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Comparison of Ventilatory Measures and 20 km Time Trial Performance

WILLARD W. PEVELER‡[1], BRANDY SHEW‡[1], SAMANTHA JOHNSON†[3], GABE SANDERS‡[1], and ROGER KOLLOCK‡[2]

[1]Department of Kinesiology and Health, Northern Kentucky University, Highland Heights, KY, USA; [2]Department of Kinesiology and Rehabilitative Sciences, University of Tulsa, Tulsa, OK, United States; [3]Department of Health and Human Performance, Middle Tennessee State University, Murfreesboro, TN, USA

*Denotes undergraduate, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 10(4): 640-648, 2017. Performance threshold measures are used to predict cycling performance. Previous research has focused on long time trials (≥ 40 km) using power at ventilatory threshold and respiratory threshold to estimate time trial performance. As intensity greatly differs during shorter time trails applying findings from longer time trials may not be appropriate. The use of heart rate measures to determine 20 km time trial performance has yet to be examined. The purpose of this study was to determine the effectiveness of heart rate measures at ventilatory threshold (VE/VO_2 Plotted and VT determined by software) and respiratory threshold (RER of 0.95, 1.00, and 1.05) to predict 20 km time trial performance. Eighteen cyclists completed a VO_{2max} protocol and two 20 km time trials. Average heart rates from 20 km time trials were compared with heart rates from performance threshold measures (VT plotted, VT software, and an RER at 0.95, 1.00, and 1.05) using repeated measures ANOVA. Significance was set a priori at $P \leq 0.05$. The only measure not found to be significantly different in relation to time trial performance was HR at an RER of 1.00 (166.61±12.70 bpm vs. 165.89 ± 9.56 bpm, p = .671). VT plotting and VT determined by software were found to underestimate time trial performance by 3% and 8% respectively. From these findings it is recommended to use heart rate at a RER of 1.00 in order to determine 20 km time trial intensity.

KEY WORDS: Performance threshold, anaerobic threshold, ventilatory threshold, lactate threshold

INTRODUCTION

A cycling time trial is a self-paced event where cyclists attempt to complete the given distance as quickly as possible. During a cycling time trial, cyclists should maintain an even pacing strategy throughout the race in order to optimize performance (7, 8, 10, 20). Maintaining a cycling intensity that is too high would induce premature fatigue and result in significant slowing during the later stages of the race. Additionally, maintaining a cycling intensity that is too low would also result in slow performance times. Controlling race pace through measures of performance threshold would allow cyclists to maintain an even pacing strategy throughout the race that would optimize time trial performance. Measures of lactate threshold (LT), ventilatory threshold (VT), and respiratory threshold (RT) share a strong relationship with race performance and therefore, are often used to predict performance (3, 5, 6, 11, 12).

Throughout this paper the term performance threshold will be used as opposed to the term anaerobic threshold to describe steady state race pace. The term anaerobic threshold is related to a conceptual definition and the specific physiological markers of anaerobic threshold are often debatable (22). The term performance threshold has been used in place of anaerobic threshold when examining steady state endurance race performance during previous studies (3). The use of the term performance threshold indicates the intensity at which an athlete can maintain race pace for that given distance, which may be above, at or below measures of anaerobic threshold depending on the distance of the race (3).

In relation to LT measures, VT and RT measures have been shown to more accurately predict cycling time trial performance and are ideal for determining performance threshold (3,5). Amann et al. compared cycling power output measures with cycling performance threshold measures (LT measures, VE/VO_2 (pulmonary ventilation over oxygen consumption), RER (respiratory exchange ratio) of 0.95 and an RER of 1.00) during a 40 km cycling time trial (3). They found no significant difference between 40 km time trial performance and VE/VO_2, RER at 0.95 and onset of blood lactate accumulation at 4 mmol/L. Based on the lack of differences, the author's recommended the use of VE/VO_2 as a primary method for estimating 40 km time trial performance.

Measures of performance threshold have also been examined in cyclists during professional time trial races. Lucia et al. examined 11 professional cyclists competing during the 1998 and 1999 Tour de France. They selected power output readings from three different tour de France time trials (56.5 km, 57 km, and 58 km) to compare to laboratory measures (14). It was determined that power at VT was the best predictor of cycling time trial performance; however, measures of RT were not examined during this study.

Determining performance threshold using RT was also examined during running. Bellar and Judge examined the relationship between measures of respiratory exchange ratios (RER) and race pace in runners (5). They estimated race speed at an RER of 0.85, 0.90, 0.95, 1.00, 1.05, and 1.10 and compared these measures to average race speeds during an outdoor cross country race (males = 8 km, females = 5 km). They found that estimated race pace at an RER of 1.05 most closely matched actual race pace during a normal season cross country race.

Prior research has not used heart rate at performance threshold as a measure to compare to time trial performance (3, 14). Previous cycling time trial studies have used power to determine intensity (3, 14). Anecdotally, practitioners in the field have stated that power meters can more accurately measure cycling intensity in relation to heart rate alone (2). However, recent research has shown that the use of both power and heart rate accurately measure cycling intensity with no significant difference between the two (14, 21). Due to the high cost of power meters, very few cyclists use power as a method for monitoring intensity during training and primarily rely on heart rate monitors to measure cycling intensity.

Previous studies have examined performance thresholds during long time trials only (40 km, 56.5 km, 57 km, and 58 km) (3,14). The 20 km time trial is a very popular race distance in cycling and occurs at a much higher intensity in relation to longer time trials (≥ 40km). Due to differences in intensity and distance, performance threshold measures may differ during shorter time trials.

To our knowledge the use of heart rate at VT and RT to determine performance threshold in a 20 km cycling time trial has yet to be examined. Therefore, the purpose of this study was to determine if heart rate measures at VT (VE/VO_2 plotted and VT determined by computer software) and RT (RER measures of 0.95, 1.00, and 1.05) are similar to heart rate measures during an indoor simulated 20 km time trial. It was hypothesized that measures of performance threshold during a 20 km time trial would differ in relation to previous studies at longer time trial distances (40 km, 56.5 km, 57 km, and 58 km) (3, 14).

METHODS

Participants

Participants consisted of 18 recreational to highly trained cyclists (male = 16, female = 2). Full descriptive statistics for participants are located in table one (insert table one). All participants had been riding for a minimum of one year. Approval for this study was obtained through the local IRB, in the spirit of the Helsinki Declaration and all participants completed an informed consent prior to participation. A physical activity readiness questionnaire and a health status questionnaire were used to screen for individuals who may be placed at increased risk during strenuous exercise. Those found at an increased risk were excluded from the study per ACSM's guidelines (1).

Table 1. Physical characteristics of subjects (n=18).

	Males (N=16)	Females (N=2)
Mass (kg)	76.86±8.10	61.59±4.82
Height (cm)	173.50±5.13	170.30±5.37
Body Fat (%)	12.56±6.23	22.25±0.21
Age (yrs)	31.43±7.88	31.00±4.24
Trial 1 (min)	33.62±2.24	36.95±3.15
Trial 2 (min)	33.71±2.24	36.98±3.18
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	58.66±7.44	47.84±4.60

Participants reported to the laboratory with their personal bike, cycling shoes and clipless pedals. The cyclist's personal bike was used during the trials and the participants cycled in their normal cycling attire. In order to promote optimal performance and ensure accurate measurements, participants were instructed to abstain from training at least one day prior to each trial. Participants were also instructed to maintain their normal diet between trials.

Protocol

The study utilized a repeated measures design consisting of three separate sessions: VO2max protocol and two 20 km time trials. Sessions were held on three separate days with at least 48 hours rest between trials. The two, 20 km time trials were conducted on a CompuTrainer within a laboratory setting. In relation to outdoor time trials indoor simulated time trials are less ecologically valid. However, simulated indoor time trials on the CompuTrainer allow for the elimination of extraneous variables (i.e. environment, traffic) and tighter control on assessment variables in question. All trials were conducted in a thermostatic controlled environment. Previous research supports the use of a CompuTrainer to simulate indoor time trials (4, 20, 17). The CompuTrainer also allows the cyclists to use their own bikes during the time trial in order to optimize performance. Research has demonstrated that cyclists perform most optimally when competing in the same riding position in which they train (9,18,19).

Measurements of VT and RT are considered accurate measures of race performance (3, 5, 6, 11, 12). Bellar and Judge used RER measures from 0.85 to 1.10 at 0.05 intervals (5). Based on their findings the use of only RER measures of 0.95, 1.00 and 1.05 are justified in this current study.

During the first session participants completed aVO_{2max} protocol on a Monark 894E cycle ergometer (Monark Exercise AB, Vansboro, Sweden).Oxygen consumption was measured utilizing automated indirect calorimetry (TrueOne 2400, ParvoMedics, Sandy UT). The TrueOne 2400 was calibrated prior to each testing session per manufacturer's instructions. The VO_{2max} protocol began at a resistance of 1 kilopond (kp) and increased by 0.5 kp every two minutes until volitional exhaustion. Participants were required to maintain 90 rpm or higher throughout the protocol (13). Achievement of VO_{2max} was determined by a heart rate equal to or greater than age-predicted maximum, a respiratory exchange ratio equal to or greater than 1.15, or a $VO_{2plateau}$ (15).

The VO_{2max} protocol was used to obtain measures of RER and VT. Ventilatory threshold was found by plotting VE and VO_2 and determining the point where the two deviated from linearity. Ventilatory threshold was also determined using the ParvoMedics software on the True one 2400. Heart rate corresponding with an RER of 0.95, 1.00 and 1.05, VE/VO2 plotted and VT determined by computer software were recorded and then later compared to heart rates from the 20 km time trials.

The two 20 km time trials were conducted on a CompuTrainer (RacerMate Inc., Seattle, WA). The first of the two time trials was used as a familiarization trial (FT) and the second was used as the comparison trial (CT). The simulated 20 km time trial course was a flat point to point course with no change in grade. The participant's personal bike was placed in the CompuTrainer and the CompuTrainer was calibrated prior to the start of each trial in accordance with manufacturer's instructions. The participants were informed to complete each trial as fast as possible. The term "familiarization trial" was not used with the participants so that the knowledge of the purpose of the first trial would not affect performance. Verbal coaching and external motivation were not provided to the participants during the time trials. Average heart rate was recorded using a Polar chest strap and the CompuTrainer software. Finishing times were recorded for each trial using the CompuTrainer software. Average heart rate for the 20 km time trials were later used for comparison with measures of performance threshold.

Statistical Analysis

Average heart rates from 20 km time trials were compared with heart rates from performance threshold measures (VT plotted, VT computer software, and an RER at 0.95, 1.00, and 1.05) using repeated measures ANOVA. Significance was set a priori at $P \leq 0.05$ (2-tailed). All statistics were calculated using IBM SPSS 19.0 statistical analysis software (SPSS Inc, Chicago, IL).

RESULTS

There were no significant differences in performance times between FT finishing times (33.99 ± 2.49 minutes) and CT finishing times (34.09 ± 2.47 minutes) at $p = 0.600$ or between FT HR(165.76 ± 9.47 bpm) and CT HR (165.89 ± 9.56 bpm) at $p= 0.932$. Ventilatory threshold HR determined by plotting VO2 and VE (160.78 ± 12.27 bpm) was significantly higher in relation to VT HR determined by computer software (153.28 ± 14.92 bpm) at $p = 0.004$. Ventilatory threshold HR determined by plotting VO_2 and VE (160.78 ± 12.27 bpm) was significantly lower in relation to FT HR (165.76 ± 9.47 bpm) at $p = 0.036$, and CT HR (165.89 ± 9.56 bpm) at $p = 0.044$. Ventilatory threshold HR determined by computer software (153.28 ± 14.92 bpm) was significantly lower than FT HR (165.76 ± 9.47 bpm) at $p < 0.001$ and CT HR (165.89 ± 9.56 bpm) at $p < 0.001$. Heart rate at an RER of .95 (157.86±12.77 bpm) was significantly lower than FT HR (165.76 ± 9.47 bpm) at $p = 0.001$ and CT HR (165.89 ± 9.56 bpm) at $p < 0.001$. Heart rate at an RER of 1.00 (166.61±12.70 bpm) was found not to be significantly different in relation to FT HR (165.76 ± 9.47 bpm) at $p = 0.622$ and CT HR (165.89 ± 9.56 bpm) at $p = 0.671$. Heart rate at an RER of 1.05 (172.97±11.49 bpm) was found to be significantly higher than FT HR (165.76 ± 9.47 bpm) at $p < 0.001$ and CT HR (165.89 ± 9.56 bpm) at $p < 0.001$. Females (n = 2) were not compared as a separate group due to low numbers. Intra-class correlations were used to determine reliability for each dependent measure and all were found to be high (0.957).

DISCUSSION

The purpose of this study was to assess heart rate at VT and RT to determine optimal performance threshold measures during a 20 km time trial. When examining table two it is apparent that heart rate at an RER of 1.00 was the only measure that was not significantly different in relation to the 20 km time trial average heart rates. There was less than 1% difference in heart rate at an RER of 1.00 and the average heart rate for the time trials (0.42%). The lack of significant difference between heart rate at an RER of 1.00 and average time trial heart rate indicates that heart rate at an RER of 1.00 obtained during a graded exercise protocol could be used to determine 20 km time trial intensity. All other measures were found to be significantly different.

Table 2. Dependent variables (n=18).

		Familiarization Trial (bpm) 165.76±9.47	Comparison Trial (bpm) 165.89±9.56
VT Plotting (bpm)	160.78±12.27	p = .032	p = .027
VT Computer (bpm)	153.28±14.92	p = .001	p = .001
RER .95 (bpm)	157.86±12.77	p = .001	p = .001
RER 1.00 (bpm)	166.61±12.70	P = .622†	P = .671†
RER 1.05 (bpm)	172.97±11.49	P = .001	P = .001

† indicates that there was not a significant difference in relation to time trial performance ($p < .05$).

Both measures of VT (VE/VO_2 plotted and VT determined by computer software) underestimated performance threshold during the 20 km time trials. Ventilatory threshold measured by plotting underestimated performance threshold by 3% and VT measured with computer software underestimated by 8%. While these percentages may appear small, they were found to be significantly different and would result in meaningful difference during a 20 km time trial. As the 20 km time trial is a relatively short cycling race it is logical that performance threshold would be slightly higher in relation to ventilatory threshold.

Measures of VT from a VO_{2max} test underestimated time trial performance during this study, which differs in relation to previous studies (3, 5, 13). However, there is supported rationale as to the occurrence of these differences. Amann et al. compared power output at VT in relation to the average power output during a 40 km time trial (3). They determined that VE/VO_2 most accurately determined average power during a 40 km time trial. Lucia et al. also examined longer time trials (58 km, 56.5 km, and 57 km) and found that VT accurately predicted time trial performance (13). This is most likely related to the differences in race pace between a 20 km and a longer time trial. As a 20 km time trial will most likely be conducted at a higher intensity it is logical that while VE/VO_2 would accurately predict a longer time trial, it would underestimate a 20 km time trial.

When examining measures of RT, an RER of 1.00 accurately predicted 20 km time trial performance. These findings differ in relation to previous studies (3,5). Amann et al. found that an RER = 0.95 accurately predicted 40 km time trial performance and that an RER of 1.00 was significantly higher in relation to time trial performance (3). During the current study an RER of 0.95 underestimated 20 km time trial performance. The difference in RT measures most likely relates to differences in intensity between a 20 km and 40 km time trial.

Bellar and Judge also used RT measures to determine performance threshold in runners. They examined race pace (male = 8 km and female = 5 km) and found that an RER of 1.05 accurately determined performance threshold (5). The authors state that the relationship of a higher RER (1.05) at race pace could have been due to the demanding terrain of the cross country race. As running and cycling greatly differ it may be complicated to compare the findings of this study with those of Bellar and Judge (5). Cycling is a non-weight bearing exercise and requires less energy in relation to running over a given distance (16). Prior research has demonstrated a significant difference in ventilation between cycling and running (16). The running races occurred outside on a cross-country course during the normal race season. During the current study the simulated 20 km indoor time trials were conducted on a completely flat course. All of these factors could explain the higher RER found during the running study in relation to the current study.

Findings from this study support the use of heart rate at an RER of 1.00 as a performance threshold marker for 20 km time trial performance. While an RER of 0.95 and measures of VT could accurately predict longer time trial performances (40 km, 58 km, 56.5 km, and 57 km) they would both underestimate 20 km time trial performance (3, 14).

The combined findings of this current study and previous studies support the term performance threshold as there appears to be different physiological thresholds for cycling performance in both a 20 km and longer cycling time trial distances (i.e., 40 km, 56.5 km, 57 km, and 58 km) (3, 14). Also, performance threshold may be specific to mode of exercise as well. When taken in conjunction with the findings of previous studies it is apparent that performance threshold measures for commonly raced distances need further assessment (3, 5, 14).

Coaches and athletes employ measures to control training and racing intensities. While this is true for all level of cyclists, it is especially true for novice cyclists who have yet to learn optimal pacing strategies. Using a graded exercise protocol to find heart rate at an RER of 1.00 would allow the athlete or coach to evaluate race intensity and to determine training intensity for 20 km time trials.

While comparisons between power and heart rate were not compared during this study, recommendations for setting intensity with the use of heart rate can be made. Power has been recommended as a training tool for controlling training intensity (2). However, due to the high cost of power meters very few cyclists use power as a method for determining intensity during training or racing. Also, previous research has determined that both power and heart rate accurately measure intensity with no difference between the two measures (14, 1). Use of heart rate to monitor intensity makes the findings of this study easier to implement.

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