

UNIVERSITY OF WISCONSIN-LA CROSSE

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PREDICTING  $VO_{2MAX}$  FOR OLDER ADULTS USING RPE  
AND THE 6 MINUTE WALK TEST

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PREDICTING  $VO_{2MAX}$  IN OLDER ADULTS USING RPE  
AND THE 6 MINUTE WALK TEST

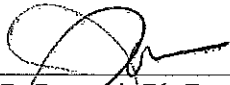
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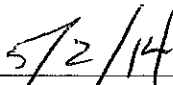
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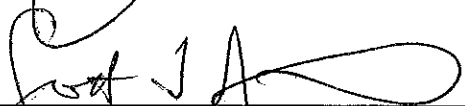
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## ABSTRACT

Brown, H.R. Predicting  $VO_{2max}$  in older adults using RPE and the 6 minute walk test. MS in Clinical Exercise Physiology, December 2014, 79pp. (C. Foster)

The purpose of this study was to determine the accuracy of estimating  $VO_{2max}$  from the 6MWT performance and RPE at the conclusion of the test. Subjects (N=28) included were 40-75yrs of age and ranged from sedentary to very active with  $VO_{2max}$  ranging 25-50ml/kg/min. Each subject performed an incremental maximal treadmill test using a modified Balke protocol. After 24-48hrs rest, subjects performed the 6MWT and gave terminal RPE using the Omni Rating Scale, Borg Category Ratio (0-10), and classical Borg 6-20 scale. The Borg 6-20 notably had higher correlations than the other rating scales. Moderate correlation was suggested between 6MWD and measured  $VO_{2max}$ . The 3 rating scales used presented low to moderate correlations. Measured vs. predicted  $VO_{2max}$  presented moderate to good correlations. The average standardized residuals suggest all prediction equations are accurate within about 1 MET.

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## INTRODUCTION

Although measures of ventilatory (VT) or metabolic threshold have become recognized as measures of exercise capacity and as a basis of exercise prescription (Haskell, Savin, Oloridg, & DeBusk, 1982; Mezzani, et al., 2012; Morris, Myers, Froelicher, Kawaguchi, Ueshima, & Hideg, 1993), the gold standard for evaluating exercise capacity, creating the exercise prescription, and defining prognosis in patients with chronic disease is still the maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) (American College of Sports Medicine, 2013). Normative values are available for  $\text{VO}_{2\text{max}}$  in the general population, allowing  $\text{VO}_{2\text{max}}$  to be expressed as easy to understand percentages of the age and sex predicted  $\text{VO}_{2\text{max}}$  (Morris, et al, 1993). The  $\text{VO}_{2\text{max}}$  is ideally measured during an incremental exercise test, with simultaneous measurement of respiratory metabolism (Foster, et al., 2007; Howley, Bassett, & Welch, 1995). Classically,  $\text{VO}_{2\text{max}}$  is thought to occur when there is a plateau in  $\text{VO}_2$  despite increasing workloads (Levine, 2008; Howley, et al, 1995). However, in normal practice, the plateau phenomenon is not widely observed without a confirmatory test (Kirkberg, Dalleck, Kamphoff & Pettitt, 2011). Direct measurement of  $\text{VO}_{2\text{max}}$  requires relatively sophisticated and expensive equipment, which makes the test costly to perform. Further, direct measurement of  $\text{VO}_{2\text{max}}$  requires maximal exertion on the part of the exerciser. In healthy individuals this is merely uncomfortable. In patients with chronic disease, maximal exertion is associated with increased risk of complications, which requires the presence of a medical



practitioner further increasing the cost and difficulty of performing direct measures of VO<sub>2</sub>max(Foster, et al, 2007).

There are a number of widely used tests for predicting VO<sub>2</sub>max using either submaximal or maximal exertion. There are many exercise test protocols based either on peak treadmill performance or maximal power output on the cycle ergometer, which are quite well accepted (Balke, 1960; Bruce, Kusumi, & Hosmer, 1973; Myers, et al., 1991; Shephard, et al., 1968). One major limitation with these tests is the variable effect of handrail support during treadmill testing (McConnell, Foster, Conlin, & Thompson, 1991; Ragg, Murray, Karbonit, & Jump, 1980). Handrail support has been shown to effect heart rate (HR) and duration of exercise tests, leading to over prediction of VO<sub>2</sub>max and miscalculation of the exercise prescription (Haskell, Savin, et al, 1982; Mezzani, et al., 2012; McConnell, Foster, et al, 1991; Ragg, et al, 1980) and can lead to overly optimistic estimates of a patient progress (Myers, Prakash, Froelicher, Do, Partington, & Atwood, 2002). Submaximal test protocols based on the heart rate-work load relationship or on the progression of the Rating of Perceived Exertion (RPE)-workload relationship (Parfitt, Evans, & Eston, 2012) have also been proposed. They are useful because of their simplicity, but have limitations on accuracy, and are primarily limited by the need to estimate maximal HR or the ability to accurately report RPE. Field performance tests, based on maximal exertion (Cooper, K.H., 1968) are reasonably accurate, with error of about 2 METs, but they require maximal exertion. They are both uncomfortable to perform and in clinical populations present unacceptable safety risk.

Submaximal field tests based on walking speed for a certain distance and HR response, such as the Rockport Test, (Kline, et al., 1987) are reasonably accurate, but are still limited by need to include HR. In patients on medications that modify the HR response to exercise, these tests may be widely inaccurate. Further, maximal predicted HR has a very large individual error (Howley, et al, 1995; Morris, et al, 1993; Robergs, & Landwehr, 2002) that greatly limits its' value in predictive tests.

In the clinical setting, the 6-minute walk test (6MWT) is a very popular, easy to perform, and sub-maximal test which obviates the need for medical supervision. It is of great prognostic value, particularly in patients with heart failure (Arslan, et al., 2007; Guyatt, et al., 1984; Ingle, Goode, Rigby, Cleland, & Clark, 2005; Jehn, et al., 2009; Rasekaba, Lee, Naughton, Williams, & Holland, 2009) and has been used as an outcome measure in more general cardiac rehabilitation populations (Ingle, et al, 2005; Jehn, et al., 2009; Rasekaba, et al, 2009). Further, there are well standardized procedures for administering the 6MWT (American Thoracic Society, 2002), and it does not suffer from the limitations related to the effect of handrail support. However, the ability of the 6MWT to predict  $VO_{2max}$  is substantially limited, in that healthy individuals and more hearty patients are typically limited by walking mechanics rather than by the ability to provide for aerobic ATP production. However, in individuals with a good exercise capacity, the RPE at the end of a 6MWT is likely to be rather low. Conversely, individuals with a low  $VO_{2max}$  will likely report a high RPE at the end of a test. This suggests that the combined information available from the average walking speed (which allows calculation of energy cost in METs) and the RPE at the conclusion of the 6MWT may combine to allow a reasonable estimate of  $VO_{2max}$  across a range of exercise

capacities in middle-aged and older healthy adults and in cardiac patients. Accordingly, the purpose of this study was to determine the accuracy of estimating  $\text{VO}_2\text{max}$  from 6MWT performance and RPE at the conclusion of the test.

## **METHODS**

Before testing, the protocol was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects. Subjects provided written informed consent prior to participating (Appendix A).

### **Subjects**

The study included 30 subjects, selected to represent a range of exercise capacities. The age range was 40-75 years, and the activity level ranged from sedentary to very active based on ACSM guidelines (American College of Sports Medicine, 2013). The target in subject recruitment was based on selecting a group of subjects with an approximately normal distribution of  $\text{VO}_{2\text{max}}$  and  $\text{VO}_{2\text{max}}$  ranging from 20-40 ml/kg. Two subjects were excluded for uncharacteristically high  $\text{VO}_{2\text{max}}$  values.

### **Procedures**

Each subject performed two tests. The first test was an incremental maximal treadmill exercise test using a modified Balke protocol (Appendix D)(Balke, 1960). During the warm-up period before testing began, the subject habituated to the treadmill and chose a 'comfortable walking speed' at 0% grade. The speed was held constant, the slope of the treadmill was increased 2% every 2 minutes, and the test continued until volitional fatigue or until there were clinical signs or symptoms suggesting exercise test termination (American College of Sports Medicine, 2013; Gibbons, et al., 1997). During the tests, respiratory metabolism was measured using open circuit spirometry with a breath by breath based metabolic system (Sensormedics, Yorba Linda, CA). Heart rate

was measured using a 12 lead electrocardiogram. Blood pressure was measured at every stage by auscultation. The RPE was measured each stage of the incremental exercise test using the Borg (6-20) scale. Metabolic responses were evaluated according to Foster & Cotter (2005), with the highest continuous 30s  $\text{VO}_2$  being accepted as  $\text{VO}_{2\text{max}}$ .

The second test was the 6MWT, performed according to the guidelines of the American Thoracic Society (Appendix C)(American Thoracic Society, 2002). The subject walked back and forth in a 100ft hallway. The number of laps was recorded, and the subject stopped at the end of the 6 min period, so that the distance of incomplete laps could be measured. During the test, HR was measured using radiotelemetry (Polar Electro Oy, Woodbury, NY), and RPE was measured immediately upon completion (Appendix E). Three RPE scales were used, the Omni scale, the Borg Category Ratio (0-10) scale, and the classical Borg 6-20 scale (Appendix B).

Analysis was conducted by performing multiple regression to predict measured  $\text{VO}_{2\text{max}}$ , from the total distance in the 6MWT, and from RPE at the end of the 6MWT. It was hypothesized that although the total distance of the 6MWT would probably not exceed 650 meters, which should be achieved in individuals with a  $\text{VO}_{2\text{max}} > 20 \text{ ml/kg}$ , subjects with higher values for  $\text{VO}_{2\text{max}}$  would have lower values for RPE at the conclusion of the test. The goodness of fit of the multiple regression solution was evaluated based on the  $R^2$  of the regression equation. Finally, residuals were computed based on the derived prediction formula in order to gain an appreciation of how accurate the derived equation was.

## RESULTS

The averaged descriptive characteristics of subject demographics ( $\pm$ sd) are presented in Table 1. The HR<sub>max</sub> information used was from subject's incremental maximal treadmill test.

Table 1. Subject Demographics

	Men	Women
Age	58 $\pm$ 7.6	55 $\pm$ 8.5
Height (m)	1.78 $\pm$ .06	1.62 $\pm$ .07
Weight (kg)	95.2 $\pm$ 19	63.9 $\pm$ 10
VO <sub>2max</sub> (ml/kg/min)	34.4 $\pm$ 6.5	34.4 $\pm$ 6.1
HR <sub>max</sub>	158 $\pm$ 22	170 $\pm$ 8
6MWD (m)	640	630
Terminal Omni	4.6 $\pm$ 1.7	3.7 $\pm$ 1.8
Terminal Borg 0-10	3.3 $\pm$ 1.2	3 $\pm$ 1.3
Terminal 6-20	12 $\pm$ 2.1	11.8 $\pm$ 2.7

Multiple regression analysis was performed using 17 men and 11 women (N=28). The relationship between measured VO<sub>2max</sub> and 6 Minute Walk Distance (6MWD) was found to have moderate correlation ( $r= 0.48$ ) (Figure 1).

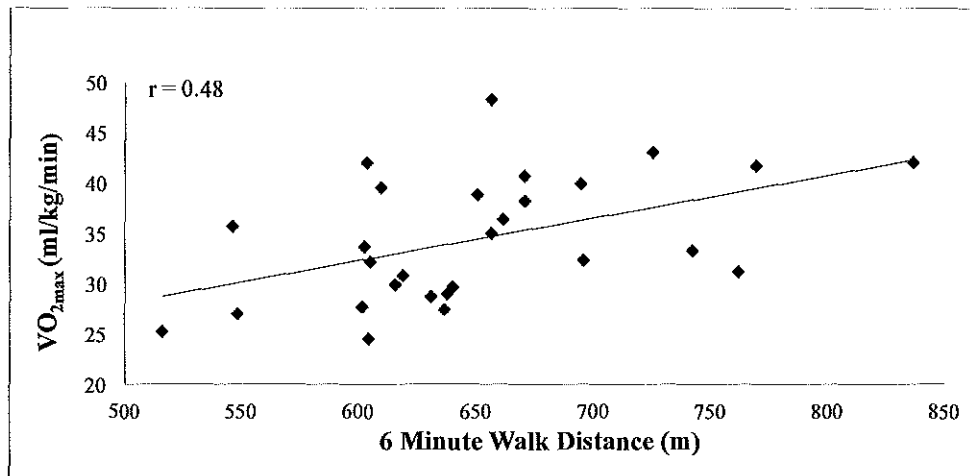


Figure 1. This figure presents each subject's measured  $VO_{2max}$  (ml/kg/min) vs. their distance walked in the 6MWT.

Figures 2a-c present the relationship between measured  $VO_{2max}$  and the subjects' terminal RPE at the end of their 6MWT. Figure 2a presents a low to moderate relationship ( $r = 0.41$ ) between measured  $VO_{2max}$  and terminal RPE using the Omni rating scale. Figure 2b presents a low to moderate correlation ( $r = 0.42$ ) between measured  $VO_{2max}$  (ml/kg/min) and terminal RPE using the Borg 0-10 rating scale. Lastly, Figure 2c presents a moderate relationship ( $r = 0.50$ ) between measured  $VO_{2max}$  (ml/kg/min) and terminal RPE using the Borg 6-20 rating scale.

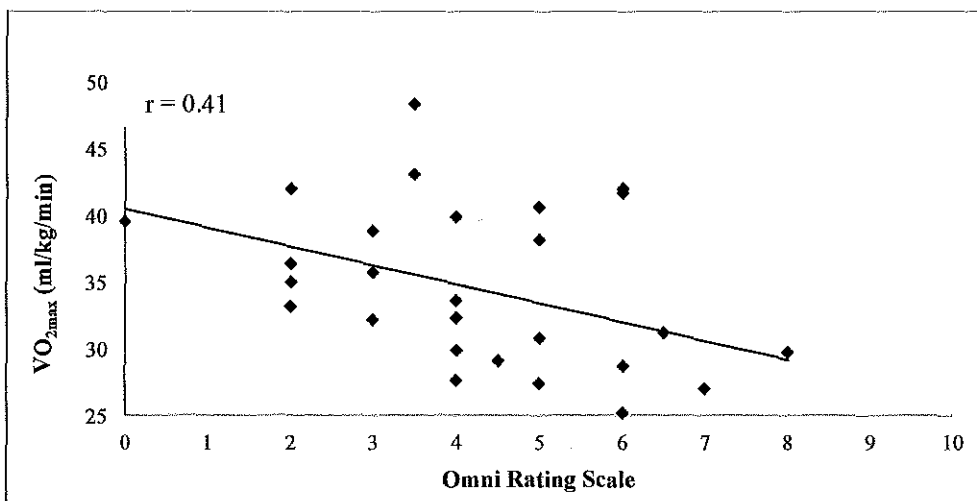


Figure 2a. This figure presents measured  $VO_{2max}$  (ml/kg/min) vs. terminal RPE using the Omni rating scale.

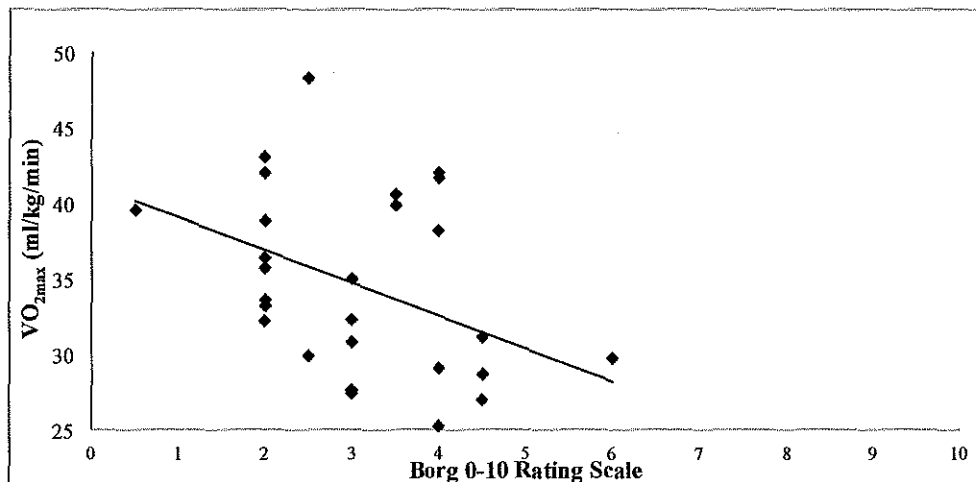


Figure 2b. This figure presents measured  $\text{VO}_{2\text{max}}$  (ml/kg/min) vs. terminal RPE using the Borg 0-10 rating scale.

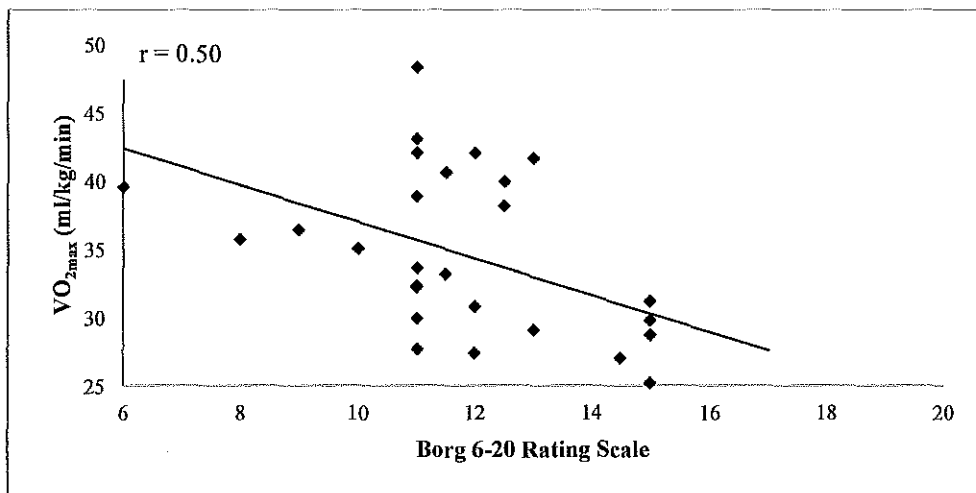


Figure 2c. This figure presents measured  $\text{VO}_{2\text{max}}$  (ml/kg/min) vs. terminal RPE using the Borg 6-20 rating scale.

Figures 3a-c present the comparison of relationships between measured and predicted  $\text{VO}_{2\text{max}}$  using the prediction formula developed based on 6MWD and the terminal RPEs from the three rating scales. The Omni dependent prediction equation used was  $p\text{VO}_{2\text{max}} = 11.517 + 0.045(d) - 1.560(\text{RPE})$  where  $d$  is 6MWD in meters and RPE is from the Omni rating scale ( $\text{SEE} = 4.84$ ). Figure 3a illustrates the moderate relationship ( $R^2 = 0.44$ ) between measured  $\text{VO}_{2\text{max}}$  and predicted  $\text{VO}_{2\text{max}}$  using subjects' terminal Omni RPE from the 6MWT. However, both 6MWD ( $p = 0.002$ ) and terminal



Omni RPE ( $p=0.006$ ) were significant additions to the  $\text{VO}_{2\text{max}}$  prediction equation. The Borg 0-10 dependent prediction equation used was  $p\text{VO}_{2\text{max}} = 11.677 + 0.047(d) - 2.480(\text{RPE})$  where  $d$  is 6MWD in meters ( $\text{SEE} = 4.73$ ). Figure 3b illustrates the moderate relationship ( $R^2 = 0.46$ ) between measured vs. predicted  $\text{VO}_{2\text{max}}$  using the Borg 0-10 rating scale. Like the Omni prediction equation, the addition of 6MWD ( $p=0.001$ ) and the Borg 0-10 RPE ( $p=0.003$ ) significantly contributed to the equation for predicting  $\text{VO}_{2\text{max}}$ . The Borg 6-20 dependent prediction equation used was  $p\text{VO}_{2\text{max}} = 22.496 + 0.044(d) - 1.393(\text{RPE})$  where  $d$  is 6MWD in meters ( $\text{SEE} = 4.56$ ). Figure 3c illustrates a good relationship ( $R^2 = 0.50$ ) between measured vs. predicted  $\text{VO}_{2\text{max}}$  between terminal RPE scores using 6MWD and the Borg 6-20 rating scale. This prediction equation significantly benefits from the addition of 6MWD ( $p=0.002$ ) and the Borg 6-20 terminal RPE ( $p=0.001$ ).

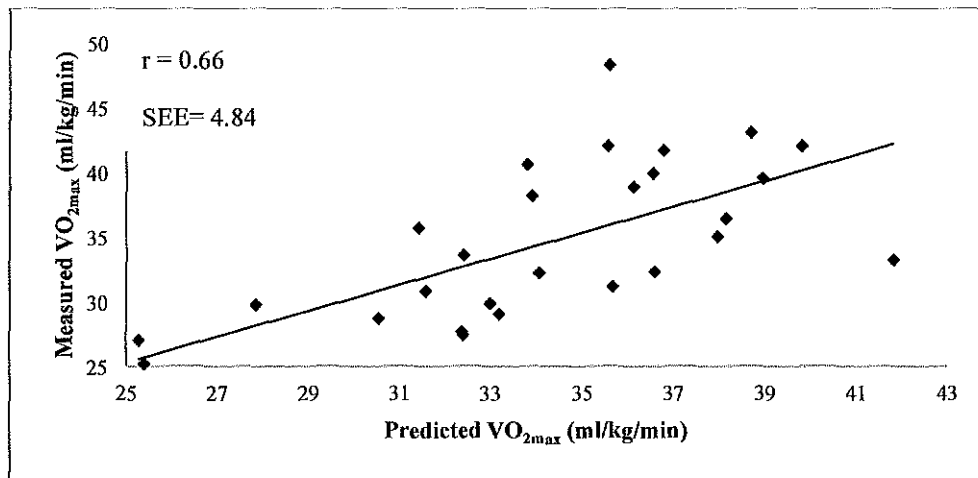


Figure 3a. This figure presents measured vs. predicted  $\text{VO}_{2\text{max}}$  (ml/kg/min) using the Omni dependent prediction equation,  $p\text{VO}_{2\text{max}} = 11.517 + 0.045(d) - 1.560(\text{RPE})$ .

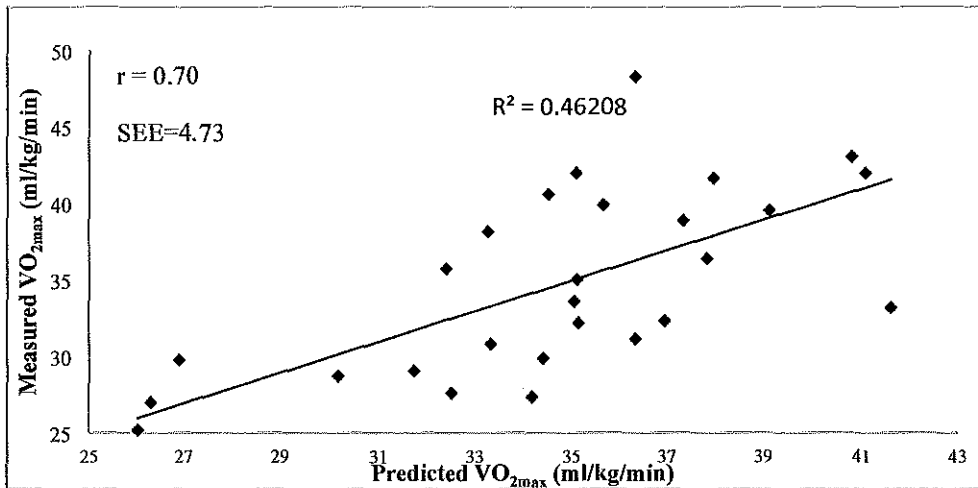


Figure 3b. This figure presents measured vs. predicted  $\text{VO}_{2\text{max}}$  (ml/kg/min) using the Borg 0-10 dependent prediction equation,  $p\text{VO}_{2\text{max}} = 11.677 + 0.047(d) - 2.480(\text{RPE})$ .

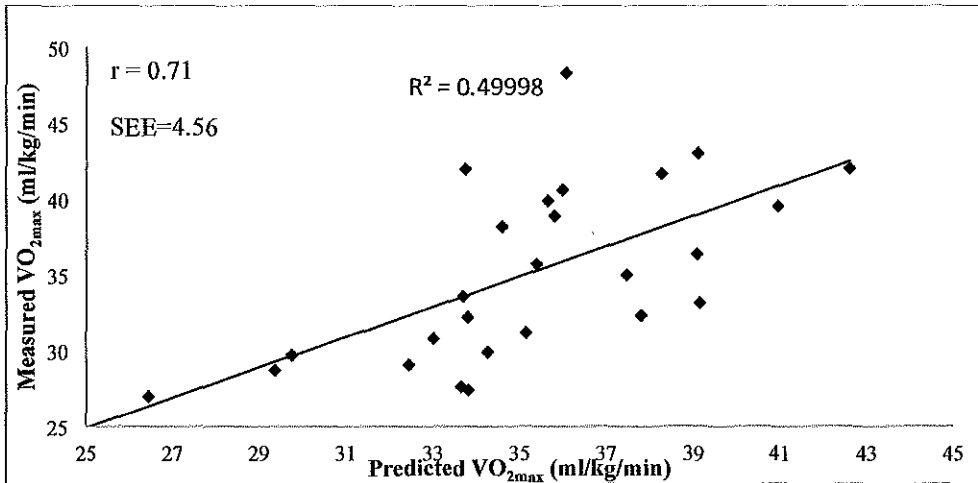


Figure 3c. This figure presents measured vs. predicted  $\text{VO}_{2\text{max}}$  (ml/kg/min) using the Borg 6-20 dependent prediction equation,  $p\text{VO}_{2\text{max}} = 22.496 + 0.044(d) - 1.393(\text{RPE})$ .

A different approach to evaluating the accuracy of a prediction equation is achieved by using residuals. Residuals are calculated by subtracting the predicted from the measured  $\text{VO}_{2\text{max}}$  for each subject. The residuals in this study were then standardized by taking each residual and turning them into a positive number. Figures 4a-c illustrates the residuals vs. the three RPE scales and 6MWD dependent prediction equations. Figure 4a illustrates the residuals from the Omni scale dependent prediction equation vs.

measured  $VO_{2max}$  and had an average ( $\pm$ sd) standardized residual of  $3.79 \pm 2.6$ . Figure 4b illustrates the Borg 0-10 dependent prediction equation vs. measured  $VO_{2max}$  and had an average standardized residual of  $3.60 \pm 2.7$ . Figure 4c illustrates the Borg 6-20 dependent prediction equation vs. measured  $VO_{2max}$  and had an average standardized residual of  $3.33 \pm 2.8$ . Collectively, these averages suggest that all the prediction equations formulated are accurate to within approximately 1 MET.

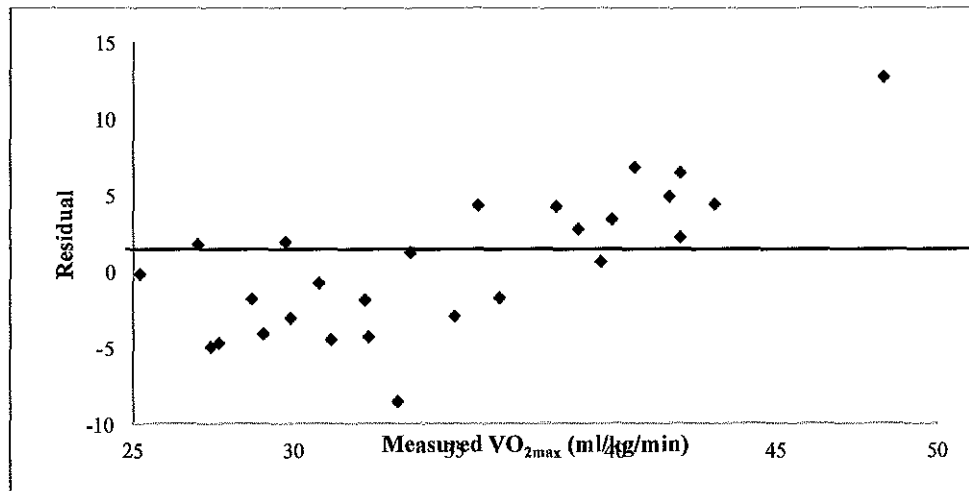


Figure 4a. This figure presents measured  $VO_{2max}$  (ml/kg/min) vs. the residuals using the Omni dependent prediction equation.

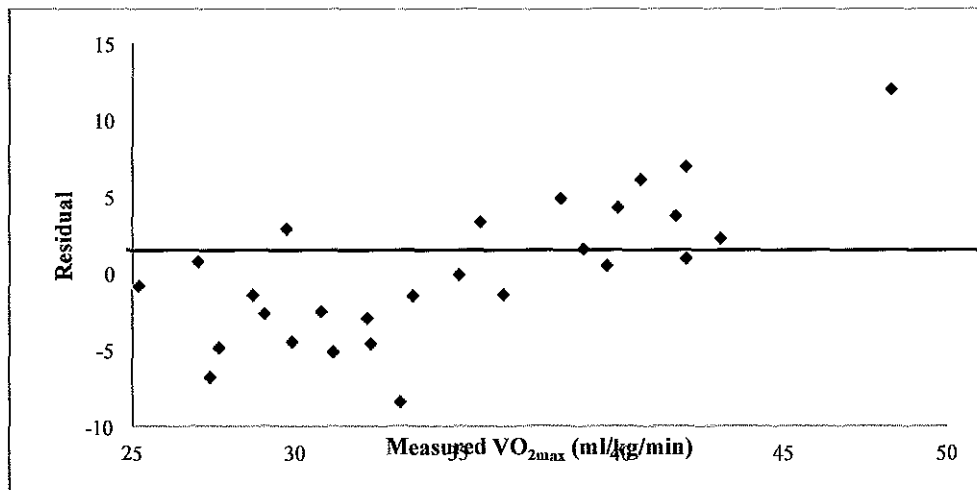


Figure 4b. This figure presents measured  $VO_{2max}$  (ml/kg/min) vs. the residuals using the Borg 0-10 dependent prediction equation.

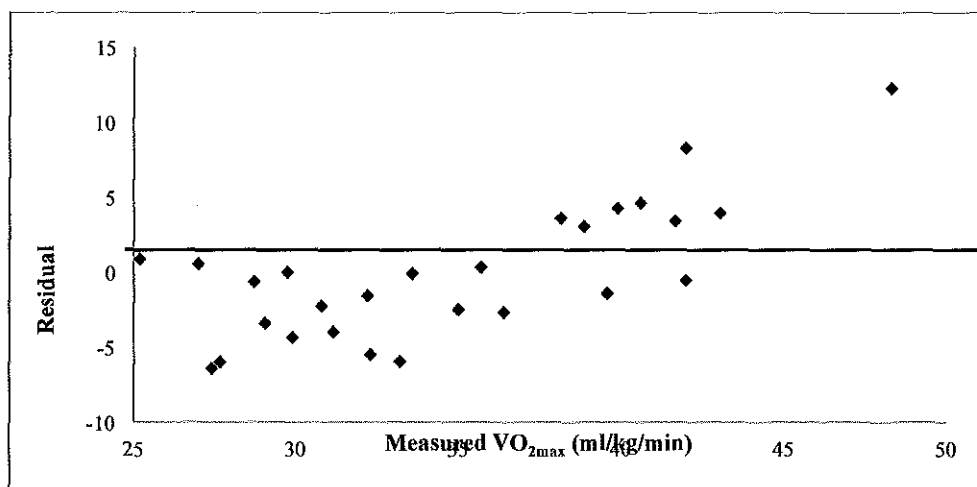


Figure 4c. This figure presents measured  $\text{VO}_{2\text{max}}$  (ml/kg/min) vs. the residuals using the Borg 6-20 dependent prediction equation.

## DISCUSSION

The purpose of this study was to determine if  $\text{VO}_{2\text{max}}$  could be accurately estimated using 6MWD and RPE at the conclusion of the 6MWT. The gold standard for evaluating exercise capacity, creating the exercise prescription, and defining prognosis in patients with chronic disease is  $\text{VO}_{2\text{max}}$  (American College of Sports Medicine, 2013). Direct measurement of  $\text{VO}_{2\text{max}}$  requires maximal exertion and significant technical resources. For healthy people this is somewhat uncomfortable (Foster, et al., 2008). For people with chronic disease, maximal exertion may cause increased risk of complications. Submaximal test protocols that have been used which factor in heart rate-workload relationship (Astrand), the RPE-workload progression (Parfitt, Evans, & Eston, 2012), or walking speed for a certain distance (Kline, et al., 1987). However, they are limited by accuracy, primarily due to the requirement to use predicted  $\text{HR}_{\text{max}}$  or the ability to accurately report RPE. Predicted maximal HR has a very large error (Howley, et al, 1995; Morris, et al., 1993; Robergs, & Landwehr, 2002), which limits its value in predictive tests. The 6MWT test is standardized (American Thoracic Society, 2002), popular in clinical settings, easy to perform, is not limited by handrail support, and by definition is sub-maximal which precludes the need for medical supervision. Individuals with a high exercise capacity should rate a lower terminal RPE value than those with a low exercise capacity.

In this study, a moderate to high correlation was found between measured and predicted  $\text{VO}_{2\text{max}}$  values based on equations using both the 6MWD and terminal RPE. For all three prediction equations it was found that both 6MWD and terminal RPE significantly contributed to the accuracy of the prediction equations. Notably, the Borg 6-20 dependent prediction of  $\text{VO}_{2\text{max}}$  vs. measured  $\text{VO}_{2\text{max}}$  had a better fit than the other two prediction equations. The correlation between terminal RPE and measured  $\text{VO}_{2\text{max}}$  had a low to moderate correlation. There is some variance due to subjects' perception of exertion. Over- or under-rating on any of the three rating scales would affect the overall correlation. However, those ratings may be more consistent and reflect the population as a whole. The residuals vs. measured  $\text{VO}_{2\text{max}}$  had a notable trend in all three rating scale residuals. Subjects who had a lower  $\text{VO}_{2\text{max}}$  tended to be underestimated whereas subjects who had larger  $\text{VO}_{2\text{max}}$  values tended to be overestimated. For all three equations it seemed to be most accurate with  $\text{VO}_{2\text{max}}$  values between 35-40ml/kg/min which was near the median of the population tested.

The Cooper Walk-Run Test (Cooper, 1968) is a suitable test for predicting  $\text{VO}_{2\text{max}}$  with healthy populations. This is supposed to be a maximal effort by the subject for 12 minutes or 1.5 miles. Motivation plays a significant factor in a person's outcome in this test. Cooper (1968) notes that due to the young age of his subjects there is potential that it doesn't work as accurately with older adults. Cooper (1968) had subjects run multiple (at least 2) trials of their field test to average the nearest 2 intervals to acquire more accurate times and distance. The Cooper test (1968) is much longer than the 6MWT and is more strenuous overall. The Cooper Run-Walk Test (1968) would not be

ideal under these circumstances since this study is focused on older adults and older adults with chronic disease.

The Rockport 1-Mile Test is a submaximal test to predict  $\text{VO}_{2\text{max}}$ . However, other researchers had found lower correlations, particularly with studies involving women (Kline, et al., 1987). Although Kline and colleagues (1987) suggest that one trial walk is sufficient, multiple trials were done to negate possible learning effects and “to establish a stable walk time”. The upper age limit suggested for this test was 69 years old (Kline, et al., 1987) which is not always sufficient when working with healthy older adults, cardiac patients and/or other older adults in rehabilitation settings. Also, in some situations this could be a time constraint whereas the 6MWT is a much shorter test, which is much less strenuous overall compared to the Rockport 1 mile test. Lastly, in patients on HR altering medications, the accuracy of the Rockport test would be limited.

The 6MWT is a submaximal test designed to test functional capacity (American Thoracic Society, 2002; Jehn, et al., 2009). The 6MWT allows a variety of people to perform this test with only a few contraindications to performing the test such as chest pain, intolerable dyspnea, leg cramps, diaphoresis, and/or ashen appearance (American Thoracic Society, 2002). The only absolute contraindications are unstable angina and myocardial infarction within the last month (Rasekaba, et al, 2009). Stable angina is not considered an absolute contraindication (American Thoracic Society, 2002). A previous study by Ingle, et al (2005) looked at predicting  $\text{VO}_{2\text{max}}$  using the 6MWT and a modified Bruce protocol (Bruce, et al, 1973). These researchers suggested that clinical incremental tests could not be avoided and attained moderate accuracy with their regression equation. However, Rasekaba, et al (2009) suggested that 6MWT has a strong correlation with

VO<sub>2max</sub>. The present results suggest that reasonable accuracy of predicting VO<sub>2max</sub> may be achievable with 6MWD and terminal RPE.

Normally, the 6MWT is limited due to individual walking mechanics. According to the American Thoracic Society (2002), median performance was 580m for healthy men and 500m for healthy women. The mean (650.42m  $\pm$  70.78m) and median (men= 640m, women= 630m) distances in this sample was well above this median for their respective genders.

A limitation of this study was the variety of subjects. The subjects tested were too fit for the 6MWT which may have affected terminal RPE ratings. Researchers noted subjects' indecision when choosing RPE ratings because the 6MWT evoked mild effort. Also, subjects of close age proximity tended to have similar measured VO<sub>2max</sub> values, which caused a cluster(s) in the VO<sub>2</sub> range instead of having values more normally distributed as intended. Since the 6MWT is generally used with non-healthy populations, such as those in a rehabilitation setting, a more ideal distribution of VO<sub>2max</sub> values would be around 20-25ml/kg/min.

More research still needs to be conducted. This study raises the question of the possible outcome using different populations. Since the 6MWT is used for people with lower functional capacity, researchers suggest the population be in some kind of rehabilitation. A Phase II cardiac or pulmonary rehabilitation may be ideal since this information could be beneficial in prescribing exercise prescription.



## REFERENCES

- American College of Sports Medicine. (2013). *Acsm's guidelines for exercise testing and prescription*. (9th ed.). Lippincott Williams & Wilkins.
- American Thoracic Society. (2002). ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med*, 166, 111-117. Retrieved from <http://www.thoracic.org/statements/resources/pft/sixminute.pdf>
- Arslan, S., Erol, M. K., Gundogdu, F., Sevimli, S., Aksakal, E., Senocak, H., & Alp, N. (2007). Prognostic value of 6-minute walk test in stable outpatients with heart failure. *Texas Heart Institute Journal*, 34(2), 166-169.
- Balke, B. (1960). The effect of physical exercise on the metabolic potential, a crucial measure of physical fitness. *The Athletic Institute*, 73-81.
- Bruce, R. A., Kusumi, F., & Hosmer, D. E. (1973). Fundamentals of clinical cardiology. *American Heart Journal*, 85(4), 546-562.
- Cooper, K.H. (1968) A means of assessing maximal oxygen intake: correlation between field and treadmill testing. *JAMA*. 203(3), 201-204.  
doi:10.1001/jama.1968.03140030033008
- Foster, C., & Cotter, H. M. (2005). *In physiological assessment of human fitness*. (2nd ed.).
- Foster, C., Kuffel, E., Bradley, N., Battista, R., Wright, G., Porcari, J. P., Lucia, A., & deKoning, J. J. (2007).  $\text{Vo}_2\text{max}$  during successive maximal efforts. *Eur J Appl Physiol*, 102, 67-72.
- Foster, C., Porcari, J. P., Battista, R. A., Udermann, B., Wright, G., & Lucia, A. (2008). The risk in exercise training. *American Journal of Lifestyle Medicine*, 1-6.

- Gibbons, R. J., Balady, G.J., Beasley, J.W., Bricker, J.T., Duvernoy, W.F.C., Froelicher, V.F., Mark, D.B., Marwick, T.H., McCallister, B.D., Thompson, P.D., Winters, W.L., & Yanowitz, F.G. (1997). Acc/aha guidelines for exercise testing: executive summary. *American Heart Association*, Retrieved from <http://circ.ahajournals.org/content/96/1/345.full>
- Guyatt, G. H., Pugsley, S. O., Sullivan, M. J., Thompson, P. J., Berman, L., Jones, N. L., Fallen, E., & Taylor, D. W. (1984). Effect of encouragement on walking test performance. *Thorax*, (39), 818-822.
- Haskell, W. L., Savin, W., Oloridge, N., & DeBusk, R. (1982). Factors influencing estimated oxygen uptake during exercise testing soon after myocardial infarction. *The American Journal of Cardiology*, 50, 299-304.
- Howley, E. T., Bassett, D. R., J., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *American Journal College of Sports Medicine*, 1292-1301.
- Ingle, L., Goode, K., Rigby, A. S. R., Cleland, J. G. F., & Clark, A. L. (2005). Predicting peak oxygen uptake from 6-min walk test performance in male patients with left ventricular systolic dysfunction. *The European Journal of Heart Failure*, 8, 198-202.
- Jehn, M., Halle, M., Schuster, T., Hanssen, H., Weis, M., Koehler, F., & Schmidt-Trucksass, A. (2009). The 6-min walk test in heart failure: is it a max or sub-maximum exercise test?. *Eur J Appl Physiol*, 107, 317-323.
- Kirkberg, J. M., Dalleck, L. C., Kamphoff, C. S., & Pettitt, R. W. (2011). Validity of 3 protocols for verifying vo2max. *Int J Sports Med*, 32(4), 266-270.
- Kline, G. M., Porcari, J. P., Hintermeister, R., Freedson, P. S., Ward, A., McCarron, R. F., Ross, J., & Rippe, J. M. (1987). Estimation of vo2max from a one-mile track walk, gender, age, and body weight. *Medicine and Science in Sports and Exercise*, 19(3), 253-259.
- Levine, B. D. (2008). Vo2max: what do we know, and what do we still need to know?. *J Physiol*, 586(1), 25-34.
- McConnell, T. R., Foster, C., Conlin, N. C., & Thompson, N. N. (1991). Prediction of functional capacity during treadmill testing: Effect on handrail support. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 11(4), 255-260.

- Mezzani, A., Hamm, L.F., Jones, A.M., McBride, P.E., Moholdt, T., Stone, J.A., Urhausen, A., & Williams, M.A. (2012). Aerobic exercise intensity assessment and prescription in cardiac rehabilitation. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 32, 327-350.
- Morris, C. K., Myers, J., Froelicher, V. F., Kawaguchi, T., Ueshima, K., & Hideg, A. (1993). Nomogram based on metabolic equivalents and age for assessing aerobic exercise capacity in men. *JACC*, 22(1), 175-182.
- Myers, J., Buchanan, N., Walsh, D., Kraemer, M., McAuley, P., Hamilton-Wessler, M., & Froelicher, V. F. (1991). Comparison of the ramp versus standard exercise protocols. *Journal of the American College of Cardiology*, 17(6), 1334-1342.
- Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S., & Atwood, J.E. (2002). Exercise capacity and mortality among men referred for exercise testing. *The New England Journal of Medicine*, 346(11), 793-801.
- Parfitt, G., Evans, H., & Eston, R. (2012). Perceptually regulated training at rpe13 is pleasant and improves physical health. *Medicine & Science in Sports & Exercise*, 44(8), 1613-1618.
- Ragg, K. E., Murray, T. F., Karbonit, L. M., & Jump, D. A. (1980). Errors in predicting functional capacity from a treadmill exercise stress test. *American Heart Journal*, 581-583.
- Rasekaba, T., Lee, A. L., Naughton, M. T., Williams, T. J., & Holland, A. E. (2009). The six-minute walk test: a useful metric for the cardiopulmonary patient. *Internal Medicine Journal*, 39, 495-501.
- Robergs, R. A., & Landwehr, R. (2002). Prediction of maximal heart rate. *JEP*, 5(2), 1-10.
- Shephard, R. J., Allen, C., Benade, A. J. S., Davies, C. T. M., Prampero, P. E., Hedman, R., Merriman, J. E., Myhre, K., & Simmons, R. (1968). The maximum oxygen intake: an international reference standard of cardiorespiratory fitness. *Bull. Wld Hlth Org.*, 38, 757-764.

APPENDIX A  
INFORMED CONSENT

## **Informed Consent for Predicting VO<sub>2</sub>max for Older Adults using RPE and the 6-Minute Walk Test**

**Principal Investigator:** Hannah Brown  
802 S 7<sup>th</sup> St Apt. 5  
La Crosse, WI 54601

**Emergency Contact:** Dr. Carl Foster  
608-785-8687  
133 Mitchell Hall

### ***Purpose and Procedure***

- The purpose of this study is to use information from a sub-maximal exercise test (heart rate, RPE) to predict maximal exercise capacity.
- Participation will involve a maximal exercise capacity test, during which participants will walk on a treadmill to fatigue, and a 6-Minute Walk Test (6MWT) per American Thoracic Society (ATS) guidelines. Heart rate will be monitored continuously using a chest strap. The maximal exercise test will involve progressive (increasingly harder) stages in grade with a constant speed (grade increases 2% every 2minutes). The 6MWT will be 100ft in length and performed on a firm and smooth surface by walking laps back and forth in a hallway. Both tests could potentially cause fatigue, muscle soreness, shortness of breath, heart arrhythmia, heart attack, stroke, and/or death.
- During the maximal test, a scuba type mouth piece will be worn to collect gas exchange, rating of perceived exertion (RPE), blood pressure, and heart rate will be asked and recorded before the end of each stage. At the conclusion of the 6MWT, the participant will immediately have their RPE recorded and distance walked measured.
- The total time required is estimated to be less than two hours. Forty-eight hours will be given between the two tests to ensure maximal recovery.

### ***Potential Risks***

- Individuals trained in CPR, Advanced Cardiac Life Support and First Aid will be in the laboratory, and the test will be terminated if complications occur.
- I may experience muscle soreness, substantial fatigue, heart arrhythmia, heart attack, stroke, and/or death.
- The risk of serious or life-threatening complications, for healthy individuals is near zero. The risk of serious or life-threatening complications in individuals with known cardiac diseases is low.

***Rights & Confidentiality***

- My participation is voluntary. I can withdraw from the study without penalty at any time.
- The results of this study may be published in scientific literature or presented at professional meetings using grouped data only.
- All information will be kept confidential through the use of number codes.  
My data will not be linked with personally identifiable information.

***Possible Benefits***

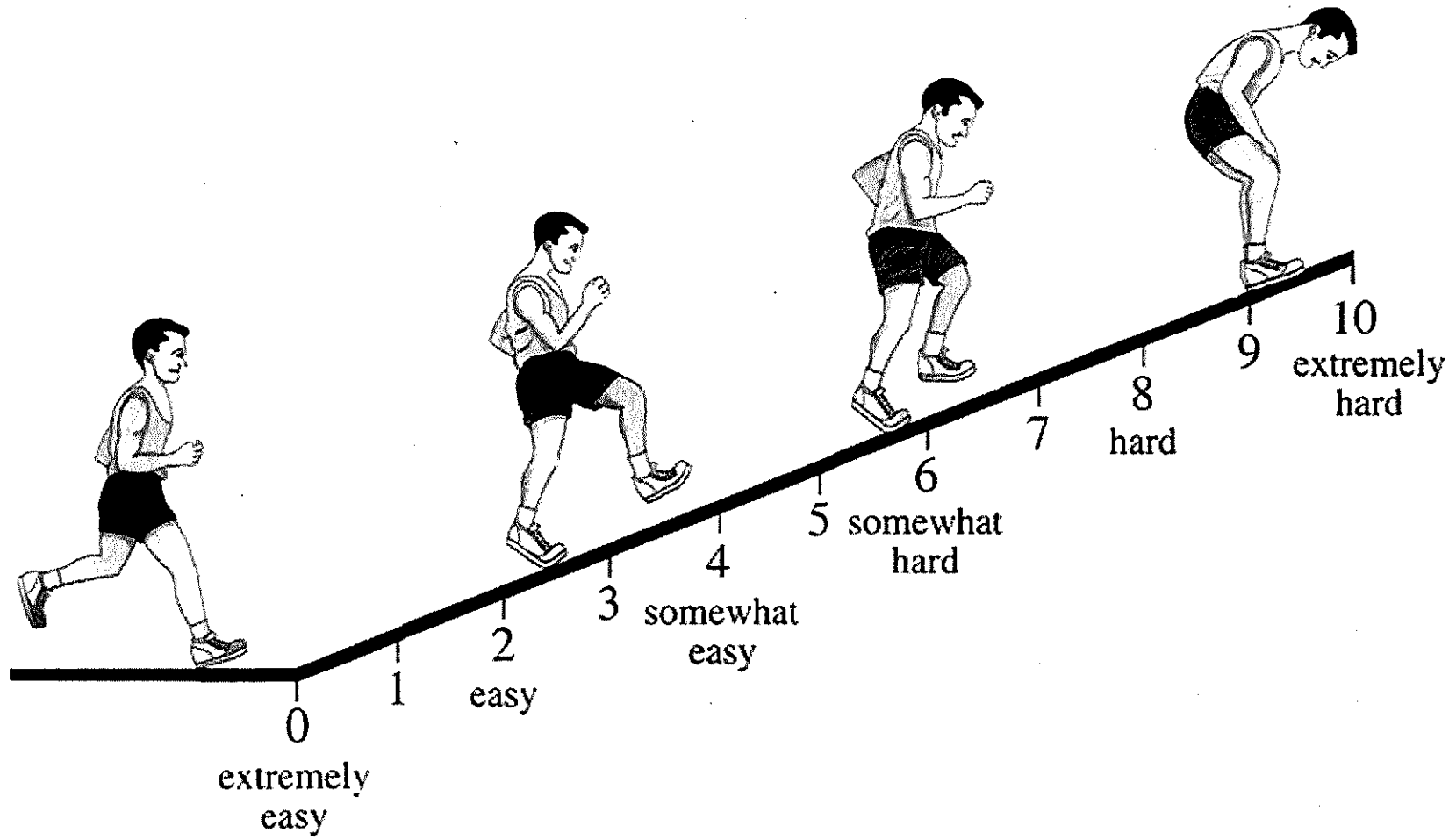
- Having aerobic capacity ( $VO_{2max}$ ) measurements could facilitate exercise prescription guidelines.
- This information could possibly motivate subject to start and/or continue active lifestyle.

Questions regarding study procedures may be directed to Hannah Brown (262-903-9978), the principal investigator, or the study advisor Dr. Carl Foster, Department of Exercise and Sport Science, UW-L (608-785-8687). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects, (608- 785-8124 or [irb@uwlax.edu](mailto:irb@uwlax.edu)).

Participant \_\_\_\_\_ Date \_\_\_\_\_

Researcher \_\_\_\_\_ Date \_\_\_\_\_

**APPENIDX B**  
**RATING OF PERCEIVED EXERTION SCALES**





# PERCEIVED EXERTION SCALE

0.0

NO EFFORT  
(STANDING AT REST)

0.5

VERY, VERY EASY

1

VERY EASY

2

EASY

3

MODERATE

4

SOMEWHAT HARD

5

HARD

6

7

VERY HARD

8

9

VERY, VERY HARD  
(NEARLY MAXIMAL)

10

MAXIMAL

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
17	VERY HARD
18	
19	VERY, VERY HARD
20	

APPENDIX C

6 MINUTE WALK PROTOCOL

## **ATS PROTOCOL FOR 6MWT**

### **Speech Pre-walk:**

“The object of this test is to walk as far as possible as for 6 minutes. You will walk back and forth in this hallway. Six minutes is a long time to walk, so you will be exerting yourself. You will probably get out of breath or become exhausted. You are permitted to slow down, and to rest as necessary. You may lean against the wall while resting, but resume walking as soon as you are able.

You will be walking back and forth around the cones. You should pivot briskly around the cones and continue back the other way without hesitation. Now I’m going to show you. Please watch the way I turn without hesitation.

Are you ready to do that? I am going to use this counter to keep track of the number of laps you complete. I will click it each time you around at this starting line. Remember that the object is to walk as far as possible for 6 minutes, but don’t run or jog.”

### **During Walk:**

@ 1min: “You are doing well. You have 5 minutes to go.”

@ 2min: “Keep up the good work. You have 4 minutes to go.”

@ 3min: “You are doing well. You are halfway done.”

@ 4min: “Keep up the good work. You have only 2 minutes left.”

@ 5min: “You are doing well. You only have 1 minute to go.”

@ 5:45: “In a moment I’m going to tell you to stop. When I do, just stop right where you are and I will come to you.”

APPENDIX D

INCREMENTAL TREADMILL DATA COLLECTION SHEET

Name \_\_\_\_\_ Subject # \_\_\_\_\_ Date \_\_\_\_\_

### Modified Balke Protocol

Speed: \_\_\_\_\_ mph Height: \_\_\_\_\_ Weight: \_\_\_\_\_ Rest BP: \_\_\_\_\_ Rest HR: \_\_\_\_\_

Stage 1: 0% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 2: 2% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 3: 4% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 4: 6% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 5: 8% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 6: 10% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 7: 12% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 8: 14% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 9: 16% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 10: 18% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 11: 20% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 12: 22% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 13: 24% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 14: 26% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 15: 28% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 16: 30% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 17: 32% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 18: 34% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 19: 36% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

Stage 20: 38% HR: \_\_\_\_\_ BP: \_\_\_\_\_ RPE: \_\_\_\_\_

APPENDIX E

6 MINUTE WALK DATA COLLECTION SHEET

Name: \_\_\_\_\_ Subject#: \_\_\_\_\_

Date: \_\_\_\_\_

### **6 Minute Walk Test**

Distance Walked: \_\_\_\_\_

RPE Borg: \_\_\_\_\_

RPE 6-20: \_\_\_\_\_

Omni Scale: \_\_\_\_\_

HR:

Pre: \_\_\_\_\_

Post: \_\_\_\_\_



APPENDIX F  
REVIEW OF RELATED LITERATURE

## **REVIEW OF RELATED LITERATURE**

### **Introduction**

This study was designed to provide evidence for a simple way to estimate exercise capacity, using the Rating of Perceived Exertion (RPE) and the 6-Minute Walk Test (6MWT). The Rating of Perceived Exertion is an accepted subjective measurement of exercise intensity (Parfitt, Evans, & Eston, 2012). The RPE scale has been found to be non-gender specific (Faulkner & Eston, 2007). Parfitt, Evans and Eston conducted an 8-week exercise program with the intensity clamped at RPE13 (somewhat hard) for both sedentary and active participants (Parfitt, Evans, & Eston, 2012). They found that both active and sedentary groups, “improved cardiovascular health and fitness” and that exercise was perceived as “pleasant” (Parfitt, Evans, & Eston, 2012). Notably, the percentage of  $VO_{2max}$  measured while participants exercised was “borderline” for ACSM standards of moderate to vigorous intensity (Mezzani, et. al, 2012; Parfitt, Evans, & Eston, 2012) and yet exercise capacity improved. Eston, Lamb, Parfitt and King found that using RPE 9-17 in submaximal trials, exercise could be extrapolated to RPE 20, with a reasonable estimate of maximal intensity.

The goal of this study was to determine if adding RPE to the 6 Minute Walk Distance (6MWD) is an effective adjunct to predicting  $VO_{2max}$  in older adults and cardiac patients.

### **Why $\text{VO}_{2\text{max}}$ is important**

Mitchell, Sproule, and Chapman (1957) took 65 “normal men” and tested them on a motorized treadmill. There was a 10 minute warm up followed by 10 minutes of rest. The first test was at 6mph with no grade. Expired air was collected in a Douglas bag. After a 10 minute rest the next run was at the same speed with a 2.5% grade. This sequence continued until the “oxygen intake leveled off”. With the healthy young subjects, a lot of unnecessary time was spent and some people did not reach maximal uptake ( $\text{VO}_{2\text{max}}$ ) at the highest grade. Maximal oxygen uptake is still subjects to debate with suggestions that  $\text{VO}_{2\text{max}}$  is only maximal relative to the set of conditions that are carefully defined. They found that  $\text{VO}_{2\text{max}}$  decreases with age and “ventilation reaches its highest value at maximal oxygen uptake level”. Maximal oxygen uptake is “dependent on both cardiac output and AV oxygen difference” (Mitchell, Sproule, & Chapman, 1957). In determining the physiological meaning of  $\text{VO}_{2\text{max}}$ , researchers suggest that the “ability to increase cardiac output” is the most important factor.

Balke (1960) defined physical fitness as having two main factors, “size of physical reserves” and “general adaptability to great physical demands”. Balke suggested that physical fitness is dependent on the “individual’s biodynamic potential” which is made up of functional and metabolic potentials. Therefore, the best way to test this would be to “survive under extraordinary biological demands”. Functional limitations become “apparent” when HR is raised to around 180bpm. Ventricular filling time is short, which may cause stroke volume to decrease, which means the individual has probably also reached maximum capacity for breathing. The relationship between  $\text{VO}_2$  and work intensity is linear. Balke had subjects walk/run on a treadmill and outside.

Balke used the treadmill data to predict outdoor run times. Participants ranged from sedentary to very active. Balke found that trained men utilized fat better and that the trained men rarely achieved complete exhaustion because they could continue at a reduced activity level. Balke tested about 700 men for  $VO_{2max}$  (18-65yrs). His findings were that individuals who are sedentary will “diminish” faster as well as have a harder time when they are older. For subjects who performed a variety of physical activities, they diminished slower and overall had greater potential as they age. These individuals can also successfully compete with younger generations. Balke suggests that if the world had to go back to before civilization, about 75% of the men would not survive and suggests that more chances need to be given for people to “employ adaptive capacities”.

Kenneth Cooper (1968) looked at maximal oxygen uptake in the field versus treadmill training. Cooper used 115 U.S. Air Force men; average age was 22. The 12-minute run was performed on a hard, flat, accurately measured 1-mile surface. Each subject ran this test at least twice. Cooper compared the  $VO_2$  for the two nearest intervals of the 12-minute run. The treadmill test was done no later than 72hrs after the field test. Gas collection was by 200-liter Douglas bag or Tissot gasometer. The treadmill protocol consisted of 3 minute runs with a 10 minute rest period. Speed and incline were adjusted based on the subject’s physical fitness. Gas collected during the last 2 minutes of each stage. There was a good correlation of the data was 0.897 which suggests that this regression equation is a good predictor of  $VO_{2max}$ . Motivation was sighted as a factor for distance variances. Cooper cites the younger age of his subjects as a possible issue with using this equation with older adults. Cooper states that the walk-run test can be

performed in large groups and is much more cost efficient than treadmill lab testing. This test is a good indicator of physical fitness and/or a measuring tool for changes in fitness.

Shephard, et al. (1968) conducted a study on  $VO_{2max}$  using stepping, cycling and treadmill running. There were 24 subjects with activity levels from sedentary to “university class athletes”. Each subject had 2 weeks of preliminary conditioning. The step test was an 18 inch step with the stepping rate controlled by a metronome at 80-140 paces/min; dependent on the subject’s fitness. The cycle ergometer was controlled at 40-90rpm, dependent on fitness. Treadmill uphill running was at speeds of 5-6mph with grades of 1-18%, dependent on fitness. The researchers found that  $VO_{2max}$  had been achieved when workload was increased but  $VO_2$  increased by less than 2ml/kg/min. The treadmill elicited a higher oxygen uptake than stepping and cycling by 3.4% and 6.6%, respectively. Maximum cardiac output and stroke volume were significantly greater on the treadmill than on the cycle ergometer. The limiting factor for the treadmill was thought to be central exhaustion.

Haskell, W. L., Savin, W., Oloridge, N., & DeBusk, R. (1982) conducted an experiment testing how applicable exercise tests were at predicting  $VO_2$  in adults shortly after having a myocardial infarction. Researchers tested in two groups; Group I and Group II. Group I had 22 men who used a “standard modified Balke protocol”, which involved 3miles/hr with 2.5 percent increase in grade every 3 minutes. Group II consisted of 25 men who were “clinically similar” and used the same protocol but accelerated, increasing 5 percent in grade every 3 minutes. The participants tested after at least two hours after their last meal and did not take their medication(s), until after the test. Both groups were tested at 3 and 11 weeks post-acute MI. The tests were symptom-

limited. At 3 weeks Group I and Group II's estimated and measured peak  $\text{VO}_2$  were nearly indistinguishable. This was also true at 11 weeks post acute event. However, the estimated peak  $\text{VO}_2$  was significantly higher than measured in the accelerated group at 11 weeks. Holding onto the railings on the treadmill caused a significant increase in estimated peak  $\text{VO}_2$  but did not change measured  $\text{VO}_2$ . When handrails were not used during the test, observed and estimated  $\text{VO}_2$  peak values were nearly identical. It was found that if exercise intensity increases rapidly, "oxygen transport lags behind oxygen requirements, with a greater portion of the energy demand being met anaerobically". This study found that after having a myocardial infarction, exercise capacity could be estimated from the data of healthy adults. However, exercise intensity must be increased slowly and holding handrails must be avoided.

Myers, et al. (1991) conducted a comparison study on "the hemodynamic and gas exchange response of ramp treadmill and cycle ergometer tests with standard exercise protocols used clinically". The patients who participated had chronic heart failure (10), asymptomatic coronary artery disease (CAD) (10), CAD limited by angina while exercising, and "age-matched normal" participants (10) for a total of 41 subjects. All participants performed 6 tests in a random order on separate days. Participants continued with routine medications. The study used the standard Bruce, modified Balke (2mph/0%grade for first 2min. then increasing to 3mph/0%grade for second stage followed by subsequent 2.5% increments in grade hence forth), and the individualized ramp treadmill test (ramp rate set to produce an approximately 10min. test duration) for the treadmill protocols. For the cycle ergometer, the study used the "25W per 2min. stage, 50W per 2 min. stage and an individualized ramp cycle ergometer test" with the

rate set to produce an approximately 10min. test duration. The ramp rate for both treadmill and cycle ergometer was determined by the individual's  $VO_{2max}$  from the baseline test. Participants with angina stopped when they reached a 3 on 5 Point rating scale. Gas exchange was monitored continuously. "Maximal oxygen uptake was 16% greater on the treadmill" compared to the cycle ergometer. Maximal HR was not significantly different. Within the protocols used for treadmill and ergometer, respectively, there was no significant difference in  $HR_{max}$  or  $VO_{2max}$ . These findings give support to previous studies on the topic.

Metabolic equivalent (METS) are a simplified measure of  $VO_2$ , converting it to multiples of an assumed resting  $VO_2$  (Morris, Myers, Froelicher, Kawaguchi, Ueshima, & Hideg (1993). The USAFSAM treadmill protocol was used with no handrail support. The group that performed the GXT with gas analysis followed a ramp protocol. Gas analysis was only used with healthy participants. The two groups were of sedentary and active populations. The nomograms created aided in updating the Bruce nomogram to help in the clinical setting.

The primary criterion for  $VO_{2max}$  is the plateau of  $VO_2$  with the increase in workload (Howley, Bassett, & Welch, 1995). Researchers note however, that it is not "uncommon" to have participants on a treadmill or cycle ergometer to perform a max GXT and not reach a plateau in  $VO_2$ . To ensure max efforts, blood lactate levels, elevated respiratory exchange ratio and a percentage of predicted max HR achieved are also monitored. One problem noted is that the Fick equation is "technically valid only during the steady state". Researchers note errors that could affect value outcomes with both Douglas bag and electronic/automated systems. Children, people with low fitness

and older adults have a more difficult time achieving the plateau seen in other populations. When adding in the secondary criterion, it is not known how to best utilize the criterion in the findings/replacement of a plateau. Researchers note this could be due to the attempts of generalizing and making standards for all protocols based on one protocol. The researchers note that continuous protocols are suggested to measure  $\text{VO}_{2\text{max}}$  accurately. The researchers suggest the possibility of making guidelines on how to set up gas analyzers and reference the 1975 ACSM guidelines on GXT and prescription. Terminology was noted to need standardization.

Robergs and Landwehr (2002) provided insight on the prediction of max HR. Age-predicted max HR has been used since 1938 but since 1971 research has shown error with this prediction method. Currently, there is no formula that has acceptable accuracy for predicting max HR. Research has shown that HR does have a max in each individual and that during incremental exercise, increases in intensity increases CO, which is mirrored by an increase in HR. Previous research on predicted max HR was either not published and/or articles had improper citations making follow up in this article difficult. The data from previous research shows that there is large error in predicted HR when using y-intercept, slope, and age is the only independent variable. The article suggests that predicted max HR is accurate within 2bpm if max is truly attained. The researchers suggest to making their own HR prediction equation for specific populations. However, they suggest the Inbar equation is the most accurate overall, but still yields too high of an error.

Foster & Cotter (2005) “noted that VE increases disproportionately during exercise at about the time that blood lactate begins to increase”. The researchers note that



VT<sub>2</sub> is difficult to detect in “slowly incremental exercise”. The researchers also mention that previous data suggest collecting 2min of resting data before starting the protocol. “In most settings, the individual anaerobic threshold is a good measure of sustained exercise, the maximal steady state”. The researchers state that, “the power output and heart rate at the point of deflection of the heart rate performance curve (HRPC) have independently shown to be associated with the second threshold”. Therefore, the “discontinuity in blood lactate accumulation and ventilation during exercise may be used as indicators of endurance capacity and guideline for exercise testing”.

In 2007, Foster and colleagues looked at  $\text{VO}_{2\text{max}}$  during successive maximal efforts using a cycle ergometer and treadmill. The ergometer had a short recovery period between bouts whereas the treadmill had longer recovery between the two bouts. All participants for Group I were active but not considered athletes. Group II were well-trained cross-country runners or triathletes. Group I and Group II did not have significantly different oxygen uptake and  $\text{HR}_{\text{max}}$  values for their bouts.  $\text{V}_E$  in Group I was larger in the second bout, but  $\text{V}_{E\text{max}}$  was not significantly different for Group II. Research suggests that there is no difference in  $\text{VO}_2$  for duration of rest between exercise bouts. This study supports the classical assumptions on  $\text{VO}_2$ . It also supports the central governor model but that it may not be expressed until after “the capacity of the oxygen transport system has been exceeded”.

There are some risks in exercise training and/or exertional tests. According to the article by Foster, Porcari, Battista, Udermann, Wright, and Lucia (2008), exercise-related complications are usually seen in people with heart disease, usually around or after age 40. Sudden death happens in people who are asymptomatic and rupture a plaque due to

exertion. The article states that “most exertion-related complications are related to acute coronary syndromes”. Complications in adults during testing are about 3/10,000 hours. The complication rate for adults with known CAD during exercise training is about 20 times less than exercise testing. Myocardial infarction triggering can be observed in sedentary people during heavy exercise intensity that they are not used to. Prescreening is not done enough in facilities that are not associated with a rehabilitative setting and should be used more for the safety of exercisers and business owners. Exercise risk comes from the intensity of the exercise(s) performed.

Levine’s (2008) article on  $VO_{2max}$  states that the classical thought is that  $VO_{2max}$  is due to maximal rates of oxygen utilization in the skeletal muscles. The muscles are limited by the body’s ability to deliver oxygen to accommodate the muscles working. Levine states that due to the central governor model that true  $VO_{2max}$  “does not reflect true maximal effort” because people choose to not use these reserves. Levine discusses the controversy of the plateau in  $VO_{2max}$  incremental tests for certain populations. Levine notes the research by Hawkins and colleagues that puts to rest the controversy of  $VO_{2max}$ . The article stresses that someone with CAD is regularly stressed beyond the threshold of their myocardial ischemia, but “does not prevent them from continuing to exercise”. Levine attributes a high  $VO_{2max}$  in athletes due to their large CO. Endurance performance of any individual may be dependent on their  $VO_{2max}$  values (i.e. elite athlete vs. recreational). This is dependent on oxygen available and individual fitness. Recent research suggests that some portion of  $VO_{2max}$  may be hereditary. Levine notes that everyone is different and some are more ‘gifted’ than others. Levine also suggests that the reason we stop at a certain point is due to failures in the body, locally in the muscles.

To have a true  $\text{VO}_{2\text{max}}$  it must be verified. Kirkeberg, Dalleck, Kamphoff, and Pettitt (2011) discuss the validity of 3 protocols to validate  $\text{VO}_{2\text{max}}$ . Healthy participants ran 3 exercise trials varying in predicted maximal exercise test. The duration of the GXT did not show significant differences in mean  $\text{VO}_{2\text{max}}$ . The middle duration (10min) had the most consistent max and verified max values for HR and  $\text{VO}_2$ . No order effect was observed.

Recently, Mezzani, Hamm, Jones, McBride, Moholdt, Stone, Urhausen, and Williams (2012) published a paper on exercise prescription in cardiac rehabilitation. “Peak  $\text{VO}_2$ , first and second ventilatory threshold are the gold standard references for the evaluation of aerobic metabolism function, exercise assessment and prescription” according to the researchers. First ventilatory threshold ( $1^{\text{st}}\text{VT}$ ) is considered when, “blood lactate, and pH start to increase and decrease, respectively”. The second ventilatory threshold is achieved around 70-80% peak  $\text{VO}_2$  and 80-90% peak HR. In trained participants, the steady state is achieved quickly versus sedentary, older populations, and those with chronic disease during the constant work rate (CWR) of light to moderate exercise (>30-40 minutes). In moderate to high-intensity exercise, “ $\text{VO}_2$  and HR steady-states are reached at higher levels according to the  $1^{\text{st}}\text{VT}$   $\text{VO}_2$  versus work rate (WR) relationship”. In this state, muscle becomes less efficient and oxygen cost is increased, which is why the steady state duration decreases for this stage of exercise intensity. High to severe intensity exercise is sustainable for a total of about 3-20 minutes. A steady state is not possible at this level but can be used for interval training. Constant work rate “means that  $\text{VO}_2$  changes not only as a function of WR, but also as a function of time in these domains”. Severe to extreme exercise intensity can be sustained

for less than 3 minutes. There is a “linear relationship between HR and both  $\text{VO}_2$  and WR increasing during incremental exercise”. The Rating of Perceived Exertion (RPE) is commonly used as an indicator for patients who cannot obtain a reliable exercise HR. Differences in the RPE for leg or arm exercises are also a noted use. Several articles support RPE use and show no difference for patients on or off beta-blockers. A drawback however, is the variance of patient’s physiologic response versus their idea of RPE, and also versus the test administrator’s observation at times. Positive effects can be seen in training as low as 40% of peak  $\text{VO}_2$  for 20-30min, 3 times per week in cardiac patients. A RPE of 13 is considered to be “light to moderate” via ACSM standards. It is still undecided whether to follow “threshold-based” or “range-based” aerobic exercise but an incremental GXT is emphasized, if possible, before suggesting exercise prescription to patients.

In summary,  $\text{VO}_2$  is based on oxygen uptake during rest and exercise. It is also dependent on cardiac output and stroke volume. The relationship between work intensity and  $\text{VO}_2$  is linear. In a study it was found that trained versus untrained men utilize fat better and have better overall endurance due to their ability to continue to work at a reduced activity level. It also states that those who are active slow the progression of aging. Using a treadmill for lab testing was found to result in higher values of  $\text{VO}_2$  and  $\text{VO}_{2\text{max}}$ . Treadmill exercise is believed to be limited by central exhaustion. Research suggests that too large of an increase during incremental  $\text{VO}_{2\text{max}}$  testing causes oxygen intake to lag behind allowing for some of the exercise to be performed anaerobically; therefore smaller increments should be used to ensure  $\text{VO}_{2\text{max}}$  is being collected accurately.

### **Lab experiments done**

Bruce, Kusumi, and Hosmer (1973) reported a study on the “functional aerobic impairment in cardiovascular disease” by measuring with  $\text{VO}_2$ . Bruce, Kusumi, and Hosmer took 295 participants who were normal healthy men and women, and cardiac men. The test used a calibrated motor-driven treadmill and stages began at 1.7mph, 10% grade and increased every 3 minutes without resting until fatigue or other limiting factors. Blood pressure was taken during each stage and again after the participant sat five minutes post test. No handrail support was allowed except for 1-2 fingers placed on the rail to keep body position centered on the treadmill. Weight bearing on handrails was not permitted. Participants had their nose occluded while air was collected into a series of neoprene-evacuated balloons; “each bag opened for 60 seconds “ via inlet valve. After the first five minutes, researchers observed that “aerobic requirement” to continue was essentially linear. The researchers found this test to “be safe and reliable to measure  $\text{VO}_{2\text{max}}$  physiologically and to estimate it clinically”. Higher  $\text{VO}_{2\text{max}}$  values were measured on the treadmill versus the cycle ergometer or step test. The estimation of  $\text{VO}_{2\text{max}}$  testing is dependent on gender more than the activity level of healthy participants. According to the researchers, “... $\text{VO}_{2\text{max}}$  closely reflects the limitations in maximal cardiac output, because of the reduction in stroke volume as well as in heart rate”.

Froelicher, Thompson, Davis, and Triebwasser, (1975) conducted a comparative study of the Bruce and Balke protocols for the treadmill while also looking at the nomogram for predicting peak  $\text{VO}_2$  following the Bruce protocol. The study had an almost equal number of volunteers for each protocol (Bruce=77, Balke=79). The study

states that, “maximal oxygen consumption is linearly related to maximal cardiac output”. However, gas collection is “costly and tedious”. Balke tests took place in the morning while the Bruce tests were performed in the afternoon; all participants fasted 5 hours prior to testing. No handrail support was permitted. Group A was considered to be sedentary, Group B performed moderate activity (20min 2-3x/wk), and Group C were heavy exercisers. Groups B and C were later combined due to no significant differences between the two groups’ data. Air from the tests was collected in weather balloons with valves. There were no significant differences in maximal HRs between the Bruce and Balke protocols. The Bruce exercising group had a greater mean  $\text{VO}_{2\text{max}}$  than the Balke exercise group. However, the Balke mean treadmill times were greater than Bruce treadmill times. There was a significant difference between the slopes of the regression equations. It could not be determined if this was due to the difference of the protocols or the difference between the two groups of participants. Submaximal data showed that the trained participants had a lower HR than those who are sedentary. Also noted was that submaximal  $\text{VO}_2$  “did not differ” between the groups. The researchers do not think either protocol is ideal but did lean more towards the Balke protocol for its consistency and smaller increments. However, researchers said that a drawback to the Balke was the longer duration of the test.

Ragg, Murray, Karbonit, and Jump (1980) discuss the errors in predicting functional capacity based on a treadmill stress test. Direct measurements of oxygen consumption ( $\text{VO}_2$ ) are more accurate than predicted values in cardiac patients, but the equipment is costly and it is tedious work. The estimation process comes from “exercise in a highly standardized nature”. It is suggested that the variances can be widespread if

tables and nomograms are not strictly followed. This study took 6 healthy untrained males. The walking speed was unchanged to “minimize mechanical efficiency”. Heart rate was monitored during the test. Volunteers performed the tests with permission to use handrail support and also when handrail support was not permitted. The conclusion was using the handrails hinders the accuracy of the Balke and Ware protocols in calculating oxygen cost and that HR is also affected.

Foster, Hare, Taylor, Goldstein, Anholm, and Pollock (1984) conducted a study on the prediction of oxygen uptake ( $\text{VO}_2$ ) using 25 men with coronary artery disease (CAD) and 12 healthy nonsmoking men. Of the healthy participants, seven were categorized as sedentary and the remaining as regularly aerobically active. The Bruce protocol was used on a motor-driven treadmill; after the first 30 seconds handrail use was not allowed. Participants with CAD were tested during weeks 2, 8, and 24 postoperative, while the healthy volunteers were only tested once. The researchers added three stages prior to Bruce protocol that involved “2-minute warm-up stages consisted of walking at: (1) 1.5 mph, 0% grade, (2) 1.5mph, 3% grade, and (3) 1.7mph, 6% grade”. Week 2 GXTs were limited to 9 minutes as the maximal duration, which is the end of Bruce stage one, and/or due to signs and symptoms observed by the researchers. During the GXT, submaximal exercise was considered everything but the final 2 minutes of the test and  $\text{VO}_{2\text{max}}$  was considered to be “the highest full minute  $\text{VO}_2$  observed during the test”. Foster et al. showed that the  $\text{VO}_{2\text{max}}$  was overestimated compared to the measured values. The researchers attribute this to making sure that the appropriate equations are being used for specific populations. The findings also suggest that GXTs with smaller increments of intensity may be better in predicting  $\text{VO}_{2\text{max}}$ . The third stage of the Bruce protocol being

a particular section that could cause miscalculation due to the participant's decision to run or walk during this stage.

Ebbeling, Ward, Puleo, Widrick, and Rippe (1991) tested 77 men and 89 women on a motor-driven treadmill. The initial speed for the test was based on a 1-mile walk test adapted for the treadmill. The first segment of the test was three 4 min. stages at 0, 5, and 10% grade with a constant walking speed. After this portion speed remained constant but the grade was increased by 2.5% every 2 minutes. Heart rate and RPE were recorded at end of each stage. The HRs of the volunteers could not be compared due to a non-standardized walking speed. However, this submaximal test is "practical for assessing functional capacity for individuals who vary in age, gender, and fitness level". The pace for the test should be 50-70% of age-predicted HR max. The article points out the multiple regression equations used for submaximal testing. For estimating  $VO_{2max}$  from a 5% single grade during a submaximal treadmill test "provides a valid and time efficient method for assessing aerobic power" for people with little to no heart disease risk and aren't on any medication that affects HR.

McConnell, Foster, Conlin, and Thompson (1991) also looked at the effects of handrail support during treadmill testing. This study looked at the inconsistency of McConnell and Foster's respective curves. McConnell's was found to have "significantly higher predicted  $VO_{2max}$ " during a Bruce protocol. This study took 41 (30 men and 11 women) volunteers. Some participants had a history of MI (myocardial infarction) (27%) but all subjects were stable. Using the Bruce protocol, each subject did two tests in random order in two independent labs. Subjects either walked without handrail support (NHRS) or were allowed to rest hands on front rail without grasping the



rail (HRS). Handrail support versus NHRS  $VO_{2peak}$  had no significant difference. The same was true in regards to HR. The results support that using handrails during treadmill exercise reduces HR and “momentary aerobic demand” allowing for longer exercise duration. This could lead to an “inappropriately favorable prognosis” or miscalculation of “occupational and/or recreational activities”. The submaximal data suggests minimal differences.

Myers and Bellin (2000) discuss the issues around ramp exercise protocols from the 1990s. The article brings up the need for protocols to be individualized for each patient. The traditional protocols mentioned were: Balke, Bruce, Ellestad, Naughton and Åstrand. The majority uses the Bruce protocol but in the last 10 years “more gradual, individualized” tests, such as a modified Balke have been used. “Large and unequal works increments” produce less accurate values for exercise capacity. This can possibly result in a, “tendency to overestimate exercise capacity, less reliable test for studying the effects of therapy, and a lowered sensitivity for detecting coronary disease”. The Bruce protocol has the advantage of having a large amount of data supporting it but its disadvantage is that after the first stage it is difficult for patients with cardiovascular disease to perform. Also, it has a large and unequal progression. The ramp test was done mainly on the cycle ergometer until 1991. It is more challenging to perform incremental test on a treadmill because grade and speed must be altered versus just adjusting watts electronically on a cycle ergometer. Greater  $VO_{2max}$  values were collected on the treadmill protocols and showed slight differences in  $VO_{2max}$  values between the different protocols. There were slight differences found in the cycle ergometer values as well. Using a Veteran’s Specific Activity Questionnaire (VSAQ), which led to a nomogram

that allowed for an easy estimation of a patient's peak MET level that fell within the recommended test duration on a treadmill. Due to the many different protocols, data is harder to obtain in a consistent translation. Exercise protocol is one of the most important factors for interpreting the results of exercise tests and could potentially affect the patients' performance.

Myers, Prakash, Froelicher, Do, Partington, and Atwood (2002) studied 6,213 men who were referred for exercise testing with a follow up of (mean) approximately 6 years. The men were classified into two groups: 3,679 men had abnormal results or "a history of cardiovascular disease or both" and 2,534 men had normal results from the exercise testing and "had no history of cardiovascular disease". Myers, et al. (2002) followed a symptom-limited standardized grade protocols (handrails discouraged). Patient's medications were not stopped or changed for the study. Mortality was the end point of this study. During the follow up, there were 1,256 deaths giving an average mortality of 2.6 percent annually. These deaths resulted in men who were older than the men who were still alive and also had "a lower  $HR_{max}$ , lower maximal systolic and diastolic BP and lower exercise capacity". The strongest predictor once age had been factored in was through METs for patients who were healthy and/or those who had cardiovascular disease. Another strong indicator was peak exercise capacity in predicting the risk of death. However, exercise capacity is the stronger "predictor of mortality for men than other established risk factors for cardiovascular disease". There is a 12 percent increase in survival for "each 1-MET increase in exercise capacity". In the risk factor subgroups, participants whose exercise capacity fell under 5 METS then approximately

doubled their risk of death compared to the participants whose exercise capacity was larger than 8 METs.

Eston, et al. (2012) performed a study with 75 volunteers, age 18-72 years, to find the validity of predicting  $\text{VO}_{2\text{peak}}$ . All volunteers “were asymptomatic of illness or disease and free from acute or chronic injury”. The study used participants who were classified sedentary or active and used a treadmill-based perceptually regulated exercise test (PRET). All volunteers completed three laboratory sessions that had a minimum of 48 hours of rest in between. All the tests were conducted using a motorized treadmill. The outcome data was concealed from the participants. The participants completed two PRETs (four, =3 min. stages) “requiring a change in speed or incline corresponding to ratings of RPE 9,11,13 and 15”. During PRET, participants were able to adjust and maintain exercise intensity as needed to comply with specific RPEs that were prescribed. The RPE data (9-15) from the tests was extrapolated to RPE 19 and 20 to predict the participants  $\text{VO}_{2\text{peak}}$ . It was then compared to the participants graded exercise test (GXT)  $\text{VO}_{2\text{peak}}$  results. Heart rate was monitored continuously and “on-line respiratory gas analysis was used” throughout the test. Eston, et al. (2012) also took the HR from the GXT to provide further information in estimating  $\text{VO}_{2\text{peak}}$ . The active participants started with the GXT to attract interest while the sedentary group started with the PRETs so as not to scare them away. Eston, et al. (2012) thought the order was particularly important in retaining their participants and receiving 100% compliance. The results showed that the “HRs produced during a GXT within the RPE range 9-15 can be used to predict  $\text{VO}_{2\text{peak}}$  in sedentary and active individuals”. This study confirms the usefulness of

recording RPE in GXTs. It also supports and validates estimating  $\text{VO}_{2\text{peak}}$  using “submaximal treadmill testing” when RPE is regulated to a maximum of 15.

In summary,  $\text{VO}_{2\text{max}}$  testing reflects the individual’s limitations of cardiac output due to the reduction in stroke volume and HR. The treadmill tests result in higher values than other modes of exercise and are suggested to be limited by central exhaustion. Handrail use affects the outcomes of tests due to the subject bearing some of their weight through their arms causing them to last longer. Handrail support can also alter the HR data. Treadmill testing for  $\text{VO}_2$  should be done using small incremental stages to ensure there is no oxygen uptake lag. The research supports that individuals with a higher  $\text{VO}_{2\text{max}}$  value have a better chance of survival after a cardiac event and in general. The submaximal testing to predict  $\text{VO}_{2\text{max}}$  alone or with other variables (TT, RPE, HR etc.) has been shown to be accurate.

### **Field experiments**

Note the Bruce Balke article (1960) in the first subcategory. Balke had men run a treadmill test and a track test.

Kline, et al. (1987) conducted a study with 343 healthy participants (males= 165, females= 178) that involved a one-mile walk test on a track to estimate  $\text{VO}_{2\text{max}}$ . The  $\text{VO}_{2\text{max}}$  test was conducted on a treadmill with expired gas being collected and analyzed. The participants, aged 30-69 years old, had to walk a minimum of two trials that recorded times within 30 seconds of each other. Heart rate was taken every quarter of a mile but was monitored continuously. There were no significant differences between predicted and observed mean  $\text{VO}_{2\text{max}}$ . This was also cross-validated by decade. Again, no significant differences between estimated and observed  $\text{VO}_{2\text{max}}$  was observed. No

differences were noted when determining the mean  $\text{VO}_{2\text{max}}$  values for males and females using gender specific equations. The cross-validation showed no significant differences in any of the estimated and observed  $\text{VO}_{2\text{max}}$  analyses.

George, Vehrs, Allsen, Fellingham, and Fisher (1993) conducted a study with 149 (m=88, f=61) college students. A max GXT, 1-mile jog track jog and 1.5 mile run were performed. All three tests were done within two weeks. The 1-mile run was steady state and also submaximal in nature. The max treadmill GXT was at a subject selected speed and increased by 2.5% every minute. Heart rate was recorded each minute and at the conclusion of test. The 1-mile jog was at subject selected speed but over 8:00min/mi pace for men and 9:00min/mi for women. The ending HR had to be less than or equal to 180bpm. Heart rate, RPE, and elapsed jog time were recorded. The 1.5 mile run was to be run as fast as possible but to be paced so the participant stayed at “optimal speed”. Elapsed time was recorded for the run. The subjects tended to select higher exercise intensity for the 1-mile jog but it was noted that there was “no indication” that subjects worked at an uncomfortable intensity. The pace was kind of slow (aforementioned time restraints) for fit students and received “fairly light” RPE scores. The researchers suggest that the 1-mile jog is a “viable alternative” to the 1.5 mile run “assuming HR monitors are accurate”. The 1-mile jog is easy to administer and provides acceptable values in predicting  $\text{VO}_{2\text{max}}$ . The 1.5 mile run was found to also be acceptable but more in favor for subjects who have high intensity exercise experience.

Grant, Corbett, Amjad, Wilson, and Aitchison (1995) compared a submaximal cycle ergometer test, Cooper 12 min walk- run test and a multi-staged progressive shuttle run test (MST). There were 22 young, healthy males for participants. The cycle

ergometer test had 3 continuous bouts of 5 min. The MST was on a hard synthetic surface; the subject ran a distance of 20m in time with a signal (sound beep). The test was done when the subject couldn't make the line in time. The MST and cycle ergometer both under predicted  $VO_{2max}$ . For this population, the Cooper walk- run test is "the best predictor of  $VO_{2max}$  among the three tests".

Quail, Vehrs, and Jackson (1999) had a study that took 30 Caucasians and 31 African Americans (A.A.), both groups split equally in gender. Each subject ran the 1-mile track jog twice on an indoor track and a max GXT on the treadmill. The track tests were run at a "steady, submaximal jogging pace". Men and women could not be faster than 8 or 9 min/mile pace, respectively. The exercise HR and lap times were monitored to ensure a consistent pace. Upon completion of the jog tests, RPE was recorded. The max GXT, after warm up, was at a self-selected pace that stayed constant for the duration. After an initial 3 min the grade increased 2.5% every minute. No handrails were allowed. There were no significant differences in HR and RPE in relation to ethnicity. The 1-mile jog test "provided highly reliable estimates of  $VO_{2max}$ ". The estimate of  $VO_{2max}$  "remains consistent due to the inverse relationship between 1-mile jog and HR".

In summary, the 1-mile submaximal test was found to be a good predictor of  $VO_{2max}$ . The Cooper test is also a valid and preferred method of field estimation  $VO_{2max}$ .

### **Talk Test (TT)**

Dehart-Beverley, Foster, Porcari, Fater, and Mikat (2000) conducted a study to look at the relationship between the TT and VT. The study took 28 healthy volunteers, gender split equally, and had them perform two "maximal exercise tests" with no more

than two weeks between each test. Test order was randomized. Dependent upon physical activity, Balke or Åstrand treadmill protocol were used. One of these tests was performed with a gas analyzer and one was performed without. During the test without gas analysis, the participant read the Rainbow Passage paragraph, standard to the study, and asked if they could speak comfortably during each stage of the test. Researchers found a “significant difference between  $\text{VO}_2$  at VT” when compared to the positive TT. There was no significant difference found “between any of the variables at VT at the equivocal” TT stage. There were significant differences between the outcomes at VT and the negative stage of the TT. These results support that  $\text{VO}_2$  at VT versus  $\text{VO}_2$  at the equivocal stage are almost identical. However,  $\text{VO}_2$  at the positive and negative stages of the TT were “below and above the line of identity, respectively”. The participants who could talk or were at equivocal were either at or below their VT. This study supports that the TT is a good marker of VT and “may be a valid subjective measure to guide exercise prescription”.

Meckel, Rotstien, and Inbar (2002) investigated gas exchange and oxygen delivery during submaximal testing while speaking in healthy young men ( $n=14$ ). According to “unpublished observations” it was observed that talking caused a “small reduction in exercise ventilation”. A different study that studied this at five different loads also found the “consistent reduction” when speaking. The participants exercised three different times with 3 to 6 days in between each test. The first test was a GXT to determine  $\text{VO}_{2\text{max}}$  on a motor-driven treadmill. It started with a speed of 4km/hr, 1% grade, and speed increased 2km/hr every 2min. until the fourth stage, then grade increased 2% every 2 min. The second test consisted of constant running with intensities

of 65%, 75%, and 85% of  $\text{VO}_{2\text{max}}$  and lasted 6 minutes each, resting 10min. between load 1 and 2, then resting 20min. between load 2 and 3. Gas exchange was analyzed during these loads. The third test was the same as the second test but participants were asked to speak during exercise. A metronome set the reading pace. A mouth breathing facemask was used to collect gas exchange so individual could speak. The second and third test order was randomized. The researchers found that speech caused a “significant decrease in oxygen consumption” during all three loads. The mechanism responsible for the drop is not clear. Heart rate remained unchanged “while speaking during exercise”. Meckel and associates determined that to maintain speech while exercising, “ventilation is reduced” to meet the “phonatory requirements”. It is noted that the responses could be “influenced by speech characteristics”.

Voelker, Foster, Porcari, Skemp, Brice, and Backes (2002) conducted a similar study to Dehart-Beverly and associates study done in 2000 but looked at the relationship of TT and VT in cardiac patients. The study had 10 subjects, mostly male, complete two maximal exercise tests, one with gas analysis and the other without. A modified Balke protocol was used for testing. During the TT maximal test, the participants recited the standard paragraph and asked if they could speak comfortably. The “physiologic responses at VT were compared to the various stages of the TT” and there was “significant difference in  $\text{VO}_2$  and HR between VT” and the negative TT stage but “not for positive or equivocal”. A good correlation was found between  $\text{VO}_2$  at VT for all three stages (positive, equivocal, negative) of the TT. As in Dehart-Beverly and associates study, participants at LP or equivocal were at or below their VT. When subjects were in the negative stage of the TT, they were above their VT. This study



supports that the TT is a “valid subjective measure of exercise intensity for guiding exercise prescription in patients with clinically stable cardiovascular disease”.

Persinger, Foster, Gibson, Fater, and Porcari (2004) performed a study to assess “the consistency of the TT by comparing responses during different modes of exercise”. The TT has been correlated with “ventilatory threshold (VT), accepted guidelines for exercise prescription, and with the ischemic threshold”. It is said that exercise intensity is sufficient if the individual can respond to conversation. This means exercise intensity is “just about right”. This has been tested with a wide variety of populations such as: “university students, clinically stable patients with cardiovascular disease (CAD), and athletes”. The TT has also been found to be around the ischemic threshold for patients who experience exertional ischemia. Volunteers (n=16) who were healthy and moderately active were used. After getting used to the equipment, participants were assigned four, randomly ordered, exercise tests to be performed on different days. The four tests included 2 incremental treadmill tests and two tests on an electrically braked cycle ergometer. The tests were individualized but all tests had 2 minute stages. The speed on the treadmill was based on the trial period and determined by a pace that could be performed “virtually indefinitely”. For the cycle ergometer, 25W was starting point and increased by 25W per stage (participants under 60kg started/increased at 20W). The exercise was maximal to the “last level sustainable”. Heart rate was monitored constantly during these tests. Heart rate was unaffected by the TT. The participants recited the Pledge of Allegiance for the TT during last 30 seconds of each stage. If the individual gave a positive response to the TT but the researcher thought they were equivocal researcher would “gently” ask if individual was sure of their response. Ventilatory

threshold was correlated on both the treadmill and cycle ergometer for positive, equivocal, and negative tests. The Talk Test was found to be able to be used on different modes of exercise reliably. The Talk Test was found to be consistent and acceptable guidelines for exercise prescription.

Foster, Porcari, Gibson, Wright, Greany, Talati, and Recalde (2009) conducted a “randomized observational study evaluated the ability of the intensity at the TT during exercise testing to define absolute training workloads”. Foster, et al. states “...HR response during steady-state or interval training may be systematically higher than predicted from the TT during incremental exercise”. Volunteers were sedentary, healthy adults split equally in gender (n=14). Researchers used a Balke protocol (3-3.5mph, 0% grade, increase 2% every 2min.) and tested HR, TT, and RPE at each stage of the incremental test. The Pledge of Allegiance was used for speaking during exercise. No handrail use was permitted. Individuals also performed “3x 20min bouts with the last 10minutes of each bout equal to the stage preceding last positive (LP-1), and the last positive (LP) of the TT”. The speech portion of each test was given during last 30 seconds of each stage. The three strategies for prescribing intensity from incremental TT indicators had HRs that fell within “recommended training range (65-94%  $HR_{max}$ )”. Stable HRs in LP-1 and LP, whereas HR at equivocal (EQ) “resulted in a progressive HR drift throughout the exercise bout”. Training intensities based off the TT markers gave RPE values that fell within recommended ranges; some individuals EQ markers made the RPE almost too difficult to finish their 20min bout. It was found that the translation of the TT was excessive for most of these volunteers “unless the intensity was

decreased by about the magnitude of 1 exercise stage (~10-12%) below the LP stage during the incremental test”.

Jeans, Foster, Porcari, Gibson, and Doberstein (2011) took 14 well-trained volunteers and had them perform two incremental tests and 3 steady state bouts (40 min.). Steady state tests were based off LP-1 and equivocal stages of the TT. The percent  $HR_{max}$ , and RPE were also measured. Volunteers ran at least 2hr per week. Rest between each test was at least 72hrs. The treadmill was used for all tests and kept at a constant grade of 1%. One of incremental tests used gas analysis, and the other used the TT. For both tests RPE, and HR was collected at end of each stage. Steady state paces were from recovery to race pace tempo. Steady state was a warm-up followed by incrementals until the level of the TT desired was reached then left for the remainder of 40min run. The orders of the three steady state tests were random. After 20min, “RPE during EQ stage was significantly greater than during LP-1 or LP bouts” and stayed that way for the duration of the test. Except for the EQ stage, RPE stayed within ACSM guidelines for exercise training. Subjects were noted to be speaking generally comfortably during LP-1 and LP stages. The findings suggest that the base of an athlete’s endurance or conditioning training should be done “at a relatively low intensity ( $\geq$ LP of TT)”. During submaximal steady state using the TT “the tendency of exercise responses to ‘drift’ over time was clearly evident”.

In summary, the TT is a valid subjective measure of  $VO_2$  at VT for healthy adults and cardiac patients. The measured and predicted values have been shown to be very similar. Based on the TT protocol, research has shown correlation of  $VO_2$  at VT to be almost identical to the  $VO_2$  at the TT’s equivocal stage. Research gives support that the

TT may be used in various modes of exercise. There is some reduction in ventilation while performing the TT; this is due to breath being held while speaking. Speech may be influenced by the individual's speaking patterns.

### **Rate of Perceived Exertion (RPE)**

Chen, Fan, and Moe (2002) put together a meta analysis of the validity of the Borg RPE scale in healthy people due to previous research being inconsistent on the relationship of RPE and other factors (HR, blood lactate,  $VO_{2max}$ , etc.). The fitness levels of the participants were sedentary to highly active, healthy adults. "Of the seven features in the study, four of them (fitness, exercise type, exercise protocol and RPE) had significantly different means". This insinuates there are "possible moderating variables that contribute to the variability of the Borg RPE Scale" when HR is the main measurement. For RPE and HR, the "production mode" produced a "higher mean  $r_{RPE}$  HR" than did the estimation. It is noted that RPE is "significantly related" to  $VO_2$  and an example given is that about 80% of variance in RPE is from the percent of  $VO_{2max}$ . It is noted that gender, RPE, and types of exercise relationships with  $VO_2$  (as the subjective criterion) showed significant differences. The relationship of RPE and  $VO_2$  is that it has a higher "validity coefficient". The same relationship of the validity coefficients is also true when ventilation is the criterion. Treadmill exercise was shown to have a "lower mean coefficient" than the cycle ergometer and swimming for both  $VO_2$  and ventilation. This study found that the "highest correlation between RPE" and the various subjective measures were when "male subjects maximally exert when the exercise is 'unusual' (i.e. swimming)". Researchers noted that environmental differences could have an impact on an individual's RPE. Respiratory rate was mentioned as the "most reliable and valid

measure” in both research and clinical settings for physical exertion. Respiratory rate was also noted as potentially the best “indicator of perceived exertion”.

Eston, Lamb, Parfitt, and King (2005) conducted a study to assess the validity of predicting  $\text{VO}_{2\text{max}}$  from submaximal  $\text{VO}_2$  testing. Researchers used RPE and  $\text{VO}_2$  to predict  $\text{VO}_{2\text{max}}$ . Subjects included ten healthy male university students who were active. All subjects performed four tests, a maximal test and three submaximal tests. Tests were completed on a cycle ergometer with 48 hours in between each test. Submax incremental RPE tests were done at 9, 11, 13, 15 and 17. Heart rate and  $\text{VO}_2$  were monitored continuously during all of the 4 min. stages. There was no significant difference between predicted and measured  $\text{VO}_{2\text{max}}$  in the trials. It was noted that when excluding RPE 9 or 17 respectively from prediction “that agreement is lessened (larger bias and random error)”. The predicted  $\text{VO}_{2\text{max}}$  values used the collected data and extrapolated it to RPE 20. Data supports that the “submaximal, perceptually guided GXT protocol can provide acceptable estimates of maximal aerobic power”. It is noted that reproducibility is capable but mentions that with protocol familiarity that subjects improved slightly from Submax trial1 to 3.

Faulkner and Eston (2007) directed a study to assess the relationship between HR and RPE during two GXTs with  $\text{VO}_2$  on a cycle ergometer. Participants (N=49) had both high and low fitness. There were 16 men, and 9 women with high fitness and 14 men, and 10 women with low fitness. Cycle ergometer test started at 40W and increased by 40W as much every 3 minutes. In both groups (high/low), overall RPE was correlated to  $\text{VO}_2$  almost as much as  $\text{VO}_2$  and HR during the  $\text{VO}_{2\text{max}}$  GXT. There were no differences in predicted versus measured  $\text{VO}_{2\text{max}}$  from extrapolated submaximal RPE (13,15,17)  $\text{VO}_2$

measures. Peripheral RPE during submaximal RPE testing predicted lower  $\text{VO}_{2\text{max}}$ .

Peripheral RPE was recorded higher than overall RPE during testing. This study supports previous research that states RPE is not gender specific.

Lambrick, Faulkner, Rowlands, and Eston (2009) conducted a study on the efficacy of RPE 13 during submaximal continuous exercise. According to ACSM guidelines from 2008 “The Borg 6-20 RPE scale is a reliable measure used to quantify, monitor, and assess an individual’s exercise tolerance and level of exertion”. The study had 11 women who were sedentary (less than 1hr/wk of physical activity). Each volunteer performed a lab-based exercise on cycle ergometer to find  $\text{VO}_{2\text{max}}$ . The individual kept a consistent pace of 60rpm for the test. Perceived exertion was also monitored. The GXT used a ramp protocol, started at 0 watts and increased 1W every 4 seconds; RPE recorded every 2 min. Researchers extrapolated RPE 13 to RPE 19 for  $\text{VO}_{2\text{max}}$  predictions. Predictions were also taken from the GXT and a combination of HR at RPE 13 and GXT. From Fig. 1 the predicted values from RPE 20, GET 19, HR at RPE 13, and HR at GET are all very similar to measured  $\text{VO}_{2\text{max}}$  and the regression equation. However, RPE 19 prediction values were lower than measured, and GET 20 predicted was above measured values. Researchers suggest that more accurate predictions of  $\text{VO}_{2\text{max}}$  can be achieved from a continuous test versus a GXT.

Parfitt, Evans, and Eston (2012) conducted a study to “confirm the efficacy of an 8-PRET program clamped at RPE13 to improve aerobic fitness and cardiovascular health”. Exercise intensity is known to be one of the most important components in exercise prescriptions in maintaining a “cardiovascular training response”. In the article, it quotes ACSM stating that “individual choice, preference, and enjoyment” help support

and motivate the individual. Researchers took approximately middle-aged sedentary participants and assigned them randomly to a control (n=10) or training group (n=16). Baseline GXT was performed to find aerobic capacity before and after involvement. The training group exercised for 8 weeks at 3 times a week for 30 minutes at RPE13, based on Borg 6-20 Scale. The Balke-Ware protocol was used on the treadmill for before and after GXTs (5.3km/h, start at 0% grade, increasing 1% per min.). A gas analyzer was used for both tests as well; HR was also continuously monitored. The training group improved their  $VO_{2max}$ , mean arterial pressure (MAP), total cholesterol and body mass index (BMI) within the 8-week training. The effect, on average, was positive and stable. Post GXTs in the training group improved whereas the GXT results decreased in control group. Parfitt, Evans, and Eston (2012) concluded that sedentary people are able to use a “PRET at RPE13 to improve their cardiovascular health and fitness and on average, the exercise intensities selected were perceived to feel pleasant”. ACSM does support the RPE method for exercise prescription. In this study, the trained group improved by 17% which supports other researchers findings. The average intensity found based off participants RPE13 was about 61% of  $VO_{2max}$  at week one and 64% at week 8. Notably, this would be “borderline” for moderate and vigorous intensity.

In summary, research has shown a correlation with RPE 13 and ACSM guidelines for exercise intensity. Extrapolating submaximal data to RPE 20 has been shown to be very similar to the measured  $VO_{2max}$  values. Peripheral versus overall RPE has evidence suggesting that peripheral RPE extrapolated to predict higher than measured  $VO_{2max}$  values.

## **6 Minute Walk Test**

Guyatt and colleagues (1984) wrote on the effects of encouragement during walking tests. Two groups were made of people who fatigued or had dyspnea while doing active daily living (ADL). Everyone was tested 6 times and time of day, order of tests along with level of encouragement were noted. A 2min and 6min walk test was performed with 20min rest in between. Initial tests for all had no encouragement; after that it was randomized who and how much (all or none) encouragement was given the remaining 5 visits. For the no encouragement group, the supervisor avoided eye contact and sat in a chair. The encouragement group every 30s had the supervisor face the subject and say a predetermined phrase of encouragement. Time of day had no noted effect. Age was observed to cause a significant difference in walking distance, younger walking further. Encouragement did not seem to help during the first 2min of the 6MWT. However, during the second and third 2min segments the effect of encouragement was greater. No 2min segment of the 6MWT had a further distance walked than any of the 2min walk tests. A 2-test baseline for training effect is suggested. To give or not give encouragement is ultimately a toss up but should be kept consistent for all trials and patients.

According to the Thoracic Society (2002) the 6 Minute Walk Test (6MWT) has been found “to perform as well as the 12-minute walk”. The 6MWT requires 100 feet of hallway or other flat hard surface space to walk. The walking course must be 30m in length, totaling 60m for 1 lap. The test measures the distance and speed that the patient can walk for 6 minutes. Speed is as fast as the patient can walk. The patient is allowed



to stop and rest if needed during the walk. The 6MWT is a submaximal exercise test to test functional capacity. Therefore, most patients do not reach maximal exertion during this test. The 6MWT has not been proven to be clinically useful as of 2002. The 6MWT does not determine  $VO_{2max}$  thus the information provided by the test should be considered “complimentary to cardiopulmonary exercise testing”. Stable angina is not considered “an absolute contraindication for the 6MWT”. The test should be terminated if the patient has chest pain, intolerable dyspnea, leg cramps, staggering, diaphoresis, and/or pale or ashen appearance.

Ingle, Goode, Rigby, Cleland, and, Clark (2005) looked at predicting  $VO_{2peak}$  using the 6MWT. All participants were male, able to walk independently and had heart failure or some other non-cardiac comorbidities. All participants were stable. A majority were prior smokers but no one was a smoker at time of the study. Besides the 6MWT, participants performed a modified Bruce Protocol. Adding a stage 0 that included a 5% grade and 1mph walking speed modified it. FEV1 and FVC were noted as “significant predictors” in  $VO_{2peak}$ . This article suggests that in a clinical setting incremental testing with gas exchange “cannot be avoided”. This article’s regression equation noted moderate accuracy.

In Arslan, et al. (2007), cardiac patients with similar diagnoses were studied in association with the 6MWT. A majority of the patients had a follow up period of about 18 months. The mortality rate was noted to be higher in patients who walked 300m or less. After the study, researchers say the prognostic value is still controversial. This study found the 6MWT to be a safe test. The study notes some limitations but that their

data suggests that the distance walked is a “highly reliable and independent predictor of cardiac death”.

In the article by Jehn, et al. (2009), the 6MWT is argued to be a maximal or submaximal test. Patients all had different stages of congestive heart failure and were familiar with the tests. Gas exchange was collected for both of the tests. The two tests were in random order and had a 2-hour recovery between tests. The maximal cycle ergometer test was the 10W/min ramp protocol. High correlations were found between the 6MWT and cycle ergometer for distance and  $VO_{2peak}$ . The data suggests that during the 6MWT HR does not reach a maximal response in patients who have mild heart failure and no functional limitations. However, patients with severe heart failure elicited maximum response. Data in this study suggest that patients with reduced exercise capacity reach “higher peak respiratory parameters” during the 6MWT than on the cycle ergometer. This was opposite for those with moderate heart failure and no functional limitations. Researchers deemed the 6MWT to be “highly dependable” depending on the patient’s range of functional limitation(s).

According to Rasekaba, Lee, Naughton, Williams, and Holland (2009) the 6MWT has been increasing in popularity for testing older adults and in studies with cardiopulmonary diseases. The 6MWT is an assessment of functional movement. Due to the high volumes of tests run, there were rare or no complications reported, and no physician is needed to be in attendance. Important determinants for this test include: age, gender, height, weight, and ethnicity. The 6MWT does not have a “strong relationship with air flow obstruction or exertional dyspnea”. Data suggests that the distance walked declines over time. The 6MWT has a “strong correlation to  $VO_{2peak}$ ”. Maximal testing

however, may be more effective testing for those with severe heart failure and/or are on the heart transplant list. Data suggests that there are only a few medications that may alter 6MWT outcome. A limitation of the 6MWT is that it does not inform on “exercise limitation and thus cannot aid in diagnosis”. The only absolute contraindication to the 6MWT is unstable angina and myocardial infarction within the last month.

In conclusion, the 6MWT needs to follow consistent guidelines for each trial. Exercise-related complications are low and rare in stable populations. The 6MWT has been found to have a correlation with  $VO_{2peak}$ . The severity of cardiovascular diseases impacted performance and efficacy of the results; for example, the difference between mild to severe heart failure. The data suggests that the distance walked will decrease over time in repeat testing.

## REFERENCES

- American College of Sports Medicine. (2013). *Acsm's guidelines for exercise testing and prescription*. (9th ed.). Lippincott Williams & Wilkins.
- American Thoracic Society. (2002). Ats statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med*, 166, 111-117. Retrieved from <http://www.thoracic.org/statements/resources/pft/sixminute.pdf>
- Arslan, S., Erol, M. K., Gundogdu, F., Sevimli, S., Aksakal, E., Senocak, H., & Alp, N. (2007). Prognostic value of 6-minute walk test in stable outpatients with heart failure. *Texas Heart Institute Journal*, 34(2), 166-169.
- Balke, B. (1960). The effect of physical exercise on the metabolic potential, a crucial measure of physical fitness. *The Athletic Institute*, 73-81.
- Bruce, R. A., Kusumi, F., & Hosmer, D. E. (1973). Fundamentals of clinical cardiology. *American Heart Journal*, 85(4), 546-562.
- Chen, M. J., Fan, X., & Moe, S. T. (2002). Criterion-related validity of the borg ratings of perceived exertion scale in healthy individuals: a meta analysis. *Journal of Sports Sciences*, 20, 873-899.
- Cooper, K.H. (1968) A means of assessing maximal oxygen intake: correlation between field and treadmill testing. *JAMA*. 203(3), 201-204.  
doi:10.1001/jama.1968.03140030033008
- Dehart-Beverley, M., Foster, C., Porcari, J. P., Fater, D. C. W., & Mikat, R. P. (2000). Relationship between the talk test and ventilatory threshold. *Clinical Exercise Physiology*, 2(1), 34-38.
- Ebbeling, C. B., Ward, A., Puleo, E. M., Widrick, J. J., & Rippe, J. M. (1991). Development of a single-stage sub maximal treadmill walking test. *Medicine and Science in Sports and Exercise*, 23(8), 966-973.
- Eston, R., Evans, H., Faulkner, J., Lambrick, D., Al-Rahamneh, H., & Parfitt, G. (2012). A perceptually regulated, graded exercise test predicts peak oxygen uptake during treadmill exercise in active and sedentary participants. *European Journal of Applied Physiology*, doi: 10.1007/s00421-012-2326-8
- Eston, R. G., Lamb, K. L., Parfitt, G., & King, N. N. (2005). The validity of predicting maximal oxygen uptake from a perceptually-regulated graded exercise test. *European Journal of Applied Physiology*, 94, 221-227.

- Faulkner, J., & Eston, R. (2007). Overall and peripheral ratings of perceived exertion during a graded exercise test to volitional exhaustion in individuals of high and low fitness. *European Journal of Applied Physiology*, 101, 613-620.
- Foster, C., & Cotter, H. M. (2005). *In physiological assessment of human fitness*. (2nd ed.).
- Foster, C., Hare, J., Taylor, M. M., Goldstein, T., Anholm, J. D., & Pollock, M. L. (1984). Prediction of oxygen uptake during exercise testing in cardiac patients and healthy volunteers. *Journal of Cardiac Rehabilitation*, 4(12), 537-542.
- Foster, C., Kuffel, E., Bradley, N., Battista, R., Wright, G., Porcari, J. P., Lucia, A., & deKoning, J. J. (2007). Vo2max during successive maximal efforts. *Eur J Appl Physiol*, 102, 67-72.
- Foster, C., Porcari, J. P., Battista, R. A., Udermann, B., Wright, G., & Lucia, A. (2008). The risk in exercise training. *American Journal of Lifestyle Medicine*, 1-6.
- Foster, C., Porcari, J. P., Gibson, M., Wright, G., Greany, J., Talati, N., & Recalde, P. (2009). Translation of sub maximal exercise test responses to exercise prescription using the talk test. *Journal of Strength and Conditioning Research*, 23(9), 2425-2429.
- Froelicher, V. F., Thompson, A. J., Davis, G., & Triebwasser, J. H. (1975). Prediction of maximal oxygen consumption: comparison of the bruce and balke treadmill. *CHEST*, 68(3), 331-336.
- George, J. D., Vehrs, P. R., Allsen, P. E., Fellingham, G. W., & Fisher, G. (1993). Vo2max estimation from a submaximal 1-mile track jog for fit college age individuals. *Journal of American College of Sports Medicine*, 25(3), 401-406.
- Grant, S., Corbett, K., Amjad, A. M., Wilson, J., & Aithchison, T. (1995). A comparison of methods of predicting maximum oxygen uptake. *British Journal of Sports Medicine*, 29(3), 147-152.
- Guyatt, G. H., Pugsley, S. O., Sullivan, M. J., Thompson, P. J., Berman, L., Jones, N. L., Fallen, E., & Taylor, D. W. (1984). Effect of encouragement on walking test performance. *Thorax*, (39), 818-822.
- Haskell, W. L., Savin, W., Oloridge, N., & DeBusk, R. (1982). Factors influencing estimated oxygen uptake during exercise testing soon after myocardial infarction. *The American Journal of Cardiology*, 50, 299-304.
- Howley, E. T., Bassett, D. R., J., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *American Journal College of Sports Medicine*, 1292-1301.

- Ingle, L., Goode, K., Rigby, A. S. R., Cleland, J. G. F., & Clark, A. L. (2005). Predicting peak oxygen uptake from 6-min walk test performance in male patients with left ventricular systolic dysfunction. *The European Journal of Heart Failure*, 8, 198-202.
- Jeans, E. A., Foster, C., Porcari, J. P., Gibson, M., & Doberstein, S. (2011). Translation of exercise test to exercise prescription using the talk test. *Journal of Strength and Conditioning Research*, 25(3), 590-596.
- Jehn, M., Halle, M., Schuster, T., Hanssen, H., Weis, M., Koehler, F., & Schmidt-Trucksass, A. (2009). The 6-min walk test in heart failure: is it a max or sub-maximum exercise test?. *Eur J Appl Physiol*, 107, 317-323.
- Kirkberg, J. M., Dalleck, L. C., Kamphoff, C. S., & Pettitt, R. W. (2011). Validity of 3 protocols for verifying vo2max. *Int J Sports Med*, 32(4), 266-270.
- Kline, G. M., Porcari, J. P., Hintermeister, R., Freedson, P. S., Ward, A., McCarron, R. F., Ross, J., & Rippe, J. M. (1987). Estimation of vo2max from a one-mile track walk, gender, age, and body weight. *Medicine and Science in Sports and Exercise*, 19(3), 253-259.
- Lambrick, D. M., Faulkner, J. A., Rowlands, A. V., & Eston, R. G. (2009). Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of rpe 13. *European Journal of Applied Physiology*, 107, 1-9.
- Levine, B. D. (2008). Vo2max: what do we know, and what do we still need to know?. *J Physiol*, 586(1), 25-34.
- McConnell, T. R., Foster, C., Conlin, N. C., & Thompson, N. N. (1991). Prediction of functional capacity during treadmill testing: Effect on handrail support. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 11(4), 255-260.
- Meckel, Y., Rotstien, A., & Inbar, O. (2002). The effects of speech production on physiologic response during sub maximal exercise. *Medicine & Science in Sports & Exercise*, 34(8), 1337-1343.
- Mezzani, A., Hamm, L. F., Jones, A. M., McBride, P. E., Moholdt, T., Stone, J. A., Urhausen, A., & Williams, M. A. (2012). Aerobic exercise intensity assessment and prescription in cardiac rehabilitation. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 32, 327-35.
- Mitchell, J. H., Sproule, B. J., & Chapman, C. B. (1957). The physiological meaning of the maximal oxygen intake test. *Journal of Clinical Investigation*, 37, 538-547.

- Morris, C. K., Myers, J., Froelicher, V. F., Kawaguchi, T., Ueshima, K., & Hideg, A. (1993). Nomogram based on metabolic equivalents and age for assessing aerobic exercise capacity in men. *JACC*, 22(1), 175-182.
- Myers, J., & Bellin, D. (2000). Ramp exercise protocols for clinical and cardiopulmonary exercise testing. *Sports Med*, 30(1), 23-29.
- Myers, J., Buchanan, N., Walsh, D., Kraemer, M., McAuley, P., Hamilton-Wessler, M., & Froelicher, V. F. (1991). Comparison of the ramp versus standard exercise protocols. *Journal of the American College of Cardiology*, 17(6), 1334-1342.
- Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S., & Atwood, J. E. (2002). Exercise capacity and mortality among men referred for exercise testing. *The New England Journal of Medicine*, 346(11), 793-801.
- Parfitt, G., Evans, H., & Eston, R. (2012). Perceptually regulated training at rpe13 is pleasant and improves physical health. *Medicine & Science in Sports & Exercise*, 44(8), 1613-1618.
- Persinger, R., Foster, C., Gibson, M., Fater, D. C., & Porcari, J. P. (2004). Consistency of the talk test for exercise prescription. *Medicine & Science in Sports & Exercise*, 36(9), 1632-1636.
- Quail, J. W., Vehrs, P. R., & Jackson, A. S. (1999). Predicting vo2max in african americans and whites with the 1-mile track jog test. *Measurement in Physical Education & Exercise Science*, 3(1), 1-14.
- Ragg, K. E., Murray, T. F., Karbonit, L. M., & Jump, D. A. (1980). Errors in predicting functional capacity from a treadmill exercise stress test. *American Heart Journal*, 581-583.
- Rasekaba, T., Lee, A. L., Naughton, M. T., Williams, T. J., & Holland, A. E. (2009). The six-minute walk test: a useful metric for the cardiopulmonary patient. *Internal Medicine Journal*, 39, 495-501.
- Robergs, R. A., & Landwehr, R. (2002). Prediction of maximal heart rate. *JEP*, 5(2), 1-10.
- Shephard, R. J., Allen, C., Benade, A. J. S., Davies, C. T. M., Prampero, P. E., Hedman, R., Merriman, J. E., Myhre, K., & Simmons, R. (1968). The maximum oxygen intake: an international reference standard of cardiorespiratory fitness. *Bull. Wld Hlth Org.*, 38, 757-764.
- Voelker, S. A., Foster, C., Porcari, J. P., Skemp, K. M., Brice, G., & Backes, R. F. (2002). Relationship between the talk test and ventilatory threshold in cardiac patients. *Clinical Exercise Physiology*, 4(2), 120-123.