

Validation of the 15 Minute Balke Field Test for Competitive, Adult 5K Runners: From Treadmill VO_{2max} Testing to Enhancing Performance

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Abstract The purpose of this study was to determine the validity of a 15 minute field test of VO_{2max} in competitive adult male and female 5k runners and analyze the factors that contribute to the VO_{2max} of runners in the field versus on a treadmill. Nineteen trained, endurance runners completed a graded treadmill test and a 15 minute field test on a 400 m track (the Balke field test) to independently determine VO_{2max} . We compared the data using a paired sample t-test, Pearson's correlation, and multiple linear regression. Treadmill VO_{2max} of runners was significantly higher than the VO_{2max} determined by the 15 minute field test (56.9 +/- 5.3 ml/min/kg vs. 52.7 +/- 4.3 ml/min/kg, $t(18) = 6.609$, $p = 000$). We found a strong correlation when both treadmill pace at VO_{2max} and treadmill VO_{2max} were used as predictive factors for field VO_{2max} ($r^2 = .848$, $p = .000$) with treadmill pace at VO_{2max} having the strongest associative power in the correlation ($\beta = .636$, $p = .001$). The 15 minute field test is an adequate test of 5K race readiness, with the addition of treadmill test giving athletes and coaches an assessment of race fitness relative to aerobic capacity. In addition to treadmill VO_{2max} , coaches and athletes must consider additional performance factors such as treadmill pace at VO_{2max} , lactate threshold, running economy, motivation, etc. for the prediction of field or performance VO_{2max} .

Keywords: running, coaching, cardiopulmonary exercise test, Balke field test, treadmill test, mathematical model

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1. Introduction

We believe that assessing aerobic capacity is of great value for running coaches to establish the performance potential of their athletes in common events such as the 5K through 15K. The gold standard for assessing aerobic capacity is the VO_{2max} test conducted in laboratory. [1,2] Due to a number of factors, however, runners are challenged to reach and sustain their full potential during competition. To determine the race readiness of their athletes, coaches would benefit from a reliable field test of race fitness that likewise demonstrates fitness relative to aerobic capacity.

VO_{2max} is expressive of cardiorespiratory fitness, endurance, performance, and aerobic capacity, with high VO_{2max} values associated with high levels of each. [3,4] Because of the high amount of information testing gives, researchers use VO_{2max} testing to understand the physiological aspects related to sports performance. [5] While VO_{2max} testing during a graded treadmill test proves to be exceptionally accurate, valid, and consistent, laboratory testing is time intensive, costly, equipment intensive, and requires specialized training. Because of these limitations, researchers have developed many alternative field tests to determine VO_{2max} . The tests are generally easy to administer, less costly, take less time, and allow users to

test multiple individuals at once. [6] Additionally, coaches can use field tests to evaluate an athlete or team's fitness before, during, or after a competitive season or change in training. [5]

As competitive 5K runners operate at or near VO_{2max} for the duration of a 5K race, duplicating such efforts requires testing that stresses runners to the maximum, and is of sufficient duration to replicate racing times of competitive runners. While researchers have evaluated 12 minute and 1.5 mile field tests, these tests do not begin to replicate the 5K race distance nor finish times of competitive runners. [7,8,9,10,11] The Balke field test (hereafter referred to as the 15 minute field test), however, is a 15 minute maximal effort running test (done on a 400 m track) that was developed by Bruno Balke in 1954 for testing VO_{2max} outside of the laboratory. [12] Balke established that since VO_{2max} testing measures the aerobic work capacity, the duration of physiologically meaningful tests should be at least 12 minutes in duration, yet not so long as to introduce fatigue and reduced motivation as compounding factors. Balke also established a relationship between running velocities and oxygen requirement in which oxygen requirements between 133 m/min (5 mph) and 290 m/min (11 mph) were found to be linearly related to running performance. In testing completed on high school boys, Balke demonstrated that the VO_{2max} determined from field test data correlated well with

treadmill test in the laboratory, yet there has not been much research on the 15 minute field test since then, particularly in trained, adult competitive runners. [12]

We seek to fill in the gaps regarding research utilizing the 15 minute field test by comparing a maximal VO_{2max} treadmill test in the laboratory on a group of trained, adult male and female runners to the 15 minute field test. In particular, we seek to determine the correlation between the VO_{2max} of these tests and to analyze the factors that contribute to VO_{2max} in the field (hereafter referred to as field VO_{2max}) versus VO_{2max} determined on the treadmill (hereafter called treadmill VO_{2max}). A validated test would provide a means for coaches to determine the race readiness of their athletes outside of the confines of a race, and allow coaches to assess fitness relative to the aerobic capacity of their runners. Finally, based on what is known and determined here about the factors that contribute to a runners VO_{2max} , we propose a regression model for the prediction of field VO_{2max} . As reviewed and further refined by George, et al., regression models to predict VO_{2max} are not without precedent given their extensive use by researchers in extrapolating VO_{2max} from exercise data [13].

2. Materials and Methods

A total of nineteen subjects consisting of males ($n = 9$) and females ($n = 10$) between 23 and 49 years of age (mean age of 32 years) considered physically active, trained runners participated in this study. All participants were familiar with both treadmill and track running. We determined medical clearance for subject participation based on criterion of the American Heart Association (AHA) and American College of Sports Medicine (ACSM). We obtained Institutional Review Board (IRB) approval for the study from The Sage Colleges IRB committee.

For treadmill (Trackmaster TMX-425CP Treadmill) testing, we maintained the laboratory at $\sim 70^{\circ}F$ and 50% humidity, and used a fan to cool runners during testing. We fit each subject with a COSMED heart rate monitor strap, and instructed each to warm up for ten minutes on the treadmill at a slope of 0 degrees at a comfortable pace. While the subject was warming up, we calibrated a COSMED Quark CPET to facilitate accurate VO_{2max} determination. After the runner's warm up and CPET calibration, we fit runners with a COSMED exercise mask. During the tests, we maintained the treadmill at a constant grade of 2% while we increased pace from a typical warm up pace by 1 km/hr per minute until the runner reached voluntary exhaustion, or three of the criterion for VO_{2max} had been met: RER (vCO_2/vO_2) greater than or equal 1.10, heart rate greater than 95% of age predicted maximum, and plateau of volume of oxygen inhaled (VO_2). We considered a plateau in VO_2 when the VO_2 value did not change more than 2 ml/min/kg over the course of a minute.

For analysis of VO_{2max} , we used 15 second averaging of the CPET raw data. We determined VO_{2max} by averaging four consecutive data points at the plateau of each runner's data.

After all participants completed the graded treadmill run in the laboratory, we conducted the 15 minute field test on a standard 400-meter running track. We completed the test within two and half weeks of treadmill testing to minimize any effects of training on VO_{2max} since all participants trained regularly. The day of the test the temperature was $50^{\circ}F$, humidity 32%, with an 8 mph wind. All participants ran the test on the track together. We gave participants a brief overview of the test including instructions to run as fast as they can when told "GO" at the beginning of the test, weighed each runner before the test, and assigned bib trackers to facilitate automatic Chronotrack timing. We then instructed participants to warm up 10 minutes prior to beginning the 15 minute field test. To make sure runners could keep track of their time during the run, we placed a large racing clock near the start line. The number of laps completed during the 15 minute period was automatically counted by the Chronotrack system. At the end of the 15 minute period, we instructed runners to stop where they were on the track. We measured the distance each runner proceeded past the 400-meter mark of their last lap with a measuring wheel, and computed VO_{2max} using the formula, $VO_{2max} = ((\text{Total distance covered} \div 15 \text{ minutes}) - 150) \times 0.178 + 33.3$. The base constant value of 150 represents the first 150 meters per minute of running during which energy is considered to be derived primarily from anaerobic metabolism and thus has little correlation with a runner's aerobic capacity. The 0.178 multiplier is used to associate the aerobic contribution in milliliters of oxygen per kilogram of body mass per minute for each meter run beyond the first 150 meters per minute. The value 33.3 represents the VO_2 of 33.3 ml/kg/min for the first 150 m [14].

We determined the correlation between treadmill VO_{2max} and field VO_{2max} using Pearson's correlation, and analyzed for differences between the treadmill VO_{2max} and field VO_{2max} values with a two-tailed paired t-test. We used regression analysis to determine the dependence of field VO_{2max} values on treadmill VO_{2max} values, and to analyze the dependence of field VO_{2max} values on both treadmill VO_{2max} and the pace at which treadmill VO_{2max} was reached. We considered statistical significance for p values less than 0.05 ($p < 0.05$).

No conflicts of interest existed that could have inappropriately influenced the study.

3. Results

Mean treadmill VO_{2max} for runners was significantly higher than their mean field VO_{2max} (Table 1).

Table 1. Mean (and Standard Deviation) of VO_{2max}

Treadmill Test	15-Minute Field Test	t-statistic	df	Significance (2-tailed)
56.9 +/- 5.3 ml/min/kg	52.7 +/- 4.3 ml/min/kg*	6.069	18	.000

* For an N of 19, data are statistically significant to $p < .001$ in the Paired samples t-test; analyzed using IBM SPSS v.24.

Table 2. Regression Analysis: Predictors of Field VO_{2max}.

	R	R Square	F Change	Significance (2-tailed)
Treadmill VO _{2max}	0.828	0.686		0.000
Treadmill pace at VO _{2max} and Treadmill VO _{2max}	0.921	0.848	44.487	0.000

For an N of 19, the data are statistically significant to $p < .001$ in the Pearson's correlation coefficient, R. Significance for the prediction of field VO_{2max} using both treadmill pace at VO_{2max} and the treadmill VO_{2max} as predictors was determined using the F-test.

Runners VO_{2max} values from the treadmill and field tests were significantly correlated as determined by Pearson's correlation coefficient, R (Table 2). This correlation, however, suggests that only 69% of the variability in the field VO_{2max} values can be explained by the treadmill VO_{2max} values. Results from multiple linear regression showed that including the pace at which treadmill VO_{2max} was reached along with the treadmill VO_{2max} value resulted in better explanatory power for field VO_{2max} compared to simply the treadmill VO_{2max} value alone, suggesting that 85% of variability in the field VO_{2max} values can be explained by the combination of treadmill VO_{2max} values and the pace at which treadmill VO_{2max} was reached (see Table 2).

Furthermore, the standardized β -coefficient from the regression analysis indicates that treadmill pace at VO_{2max} is associated with 64% of the correlation between the treadmill and field tests (Table 3).

Table 3. Prediction of Field VO_{2max} Using Both Treadmill Pace at VO_{2max} and Treadmill VO_{2max} as Predictors

	Standardized β -Coefficients	Significance
Treadmill VO _{2max}	0.334	.000
Treadmill pace at VO _{2max}	0.636	.001

4. Discussion

Field testing is a more practical and readily available method of assessing VO_{2max} as compared to treadmill testing in the laboratory for a variety of reasons. [1,4] In this study of adult female and male trained runners, the correlation (albeit lower) between treadmill VO_{2max} and field VO_{2max} is consistent with what Balke reported for testing in boys. [12] Our result is also consistent with the high correlations researchers found between treadmill tests and other maximal field test studies completed on physically active males utilizing either 12 minute run tests completed on a flat surface [7] or indoor track [11], and a test utilizing a 1.5 mile run conducted on adult males and females. [15] The lower correlation we observed is likely due to having trained runners of varying levels of race fitness and ability, and the wide age range of subjects in this study. However, we believe that the higher correlation of field VO_{2max} as predicted by the combination of treadmill pace at VO_{2max} and treadmill VO_{2max}, along with the strong association of treadmill pace at VO_{2max} with field VO_{2max} identified here is particularly useful for helping to explain why many of the runners in this study with similar treadmill VO_{2max} displayed very different field VO_{2max} results; they're treadmill pace at VO_{2max} was different.

In this study, we found significantly higher treadmill VO_{2max} values in comparison to the VO_{2max} values

determined by the 15 minute field test on the track. In a study conducted by Meyer et al., researchers did not find significant differences between track and treadmill VO_{2max} values, yet, they did find higher submaximal VO₂ values on the treadmill. [16] The consistently lower field VO_{2max} values for runners found in our study may be related to the fact that treadmill testing only requires runners to be at maximal effort for a brief period of time, thus limiting the cumulative effects of performance factors such as motivation, pain tolerance, psychological makeup, and running economy. [17,18] Unless runners have mastered these factors, these have the effect of limiting the extent to which one can run to their lab tested, treadmill VO_{2max} during a competitive event of significant duration such as a 5K. On the other hand, competitive runners may find it useful to work toward their VO_{2max} determined aerobic capacity to make the most of their aerobic engine.

Our data suggests that while treadmill VO_{2max} measurements correlate with the 15 minute field test of VO_{2max}, treadmill VO_{2max} is not sufficient for coaches to predict field VO_{2max} nor should treadmill VO_{2max} data alone be used to set up training recommendations for 5K runners. On the other hand, we believe that coaches could use data from the combination of treadmill VO_{2max} testing and 15 minute field tests to determine training recommendations. We believe that the field VO_{2max} is analogous to the runner's performance VO_{2max} ("VDOT") giving a test of race readiness outside of the confines of a race, and gives an assessment of fitness relative to the aerobic capacity of runners. VDOT was developed by Jack Daniels and represents the amount of oxygen consumed per minute by an athlete determined by race performances, or performance in regard to time to run a specific distance. [17,18] Daniels described that performance VO_{2max} data encompasses many factors such as motivation, lactate threshold, pain tolerance, psychological makeup, and running economy. Thus, we believe that coaches and therapists could assist runners in working toward their laboratory determined aerobic capacity by making concerted efforts to understand and control the contribution that each of the factors have on their performance.

Although we found that 15 minute field test and the treadmill determined VO_{2max} values are strongly correlated and the mean difference in VO_{2max} is significant in trained adult male and female runners, a meaningful % difference cannot be applied to a runners' treadmill VO_{2max} to calculate their field VO_{2max} given the inconsistent nature of the individual differences amongst runners. In the future, however, additional research may allow coaches to estimate field VO_{2max} and thus 5K performance based on factors identified by Daniels and others, and as highlighted here. In this study, regression analysis indicated that only 85% of the variability in the field VO_{2max} of runners is due to treadmill pace at VO_{2max} and treadmill VO_{2max}, suggesting that other factors must be

present. And, 64% of this variability is associated with treadmill pace at VO_{2max} ; 33% associated with treadmill VO_{2max} . Thus, a regression model of field or performance VO_{2max} for an individual runner begins to take shape in which their unique performance $VO_{2max} = (\beta_{weight} \times \text{treadmill pace at } VO_{2max}) + (\beta_{weight} \times \text{treadmill } VO_{2max}) + (\beta_{weight} \times \text{lactate threshold}) + (\beta_{weight} \times \text{running economy}) + (\beta_{weight} \times \text{psychological factors}) + (\beta_{weight} \times \text{tolerance to environmental challenges (heat and humidity)})$. β_{weight} represents standard multiple regression coefficients thus requiring researchers to apply multiple linear regression and a stepwise model selection tool to determine the unique contribution and significance that each of these factors have toward predicting field VO_{2max} of a runner. [13] In a regression model for prediction of VO_{2max} from exercise and non-exercise data, George et al. incorporated questionnaire data for perceived functional ability (PFA) and a physical activity rating (PA-R) to generate meaningful coefficients, in which PFA may account for factors such as lactate threshold and running economy. [13,19] Thus, in the model proposed here, PFA may provide a reasonable solution to gauging lactate threshold (also measureable directly in the laboratory) and running economy. Similarly, a questionnaire may provide a suitable approach for researchers to determine the contribution that motivation/psychological factors and tolerance to environmental challenges have on the proposed regression model.

5. Conclusion

In this study, we determined that the field VO_{2max} of trained, adult 5K runners is strongly correlated with their treadmill VO_{2max} with treadmill pace at VO_{2max} having the greatest explanatory power in the correlation. These data help to inform coaches why runners of the same VO_{2max} determined in the laboratory do not run to the same VO_{2max} in a 15 minute field test on the track. The 15 minute field test can be used by coaches to determine training recommendations and to assess the race fitness of runners relative to their aerobic capacity. Due to individual differences between runners in the relationship between VO_{2max} determined by treadmill and field testing, it is not possible to extrapolate field or performance VO_{2max} from laboratory data alone. This will require knowledge of the relationships between multiple performance factors for each runner.

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