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Respiratory Rate and the Ventilatory Threshold in Untrained Sedentary Participants

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ABSTRACT

O'Leary CB, Stavrianeas S. Respiratory Rate and the Ventilatory Threshold in Untrained Sedentary Participants. **JEPonline** 2012;15(4):1-10. Identifying the transition from mostly aerobic to mostly anaerobic is critical for predicting physical performance and prescribing exercise programs. The ventilatory threshold (VT) is a common gas exchange variable linked to this transition, but its determination requires sophisticated equipment, tester expertise, and money. In contrast, the respiratory rate (RRB) breakpoint has been highly correlated with VT and is easier to establish than VT. The purpose of this study was to examine whether the relationship between VT and RRB holds true in sedentary untrained individuals as it does in trained participants. Seventeen healthy college-aged participants (7 males, 9 females) completed a graded treadmill protocol to exhaustion to establish VO_2 max. Ventilatory threshold and RRB were determined during the maximal and a subsequent submaximal test. A 6th degree polynomial regression identified the RRB for both exercise bouts. Dependent t-tests and Pearson's correlations were calculated between VT and RRB. Ventilatory threshold and RRB from the submaximal exercise were highly correlated (r=.84, P<0.001) and not statistically different (P=.182). The VT and RRB from the maximal exercise were not statistically different (P=0.706), but were not correlated (r=.04, P=0.882). The RRB from both tests were statistically different (P=0.047). Considering the difference in relationship between the two tests, future studies should consider the testing protocol when examining VT. The results indicate that the RRB can estimate the VT in untrained individuals during submaximal exercise.

Key Words: Breathing Frequency, Polynomial Regression

INTRODUCTION

Gas exchange measurements are used to determine the appropriate exercise intensity to safely prescribe exercise (10). The ventilatory threshold (VT) is a non-invasive technique based on gas exchange variables that describe the respiratory changes associated with the increase in physical work of incremental exercise (19). It is characterized by disproportionate increases in expired ventilation (V_E) with respect to oxygen consumption and carbon dioxide production due to the increased proton buffering of the bicarbonate system and other physiological responses to exercise (2). The methods used to identify VT are highly reproducible, accurately measureable, and securely achievable parameters for the non-invasive identification of exercise intensity (28). The VT has also been shown to be a valid measure of the anaerobic threshold (2) and predictor of performance (1). Yet, the determination and use of VT have been controversial since multiple approaches have been proposed over the years (12).

Given the ambiguity surrounding the determination of VT, other techniques have been proposed to further facilitate the identification of exercise intensity and VT, such as the use of the respiratory rate (6,8-10,15,19). At the onset of exercise, V_E increases linearly in parallel to the increase in tidal volume (TV) since respiratory rate (RR) stays relatively constant (17). Yet, just prior to exhaustion TV plateaus due to the work of deeper breathing becoming excessive for the pulmonary muscles (6,9). Once TV plateaus, RR increases in response to the decrease in pH, the increase in CO_2, and other physiological demands of exercise (6). This exponential increase or respiratory rate breakpoint (RRB) has been identified as a possible indicator for VT (6,9,27) and, therefore, could be used as a noninvasive measurement to determine VT.

Several studies investigating trained athletes have found a high correlation between the RRB and VT (5,8-9,20). It has been proposed the mechanical limitations of V_E and TV are reached in highly trained athletes (6). Therefore, an increase in ventilation would be due to increases in RR when completing exercise to exhaustion in highly trained endurance athletes because of the inevitable plateau in TV (20). Studies examining highly trained athletes are also likely to find consistent results due to the homogeneity of the population and the parameters measured(20), thus making RR an effective measurement for identifying VT in trained athletes.

Valuable as this knowledge is for trained athletes, few studies have examined the RR as a marker for VT in untrained individuals (10,13,19). While these studies showed good correlation between the RRB and VT, the findings are not applicable to the untrained sedentary population since the participants were not entirely untrained and sedentary individuals. Thus, if a relationship between RRB and VT exists, RR could estimate exercise intensity for untrained individuals and provide additional criteria for improving the confidence in the determination of VT. The purpose of this study was to examine if the RR is an accurate predictor of exercise intensity and VT using an untrained sedentary population. A secondary purpose of this study was to examine if a more accurate determination of VT could be made from the maximal or a more gradual submaximal test.

METHODS

Subjects

College-aged students (n=17, age: 20.53 ±1.33 yrs, height: 169 ±7.79 cm, weight: 67.90 ±9.95 kg) were recruited for the present study. The participants had no prior history of cardiac dysfunction. Theywere sedentary (i.e.,less than 1 hr/week of physical activity) and at least 8 months removed from any kind of rigorous training program. The participants completed a written informed consent and modified physical activity readiness questionnaire (PAR-Q) to document their ability to engage in rigorous exercise. The research design was approved by the Willamette University Institutional Review Board.

Procedures

The participants reported to the laboratory on two separate occasions without having engaged in physical activity during the previous 24 hrs. On the first day, the participants performed a maximal oxygen consumption test (VO_2 max) on a treadmill (Trackmaster, Newton, KS, USA). On the second day, they performed a submaximal treadmill test that lasted 25 min. The participants arrived at the same time of day to the laboratory for both tests to avoid diurnal variations, with the submaximal test being no less than two days and no more than one week after the first test. They were asked to dress in proper athletic clothing including running shoes for both tests, to arrive at the laboratory in a rested and fully hydrated state, and to avoid the consumption of food, alcohol, and caffeine for at least 3 hrs prior to either test.

After completing a self-selected warm-up, the participants were asked to choose a pace at which they could exercise for 45-60 min. The test started at 1 mile per hour (mph) below the selected pace at 0% grade. For the next 3 stages, the treadmill speed was increased by 1 mph every 2 min with the grade constant at 0%. Each additional stage lasted 1 min, with the grade increasing by 2% each stage until the participant reached exhaustion. Rating of perceived exertion (RPE) was recorded halfway through each stage. Heart rate (HR) was recorded constantly throughout the test using a Polar watch and a HR monitor (Polar Electronics, Port Washington, NY, USA). Expiratory gases were measured using a calibrated metabolic measurement system (PARVO Medics, Sandy, UT, USA). The participant's VO_2 max was considered the greatest VO_2 in $mL \cdot kg^{-1} \cdot min^{-1}$ achieved during any 30-sec period. All participants demonstrated 2 of the following 3 criteria for the attainment of VO_2 max: (a) terminal respiratory exchange ratio (RER) greater than 1.10; (b) 95% or greater of theage-predicted maximal heart rate (HR = 220 – age); and (c) an increase in VO_2less than 200 $mL \cdot min^{-1}$ over the final 3 stages. Following the maximal test, each participant's VT was established using the ventilatory ratio method (i.e., when an increase in V_E/VO_2 occurred without a concurrent increase in V_E/VCO_2 was observed). It was reported as a percentage of the participant's VO_2 max (%VO_2 max).

On the second testing day, the participants performed a submaximal treadmill test designed to better identify the VT and RRB. The test consisted of a self-selected warm-up, a 25-min testing protocol, and a cool down. The testing protocol started at a pace and grade that was 80% of the previously established VT. Each participant maintained this initial pace for 5 min. Each additional stage lasted 5 min, with the intensity level increasing 10% until 120% of the VT was reached. The intensity level was increased by either .5 or 1 mph for the first 3 stages, based on each participant's fitness exhibited during the maximal test, as to reach 100% of the previously estimated VT intensity by the third stage. For the 4th and 5th stages, the grade was increased by either 1% or 2% each stage until completion of the test. Gas exchange measurements, RPE, and HR were recorded throughout the submaximal test. The VT was established using the same ventilatory ratio method (19).

To identify RRB a polynomial regression methodology was adopted from Cross and colleagues (10). A 6^{th} order polynomial function was fit to the RR data plotted against %VO_2 max obtained during the submaximal exercise test. The second derivative (i.e., d^2y/dx^2) of the best-fit polynomial function was then calculated. The second derivative was therefore two orders of magnitude less than the original polynomial regression. For any *n*th order polynomial, a maximum of $n - 1$ extrema can be observed, which denotes the abrupt accelerations and decelerations in the data set. Therefore, once a 6th order polynomial function was fit to the data, a second derivative yielded three extrema. The RRB was defined as the local maxima extrema within the second derivative of the linear regression fit to the RR data and was denoted as a %VO_2 max (Figure 1). Microsoft Excel (Microsoft, Redmond, WA, USA) was used to find the polynomial regression and the constants that best fit the data by minimizing the distance from the regression line to the actual y-values after squaring (i.e., least squares regression).

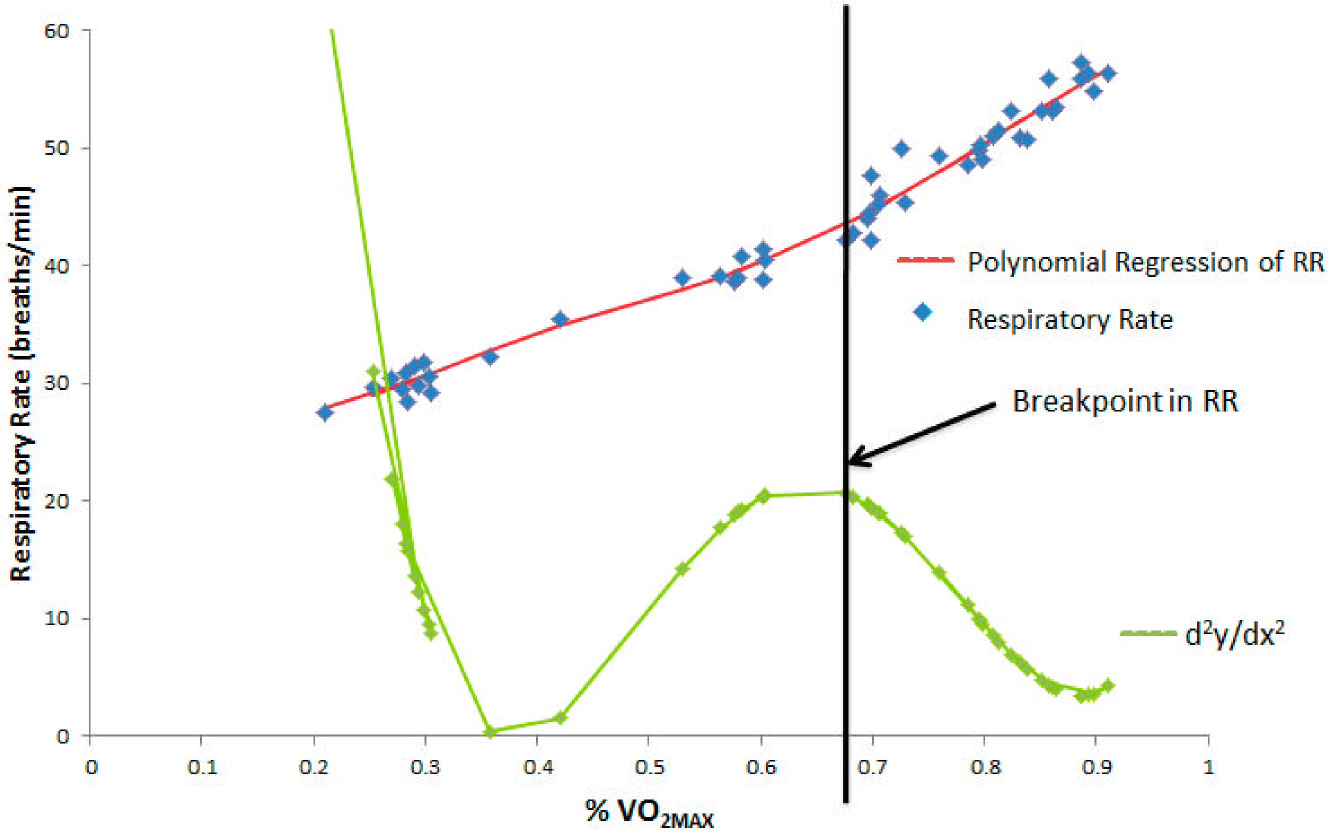

Figure 1. An example of the polynomial regression and 2nd derivative of the respiratory rate data used to determine breakpoint in respiratory rate.

Statistical Analyses

Paired t-tests were used to compare the %VO_2max at the RRB to the %VO_2 max at the VT for the maximal and submaximal tests. Paired t-tests were also used to compare the %VO_2 max of the VTs and RRBs from both tests. Linear regressions were performed to determine the strength of association between the variables. The significance was set at analpha of 0.05 for all analyses. The data were analyzed using SPSS 13.0 (SPSS INC., Chicago, IL, USA).

RESULTS

Maximal Test

The results from the first maximal test are shown in Table 1. The participants achieved an average VO_2 max of 48.71±8.63 mL·kg^{-1}·min^{-1}. Their estimated VT occurred at 83.82±8.19% of VO_2max (n=16). The RRB was 81.00±12.10% of VO_2 max for this test. There was no statistical difference between the VT and RRB from the maximal test (P=0.706), but the regression exhibited no association between these two variables (r=.04, P=0.882).

Table 1. Physiological and Performance Variables from the Maximal Test Including the Total Group Data and Data divided into Gender.

	Total (n=17)	Males (n=8)	Female (n=9)
VO_2 Max ($mL \cdot kg^{-1} \cdot min^{-1}$)	48.71 ± 8.63	54.44 ± 6.85	43.62 ± 6.78
Max HR ($beats \cdot min^{-1}$)	199.59 ± 9.66	199.63 ± 13.41	199.56 ± 5.43
Max RER	1.19 ± 0.07	1.18 ± 0.06	1.19 ± .08
Estimated VT (%VO_2max)	83.82 ± 8.19†	80.27 ± 7.85	87.38 ± 7.28§
Breakpoint RR (%VO_2max)	81.00 ± 12.10	74.32 ± 13.70	86.19 ± 8.02

†n=16, §n=8, VO_2 max: Maximal oxygen uptake, Max HR: Maximum heart rate, RER: respiratory equivalent ratio, VT: Ventilatory threshold, RR: Respiratory rate

Submaximal Test

The results from the submaximal test are shown in Table 2. The VT was 75.35±12.63% of VO_2 max. After applying the polynomial regression to the submaximal RR data, the %VO_2 max of the RRB occurred at 73.02±11.10% of VO_2 max. A significant correlation was found between the VT and RRB of the submaximal test ($r=.84$, $R^2=.70$, $P<0.001$, Figure 2). A dependent t-test also exhibited no statistical difference between the VT and RRB from the submaximal test ($P=0.182$).

Table 2. Physiological and Performance Variables from the Submaximal Test Including the Total Group Data and Data Divided into Gender.

	Total (n=17)	Males (n=8)	Female (n=9)
VT Submaximal Test (%VO_2max)	75.35 ± 12.63	72.84 ± 9.89	77.57 ± 14.89
Breakpoint RR (%VO_2max)	73.02 ± 11.10	71.37 ± 12.36	74.50 ± 10.38
RR at VT ($breaths \cdot min^{-1}$)	38.14 ± 6.58	35.99 ± 6.30	40.06 ± 6.56
RPE at VT	12.82 ± 2.53	12.75 ± 1.67	12.89 ± 3.22
HR at VT ($beats \cdot min^{-1}$)	175.53 ± 13.22	174.25 ± 12.22	176.67 ± 14.68

VO_2 max: Maximal oxygen uptake, HR: heart rate, RPE: Rate of perceived exertion, VT: Ventilatory threshold, RR: Respiratory rate

There was no statistical difference between the VT for the maximal and the submaximal test ($P=0.083$). However, after a linear regression was applied, there was no relationship between the two VTs ($r = -.303$, $P=0.254$). There was a statistical difference between the %VO_2 max of the RRB from both of the tests ($P=0.047$).

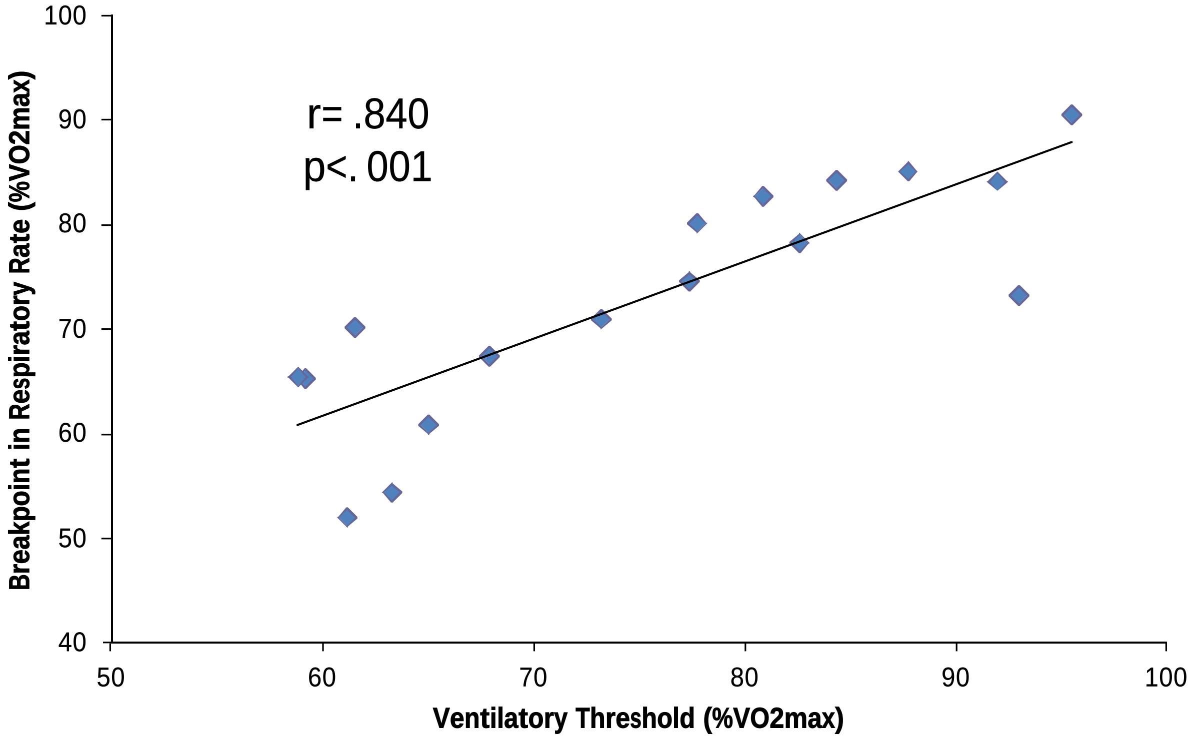

Figure 2. Correlation between the ventilatory (% VO_2 max) and breakpoint in respiratory rate (% VO_2 max) from the submaximal test (n=17). The results suggest that a submaximal test might be a better protocol for establishing ventilatory threshold and other submaximal physiological variables in untrained participants.

DISCUSSION

The primary purpose of the current study was to examine the relationship between the VT and RRB in untrained sedentary participants using a treadmill protocol. Identification of the RRB was accomplished using a 6th order polynomial regression applied to the results of both the maximal and submaximal treadmill tests. During the submaximal test, the RRB occurred at 73.11% VO_2 max, which is in agreement with Cross and colleagues (10) using the polynomial regression technique. The VT occurred at 75.13%, which is also in agreement with Berry and colleagues (3) using untrained participants.

Submaximal Test

The results of this study imply that a relationship exists between the increase in breathing rate and the transition from primarily aerobic metabolism to primarily anaerobic metabolism. This transition has been speculated to occur as the body optimizes its breathing pattern, placing less strain on the respiratory muscles (6,13). The stimulation of cardiovascular chemoreceptors due to the metabolic acidosis and creation of excess CO_2 is the prevailing theory for this physiological change in breathing (4,8-10,13). Other theories supporting a relationship between increased breathing rates and VT include the expression of the mammalian panting strategy, corollary activation of respiratory centers secondary to increased central and peripheral neurogenic stimuli, changed ion concentrations, increased core body temperature, entrainment to the increasing step frequency, and an abrupt decline in cerebral oxygenation (10,15,19,21). At the present time, it is unknown whether one specific physiological mechanism causes the RR and VT relationship or if several of the above factors act on a more individual basis.

Maximal Test

The initial maximal test was primarily used to produce the participant's VO_2 max measurement and to estimate the VT so the appropriate intensity could be set for the submaximal test. To compare the two different testing protocols, the VT and RRB were also calculated for this initial maximal test. While there was no statistical difference between the VT and RRB from the initial maximal test, the two variables exhibited no correlation. This dissociation is not consistent with other studies that examined the relationship between the VT and RRB using a maximal test protocol (6,10,13), which questions whether a maximal test can be used to establish a submaximal parameter like VT.

Previous studies have examined if either the stage length or intensity of the exercise protocol affect the VT during maximal testing. In some cases, the literature suggests no difference for tests using longer or shorter stage durations and different intensities (12,18,24). In opposition to these findings, Cheatham and colleagues (7) found the VT was elevated for tests with large changes in intensity between stages. Shimizu and colleagues (26) reported a significantly higher VT when a shorter duration, but more intense maximal test was used versus a more gradual maximal test. Kang and colleagues (16) indicated that a high starting speed of some tests might place untrained individuals in an anaerobic state before their bodies can adjust to the test, inflating their VT. The larger increase in metabolic demand from one stage to the next during a maximal test may induce a premature departure from linearity in VCO_2 due to hyperventilation and the inability for participants to control their breathing (11). Longer and more gradual stages, such as during a submaximal test, should better identify the VT, since the participant's body and breathing are allowed to reach a steady-state within the longer stages, thus eliciting a true VT. This is especially pertinent to untrained individuals who are naïve to testing procedures and equipment. Considering the lack of consistency in the literature regarding the VT and testing procedure, future studies should examine if the VT and the relationship to RRB is specifically affected by the testing protocol.

Polynomial Regression

To identify the RRB in the current study, a 6th degree polynomial regression was fit to the RR data using a protocol adopted from Cross and colleagues (10). Previous studies have had problems identifying RRB, which has led to null conclusions about the relationship between RR and VT (4,6,15). However in the current study, deriving the polynomial and finding the local maxima of the 2nd derivative easily identified RRB. Polynomial regression has been successfully utilized to identify gas exchange variables in previous studies and does not employ the typical "piece-wise" regression model (10,25). Yet, this relative new polynomial methodology is not without its potential fallbacks. By using a 6th degree polynomial, it guarantees three extrema when the polynomial is derived, potentially creating an artificially local maxima or breakpoint. The use of warm-up and recovery data in the model can also skew the fit of the polynomial regression, affecting the constants used to fit the line. The utilization of polynomial regression could decrease the relative practicality of using RRB to identify the VT, as sophisticated computer software and technician expertise are required. Even considering these drawbacks, this technique proves useful in the detection of RRB. Future research should examine applying polynomial regressions of different degrees to confirm if this technique is applicable to identifying gas-exchange thresholds.

Limitations

Studies examining trained athletes (5,8-9) and moderately physically active individuals (10,13,19) have also shown a strong correlation between RRB and VT. However, other studies are dubious of this same relationship (4,6,15). In these reports, the variability of each participant's breathing as exercise intensity increased did not allow for the identification of a RBB in some participants. Instead, the RRB and its association with VT could only be identified in participants exhibiting a plateau in TV. Testing more participants, using a polynomial regression to identify the RRB, and doing submaximal tests instead of the maximal tests done in the studies reporting no relationship might give a better indication if RR is an accurate marker for the VT.

Previous studies have also been doubtful of using the RRB as an estimate for the VT due to the entrainment of breathing rates (6,15,19). Entrainment occurs when the rhythm and movement of exercise controls the breathing pattern (14). Jones and Doust (15) found entrainment of RR to cadence was evident in 8 of 12 trained participants. However in the aforementioned study, entrainment did not always prevent the participants from exhibiting a RRB. Paterson and colleagues (22) found entrainment to cadence was secondary to achieving optimal ventilation. This suggested if a plateau in tidal volume was to occur, then RR would have to increase for V_E to increase. Both the use of a treadmill protocol and untrained participants, as was the case in the current study, may reduce the entrainment (3,19).

It is unreasonable to think individuals could identify transitions in their respiratory rates, limiting the usefulness of this relationship between the RR and VT in the field. However, if future research continues to confirm that RR and VT are linked under most conditions, the development of a device could potentially increase the practicality of this information for use outside of the laboratory. For example, the device could consist of an adjustable elastic band capable of counting RR along with an easily readable screen much like a HR monitor. At the current time, no device exists for such use, but recent literature supports the use of such an apparatus (6). The development of this type of device could lead to a more comprehensive understanding of how the body responds to exercise, thus allowing for more effective training and exercise program prescription.

CONCLUSIONS

The current study was the first to identify the association between the RRB and VT in untrained sedentary participants using a submaximal treadmill protocol. We also found no association between the same physiological variables during the initial maximal test, which suggests that a maximal test might be too intense to identify a submaximal parameter like VT. This study also utilized a relatively new, yet previously validated polynomial regression technique to identify the RRB. Using RR to estimate the VT becomes attractive since RR can be measured by the movements of a two-way non-rebreathing valve or by data recorded from wearable respiratory movement sensors, instead of the standard expensive metabolic cart. Even if these recording devices are not available to researchers, RR analysis can provide additional criteria for improving the confidence in VT determination. As the RRB method becomes validated, RR could even become the sole physiological marker used when doing threshold testing.

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