION

Using both the lab-developed equation and the original 1-mile Rockport walking test equation, the brisk walking pace has a stronger correlation ( $r = 0.501$  and  $r = 0.690$ ) with measured maximal METs than the comfortable walking pace ( $r = 0.465$  and  $r = 0.424$ ). The brisk walking pace also predicts maximal METs more accurately when using the original Rockport and the lab-developed equations ( $p = 0.454$ ,  $p = 0.323$ ). While the comfortable walking pace does not accurately predict maximal METs using the Rockport and lab-developed equations ( $p < 0.01$ ,  $p < 0.01$ ). In addition, both the brisk and the comfortable walking paces do not accurately predict the VT METs ( $p < 0.01$ ,  $p < 0.01$ ) using the lab-developed equation. Ultimately, these findings suggest that the brisk walking pace is superior to a comfortable walking pace for the prediction of maximal effort using the lab-developed equation, and even more so when using the original Rockport equation.

In addition, this study attempted to utilize a lab-developed equation as a modification to the Rockport equation (Kline et al. 1987). Since it only included walking time and terminal RPE as the predictor variables, it represents a simpler tool to predict maximal effort. However, the lab-developed equation does not predict  $VO_{2max}$  as well as the original Rockport equation (lab-developed  $R^2 = 0.4859$  versus the original Rockport  $R^2 = 0.7744$ ). Implementing this simplified equation into clinical populations and the general public can allow quicker and easier estimations of functional capacity and fitness.

We hypothesized that the comfortable walking pace would predict maximal effort with similar accuracy as a brisk walking pace. However, the previously discussed results do not support such a conclusion. Both the lab-developed and the Rockport regression equations rely heavily on one predictor variable: walking time. Walking time holds almost half the predictive power for both regression equations due to its large coefficient: 1.13 for the lab-developed and 0.2240 for the Rockport equation. Any additional variables only make small-scale contributions to the prediction of maximal effort, such as RPE with only 0.305 as a coefficient in the lab-developed equation. While the RPE during comfortable walking does decrease as walking time increases, the weighting of RPE, as a predictor of exercise capacity, is not enough to counterbalance the increase in walking time. Thus, any pace slower than a brisk walk results in lower predictive accuracy of maximal effort from the regression equations.

George et al. (1998) first proposed the idea of performing the 1-mile Rockport walking test at a less than maximal pace. They found that walking at a brisk pace (nearly as fast as possible) still predicted  $VO_{2max}$  with acceptable accuracy compared to the original Rockport protocol. Our study took this idea further by allowing subjects to walk even slower at their own comfortable pace, however this was not validated and the brisk pace proposed by George et al. (1998) is the slowest pace acceptable.

The Kline et al. (1987) equation for the 1-mile Rockport walking test is a generalized equation recommended for use in adults between 30 and 69 years. Modified equations arose to further improve predictive accuracy, such as age and gender specific equations. Age-specific equations were developed for older and younger populations (Fenstermaker et al., 1992; Dolgener et al., 1994). Increased accuracy was found in the

age-specific equations for older populations (Fenstermaker et al., 1992), while Kline et al.'s (1987) generalized and age-specific equations did not apply to younger populations (Dolgener et al., 1994). Dolgener et al. (1994) found that age, as a predictor variable, did not contribute to an improved prediction of  $VO_{2max}$ , so they created new generalized equations that removed age and included only weight, walking time, and terminal HR. These new generalized equations applied to younger populations and were simpler due to fewer variables used. The lab-developed equation used in our study further simplifies the use of the regression equation to only include walk time and RPE. With similar accuracy of predicting maximal effort compared to Kline et al.'s equation (1987), the lab-developed equation also supported the use of a brisk paced walk due to its better prediction of  $VO_{2max}$  than a comfortable paced walk.

Since the Kline et al. (1987) equation is only recommended for adults ages 30 to 69 years, age should be investigated further to determine if it truly impacts the prediction of  $VO_{2max}$ . According to Dolgener et al. (1994), age does not contribute to the predictive accuracy of  $VO_{2max}$  in a walking test such as the 1-mile Rockport test. However, this finding needs further validation. The mean ages of the subjects in this study were  $27.8 \pm 3.75$  for males and  $24.3 \pm 1.02$  for females, which is younger than recommended for use of the Kline et al. (1987) equation. Another limitation of this study is the performance of only one walking test. Fenstermaker et al. (1992) found a learning effect when they administered multiple 1-mile Rockport walking tests. They noticed a decrease in walking time and an increase in HR with more than one walking test. Thus, they encourage a practice trial to familiarize the subject with the test.

## CONCLUSION

This data suggests that a brisk walking pace is the most accurate way to perform the 1-mile Rockport test. Any pace slower than a brisk walk, decreases the predictive accuracy of maximal effort, whereas paces higher than a brisk walk are encouraged. Previously, little value was placed on the pace of a walking test. These findings emphasize the true importance of a subject's walking pace to ensure they are truly performing at their subjective level of a brisk or higher intensity pace. If an individual is unable achieve a quick pace, due to physical or other limitations, the 1-mile Rockport test may not be appropriate for them in obtaining the best prediction of their maximal effort.

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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  $VO_{2max}$ . 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 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  $VO_{2max}$  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)  
Date

\_\_\_\_\_  
Subject Signature

\_\_\_\_\_  
Witness Name (printed)  
Date

\_\_\_\_\_  
Witness Signature

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

Despite the continued use of various submaximal methods to determine exercise capacity, maximal oxygen uptake ( $VO_{2max}$ ), as determined during graded exercise testing (GXT), remains the gold standard assessment tool. However, the direct measurement of  $VO_{2max}$ , and/or ventilatory threshold (VT) is expensive: often requiring physician availability, sophisticated equipment, and maximal exertion from the subject. Thus, the implementation of submaximal tests arose to ease the assessment of work capacity. While the utility of submaximal testing is far simpler, the accuracy of any submaximal test is lower in comparison to the direct measurement of  $VO_{2max}$ . Despite the ease of performing submaximal tests, an increase in the predictive accuracy is necessary to continue using them for exercise prescription and functional assessments. In response, numerous submaximal tests exist with the hopes of finding the correct protocol for optimal prediction. One such submaximal test is the 1-mile Rockport walking test, which holds the potential to accurately predict of  $VO_{2max}$  if the protocol is modified.

### Graded Exercise Testing

The discovery and standardization of the  $VO_{2max}$  began with Hill and Lupton in 1923. They observed the body's utilization of oxygen during exercise and noticed that, after a certain point, oxygen intake failed to increase despite increasing workloads. They coined this plateau of oxygen intake as "maximal oxygen intake" ( $VO_{2max}$ ) where any further increases in workload would not result in further oxygen consumption by the muscles and tissues.

Mitchell, Sproule, and Chapman (1957) conducted a study to verify the results of Hill and Lupton (1923) by explaining the physiology behind the  $VO_{2max}$ . They conducted a treadmill  $VO_{2max}$  test on 65 men split into four different age groups. A 10-minute warm-up followed by a 10-minute rest period, were employed before increasing the speed to 6 miles per hour (mph) with 0% grade. Grade was increased by 2.5% until oxygen intake ( $VO_2$ ) ceased to rise, which was defined as the  $VO_{2max}$ . The test took 1.5 hours, for most subjects, which is too much time: indicating the grade increases were too low. In addition, 15 normal subjects still conducted two additional trials to examine the reproducibility of these methods. Unintentionally, Mitchell et al. (1957) validated the finding that  $VO_{2max}$  decreases with age due to a decrease in ventilation and oxygen ( $O_2$ ) removal rates at increasing and maximal workloads. Additionally, they determined that  $VO_{2max}$  is dependent on cardiac output (CO) and arteriovenous oxygen difference (av- $O_2$  diff). While CO is the primary determinant of  $VO_{2max}$ ; the widening of the av- $O_2$  diff allows further increases in oxygen intake. Mitchell et al. (1957) determined that the measurement of  $VO_{2max}$  not only exhibited the ability of the heart to pump blood to the tissues during exercise, but also represented an assessment of how well the tissues extract  $O_2$  from this blood: functional capacity.

After defining  $VO_{2max}$  as a measurement of an individual's work capacity, Bruno Balke sought to determine the normal range for  $VO_{2max}$ . Balke and Ware (1959) recruited 500 male military and civilian Air Force personnel to develop standards of physical fitness. Each subject completed a treadmill or bicycle ergometer test to maximal effort. While HR reflected work capacity the best, defining the test cut-off point at 180 bpm was not reliable due to individual differences. Balke and Ware (1959) found that age, weight,

activity, and personal habits are all factors that affect  $VO_{2max}$ . Of these factors, activity level represented the most influential factor in determining an individual's work capacity, so subjects were grouped according to their activity: sedentary, intermittent, and regular exercise. Balke and Ware (1959) discovered that those subjects who engaged in regular activity had higher work capacities and thus more physical fitness. In response, they developed a crude scale to rate an individual's work capacity as poor, fair, or good, which correlated to sedentary, intermittent, and regular exercisers, respectively. Of the 500 subjects tested, 42%, 40%, and 18% of subjects belonged in the poor, fair, and good physical fitness categories, respectively. The development of these standards allowed further interpretation of maximal tests by categorizing individuals into fitness categories and thus influenced the start of physical fitness testing.

Ragg, Murray, Karbonit, & Jump (1980) emphasized the importance of measuring  $VO_{2max}$  directly, especially for cardiac patients, since the methods used to estimate  $VO_{2max}$  yielded values within a wide range. Ragg et al. (1980) conducted a study to compare  $VO_2$  values during an exercise test while using the handrail and when not using the handrail for support. Six active, male subjects completed a progressive, walking treadmill exercise stress test to maximum where HR and  $VO_2$  were collected. When allowed handrail support, HR and  $VO_2$  were lower and the subject could exercise longer ( $25.2 \pm 7.16$  minutes with handrail and  $15 \pm 2.76$  minutes without). This suggests the subject has a higher exercise capacity than is true, which creates safety issues for exercise prescription. The average error to estimate  $VO_2$  was 17.5%. Thus, they strongly discouraged the use of handrail support during exercise testing to avoid masking a subject's true exercise capacity.

As defined by Hill and Lupton (1923),  $VO_{2max}$  occurs when the oxygen uptake plateaus, which is known as the primary criterion. In addition, Howley, Bassett, & Welch (1995) compiled a review to examine the secondary criteria of  $VO_{2max}$ : high lactate levels following exercise, elevated respiratory exchange ratio (RER), and achieved age-predicted  $HR_{max}$ . These secondary criteria arose to account for those individuals who reach a  $VO_{2max}$  without producing a plateau. While blood lactate levels can indicate maximal effort, not all populations demonstrate it and not all protocols produce such high levels. Uncertainty also arises when using RER as a secondary criterion for  $VO_{2max}$ . While an  $RER > 1.15$  is suggested, this cut-off is not universally verified. In addition, age-predicted  $HR_{max}$  method has existed for quite some time, however the wide ranges it produces for maximum heart rate are not precise enough to exist as a criterion for  $VO_{2max}$ . Thus, Howley et al. (1995) suggest redefining the criterion of  $VO_{2max}$  by creating different standards of  $VO_2$  measurement, higher  $VO_2$  values, and generalizing the plateau phenomenon to more populations. In addition, the current criterion of  $VO_{2max}$  may simply need to be combined into one universal protocol to standardize  $VO_{2max}$  testing.

In response to the period of disbelief regarding the plateau phenomenon defining  $VO_{2max}$ , Foster et al. (2007) decided to conduct another study to uphold the plateau phenomenon as a gold standard criterion. The study involved two parts with 20 subjects each: 1) cycle ergometer with a short recovery (1 minute) and 2) treadmill with a longer recovery (3 minutes). Each part completed a maximal effort test followed by another exercise bout of higher workload to ensure the  $VO_{2max}$  was in fact reached: only subjects who reached the plateau were considered. They found that  $VO_2$  stayed the same between

the preliminary maximal bout and the secondary bout where workload was increased, indicating that a plateau was in fact reached even with the varied recovery times. Previous researchers disputed the plateau phenomenon because original  $VO_{2max}$  studies did not continue the exercise test after reaching maximal exertion to verify the maintenance of  $VO_2$ . This study shows that another exercise bout was in fact not necessary and the pioneering  $VO_{2max}$  studies and criteria remain valid.

In 2008, Benjamin D. Levine compiled a review to discuss the known and unknown concepts concerning  $VO_{2max}$ : labeling it as a “marker of population-based fitness and cardiovascular disease.” The “classical view” of  $VO_{2max}$  is that the skeletal muscle’s ability to maximally utilize oxygen depends on the heart’s ability to deliver oxygen. However, the controversy around whether a true  $VO_{2max}$  exists revolves around the plateau phenomenon. Some scientists believe the body only reaches this “maximal” plateau because the brain turns off muscle motor recruitment not because  $VO_2$  has reached a maximum. Levine (2008) describes a study by Hawkins, Raven, Snell, Stray-Gunderson, & Levine (2007) that solves this battle: subjects completed a GXT followed by a supramaximal test where they completed 30% more work past their defined  $VO_{2max}$ . Completing the supramaximal test showed no further significant increase in  $VO_{2max}$  compared to the original GXT: indicating that the brain is not the final decision maker. In addition, Levine (2008) notes the dependence of  $VO_{2max}$  on the Fick equation, which encompasses variables with finite limits and further indicates the definite existence of  $VO_{2max}$ .

The importance in accurately assessing and prescribing exercise intensity becomes increasingly important in clinical populations. Mezzani et al. (2012) recently

released a joint position statement addressing all aspects related to exercise intensity. They immediately define “peak  $\text{VO}_2$  and the first and second ventilatory thresholds (VT) [as] the gold standard references for the evaluation of aerobic metabolism function and, consequently, for aerobic exercise intensity assessment and prescription.” The first VT occurs when blood lactate increases and pH decreases: indicating the change from light/moderate to moderate/high intensity at around 50-60% peak  $\text{VO}_2$  and 60-70% peak HR. Whereas, the second VT occurs at around 70-80% peak  $\text{VO}_2$  and 80-90% peak HR. Peak  $\text{VO}_2$  is determined by averaging the  $\text{VO}_2$ , whereas a maximal  $\text{VO}_2$  is directly measured. Mezzani et al. (2012) confirmed the definition of  $\text{VO}_{2\text{max}}$  as being a plateau in  $\text{VO}_2$  despite continued increases in workload: the gold standard of exercise testing.  $\text{VO}_{2\text{max}}$  can only be measured using a GXT or cardiopulmonary exercise test (CPX) with respiratory gas analysis to produce this gold standard criterion. If direct assessment is not feasible, the gold standard indirect assessment is %HRR due to the linear relationship between HR and  $\text{VO}_2$ . However, some clinical populations have difficult HRs to monitor, so RPE is commonly used in cardiac rehabilitation programs, most notably the Borg 6-20 scale (Borg, 1998). However, RPE responses can vary in response to a person’s psychological state. When exercise testing is not available, the 6-MWT is encouraged along with RPE monitoring at the end of the test.

In summary, the proclamation and discovery of the plateau phenomenon as the primary criterion of  $\text{VO}_{2\text{max}}$  caused an eruption of research to validate and standardize  $\text{VO}_{2\text{max}}$ .  $\text{VO}_{2\text{max}}$  was studied further to uncover the physiological mechanisms behind it. Interestingly, some individuals do not exhibit the plateau of oxygen intake despite reaching their maximum, so secondary criterion arose to further mark the  $\text{VO}_{2\text{max}}$ . While

useful, these criteria need further verification. Overall,  $VO_{2max}$  depends on CO and  $av-O_2$  difference with primary dependence on CO. To obtain the most accurate measure of  $VO_{2max}$ , the protocol duration must be of appropriate length. Despite the disputes about the plateau phenomenon, this criterion holds as a gold standard marker of  $VO_{2max}$  with subsequent bouts thereafter are unnecessary. The  $VO_{2max}$  represents such an important assessment and diagnostic tool due to its ability to assess the heart's ability to pump blood to the tissues and how well these tissues extract the oxygen from the blood.

### **Types of Exercise Testing Protocols**

To further validate  $VO_{2max}$ , Shephard et al. (1968) set out to promote  $VO_{2max}$  as an international reference standard with the hope of conducting longitudinal studies of fitness in response to the modernizing society. Three modes of exercise were tested including treadmill, bike, and step using discontinuous and continuous exercise to determine the best procedure for testing. Twenty-four males with varied fitness completed a preliminary 2-week submaximal-conditioning program followed by 10 days of maximal testing. While there was little difference in  $VO_{2max}$  between the three modes of exercise, the treadmill had the greater  $VO_{2max}$ . Thus the treadmill is the recommended and preferred mode for lab use and as the ideal mode for exercise testing. Stepping  $VO_{2max}$  was only 3.4% smaller and biking was 6.6% smaller with both these methods being recommended for field use. In addition, continuous exercise is the ideal choice for exercise pattern with load being increased every two minutes. Shephard et al. (1968) also confirmed CO as the main determinant of  $VO_{2max}$  with most of the increase in CO from stroke volume (SV) due to the large venous return, especially on the treadmill.

In 1975, Froelicher, Thompson, Davis, Stewart and Triebwasser compared the Bruce and Balke treadmill protocols to determine which predicts  $VO_{2max}$  more accurately from maximal treadmill time. Seventy-nine subjects completed the  $VO_{2max}$  test using the Balke protocol and 77 subjects completed the  $VO_{2max}$  test using the Bruce protocol. Each set of subjects were split into three groups dependent on their activity status prior to the study: Group A was sedentary, Group B exercised moderately, and Group C exercised heavily. The Balke protocol involves walking at a constant speed with a 1% increase in grade every minute, while the Bruce protocol involves increases in both grade and speed every three minutes. It was found that the prediction of  $VO_{2max}$ , using either the Balke or Bruce protocol produced a wide range of possible values for any age and fitness. Those with higher fitness levels exhibited lower HRs compared to sedentary individuals at the same workload, while also experiencing a faster decline in exercise HR during recovery. No difference existed between Group B and C for the estimated submaximal  $VO_2$ . Overall, both the Balke and Bruce protocols produced widely variable  $VO_{2max}$  results. While the Balke protocol decreases artifact due to the constant speed, it takes longer than the Bruce to complete, so either protocol can be used: no preferential choice exists, since they both poorly produce  $VO_{2max}$  values to the same variability. Instead, choosing the treadmill protocol should be based on the goal of the test and the individual being tested.

The suggestion from Froelicher et al. (1975) to individualize exercise testing increased the usage of ramp protocols. Ramping bypasses the limitations of standard protocols (Bruce, Balke, Ellestad, etc.) by “employing a constant and continuous increase in external work” (Myers et al., 1991). Making sure the workload increases are not too

fast or too short yields a more accurate measure of exercise capacity. In response to the increased popularity in the usage of ramping, Myers et al. (1991) sought to compare the ramp protocols to standard exercise protocols during exercise testing, while also examining the hemodynamic and gas exchange responses of ramp protocols. Forty-one men participated and were split into four groups: 10 with angiographically documented coronary artery disease (CAD) without angina limitations during exercise, 11 who were limited, 10 with chronic heart failure (CHF) and an ejection fraction (EF) of <40%, and 10 normal subjects. Each subject completed six exercise tests: three treadmill protocols including standard Bruce, modified Balke and individualized ramping for 10 minutes, along with three cycle ergometer protocols including 25 watts (W)/2 minute stage, 50 W/2 minute stage, and individualized ramping for 10 minutes. Consistent with other studies, treadmill protocols yielded a  $VO_{2max}$  higher than the cycle ergometer protocols (16%). Cycle ergometer protocols were also less sensitive due to increased leg fatigue. Exercise protocol and disease status influenced gas exchange dynamics where  $VO_{2max}$  was more accurately predicted using a ramp treadmill test on normal patients. Whereas “protocols with large increments between stages have the poorest relation between oxygen uptake and work rate.” Thus, recommended exercise protocols include those lasting 10 minutes duration with short and small increments between stages to more accurately predict  $VO_{2max}$ : preferably ramp protocols on either the treadmill or cycle ergometer.

Myers and Bellin (2000) compiled the existing research on ramp protocols to determine their clinical use in cardiopulmonary exercise testing. They surveyed a group of VA health facilities and found 82% of these used the Bruce or modified Bruce

protocols for exercise testing. These protocols, along with other traditional protocols (Åstrand, Naughton, Ellestad, etc.) have large and inconsistent increases in workload with the initial stage of the test being too hard for many deconditioned or diseased individuals. Such large and inconsistent progressions cause an overestimation and large variability in predicting  $VO_2$  compared to ramp protocols. Whereas ramping tailors the exercise protocol to the abilities of the individual being tested as recommended by the American College of Sports Medicine (ACSM, 1998) to optimize exercise testing: test duration of 8-12 minutes, decreasing increments in work rate, and individualization in accordance to the purpose of the test and individual. Ramping constantly and continuously increases the workload as tailored to the individual, instead of the large jumps traditionally. Additionally, a higher  $VO_{2max}$  is obtained using a treadmill protocol compared to a cycle ergometer. Thus, ramping protocols administered on a treadmill are preferred to achieve accurate predictions of  $VO_{2max}$ .

Kirkeberg, Dalleck, Kamphoff, and Pettitt (2007) examined a few of the criterions claiming to establish a true  $VO_{2max}$  including: proper test duration, subsequent verification bouts,  $RER > 1.10$ , and a HR within 10 beats per minute (bpm) of age-predicted  $HR_{max}$ . Twelve men completed three GXTs of different duration: short (8 minutes), middle (10 minutes), and long (14 minutes). A verification bout was also completed at the end of each GXT at an intensity equivalent to the end speed minus two stages. Almost all subjects reached within 10 bpm of their age-predicted  $HR_{max}$  with the long duration GXT producing the highest  $HR_{max}$  values. However, the long duration GXT infrequently achieved an  $RER > 1.10$ , unlike the short and middle GXTs that consistently achieved this criterion.  $VO_{2max}$  values and verification bouts did not differ

for the short, middle, or long duration tests. Yet, the middle (10min) duration GXT produced the strongest validity of  $VO_{2max}$  and maximum values of  $VO_2$  and HR for the verification bouts. This indicates that a 10-minute GXT protocol produces the most valid results of  $VO_{2max}$ . In addition, a verification bout is considered valid during a single visit to measure a true  $VO_{2max}$ .

Foster et al. (2008) further highlight the importance of conducting “gold standard” exercise testing for precise exercise prescription by reviewing the literature on the risks of exercise training. If  $VO_{2max}$  testing is not feasible, Foster et al. (2008) do not recommend the age-predicted  $HR_{max}$  formula, rather they suggest the use of subjective methods to prescribe exercise: RPE and the talk test (TT) being the most favorable. Exercising at a moderate to somewhat hard level or where speech is just comfortable, represents the appropriate exercise intensity to avoid ischemia and other complications. The risk of sudden death or other exertion-related events in young individuals is much lower compared to adults. Foster et al. (2008) estimate the risk of exertion-related complications to be 0.2 per 10,000 hours and are commonly due to the sedentary/inexperienced individuals beginning an exercise program at an inappropriately high intensity with known/unknown cardiovascular disease. This raises the importance of pre-exercise screening to assess an individual’s risk to exercise by appropriately trained healthcare staff. While the benefit of exercise training is usually larger than the risk, gold standard exercise testing is necessary to identify those individuals who are at risk for sudden death before engaging in exercise, especially during high intensity exercise.

In summary, to achieve the highest, and thus most maximal measure of  $\text{VO}_2$ , a continuous treadmill protocol should be employed as the recommended method for a GXT. Specifically, the Balke and Bruce protocols are commonly used in GXTs. The Balke increases grade by 1% each minute taking longer to complete whereas the Bruce increases both grade and speed. Determining which to use should be based on the population being studied and on the intended goal of the test. During a continuous exercise protocol, load should increase every two minutes to ultimately achieve a  $\text{VO}_{2\text{max}}$  within 10 minutes. Any test shorter or longer may not reach a truly maximal measure of oxygen uptake. The key is to individualize the exercise protocol to achieve the most maximal and accurate  $\text{VO}_{2\text{max}}$ . Ramping protocols are one such mode to improve the individualization of an exercise protocol. In addition, step and cycle ergometer modes can be employed to determine  $\text{VO}_{2\text{max}}$ , however these are best used during field tests.

### **Submaximal Field Tests**

In 1963, Bruno Balke introduced the idea of using a submaximal 15-minute field test to predict work capacity instead of directly measuring  $\text{VO}_{2\text{max}}$ . Even at this time, the complexity of  $\text{VO}_{2\text{max}}$  testing nudged scientists to search for simpler options. Four series of tests were conducted: 1) measured the respiratory gas exchange on the treadmill at different speeds, 2) after a 10-week training period work capacity was assessed on a treadmill and compared to field runs of 1, 5, 12, 20, and 30 minutes, 3) treadmill run versus a 2 mile run, and 4) treadmill run versus 15 minute field run. Balke emphasizes the importance of using the aerobic phase to assess work capacity, since it describes the complimentary work of the organ systems during exercise, whereas the anaerobic phase relies on an oxygen debt. A linear relationship was discovered between the oxygen

requirements and running speed. In addition, Balke found the aerobic phase to dominate in runs exceeding 12-15 minutes with the anaerobic phase increasing as the run time shortened. This indicates that field tests created to assess work capacity and predict  $VO_{2max}$  should be at least 12 minutes in length.

In 1968, Kenneth Cooper adjusted Balke's field test protocol and compared it to  $VO_{2max}$  using 115 male US Air Force officers and airmen. The men completed a 12-minute performance field test where they ran as far as possible in the 12 minutes with walking permitted if necessary. They then ran a  $VO_{2max}$  treadmill test where expired air and HRs were collected. Cooper found a correlation of 0.897 between the field and lab test indicating that the 12-minute performance test adequately predicted maximal oxygen consumption. The 12-minute performance test is less expensive, applies to large groups, and can be conducted almost anywhere: an even simpler method than Balke's proposed 15-minute test.

To accommodate individuals with respiratory disorders and to further simplify Cooper's (1968) 12-minute walking test, Butland, Pang, Gross, Woodcock, and Geddes (1982) proposed shortening the duration of the walking test. They conducted three subsets of experiments, with different subjects, within one study: 1) 10 patients walked a 12-minute test five times to examine pacing, 2) 30 patients performed one 12-minute, one 6-minute, and one 2-minute walking test, and 3) 13 patients performed four 2-minute walking tests to examine reproducibility. Each walk the patients were instructed to cover as much distance as they could within the time allotted. The first experiment showed the patients walked furthest within the first 2 minutes of the 12-minute test and the remaining 10 minutes patient's covered constant distances for each 2-minute recording. The second

experiment produced high correlations between the 12-minute test and the 6- and 2-minute walk tests, with a slightly higher correlation seen between the 6- and 12-minute test ( $r=-.955$  and  $r=0.864$ , respectively). Lastly, the third experiment showed high reproducibility for subsequent 2-minute walks, but suggests a practice trial to overcome the learning effect of the first walk. Butland et al. concluded that the 6-minute walk test (6MWT) represented a nice compromise for shortened duration, while leaving room for a training role. Since then, the American Thoracic Society (ATS) has published standardized guidelines to conduct the 6MWT (ATS, 2002).

Kline et al. (1987) also sought to improve the prediction of  $VO_{2max}$  through the implementation of a new submaximal test: 1-mile walk test, named the Rockport Fitness Walking Test. The Rockport test addressed three factors that commonly limit an exercise test's applicability: accuracy and validity, ease of the testing protocol, and generalizability. There were 343 subjects, ages 30-69 that participated in the study, which were divided into a validation ( $n=174$ ) and a cross validation ( $n=169$ ) group to estimate  $VO_{2max}$ . Each subject performed a treadmill GXT to directly measure  $VO_{2max}$ , while also completing at least two 1-mile walks on a track. Each one-mile walk was completed at a brisk pace where the subject walked nearly as quickly as possible. The walk time was used to develop six equations, and one recommended generalized equation, for estimating  $VO_{2max}$ , in addition to these other predictor variables: age, gender, weight, and HR. The results indicated a valid and accurate estimation of  $VO_{2max}$  from all six equations. Further research is needed to determine which equation works best for a given population, since these only applied to the broad sample in this study.

This Rockport test represents a valid, simple, and generalizable submaximal method to estimate  $VO_{2max}$  when direct measurement of  $VO_{2max}$  is not feasible.

To further specify the equations created by Kline et al. (1987) to an older population, Fenstermaker, Plowman, and Looney (1992) tested 16 females of ages 65 years and older. The women completed a treadmill GXT and three 1-mile Rockport tests around a track. The GXT held a constant speed and increased in grade by 2% for each stage. The Rockport test was self-administered by design, so for each of the three tests the women walked a mile as quickly as they could and took their HRs at the end of the test. Results were compared to the two sex-specific (female) and the two generalized equations from Kline et al. (1987). They discovered a learning effect between the first and third Rockport test due to an increase in mean HR and a decrease in mean duration of the test. While all four Kline et al. (1987) equations are approved to estimate  $VO_{2max}$ , a practice trial is encouraged to obtain the most accurate and reliable estimations for this age group. In addition, the sex-specific, female equations estimated  $VO_{2max}$  slightly better than the generalized equations.

While the Rockport test is validated for middle-aged to older adults, it lacks validation for the younger population. In response, Dolgener, Hensley, Marsh, and Fjelstul (1994) recruited college age males and females to validate Kline et al.'s (1987) version of the Rockport test to younger adults, while also creating prediction equations specific to this age group. Subjects were divided into a validation (n=196) and cross-validation group (n=78). Subjects completed a GXT maintaining a treadmill speed of 6 mph and increasing in grade every minute by 2.5% until exhaustion to obtain  $VO_{2max}$ . Within a week of the GXT, the subjects performed a Rockport test being instructed to

walk as quickly as possible. In the attempt to validate Kline et al.'s (1987) gender-specific and generalized equations, Dolgener et al. (1994) found a significant overestimation of  $VO_{2max}$  from these equations compared to measured  $VO_{2max}$  values: indicating that Kline et al.'s (1987) prediction equations of  $VO_{2max}$  are not valid for college age students. New prediction equations were created, however age did not contribute to an improved prediction of  $VO_{2max}$ , so it was removed leaving weight, walk time, and terminal HR as the predictor variables. The new gender-specific equations also predicted  $VO_{2max}$  poorly, leaving the new generalized equations as the only recommended equations to estimate  $VO_{2max}$  in college age adults. More research is needed to improve the prediction of  $VO_{2max}$  using the Rockport test in young adults.

While Dolgener, Hensley, Marsh, and Fjelstul (1994) specified the regression equations to predict  $VO_{2max}$ , George, Fellingham, and Fisher (1998) sought to modify the Rockport protocol. They proposed a decrease in the walking distance and pace of the test, while still maintaining the predictive accuracy of  $VO_{2max}$ . Eighty-five college students of ages 18-29 years each completed a maximal GXT on a treadmill and a 1-mile walk around an outside track. From that 1-mile walk, George, Fellingham, and Fisher (1998) examined the difference in  $VO_{2max}$  from the  $\frac{1}{4}$  mile marker compared to the full mile. Subjects walked the mile at a brisk pace (not maximal) where HR and time were recorded with each lap.  $VO_{2max}$  was estimated using an age-generalized equation from Kline et al. (1987) and an age-specific equation from Dogener et al. (1994). While the age-generalized equation overestimated  $VO_{2max}$ , the age-specific equation estimated  $VO_{2max}$  appropriately at both the quarter and full mile. This indicates that the Rockport test can utilize a shorter duration to predict  $VO_{2max}$ , which further simplifies the test. In

addition, conducting the test using under a maximal pace still estimates  $VO_{2max}$  adequately, which helps decrease lower leg injuries commonly experienced during maximal effort. Future studies are needed to generalize and verify these results. The authors recognize that completing only one walk test does not yield ideal results, so future studies should also consider conducting separate walking tests with a shorter walk on one day and the full mile on another. This study commences the modification of the Rockport test to further simplify the utility of the test and improve the prediction of  $VO_{2max}$ .

For facilities that lack a large enough track to complete the Rockport test, Poper, Freedson, Kline, McInnis, and Rippe (2002) examined the ability of the generalized Rockport equation (Kline et al. (1987) to predict  $VO_{2max}$  values for a 1-mile treadmill walk. Three hundred and four subjects completed a  $VO_{2max}$  test using a modified Balke protocol and a 1-mile treadmill walk test using the protocol proposed by Widrick, Ward, Ebbeling, Clemente, and Rippe (1992). The estimated  $VO_{2max}$  values from the general Rockport equation yielded a reasonable correlation ( $r=0.80$ ) to the observed  $VO_{2max}$  values, however the residual plots were abnormally distributed. Poper et al. (2002) generated a new equation to predict  $VO_{2max}$  when completing a one-mile treadmill walk: TREADWALK. This new equation used the following predictor variables to predict  $VO_{2max}$ : age, walk time, walk HR, activity level, body mass, and gender. The TREADWALK equation found a higher correlation ( $r=0.87$ ) between the observed and predicted  $VO_{2max}$  values with normally distributed residual plots compared to the general Rockport. While this equation and protocol for the 1-mile treadmill Rockport test predict  $VO_{2max}$  values accurately, Poper et al. (2002) warn against immediate implementation to

determine individual fitness. The TREADWALK equation tends to underestimate  $VO_{2max}$  values for those  $>50$  ml/kg/min and overestimates  $VO_{2max}$  for those  $<19$  ml/kg/min, which is particularly concerning clinically. This treadmill based equation for the Rockport test is an accurate predictor of  $VO_{2max}$ , however further research is needed to generalize and validate these findings to use on larger populations.

Field tests represent a simpler and less expensive method to determine  $VO_{2max}$ , since a physician's presence and lab equipment are not required, in addition to the ability to conduct the test anywhere. Field tests should last for around 12 minutes to ensure the aerobic phase of exercise is dominant compared to the anaerobic phase to accurately predict  $VO_{2max}$ . Walking tests in particular are quite popular due to the familiarity of walking and lack of required equipment. Two common walking tests include the 6MWT and the Rockport Fitness Walking Test. The 6MWT is commonly used in clinical settings, while the Rockport Fitness Walking Test is used more generally for fitness assessment. While already quite simple, modifications to the RFWT protocol help generalize the test. The RFWT is validated in old and young populations, however more work is needed to verify the relationship between the RFWT and college age subjects. In addition, a brisk pace and shorter duration of the RFWT were shown to be acceptable changes in comparison to the maximal pace and 1-mile length of the original test. New modalities are also being employed, such as the treadmill, to extend the use of the RFWT to more populations and facilities.

### **Rating of Perceived Exertion**

In addition to the objective measurements of an individual's fitness, subjective methods can also be used. In the mid to late twentieth century, scientists began

recognizing the importance of an individual's perception in accordance with physical exertion. Gunner Borg believed that "perceived exertion is the single best indicator of physical strain" because it can integrate signals from every part of the body: central, periphery, respiratory, cardiovascular, and etc. (1982). Borg (1982) created a 6-20 Rating of Perceived Exertion (RPE) scale that increased linearly with increases in exercise intensity: mirroring the linear increase of HR and  $VO_2$  with exercise intensity. The 6-20 scale represents HRs of 60-200 bpm, which correlated highly with RPE, but varied depending on activity. Borg (1982) argued that neither, HR or RPE, should be used alone as an indicator for risk, because each can change every day. However, when used together, they complement each other to provide an indication of bodily strain. Borg (1982) created a new category scale, rating from 0-10, to improve mathematical properties by incorporating ratio elements. Borg (1982) encourages the use of the 6-20 scale in exercise settings, while the 0-10 scale defies other strains, such as breathlessness.

To track the volume and intensity of each workout session one can objectively measure duration, intensity, frequency, repetitions, and etc. The search began for a single term to quantify training. Banister et al. (1975) created the training impulse (TRIMP) score to objectively monitor training. However, the TRIMP score does not work well during high intensity training sessions. To further simplify the quantification of training, Foster et al. (2001) created a modified version of the TRIMP score to include rating of perceived exertion (RPE). Subjects rated their perceived effort based on the entire workout to provide a global rating, known as session RPE. Foster et al. (2001) tested a group of well-trained cyclists and a team of male college basketball players to examine the relationship between session RPE and HR-based methods in the TRIMP score to

monitor training during different exercise intensities. The cyclists performed a GXT and eight exercise training bouts where they were asked session RPE 30 minutes after each bout. The basketball players also completed a GXT and were monitored during play where they were asked their session RPE 30 minutes after exercise. Two TRIMP scores were calculated for each exercise bout: 1) multiplying exercise duration by session RPE and 2) using the tradition HR zone method. They found a high correlation existed between each TRIMP score, which indicates the acceptable usage of either session RPE or HR methods to calculate a TRIMP score for exercise monitoring. However, the differences in data collection between the session RPE and HR methods favors the use of session RPE due to it's simplicity. Session RPE is also a practical tool for any individual, whereas HR methods cost money and may be unreliable. In addition, session RPE can evaluate various intensities of exercise, unlike HR methods, which cannot accurately monitor high intensity exercise. Overall, session RPE represents a valid, subjective measure to monitor exercise training.

The most common method to subjectively measure perceived exertion or exercise intensity is the Borg RPE scale (Borg, 1998). However, research has yielded inconsistent results in regards to the relationship between RPE and physiological variables, so Chen, Fan, and Moe (2002) compiled a meta analysis to further scrutinize the relationship between the RPE scale and the following physiological variables: HR, blood lactate,  $\%VO_{2max}$ ,  $VO_2$ , ventilation, and respiration rate. They included articles that studied the relationship between the RPE scale and one/more of the physiological variables, while also searching for articles with different study features to categorize their findings: sex, fitness/activity level, type of RPE scale, exercise type, exercise protocol, RPE mode, and

quality of study. No significant differences were found between the physiological variables and RPE. Instead the highest correlations with RPE were found in males completing maximal exertion tests, unusual exercise tasks, and when using the 15-point RPE scale. Respiration rate was found to be the strongest indicator of RPE. Yet, the calculated validity coefficients between RPE and these variables were weak compared to past understanding: likely due to the small, homogenous sample sizes. Important to note is the validity between RPE and exercise intensity, which is lower than some studies want to report ( $r=0.80-0.90$ ).

In order to use perceived exertion methods with more confidence, Eston, Lamb, Parfitt, and King (2005) examined the validity of predicting  $VO_{2max}$  from submaximal  $VO_2$  values of a perceptually regulated GXT. If validated, patients could use RPE to self-regulate their exercise intensities. Ten active men completed four exercise tests on a cycle ergometer: one  $VO_{2max}$  test with a continuous, incremental protocol and three submaximal trials using the Borg 6-20 RPE scale. The three submaximal GXTs, which were performed 48 hours apart, required the subjects to self-regulate their exercise intensity by reaching RPEs of 9, 11, 13, 15, and 17. Once the subject chose the intensity that matched the required RPE, they stayed at the stage for four minutes where gas analysis and HR were measured during both maximal and submaximal tests. Eston et al. (2005) found the prediction of  $VO_{2max}$  from a submaximal, perceptually-GXT to be valid and reliable, which increased with practice. There was no significant difference between predicted  $VO_2$  compared to the measured  $VO_{2max}$ : establishing the validity of perceptual rating to predict  $VO_{2max}$ . The repeatability of predicting  $VO_2$  at the five RPE ranges was similar from trial one to three, however small improvement was noted by trial three:

indicating improved repeatability with protocol familiarity. This study supports the use of RPE due to its validity and reliability of estimating  $VO_2$  and as a self-regulation tool for exercise intensity.

Faulkner and Eston (2007) continued to verify the ability of submaximal RPE to predict  $VO_{2max}$ , while also investigating if gender or fitness influenced the margin of error. Due to inconsistent results, they also examined the relationship between differentiated RPE (peripheral versus overall), HR, and  $VO_2$  in subjects of different gender and fitness. Subjects completed two-cycle ergometer GXTs in the lab where gas analysis, heart rate, and peripheral and overall RPE were recorded. Ultimately, RPE correlated almost as highly compared to HR in relationship to  $VO_2$ . Specifically, no differences existed in the correlation between peripheral and overall RPE with  $VO_2$ , however overall RPE was reported more consistently and estimated  $VO_{2max}$  more accurately. Gender and fitness did not impact these relationships significantly. This provides promising possibilities for using overall RPE to assess exercise intensity in CR populations due to its reliability and accuracy. The most accurate predictions of  $VO_{2max}$  occurred at overall RPEs of 13, 15, and 17. Future research is needed to generalize these results to clinical populations.

Lambrick, Faulkner, Rowlands, and Eston (2009) tested a ramp protocol to predict  $VO_{2max}$  from submaximal HR and RPEs during a single bout of exercise. Eleven healthy women with low fitness completed one GXT to establish  $VO_{2max}$  using a ramp protocol: starting at 0W as a baseline measure for two minutes followed by an increase of 1 W every 4 seconds until  $VO_{2max}$ . Expired air, HR and overall RPE were recorded and gas exchange thresholds (GET) were determined from the  $VO_{2max}$ . Lambrick et al.

(2009) confirmed the strong relationship between the 6-20 Borg RPE scale and physiological variables of  $VO_2$  ( $r=0.97$ ). Strong correlations with  $VO_2$  also occurred with HR ( $r=0.98$ ), RPE 13 ( $r=0.97$ ) and GET ( $r=0.98$ ). Additionally, estimation of  $VO_{2max}$  was accurate for extrapolations from RPE 13 to RPE 19 and 20. Compared to a GET and HR, RPE 13 predicted  $VO_{2max}$  more precisely (narrower limits of agreement) and more strongly (higher intraclass correlation). Thus, GET are not recommended to predict  $VO_{2max}$  and due to RPEs strong correlation with  $VO_2$ , RPE can be considered an adjunct to HR for additional insight when predicting  $VO_{2max}$ .

In hopes of improving adherence and enjoyment in an exercise routine, Parfitt, Evans, and Eston (2012) studied the effect of an exercise training program clamped at a RPE of 13 on cardiovascular health improvements and positive affect. Such a program is known as perceptually regulated exercise training (PRET), since the individual chooses their desired exercise intensity that matches with an RPE 13 or “somewhat hard” on the Borg 6-20 RPE scale. Twenty-six sedentary subjects completed baseline health measurements along with two GXT to directly measure  $VO_{2max}$  at pre- and post-intervention phases. Overall RPE, affective state, respiratory gas analysis, and HR were recorded during the GXT. During the intervention phase of eight weeks, subjects were split into either the control or training group. The control continued normal physical activity. The training group completed three, 30-minute treadmill exercise sessions/week, while continuously adjusting speed and grade to maintain an RPE of 13. The application of PRET at a RPE 13 for three times/week at 8 weeks resulted in increased fitness and cardiovascular health improvements, along with increased positive affective responses to exercise. Specifically, fitness improved by 17% and the affective

response with the chosen exercise intensity at RPE13 was “good” as described by the Feeling Scale.

While the PRET at a RPE13 yielded improved health benefits and personal outlook, Eston et al. (2012) examined whether PRET could accurately predict  $VO_{2peak}$  in comparison to the HR: $VO_2$  relationship. Seventy-five healthy, active (n=49) and sedentary (n=26) volunteers completed two submaximal treadmill PRETs to predict  $VO_{2peak}$  and one treadmill GXT to directly measure  $VO_{2peak}$ . Each PRET consisted of four, 3-minute perceptually regulated stages corresponding to intensities of RPEs at 9, 11, 13, and 15 at a fixed 1% grade. The mean  $VO_2$  data from RPE stages 9-15 was then extrapolated to an RPE 19 and 20 to predict  $VO_{2peak}$ . GXTs were also set at 1% grade and increased in speed by 1 kilometer per hour every 3 minutes for the active participants, while the sedentary participants followed a Balke-Ware protocol.  $VO_2$  was predicted from the GXT by utilizing the HR's at RPEs of 9-15, which were extrapolated to the subject's age-predicted  $HR_{max}$ . A single PRET was found to be a valid method of predicting  $VO_{2peak}$  from a range of RPE 9-15 extrapolated to RPE 19 as compared to the directly measured  $VO_{2peak}$  from a GXT. Using only a single PRET to produce such valid results indicates a familiarization trial is unnecessary, likely due the treadmill use, since it represents a familiar mode of exercise unlike the cycle ergometer. With such valid results, Eston et al. (2012) recommend the PRET to gauge exercise intensity and to predict  $VO_{2max}$  in active and sedentary adults, which is especially important when GXTs are not feasible. Future research is needed to determine the usage of PRET in clinical settings.

Despite RPE's moderate validity with  $VO_{2max}$ , these results are still applicable and useful during exercise. Specifically, overall RPE, compared to peripheral, is best to

predict  $VO_{2max}$  and monitor exercise intensity. Increased accuracy occurs at overall RPEs of 13, 15, and 17 and the high repeatability during perceptually rated exercise. This encourages self-regulation of exercise intensity. Gender and fitness level do not impact the relationship between RPE and  $VO_{2max}$ . In addition, the 6-20 RPE scale can, at times, predict  $VO_{2max}$ , with more accuracy than HR. Specifically, an RPE13 is the most accurate and can extrapolate to an RPE of 19 and 20 to predict  $VO_{2max}$ . Many CR programs use an RPE13 to gauge exercise intensity because it represents an ideal comfort and safe zone along with promoting cardiovascular health and fitness. Increased adherence to an exercise program is also seen at an RPE13 due to increased enjoyment. While RPE is not the strongest predictor of  $VO_{2max}$ , it provides important and valid subjective assessments of perceived exertion during exercise.

### **The Ventilatory Threshold (VT)**

While RPE judges exercise intensity by its total impact on all bodily processes, other methods to assess exercise intensity focus on the body's ability to deliver and utilize  $O_2$ . As workload increases, the body reaches a certain exercise intensity where ventilation ( $V_E$ ) increases disproportionately to  $VO_2$ . At this point lactate also starts increasing dramatically due to diminished lactate buffering. This point was initially identified as early as the 1920s (Hill, Long, & Lupton, 1924) and remained a point of controversy for many years due to differing opinions on the relationship (or lack there of) between lactate and  $V_E$ . Researchers mostly agreed on these physiological changes with increasing exercise, which is the transition from aerobic to anaerobic fuel use. This was initially known as the anaerobic threshold (AT) (Wasserman & McIlroy, 1964), and also referred to as the lactate threshold (LT), or more recently accepted as the VT.

Skinner and McLellan (1980) provided a detailed paper describing the physiological processes occurring at the VT. They wanted to address the controversy on the transition from steady-state increases in lactate and  $V_E$  compared to the disproportionate increases seen with increasing exercise intensity. At low exercise intensities below 40%, there are increases in  $O_2$ ,  $CO_2$ ,  $VO_2$ ,  $V_E$ , and HR. The first increases in exercise lead to an increase in  $O_2$  utilization by the tissues, so less can be exhaled, thus  $CO_2$  increases in production and increases the amount exhaled ( $VCO_2$ ).  $VO_2$ ,  $V_E$ , and HR all increase linearly and lactate changes very little. They denote this phase as solely undergoing aerobic metabolism. Once exercise intensity increases to 40-60%,  $VO_2$  and HR rise linearly and lactate levels rise to around 2 mmol/L. The increase in lactate levels are buffered by bicarbonate, which increases the production of  $CO_2$  and will soon lead to metabolic acidosis.  $V_E$  increases as an attempt to counteract the decrease in pH, while  $VCO_2$  also increases. However, the increase in  $V_E$  and  $VCO_2$  is disproportionate, since  $V_E$  increases more. They in turn label this transitional phase as the aerobic threshold (AerT). Lastly, as exercise intensity increases above 65% towards maximum,  $VO_2$  and HR are still increasing linearly until maximal intensity is reached where they plateau. At such high intensities, lactate levels increase quickly to 4 mmol/L or above. In response,  $V_E$  and  $VCO_2$  also increase, to a point of hyperventilation. Skinner and McClellan (1980) label this transition as the anaerobic threshold (AnT). They also note that the blood lactate concentrations are indicative of muscle lactate, which are influenced by muscle fiber type. In addition, as exercise intensity increases causing large increases in lactate and  $V_E$ , Skinner and McClellan (1980) remark that such hypoxic conditions cannot be maintained for prolonged periods of exercise.

Wasserman (1986) formally defined the VT and its physiological differences as the point where aerobic energy production must be supplemented by anaerobic sources to continue work. As anaerobic sources help produce energy, lactate levels increase above the VT leading to metabolic acidosis. In addition, once above the VT, the disproportionate increase in  $V_E$  decreases the oxygen delivery to the muscles. Thus, exercise endurance decreases once above the VT. He notes that those individuals with diminished fitness will experience their VT sooner due to their inability to deliver and use oxygen efficiently, while trained individuals can experience the AT later and at higher intensities. While an increase in lactate and  $V_E$  are well recognized, the debate continues on whether these two physiological markers are related.

In 2006, Foster and Cotter reviewed the research conducted on the VT. They describe the physiological mechanisms behind this threshold and describe it as a comparable, and even better, assessment of sustainable exercise intensity in comparison to  $VO_2$ . While many terms have developed over the years, the threshold is still indicative of discontinuous increases in lactate and  $V_E$ , to which there are two: the first and second VT. The first threshold ( $VT_1$ ) begins when the first increases in  $V_E$  occur relative to  $VO_2$  and blood lactate levels increase above resting values. Whereas, the second threshold ( $VT_2$ ) begins when  $V_E$  increases relative to both  $VO_2$  and  $VCO_2$  and blood lactate levels increase more rapidly. These physiological markers of  $V_E$  and blood lactate are representative of exercise intensity and determine exercise duration: the higher the exercise intensity, the higher the levels of  $V_E$  and blood lactate causing quick exhaustion. Thus, exercise intensities below the VT, where  $V_E$  and blood lactate are steady, represent manageable and sustainable exercise. Due to its relationship with exercise intensity,

Foster and Cotter (2006) also highlight the role and practical significance of the VT in exercise training. They believe the VT is a better indicator of fitness changes in comparison to the  $VO_{2max}$  due to the VT's sustainable and prolonged nature at a certain percent of  $VO_{2max}$ . VT also has a good relationship with performance, so it represents a better marker of endurance capacity than  $VO_2$ . Any exercise intensity above the VT limits training and potentially causes a lull in performance gains, whereas exercise intensities at or below the VT permit longer duration exercise.

Mezzani et al. (2012) further describe the relationship between the VT and exercise intensity in their review of aerobic exercise assessment and prescription. These authors extend the credibility of the VT by acknowledging it as a gold standard reference to evaluate aerobic function along with  $VO_2$ : for both  $VT_1$  and  $VT_2$ . In addition to the previously discussed definitions, the  $VT_1$  is also recognized as the limit between light and moderate exercise (50-60%  $VO_2$ ) where exercise is sustainable for prolonged periods of time (>30 minutes). The  $VT_2$  represents the limit between moderate to high intensity exercise (70-80%) and is the upper limit for any prolonged aerobic exercises. With such a strong connection between the VT and exercise intensity, Mezzani et al. (2012) suggest the use of the  $VT_1$  and  $VT_2$  for future exercise guidelines.

To utilize the VT as a marker of exercise intensity, Condello et al. (2014) sought to simplify the estimation of the VT and the respiratory compensation threshold (RCT) through the percentage of maximal incremental running velocity ( $V_{max}$ ). Thirty-one well-trained athletes performed an incremental running test to determine VT and RCT as a percent of  $V_{max}$  (Phase 1). In addition, 20 well-trained athletes performed an incremental running test (Phase 2) to cross validate the results with the results from Phase 1. In

addition, the subjects in Phase 2 also completed two 30-minute submaximal running bouts at 64% and 86% of  $V_{\max}$ , which represented intensities related to  $\leq VT$  and  $\geq RCT$ , respectively. These steady state runs did produce exercise intensities at the desired  $\leq VT$  and  $\geq RCT$  levels. Condello et al. (2014) suggest the use of  $\%V_{\max}$  as a simplistic tool to determine an athlete's VT and RCT thresholds. Finding these thresholds as a  $\%VO_{2\max}$  could promote the creation of training zone guidelines for athletes and recreational use.

Despite the controversy on threshold terminology, a consensus exists for the physiological processes that occur as exercise intensity increases. Intensities above light exercise instigate  $VT_1$  as seen by the first disproportionate increases in lactate and  $V_E$ . The second occurrence of disproportionate increases in lactate and  $V_E$  represent  $VT_2$  at intensities above moderate exercise. The  $VT_1$  also indicates the supplementation of the aerobic system with anaerobic fuel, whereas the  $VT_2$  occurs at higher intensities, so the primary sources of fuel are anaerobic. Due to its relationship with these physiological markers, the VT is a valid indicator of exercise intensity. Specifically, the VT represents a measure of sustainable exercise. Intensities above the VT decrease the ability to perform prolonged exercise, whereas intensities below the VT are much easier to maintain for longer periods of time. Thus, the VT is an important variable to consider during exercise testing and training to determine what intensity is appropriate for a given exercise session.

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