COMPARISON OF NON-MAXIMAL TESTS FOR ESTIMATING EXERCISE CAPACITY

Reem A. Alajmi, Carl Foster, John P. Porcari, Kimberley Radtke, and Scott Doberstein

Department of Exercise and Sport Science, University of Wisconsin-La Crosse, USA

Abstract:

Although maximal incremental exercise tests (GXT) are the gold standard for outcome assessment and exercise prescription, they are not widely available in either fitness or clinical exercise programs. This study compared the prediction of VO_2max in healthy, sedentary volunteers using a non-exercise prediction (Matthews, et al., 1999), RPE extrapolation to 19 and 20 and the Rockport Walking Test (RWT), and of ventilatory threshold (VT) using the Talk Test and RPE @ 13,14,15. Subjects performed a treadmill GXT with gas exchange, a submaximal treadmill with RPE and Talk Test, the RWT and Matthews. All methods provided reasonable estimates of both VO_2max and VT, with correlations of >0.80 and SEE~1.3 METs. VO_2max was best estimated with the extrapolation to RPE=19. VT was intermediate between the TT Last Positive and Equivocal stages and between RPE 13 and 14. Non-maximal evaluation can be used in place of maximal GXT with gas exchange to make reasonable estimates of both VO_2max and VT.

Key words: exercise prescription, exercise test, VO₂max, ventilatory threshold

Introduction

Maximal graded exercise testing (GXT) has been the standard test performed for exercise evaluation and prescription and prognosis estimation (ACSM, 2017; Mezzani, et al., 2012). Although GXT is the gold standard, it has several limitations. One is that it is primarily performed for diagnostic and prognostic purposes rather than for exercise prescription (Myers, Voodi, Umann, & Froelicher, 2000), and it requires physician's involvement. Also, the use of GXT is limited in individuals who have pain/fatigue or who have contraindications to GXT (Noonan & Dean, 2000). Performing GXT is also limited by its cost and the availability of equipment.

To overcome the limitations of GXT, it would be useful to find simpler, safer, and lower cost alternatives. Several non-maximal tests have been used to estimate exercise capacity and guide exercise training intensity, including the Talk Test (TT), the Rating of Perceived Exertion (RPE), and Rockport 1-mile Walk Test (RWT). However, how well these tests measure the same exercise capacity qualities has not been established yet. Further, as each of these tests was developed in different samples of the population of nominally healthy individuals, the degree to which they are actually interchangeable remains uncertain.

The TT is easily conducted by asking the participants to carry on a conversation or to read a standard passage at the end of each exercise stage. If the individual can speak comfortably, the exercise intensity is typically below the ventilatory threshold (VT). If they have some difficulties speaking, the exercise intensity is typically above the VT. Numerous studies have demonstrated the validity of TT as a method for exercise prescription by predicting the VT in samples from different populations, including healthy sedentary individuals, healthy active individuals, athletes, and patients with stable cardiovascular disease. The TT has also been used to identify the ischemic threshold in patients who had exertional ischemia (Foster, et al., 2018).

The Rating of Perceived Exertion (RPE) is a well-known method for determining, guiding, and monitoring exercise intensity (Eston, 2012). The RPE assesses how easy or hard a physical activity feels at any point in time. The RPE is based on its very robust relationship with training intensity and with objective physiological markers (HR, VO_2, VT, RCT, and blood lactate). The two most commonly used RPE scales are the original scale (Borg 6-20 Category Scale) and the Borg Category-Ratio-10 Scale (CR-10) (Borg, 1982). Both scales are widely used in cardiac rehabilitation and preventive medicine as methods of gauging exercise intensity (Mezzani, et al., 2012). Since HR can be uniquely variable in cardiac patients secondary both to pathology and medication effects, and is also

highly variable amongst healthy persons, the use of RPE is an attractive alternative to HR (Mezzani, et al., 2012). Earlier studies have shown a good correspondence between RPE 13 'somewhat hard' and the VT (Purvis & Cukiton, 1981) and training at RPE=13 has been shown to be both pleasant and effective (Parfitt, Evans, & Eston, 2012).

Because of the strong linear relationship between RPE and VO_2, the $RPE:VO_2$ relationship can be utilized to predict the maximal oxygen consumption (VO_2max) from non-maximal exercise tests. There are two main procedures that can be used to predict VO_2max from linear regression: an estimation procedure and a production procedure (Coquart, Garcin, Parfitt, Tourny-Chollet, & Eston, 2014). The estimation procedure is a passive process in which individuals rate their physical exertion using the RPE scale at the end of each GXT stage. Conversely, the production procedure is an active process in which individuals self-regulate the intensity equivalent to a pre-determined RPE during each exercise test stage. By using either procedure, individual linear regression between $RPE:VO_2$ can be extrapolated to the theoretical endpoint at RPE 20 (or RPE 19) to predict VO_2max (Coquart, et al., 2014b). Several studies have shown RPE to be a valid method to estimate VO_2max and to monitor exercise intensity in healthy older adults (Chung, Zhao, Liu, & Quach, 2015), healthy participants (Eston, Faulkner, Mason, & Parfitt, 2006; Eston, Lamb, Parfitt, & King, 2005; Faulkner & Eston, 2007; Faulkner, Lambrick, Parfitt, Rowlands, & Eston, 2009; Lambrick, Faulkner, Rowlands, & Eston, 2009), athletes (Coquart, Eston, Nycz, Grosbois, & Garcin, 2012a), clinical participants (Coquart, et al., 2009), healthy and clinical populations (Al-Rahamneh & Eston, 2011; Al-Rahamneh, Faulkner, Byrne, & Eston, 2011), and in physically active and sedentary individuals (Eston, et al., 2012; Eston, Lambrick, Sheppard,& Parfitt, 2008; Faulkner, Parfitt, & Eston, 2007). RPE is also useful for estimating the anaerobic threshold (e.g. VT) (Parfit, Evans & Eston, 2012).

The Rockport Walking Test (RWT), also known as 1-Mile Walk Test (1-MWT), is a popular submaximal field test used to predict VO_2max among a wide range of age categories and fitness levels (Kline, et al., 1987). The RWT is a brisk walking field test performed on a level surface track, for a distance of 1-mile (1,609 meters). Predicting VO_2max using the RWT is dependent on the age, gender, body weight, terminal HR, and time required for completion. Dolgener, Hensley, Marsh, and Fielstul (1994) found that the original RWT equation should not be used for young individuals. Thus, an age-specific equation for RWT was established to predict VO_2max for young individuals.

Several previous studies have shown the validity of estimating VO_2max without the requirement for

exercise testing based on personal information collected from questionnaires (Jackson, et al., 1990; Matthews, Heil, Freedson, & Pastides, 1999). These questionnaire-based models have been shown to be of equivalent accuracy compared to submaximal exercise tests, particularly field tests such as the RWT (Jackson, et al., 1990). As an example of these models, Matthews et al. (1999) developed an equation, including age, age^2, gender, physical activity status, height, and body mass to predict VO_2max. Non-exercise questionnaire-based predictive equations can reasonably categorize individual fitness levels. Physical activity status was assessed using the NASA Physical Activity Rating (PA-R) questionnaire (Matthews, et al. 1999; Ross & Jackson, 1990).

There is a lack of evidence supporting non-maximal or non-exercise tests as a primary outcome measure and comparing these tests simultaneously relative to each other. Because different studies were used to create the predictions of VO_2max or VT, there remains an open question of how well they actually correspond with each other, or with objective measurements. Accordingly, the purpose of this study was to compare three non-maximal tests: the TT, the RPE, and the RWT relative to the accuracy of predicting exercise capacity, reflected by VO_2max and VT. The secondary aim was to examine the accuracy of questionnaire-based prediction equation compared to maximal as well as non-maximal testing. We hypothesized that there would be no significant difference between the non-maximal tests and the GXT and that the non-maximal methods could be used as primary methods for predicting exercise capacity.

Methods

Participants

The subjects in this study were 20 healthy adults, eight men and 12 women. All were of a low to moderate fitness level (no regular physical activity in the three months prior to the study). Prior to testing, there was an introductory session designed to define participants' characteristics and to familiarize them to the laboratory setting, exercise testing and equipment. The study protocol was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects. Written informed consent was provided by participants. They completed the following assessment forms: (1) Physical Activity Readiness Questionnaire (PAR-Q), (2) AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire to identify contraindications to GXT, and (3) the NASA Physical Activity Rating (PA-R) (Jackson, et al., 1990; Ross & Jackson, 1990) to assess the participants' level of physical activity.

Experimental design

Participants performed four tests, with at least 48 hours between the tests. The procedures included a maximal test and three non-maximal tests. Test 1 was a maximal incremental exercise test conducted on the treadmill to the point of fatigue using a modified Balke protocol (ACSM, 2017), with respiratory gas exchange measurements using open circuit spirometry using a mixing chamber based metabolic cart (AEI, Bastrop, TX). The treadmill velocity/grade were initially set at 3.0 mph (4.8 kph)/0% grade for 2 minutes and increased by 2.5% grade every two minutes until fatigue. The RPE was reported at the end of each 2-minute stage using the Borg (6-20) scale (Borg, 1982). The gas analyzers were calibrated with reference gases (16% O_2, 5% CO_2) and room air. The pneumotach was calibrated with a 3-L syringe. Gas analysis data were summated every 30 seconds, with the highest 30 second value accepted as VO_2max. The VT and RCT were determined using both the V-slope and ventilatory equivalent methods (Foster & Cotter, 2006; Schneider, Phillips, & Stoffolano,

1993). Heart rate was measured using radiotelemetry (Polar Electro Oy, Port Washington, NY), integrated every 5 seconds.

Test 2 was similar to Test 1, but without respiratory gas exchange measurement. During the last 30 seconds of each stage, the TT was performed by instructing the subjects to read a 101-word paragraph, the "Rainbow Passage", out loud and respond to the question "Can you speak comfortably?" Possible answers were: "Yes", which indicated the positive (POS) stage, any equivocal expressions like "Yes, but" or "I am not sure", which indicated the equivocal (EQ) stage, and "No" indicated the negative (NEG) stage of TT. Based on previous studies (Foster, et al., 2018), the highest exercise intensity at which the subject indicates that they can speak comfortably is the last positive (LP) stage, which is typically below the VT. The EQ stage typically approximates the VT. The first NEG stage typically approximates the RCT. The RPE was assessed during the last 10 seconds of each 2-minute stage, immediately following the TT. The participant walked on the treadmill until the NEG stage of TT (or fatigue), and the RPE was recorded until the subject reached or exceeded RPE=15. By using the estimation procedure, RPEs reported throughout the exercise test and VO_2 values calculated from metabolic calculations (ACSM, 2017) (VO_2:RPE) were extrapolated to RPE=19 and RPE=20 to estimate VO_2max (Faulkner & Eston, 2007; Lambrick, et al., 2009; Faulkner, et al., 2009) (Figure 1).

For Test 3, the RWT test was performed on an indoor track (8 laps=1 mile). The subjects walked briskly for one mile. At the end of the walk, the time and terminal HR were recorded. VO_2max was calculated using the Rockport formula (Kline, et al., 1987):

VO_2max (ml·kg^{-1}·min^{-1}) = 132.853 + (6.315*gender) - (0.3877*age) - (0.0769*weight [pounds]) - (3.2649*time [min]) - (0.1565*final heart rate) [Equation 1],
where gender = 1 for male, 0 for female.

Additionally, VO_2max was calculated using the non-exercise prediction equation of Matthews et al. (1999):

VO_2max (ml·kg^{-1}·min^{-1}) = (0.133× age)-(.005× age^2) + (11.403× gender) + (1.463× PA-R score) + (9.17× height [m]) - (.254×body mass [kg]) +34.142 [Equation 2],
where gender = 1 for male, 0 for female. The PA-R score was obtained from the NASA PA-R questionnaire (Jackson, et al., 1990; Ross & Jackson, 1990).
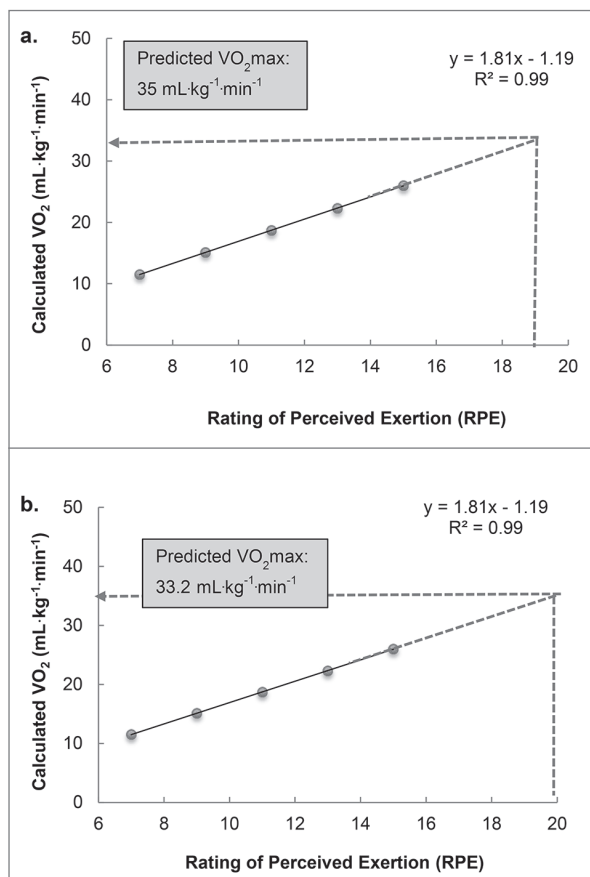

Figure 1. Example of VO₂max prediction using the individual linear regression between RPE ≤ 15 and VO₂ calculated from metabolic calculations (ACSM, 2017) for one subject. The dotted lines represent the extrapolation of the individual RPE ≤ 15: VO₂ linear regression to a.) RPE 19 (predicted VO₂max: 1.81(19) − 1.19 = 33.2 mL·kg⁻¹·min⁻¹), and to b.) maximal theoretical RPE (i.e. RPE 20) (predicted VO₂max: 1.81(20) − 1.19 = 35 mL·kg⁻¹·min⁻¹).

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA). Standard descriptive statistics were used to assess the baseline physical characteristics. Comparisons between the measured and the predicted VO_2max

and VT were made using repeated measures analysis of variance (ANOVA). If ANOVA showed a significant difference, *post-hoc* analyses were performed using the Tukey's Honestly Significance Difference (HSD) test. A p value of ≤0.05 was considered statistically significant. Linear regression analysis between the calculated VO_2 values and RPE ≤ 15 values was made for each subject. The resultant equation ($VO_2max = a + b$ [RPE 19 or 20]) was used to predict VO_2max (Figure 1). Pearson product-moment correlations and standard errors of the estimate (SEE) versus the predicted VO_2max were used to compare values.

Results

The characteristics and maximal exercise test data of the 20 participants are presented in Table 1. VO_2 at RCT was indeterminate in six subjects; thus, VO_2 at RCT and VO_2 at NEG stage of the TT were not analyzed in the study.

Overall, mean measured VO_2max was 38.1 ± 6.52 mL x kg^{-1} x min^{-1} and mean predicted VO_2max was 40.1 ± 6.9, 40.1 ± 7.03, 42.6 ± 7.43, and 40.0 ± 7.8 mL x kg^{-1} x min^{-1} for the Matthews et al. (1999) equation, extrapolation to RPE 19, extrapolation to RPE 20, and the RWT equation, respectively (Table 2, Figure 2). Tukey's *post-hoc* test found that there was no significant difference between the measured and the predicted VO_2max using the Matthews et al. (1999) equation, extrapolation to RPE19 and the RWT equation (Kline, et al., 1987). VO_2max

Figure 2. Mean (±standard error, SE) values for the measured VO_2max (mL·kg^{-1}·min^{-1}) in relation to the predicted VO_2max (mL·kg^{-1}·min^{-1}) using the Matthews et al. (1999) equation, extrapolation to RPE 19 and 20, and the RWT original equation. The dashed line represents a referent to the measured VO_2max.

was significantly less than predicted VO_2max using extrapolation to RPE 20 (p≤.05).

Figure 3 shows the relationship between the measured and the predicted VO_2max using the non-maximal tests. The R values indicated a moderate to good correlation between the measured and the predicted VO_2max, with values of R^2= 0.75, 0.85, 083, and 0.73 for the Matthews et al. (1999) equation, extrapolation to RPE 19, extrapolation to RPE 20, and the RWT equation, respectively. There was a good correlation between the measured and the predicted VO_2max values using extrapolation to RPE 19 and RPE 20. The predicted VO_2max values using either the Matthews et al. (1999) equation or the RWT equation (Kline, et al., 1987) were moderately correlated with the measured VO_2max.

The means of the VO_2 at VT and VO_2 at the LP and EQ stages of the TT, and at the RPE13, 14, and 15 were compared. Tukey's *post-hoc* test revealed that there was no significant difference between the VO_2 in ml x kg^{-1} x min^{-1} at VT (26.9 ± 5.51), the LP (25.7 ± 5.32), and EQ (29.4 ± 5.30) stages of the TT, at RPE13 (25.9 ± 5.07) and RPE14 (28.5 ± 5.26). However, the VO_2 at RPE 15 (31.0 ± 5.55) was significantly higher than VO_2 at the VT (Table 3, Figure 4).

The VO_2 at VT was well correlated with VO_2 at the LP (R = 0.76) and EQ (R = 0.77) stages of the TT, and at the RPE13 (R = 0.73), RPE14 (R = 0.71) and RPE15 (R = 0.70) (Figure 4). Although VO_2 at VT versus VO_2 at EQ stage of the TT and RPE14 slightly overestimated VT, they fit very close to the line of identity. Likewise, VO_2 at VT versus VO_2 at LP stage of the TT and RPE13 fit very close to the line of identity, although they slightly underestimated VT. Therefore, the LP and EQ stages of the TT as well as RPE13 and 14 were relatively accurate predictors of VT.

Table 1. Descriptive characteristics of subjects (N=20)

Variable	Male (n=8)	Female (n=12)
Age (year)	25.2 ± 7.90	28.3 ± 9.37
Height (cm)	181.5 ± 6.42	164.8 ± 8.67
Weight (kg)	87.3 ± 11.85	66.9 ± 14.80
VO_2max (L·min^{-1})	3.67 ± 0.689	2.33 ± 0.426
VO_2max (mL·kg^{-1}·min^{-1})	42.1 ± 5.84	35.5 ± 5.71
VO_2 @ VT (L·min^{-1})	2.55 ± 0.754	1.67 ± 0.373
VO_2@VT (mL·kg^{-1}·min^{-1})	29.1 ± 6.38	25.4 ± 4.54
HRmax (bpm)	175.6 ± 14.64	183.7 ± 10.86
HR@VT	140.3 ± 22.33	150.9 ± 14.58
RPE@VT	13.6 ± 1.84	14.0 ± 1.78
RPEmax	19.2 ± 0.46	19.0 ± 0.28

Note. Data are reported as mean ± standard deviation.

Table 2. Comparison of the measured and the predicted VO_2max values (means±SD) in mL·kg^{-1}·min^{-1}

Test	Mean ± SD	r	R^2
Maximal test (GXT)	38.1 ± 6.52		
Matthews et al. equation[27]	40.1 ± 6.91	0.76	0.57
Extrapolation to RPE 20	42.6 ± 7.43*	0.84	0.70
Extrapolation to RPE 19	40.1 ± 7.03	0.85	0.73
RWT equation[24]	40.0 ± 7.82	0.71	0.51

Note. r = Pearson product-moment correlation. R^2= coefficient of determination. * significantly different than maximal test (p<.05).

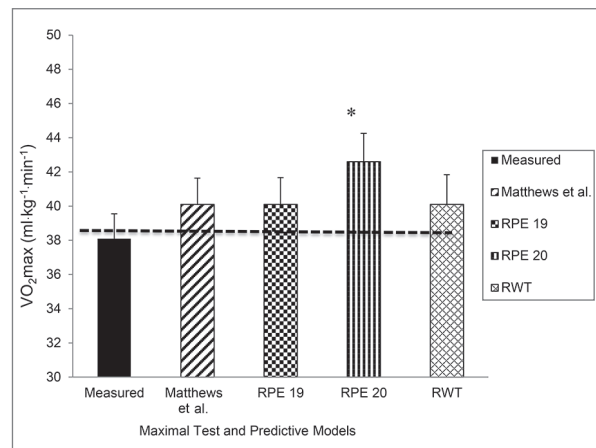*Figure 3. The relationship between the measured VO₂max (mL·kg⁻¹·min⁻¹) and the predicted VO₂max (mL·kg⁻¹·min⁻¹) using the Matthews et al. (1999) equation, extrapolation to RPE19 and RPE20, and the RWT original equation.*

Table 3. Means (±SD) VO₂ at VT (ml·kg⁻¹·min⁻¹), VO₂ at LP and EQ stages of the TT, and the VO₂ at RPE13, RPE14, and RPE15 (ml·kg⁻¹·min⁻¹)

	Mean ± SD	r	R²
VO₂ @VT	26.9 ± 5.51		
TT			
VT @ LP	25.7 ± 5.32	0.76	0.58
VT @ EQ	29.4 ± 5.30	0.76	0.59
RPE			
VT @ RPE13	25.9 ± 5.07	0.74	0.54
VT @ RPE14	28.5 ± 5.26	0.71	0.51
VT @ RPE15	31.0 ± 5.55*	0.70	0.49

Note. *Significantly different than VO₂ at VT (p<.05).

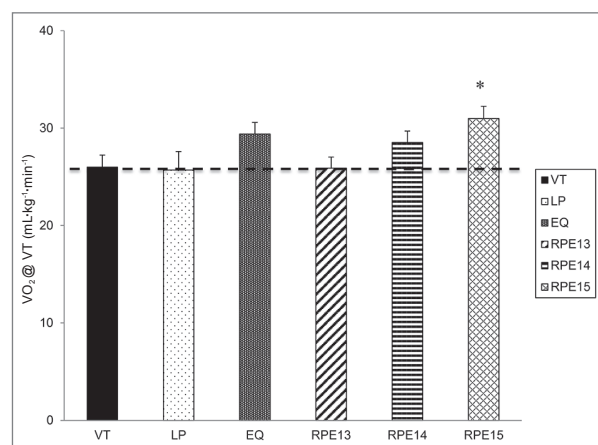*Figure 4. Mean (±SE) values for VO₂ at the VT (mL·kg⁻¹·min⁻¹) in relation to the VO₂ at the LP and EQ stages of the TT, and at the RPE 13, 14, and 15. The dashed line represents a referent to the measured VT.*
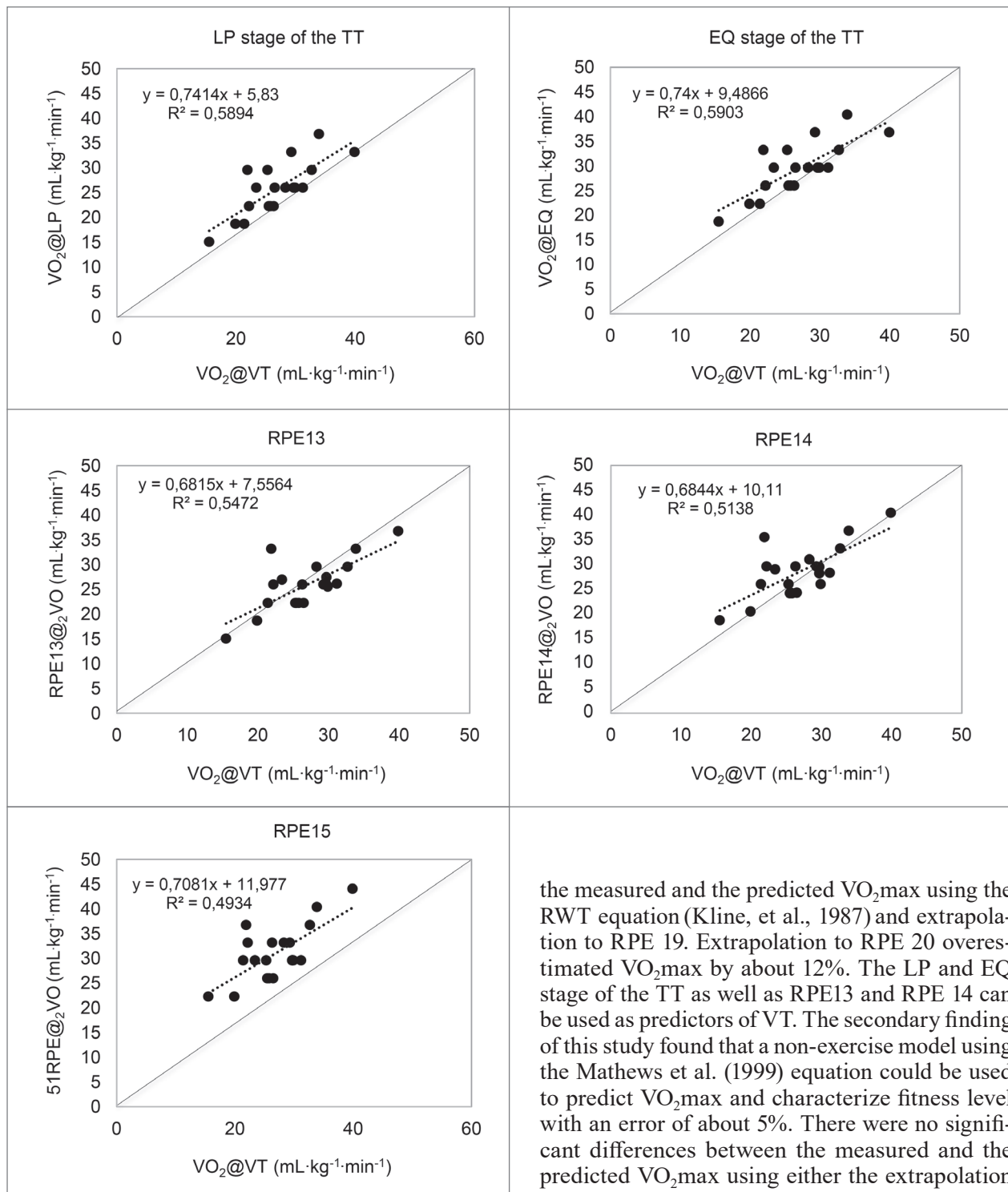
Figure 5. The relationship between the VO$_2$ at VT (mL·kg^{-1}·min^{-1}) and the VO$_2$ during the LP and EQ stages of the TT, and the VO$_2$ at each of RPE 13, RPE 14, and RPE 15 (mL·kg^{-1}·min^{-1}).

Discussion and conclusion

The overall results of the current study suggest that sub-maximal tests, and even non-exercise tests, can be used as relatively accurate methods for predicting VO$_2$max and VT, at least in healthy, sedentary individuals. The primary findings showed that there were no significant differences between

the measured and the predicted VO$_2$max using the RWT equation (Kline, et al., 1987) and extrapolation to RPE 19. Extrapolation to RPE 20 overestimated VO$_2$max by about 12%. The LP and EQ stage of the TT as well as RPE13 and RPE 14 can be used as predictors of VT. The secondary finding of this study found that a non-exercise model using the Mathews et al. (1999) equation could be used to predict VO$_2$max and characterize fitness level with an error of about 5%. There were no significant differences between the measured and the predicted VO$_2$max using either the extrapolation to RPE 19, the RWT equation (Kline, et al., 1987), or the Matthews et al. (1999) equation.

The results of the current study confirmed that the TT can be used to accurately predict VT. Although VO$_2$ at VT was not significantly different than VO$_2$ at either the LP or EQ stages of the TT, the EQ stage more closely correlated with VT. These results are in accordance with previous studies that have also observed that the EQ stage of the TT can be used as a surrogate of VT in different populations (Foster, et al., 2018). We conclude that when subjects were at the LP or EQ stage of the TT, they were very close to VT.

Interestingly, when the 6-20 RPE scale was used in conjunction with the TT, the results showed the comparability of the TT (LP and EQ) and RPE 13 and 14 for predicting VT. The VO_2 at the EQ stage of the TT as well as at RPE 14 were close to the measured VO_2 at VT. Exercising at the LP stage of the TT, as well as RPE 13, slightly underestimated VT. However, exercising at RPE 15 or the NEG stage of the TT significantly overestimated VT. The current results generally support the results of Purvis and Cukiton (1981), which indicated a strong correlation between the VO_2 at VT and VO_2 at RPE 13. The current results indicated that the estimation procedure for VO_2max prediction by extrapolating the measured RPEs ≤ 15 to RPE 19 yielded a prediction that was not significantly different to the measured VO_2max. The findings are in agreement with previous studies in healthy participants (Faulkner, et al., 2009; Faulkner & Eston, 2007; Lambrick, et al., 2009) and competitive cyclists (Coquart, et al., 2012b). However, two studies (Faulkner, et al., 2009; Lambrick, et al., 2009) found that there was no significant difference between the actual and the predicted VO_2max when the VO_2 :RPE ≤ 13 values were extrapolated to either RPE 19 or RPE 20. Conversely, the current study showed that extrapolation to RPE 20 overestimated VO_2max by 4.5 ml x kg x min^{-1} (~12%). This finding is in opposition to previous studies in clinical participants (Coquart, et al., 2009), and in healthy and clinical participants (Al-Rahamneh & Eston, 2011; Al-Rahamneh, et al., 2011), which found that extrapolation to RPE=20 yielded the best fit with the measured VO_2max. The opposing finding observed in the current study may be due to the differences in the exercise test protocol and the exercise modality (treadmill vs. cycle ergometer). The other possible explanation is the perceptual end point of extrapolation (RPE 20). Although the RPE 20 is theoretically considered the point of maximal effort or exhaustion, a submaximal RPE, specifically RPE=19, is more often observed (Coquart, et al., 2012a; Demello, Cureton, Boineau, & Singh, 1987; Eston, Faulkner, St Clair Gibson, Noakes, & Parfitt, 2007). In this regard, it has earlier been suggested that the brain increases RPE consistently with the residual time to the end of the test, and that the time to fatigue relates to the reasonably tolerated maximal RPE (i.e. RPE 19 rather than RPE 20) (Coquart, et al, 2012a; Eston, et al., 2007; Noakes, 2004). The current results are in agreement with previous studies (Eston, et al., 2012; Smith, Eston, Norton, & Parfitt, 2015), which revealed that predicting VO_2max by extrapolating RPE:VO_2 values to RPE=19 is more accurate compared to RPE=20.

The current study revealed the predicted VO_2max using the RWT equation was not significantly different than the measured VO_2max. The results yielded a strong correlation (R = 0.71) and low standard error of estimate (SEE = 4.6 ml x kg^{-1} x min^{-1}) between the actual and the predicted VO_2max. The current results are in accordance with the finding of Kline et al. (1987), which showed a strong correlation between the measured and the predicted VO_2max for validation and cross validation groups (R = 0.88 and 0.88, respectively), and the SEE = 5.0 and 4.4 ml x kg^{-1} x min^{-1}, respectively. The better results from Kline et al. (1987) study may be attributable to a large sample size (343 subjects) and a wider range of subject's VO_2max. Another possible reason could be the testing procedure that allowed the subjects to do several walks with the two fastest walks being used. Although the age-specific equation developed by Dolgener et al. (1994) might be more appropriate for many of the participants in the current study, it is only applicable for a narrow range of ages (18-30 years), which limits its use, and makes the original equation more attractive. However, the original equation includes HR during the last part of the 1-mile walk, which can be highly variable in some conditions, such as in patients on HR altering medications. Therefore, there is a need to find an alternative variable to HR. Additionally, further research needs to be done to find accurate alternative protocols for the RWT. Recently Cress et al. (2015) have shown promising results relative to predicting both VO_2max and VT using 6-minute walk distance and terminal RPE (as a replacement for the HR used in the RWT). Whether this approach will prove useful relative to adapting the RWT remains to be documented.

An impressive secondary result for the current study showed that a non-exercise VO_2max prediction model could be used with reasonable accuracy. The results showed that there was no significant difference between the measured and the predicted VO_2max using the equation of Matthews et al. (1999) (R = 0.76, SEE = 4.3 ml·kg^{-1}·min^{-1}). This finding is in accordance with the results of Matthews et al. (1999), who found a stronger correlation but a slightly larger SEE than the current study (R = 0.86, SEE = 5.7 ml x kg^{-1} x min^{-1}). The stronger correlation was arguably because of the very large sample size (N = 799, healthy adults) with a very wide range of ages (19-79 years). Further studies would be useful in determining the accuracy of using this equation in different populations.

The present study has some technical limitations. For the TT, frequent concerns were the subjects' ability to correctly determine the EQ stage and reading a relatively long and novel passage, requiring about ~30 seconds, the "Rainbow Passage", within a short duration (two minutes) exercise stage. A recent study (Schroeder, Foster, Porcari, & Mikat, 2017) found that longer speech passages, such as the "Rainbow Passage", better predicted VT and RCT, compared to shorter (30

words) speech passages, using the EQ and NEG stages of the TT. Another study (Foster, et al., 2018) pointed out that stage duration affected the power output when trying to identify the VT and RCT, but had no effect on other physiological markers (HR, VO_2, RPE). Further research is needed to indicate the stage duration that optimally predicts VT and RCT, using shorter and more familiar speech passages. In using the Borg 6-20 RPE scale, some subjects found it difficult to identify appropriate RPE at the end of each stage. For this reason, it might be ideal to have subjects perform several trails in order to optimize the prediction of VO_2max. However, both the TT and RPE are attractive because both are very robust and intuitive. Protocols that require multiple trials to achieve better results would be somewhat self-defeating, as the purpose of sub-maximal tests is to simplify the process of exercise evaluation. The present study compared the accuracy of three non-maximal tests, the TT, RPE extrapolation, and the RWT, for predicting VO_2max and VT. Additionally, the non-exercise prediction models are of comparable accuracy to the non-maximal exercise tests when the exercise testing is not feasible. Future studies are required to further support the present results by examining the accuracy of these non-maximal tests in different populations.

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Correspondence to:
Carl Foster, Ph.D.
Department of Exercise and Sport Science
133 Mitchell Hall
University of Wisconsin-La Crosse
La Crosse, WI 54601, USA
Phone: 608-792-2170
E-mail: cfoster@uwlax.edu