Journal of Exercise Physiologyonline
(JEPonline)

Volume 8 Number 2 April 2005

Official Research Journal of The American Society of Exercise Physiologists (ASEP)

ISSN 1097-9751

Systems Physiology: Cardio-pulmonary

THE RESPIRATORY RATE AS A MARKER FOR THE VENTILATORY THRESHOLD: COMPARISON TO OTHER VENTILATORY PARAMETERS

DANIEL G. CAREY[1], JULIE M. HUGHES[1], ROBERT L. RAYMOND[2], GERMAN J.PLIEGO[2].

[1] Health and Human Performance, University of St. Thomas, St. Paul, Minnesota
[2] Quantitative Methods and Computer Science, University of St. Thomas, St. Paul, Minnesota.

ABSTRACT

Daniel G. Carey, Julie M. Hughes, Robert L. Raymond, German J.Pliego. THE RESPIRATORY RATE AS A MARKER FOR THE VENTILATORY THRESHOLD: COMPARISON TO OTHER VENTILATORY PARAMETERS. ***JEPonline*** 2005;8(2):30-38. The primary objective of this study was to assess the efficacy of using the respiratory rate (RR) breakpoint during incremental exercise as a marker for the ventilatory threshold. Secondary objectives were to compare visual and computer-generated breakpoints for RR, ventilatory equivalent (VE/VO_2), and ventilation (VE) breakpoint measurements. Twenty-six fit male cyclists were recruited as subjects and given an incremental exercise test commencing at 25 Watts and increasing 25 Watts/minute to exhaustion. RR breakpoint by visual assessment demonstrated good intra-observer reliability (R=0.827), good inter-observer reliability (R=0.813), and resulted in no significant difference (p=0.14) when compared to computer-assessed breakpoint. Comparison of RR to the standard methods of anaerobic threshold assessment (VE/VO_2 and VE) using computer-assessed breakpoints resulted in no significant differences for any pair-wise comparisons (F=2.81, p=0.067). Computer-assessed HRBP indicated that only 13 subjects (50%) demonstrated a breakpoint, indicating that this method is not valid for AT assessment. As a result of this study, it was concluded that assessment of RR breakpoint is a simple, non-invasive and practical method of anaerobic threshold assessment.

Key Words: Lactate threshold, Ventilation, Heart rate deflection, Tidal volume

INTRODUCTION

The anaerobic threshold (AT) has been defined as the highest level of exercise that can be maintained for prolonged time periods (1). Due to the historical debate surrounding the label "anaerobic threshold", the term maximal steady state intensity (MSS) will be used throughout this manuscript. MSS has been shown to be highly correlated with aerobic performance (2,3) , is used to assess health and fitness (4), and is instrumental in planning training programs (5). The "gold standard" in MSS assessment is considered to be the maximal lactate steady state" (MLSS) (6), which is the highest level of steady state work output in which there is no increase in blood lactate. Other methods involve frequent blood sampling during incremental exercise to volitional exhaustion, followed by lactate assay of blood samples to produce a lactate curve and the detection of a lactate threshold. In addition, the lactate breakpoint may be difficult to assess visually (7).

Several ventilatory parameters have been identified that coincide with the MSS. These include ventilation (VE) (4,8,9), carbon dioxide production (VCO_2) (4,8,9), respiratory exchange ratio (RER) (10), ventilatory equivalent for oxygen (VE/VO_2) (8,11), non-linear increase in the VCO_2/VO_2 slope (V-slope method) (12), and the end-tidal partial pressure of oxygen pressure (PET O_2) (4,9,11). Several (4,8,9,11,12), but not all studies (7,13,14), support a physiological relationship between changes in blood lactate and corresponding changes in these ventilatory parameters. Some contend that the relationship is coincidental and not causal (14,15), while others report significant differences in the time course of thresholds (13).

Both ventilatory and blood lactate based analyses require sophisticated equipment and/or tester expertise that precludes their use in most settings except exercise physiology labs and medical clinics. Consequently, non-invasive procedures for estimating the MSS have been devised. The exercise intensity where there is a non-linear change in the heart rate/work rate relationship has been proposed (16) as a method to estimate the MSS, with studies both supporting (17,18,19) and refuting its validity (20,21,22).

As an alternative to a heart rate threshold, a surprisingly simple, non-invasive measurement that might prove valid in assessment of the MSS is respiratory rate. A search of Medline revealed only one study examining the relationship between ventilation rate and MSS. James (23) reported a correlation of 0.834 between the VE/work rate and respiratory frequency/work rate and concluded that this parameter could be used as a marker for the MSS. If validated, this test could be administered inexpensively by health professionals or even by the athletes themselves using either home exercise equipment or at local health clubs.

METHODS

Approval to conduct this study was granted by the Institutional review Board (IRB) of the University of St. Thomas. Subjects read and signed consent forms prior to participation. Subjects were recruited following an advertisement for the study on the Minnesota Cycling Federation (MCF) website.

Subjects were required to be between the ages of 18 and 50 years, and be categorized by the United States Cycling Federation (Category I through V). Subjects were asked to report to the laboratory in the post-absorptive state with no exercise prior to the test. Height and weight (cycling shorts only) were measured with a balance scale to the nearest cm and 0.25 kg respectively. All tests were conducted on a Quinton Excalibur Sport electrically braked isokinetic ergometer, in which the drop bars and seat could be adjusted both vertically and horizontally to best fit the subject. The protocol began at 25 Watts and increased in 25-Watt/min increments to volitional fatigue or when pedal revolutions dropped below 40 rev/min. Subjects self-selected a pedal cadence and were allowed to stand at anytime during the test. Verbal encouragement was given throughout the test. A Medical Graphics CPX-D Metabolic Measurement System was used for gas acquisition and analysis and was calibrated for barometric pressure, temperature, and gas concentrations using a calibration gas of known concentration(12% O_2, 5% CO_2) as well as room air. Breath by breath measurement with 10 s averaging was performed on all gas analysis variables. VO_2 max was assumed to be the highest recorded 10 s averaged value. The Polar Vantage heart rate monitor (Polar Electro, Woodbury, New York) was used to assess heart rate at each minute of the test and at exhaustion.

Assessment of the ventilatory threshold by breakpoints in VE, VE/VO_2 and respiratory rate (RR) were done both visually and by a Minitab Macro program designed to assess a breakpoint in linearity using the smallest residual sum of squares (Quantitative Methods and Computer Science Department, University of St. Thomas, St. Paul, Minnesota). The heart rate breakpoint (HRBP) was assessed both visually and by computer analysis in a similar manner. Visual assessment of the breakpoints were done by 3 observers on 2 separate occasions at least one week apart. Observers were instructed to draw lines of their visual best fit for the 2 segments and circle the data point that coincides with change in linearity. If subjects viewed the data points as linear rather than best represented by 2 lines with a breakpoint, they were instructed to draw a single straight line. Since ventilation is the product of respiratory rate and tidal volume, it was deemed important to examine the acute changes in tidal volume from rest to maximal exercise. Tidal volume was calculated every 30 s and results assessed by computer analysis only.

Analysis of variance was performed to assess inter- and intra-individual reliability and determine difference in methods. Adjustment for multiple pair-wise comparisons was performed according to Bonferroni (25). Analysis of residuals was performed and results met assumptions needed to validate use of analysis of variance.

RESULTS

Table 1. Subject Characteristics.

Measurement	Mean±SD
Age (yrs)	29.3±3.5
Height (cm)	179.3±6.6
Weight (kg)	76.6±7.6

Table I contains descriptive characteristics of the subjects. The mean VO2 max (58.3±7.81 mL/kg/min) and anaerobic threshold as a percent of VO_2 max (72.8%± 8.54%) indicated that these subjects were good, but not elite, athletes.

Intra-Tester Reliability

Table 2 contains means, standard deviations, correlation coefficients, t-values and p-values for the 3 methods of MSS assessment from three observers. Assessment of MSS using the VE/VO_2 method was most reliable, demonstrating the greatest mean test-re-test correlation coefficient (0.929), lowest t-value (0.79), and smallest absolute mean difference (11.4 Watts) among comparisons. None of the comparisons within observers were significantly different for VE/VO_2.

The respiratory rate (RR) demonstrated moderately good reliability, with a mean correlation coefficient of 0.827, t-value of 1.60 (p= 0.28), and an absolute mean difference of only 14.2 Watts. Of the 3 observers, only one obtained a significant difference for RR from the 2 visual observations.

The VE method demonstrated the poorest reliability, with the mean correlation coefficient (0.732) being the lowest of the 3 methods of MSS assessment. The highest t-value (1.89) and largest absolute mean difference (21.9 Watts) was obtained with this method.

Inter-Tester Reliability

Table 3 contains t-values and p-values for comparisons between observers. Methods were grouped because there was no observer-method interaction (p=0.572). The overall F-ratio of 2.31 and p-value of 0.077 indicated no significant differences between observers for any of the 3 methods of AT assessment.

Table 3. T-Values and P-Values for Inter-observer Reliability.

All Methods	*T*	*P*
1 vs. 2	0.938	1.000
1 vs. 3	0.925	1.000
2 vs. 3	1.859	0.384

The average mean variability between observers were as follows: VE=19.2 Watts, VE/VO_2=12.8 Watts, RR= 14.8 Watts. Since increments in stages of the VO_2max test were 25 Watts, these results indicate that average variability was only 37.4 s between observers.

Comparison Of The Three Methods (Visual)

The overall F-ratio (F=8.04, p=0.000) for comparisons of visual assessment for the 3 methods of MSS measurement indicated significant differences for the RR and VE comparison only (t=4.04, p=0.0002). Table 4 displays means, standard deviations, correlation coefficients, T-values and P-values for comparisons between methods. The VE to VE/VO_2 comparison resulted in the highest correlation coefficient, lowest T-value, and greatest P-value of any of the comparisons, with a mean difference of only 7.2 Watts. The respiratory rate method produced relatively larger mean differences (20.7 and 13.5 Watts for VE and VE/VO_2, respectively), although only the former comparison was significant.

Table 2. Means, Standard Deviations, Correlation Coefficients, T-values and P-values: Intra-observer Reliability.

	Mean±SD	r	T	P
Observer 1				
VE (Watts)	258.0±39.0 253.8±33.3	0.751	0.85	0.42
VE/VO_2 (Watts)	262.0±41.3 263.0±42.3	0.903	-0.24	0.814
RR (Watts)	272.0±33.0 279.5±33.3	0.772	-0.24	0.100
Observer 2				
VE (Watts)	263.0±48.5 248.3±40.8	0.571	1.79	0.086
VE/VO_2 (Watts)	272.5±31.8 268.0±42.3	0.952	1.45	0.159
RR (Watts)	284.0±27.8 283.0±32.8	0.891	0.36	0.720
Observer 3				
VE (Watts)	268.8±34.8 278.8±33.8	0.874	-3.03	0.006
VE/VO_2 (Watts)	272.5±38.8 274.5±40.8	0.933	-0.67	0.511
RR (Watts)	282.5±30.3 292.8±32.8	0.817	-2.72	0.012

Note the data for the two observations

Table 4. Means, Standard Deviations, Correlation Coefficients, T-values and P-values: Comparison Between Methods.

	Mean±SD	r	T	P
Observer 1				
VE (Watts)	262.3±35.0 269.5±38.8	0.715	2.20	0.085
VE/VO_2 (Watts)	262.3±35.0 283.0±41.3	0.581	4.00	0.0002
RR (Watts)	269.5±38.8 283.0±41.3	0.484	1.80	0.218

Since the RR method produced an MSS that was above the other 2 standard methods of MSS assessment, a comparison of RR MSS and the VE/VCO_2 breakpoint was examined. This comparison was made because VE/VCO_2 breakpoint has been shown to occur shortly after the VE/VO_2 breakpoint during incremental exercise (30). The VE/VCO_2 to work rate ratio is flat or slightly decreasing at moderate to high workloads, abruptly increasing at workloads above MSS (26,30). Thus, VE responds to a relative decrease in O_2 availability before CO_2 increases exponentially because of increased buffering of metabolic acidosis (isocapnic buffering period). The VE/VCO_2 breakpont (307.5±39.8 Watts) was significantly greater than the RR breakpoint (282.5±28.0 Watts) (r=0.477, t=3.47, p=0.002), indicating that RR breakpoint does not represent isocapnic buffering.

Validity Of Visual Assessment

A non-significant F-ratio of 2.31 (p=0.077) indicated agreement between visual and computer-assessed breakpoints for all methods. Again, due to no observer-method interaction, all methods have been grouped. Table 5 displays t-values and p-values for comparison of visual and computer-assessed breakpoints. The small mean difference of only 1 Watt for VE indicates excellent agreement between the 2 methods of breakpoint assessment. The 4.2 Watt difference for RR also was small and non-significant. The mean difference for VE/VO_2 of 15.5 watts was somewhat larger, but insignificant.

Table 5. Comparison of Visual and Computer-Assessed Breakpoints.

All Methods	*T*	*P*
1 vs. computer	1.859	0.384
2 vs. computer	1.523	0.773
3 vs. computer	0.589	1.000

Table 6. Computer-Assessed Breakpoints.

Measurement	Mean±SD
VE	263.3±40.8
RR	278.8±26.5
VE/VO_2	284.6±33.3

Table 7. Computer-Assessed Comparison of Methods: SEE and TE.

All Methods	*T*	*P*
VE/VO_2 and VE	27.1	34.4
VE/VO_2 and RR	34.0	47.5
VE and VE	28.5	49.3

SEE=Standard error of estimate
TE=Total error

Computer-Assessed Comparison Of Ventilatory Methods

General linear regression analysis of variance resulted in an overall F-ratio of 2.81 (p=0.067), indicating no significant differences in the 3 pair-wise comparisons of methods. Table 6 displays means and standard deviations for computer-assessed breakpoints for the 3 methods of MSS assessment. Table 7 gives standard errors of estimate (SEE) and total errors (TE) for all comparisons. The smallest SEE (27.1 Watts) and TE (34.3 Watts) were obtained for the VE/VO_2 and VE comparison, thus indicating good agreement for these 2 commonly accepted methods of MSS assessment. While SEE's (28.5 and 34.0 Watts) and TE's (47.5 and 49.2 Watts) were slightly higher for the RR comparisons, an examination of individual data identified 2 "outliers" that significantly affected the results. These 2 subjects had mean differences for VE/VO_2 and RR comparisons of 181.3 Watts. Elimination of these 2 subjects from the data set resulted in an SEE of 27.1 Watts and a TE of 32.1 Watts, which is comparable to the 27.1 Watts and the 34.3 Watts for SEE and TE, respectively, for the VE/VO_2 and VE comparison. An examination of individual subjects revealed that 19 of 26 subjects (73.1%) had breakpoints within 25 Watts when comparing the VE/VO_2 and RR methods.

Visual Assessment Of HR Breakpoints: Intra- And Inter-Observer Variability

To make intra-observer comparisons, individual t-tests rather than ANOVA were conducted, since there was a great deal of variability both within observers from observation 1 and 2 and between observers as to which subjects demonstrated HRBP from visual assessment. Pooled comparisons within observers resulted in no significant differences (t=0.96, p=0.47), indicating that observers were reliable in their assessment of the breakpoint, if and when it was observed. However, of the 156 observations (3 observers, 2 observations each, 26 subjects), 95 observations (60.9%) were determined to be linear.

Inter-observer comparisons also indicated no significant differences (t=1.32, p=0.253) between observers for visual assessment of HRBP. These results would seem to indicate relatively good reliability within and between observers when the HRBP was observed.

Computer-Assessed Comparison: HR Breakpoint And Ventilatory Equivalent(VE/VO2)

Of the 26 subjects, 13 subjects (50.0%) demonstrated no HRBP. For those 13 subjects demonstrating breakpoints for both variables, VE/VO_2 breakpoints occurred at significantly higher Watt output (275.0±24.8 Watts) compared to the HR breakpoint (205.0±20.0 Watts (t=3.96, p=0.002, R=0.093). The SEE and TE for HRBP was 24.7 and 94.7 Watts, respectively.

Computer-Assessed Comparison: HR Breakpoint And RR Breakpoint

Since both HR and RR are very practical measurements that could be measured without expensive equipment, these 2 methods of MSS were compared. Again, since only 13 subjects demonstrated a HR breakpoint, comparisons included only these subjects. Similar to VE/VO_2, RR breakpoints occurred at significantly higher Watts (299.0±41.0) compared to HR breakpoints (230.8± 44.5) (t=5.07, p=0.000).

Tidal Volume Dynamics

Tidal volume demonstrated 4 distinct patterns during the incremental test; 1) linear increase to exhaustion (23.1%); 2) initial rapid increase, then breakpoint with a more gradual increase (23.1%); 3) initial increase, then plateau (15.4%), and 4) linear increase, then decrease (38.5%). Of the 20 subjects (76.9%) that demonstrated a breakpoint during incremental exercise, this breakpoint occurred at 83.8% VO_2max. To determine if breakpoint in tidal volume (TV) coincided with RR breakpoint (i.e. tidal volume decreased or plateaued coincident with non-linear increase in RR), it was determined that, while there was no significant difference in Watts at breakpoint for these 2 parameters (277.5±25.8 vs. 295.0±65.9 Watts for RR and TV, respectively, t=-1.19, p=0.248), the relatively large mean difference (17.5 Watts) and poor correlation (R=0.206) would preclude assuming a coincidental relationship.

DISCUSSION

RR Comparison To VE And VE/VO_2

The primary objective of this study was to assess the efficacy of using the breakpoint in respiratory rate (RR) during incremental exercise as a marker of the MSS. Computer-assessed breakpoints indicated no significant differences in any of the 3 methods of MSS assessment and validates the use of RR breakpoint as a method of MSS measurement. In the only similar study reported in the literature, James (23) has reported no significant difference for either the RR and VE/VO_2 and RR and VE comparison and has concluded that RR is a valid method of MSS assessment. Our results support these previous findings.

Since assessment of the MSS is often done for purposes of exercise prescription for the competitive endurance athlete (13), differences in heart rate guidelines among the 3 methods were assessed. The comparison of mean heart rates assessed by the 3 methods (163.4±3.4, 168.5±4.1, and 170.2±3.7 beats/min for VE, RR and VE/VO_2, respectively) indicated that VE heart rates were significantly lower than both RR (t=3.30, p=0.003) and Ve/VO_2 (t=3.57, p=0.001) heart rates However, the mean differences of 5.1 and 6.8 beats/min for the VE to RR and VE to VE/VO_2, respectively, would seem to indicate that this statistical difference is of little practical significance. The very small difference in heart rates (1.7 beats/min) between RR and VE/VO_2, coupled with the recommendation that VE/VO_2 seems to correlate best with lactate threshold (30), further supports the validity of RR as a method of MSS assessment. In addition, the observation that 58.0% of subjects had differences of 4 beats/min or less between RR and Ve/VO2 supports the practical value of RR breakpoint in MSS assessment.

VE/VO2 And VE Comparison

Our finding of no significant difference for VE/VO2 (284.6±33.3 Watts) and VE (263.3±40.8 Watts) breakpoints is supported by results previously reported that have concluded that both VE and VE/VO_2 breakpoints coincide with each other and with the lactate threshold (4,11).

Tidal Volume

Since all visual assessments (3 observers, 26 subjects, total of 78 observations) and all computer results (26 subjects) determined that the data was best represented by a breakpoint rather than linearity, there is little doubt that a breakpoint in RR occurs. Since VE has consistently demonstrated a breakpoint during incremental exercise (4,9,10,26), and tidal volume has been shown to plateau at submaximal exercise (20), it is logical to conclude that RR must increase in a curvilinear fashion. VE increases exponentially due to its dual role of eliminating metabolic CO_2 and the CO_2 produced from the buffering of protons from metabolic acidosis at higher workloads (1). In addition to CO_2 elimination, alveolar oxygen pressure must be maintained to prevent arterial O2 desaturation.

Changes in the tidal volume/work rate relationship is probably the result of the inefficiency of both mechanical work of expanding the chest wall (27) and physiological inefficiency of increased O_2 consumption for a given change in ventilation as ventilation increases from moderate to high work rates(28). It has been demonstrated that, at high intensity exercise, respiratory oxygen consumption is at a lower percent of respiratory maximal O_2 consumption (i.e., more efficient) when respiratory work is done at high velocity and lower muscle tension (i.e. high respiratory rate), when compared to lower velocity and higher tension (i.e. low respiratory rate and higher tidal volume) (28). Efficient use of oxygen intake becomes critical at high levels of exercise, since respiratory muscle oxygen consumption is approximately 13% of total body O_2 consumption and accounts for approximately 39% of the increase in whole body O_2 requirements between moderate and high intensity exercise (27). It has been shown that athletes show lower ventilation (VE) for a given level of CO_2 production (29). It is hypothesized that athletes may have a lower chemosensitivity to hypoxia than non-athletes (29). It is also possible that athletes intuitively sense that a relative hypoventilation and the resulting desaturation may be more efficient than hyperventilation and the corresponding increase in respiratory work. In addition, of the many physiological measurements monitored during exercise, respiratory rate has been shown to have the highest correlation with Rating of Perceived Exertion (RPE), indicating that athletes may monitor their exercise intensity by monitoring their respiratory rate(30).

For those subjects that demonstrated a breakpoint in tidal volume, this breakpoint occurred at 83.8% VO_2max. This is almost identical to the results of Johnson (27), who obtained tidal volume plateau at 83% VO_2max. However, caution is warranted in interpretation of these results, since the dynamics of tidal volume were highly variable.

VE Intra- And Inter-Observer Reliability

A secondary objective of this study was to assess the intra- and inter-observer reliability in visual assessment of breakpoints in VE, VE/VO_2 and RR during incremental exercise. Orr et al. (31) has reported a test-retest correlation coefficient of 0.87 for visual assessment of VE, which is somewhat better than the results of this study (R=0.732) Our finding of only a moderate intra-observer reliability (mean R= 0.732) and inter-observer reliability (R=0.781) for VE would indicate some difficulty in visual assessment of this breakpoint. However, when visual assessments of breakpoints were averaged across observers, mean VE breakpoint showed excellent agreement with computer-generated breakpoints (262.3 vs. 263.3 Watts, R=0.667, p=0.857). While our correlation coefficient of 0.667 was considerably lower than that obtained by Orr et al. (0.94) (31), it was slightly greater than that obtained by Gladden (0.58) (7), who concluded that experience of the observer was a significant factor in visual assessment of the anaerobic threshold. From these results, it is recommended that mean values from several observers be used to assess VE breakpoints.

VE/VO_2 Intra- And Inter-Observer Reliability

In contrast, VE/VO_2 visual assessment of breakpoints demonstrated excellent intra-observer reliability (mean R= 0.929) and excellent inter-observer reliability (mean R= 0.933). In addition, visual assessment of VE/VO_2 breakpoint was not different from computer-assessed breakpoint (F=2.31, p=0.077) for any of the 3 observers, which would suggest that this breakpoint is easily discernible to the observer.

RR Intra- And Inter-Observer Reliability

The mean correlation coefficient for intra-observer reliability for RR was 0.827, indicating good agreement within observers. Mean differences within observers were only 6.3 Watts. Inter-individual reliability (mean R=0.813) and a small mean difference between observers (7.9 Watts) would indicate that visual assessment of RR breakpoint is a reliable method of anaerobic threshold assessment. In addition, visual assessment of RR was highly related to computer-generated RR breakpoint (mean R=0.873), with a mean difference between the 2 methods of just 4.2 Watts. It is concluded that visual assessment of RR is both reliable and valid when compared to a computer-generated breakpoint.

Validity Of HRBP

The incidence of occurrence of HRBP (50.0%) in this study would preclude its use as a valid method of MSS assessment. When HRBP did occur, significant differences (70.0 Watts) with VE/VO_2 breakpoints further question its validity. These results have been both refuted (16,17,18,19) and supported by others (20,21,22).

CONCLUSIONS

From the results of this study, the following conclusions are warranted:
1) Respiratory rate (RR) breakpoint is a valid method of assessing the MSS.
2) Non-significant differences in visual and computer-assessed RR breakpoint would indicate that visual assessment of the breakpoint is valid.
3) High correlation coefficients, both between and within testers, would indicate that visual assessment of RR breakpoint is reliable.
4) HRBP does not always occur, its occurrence does not coincide with commonly accepted methods, and it should not be used to assess MSS.

Address for Correspondence: Daniel G. Carey,Ph.D., Assistant Professor, Health and Human Performance, University of St. Thomas, 2115 Summit Ave. Mail #5003, St. Paul, Minnesota 55105. Phone:651-962-5972, fax 651-962-5910. Email dgcarey@stthomas.eduT

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