Transferability of Running and Cycling Training Zones in Triathletes: Implications for Steady-State Exercise

Daniel G. Carey,[1] Courtney Tofte,[1] German J. Pliego,[2] and Robert L. Raymond[2]

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

Abstract

Carey, DG, Tofte, C, Pliego, GJ, and Raymond, RL. Transferability of running and cycling training zones in triathletes: implications for steady-state exercise. *J Strength Cond Res* 23(1): 251–258, 2009—The primary objective of this study was to determine whether physiological measurements obtained from one mode of testing and training could be applied to another mode, as in prescribing heart rate (HR) zone training from cyling to running. Secondary objectives were 1) to assess the validity of applying data from incremental testing to steady-state exercise, and 2) to compare breakpoint in respiratory rate (RR) with the conventional method of anaerobic threshold (AT) breakpoint, the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$). Sixteen experienced triathletes performed $\dot{V}O_2$max testing on a cycle ergometer (CE) and treadmill (TM). In addition, a 30-minute time trial (TT) was performed on a CE. No significant differences were observed between modes of testing for $\dot{V}O_2$max (CE = 68.4 ± 11.1 ml·kg^{-1}·min^{-1}, TM = 69.0 ± 13.2 ml·kg^{-1}·min^{-1}), maximum HR (CE = 177.1 ± 6.1 bpm, TM = 178.1 ± 7.4 bpm), or AT (CE AT HR = 153.9 ± 10.5 bpm, TM AT HR = 157.0 ± 9.5 bpm). Although the mean difference in AT HR was small (3.1 bpm), a small correlation coefficient (0.321) between the AT for the 2 testing modes resulted in a large total error (TE = 12.1 bpm), indicating limited practical application of training zones between modes of testing. Mean TT HR and mean TT RR were significantly greater than mean AT HR (159.4 ± 8.9 vs. 153.9 ± 10.5 bpm) and mean AT RR (37.8 ± 6.0 vs. 32.4 ± 3.2 breaths per minute) because of significant "drift" in these 2 variables over time, whereas TT watts and AT watts were not significantly different (249.1 ± 47.8 vs. 240.6 ± 71.1 W). Finally, a significant difference and large TE (9.0 bpm) between $\dot{V}E/\dot{V}O_2$ AT HR and the RR AT HR (153.9 ± 10.5 and 158.4 ± 10.0 bpm) may preclude the practical use of the RR breakpoint. From the results of this study, it is recommended that the triathlete perform sport-specific testing to assess training zones for cycling and running. In addition, because both HR and RR "drift" upward with steady-state exercise, AT RR and AT HR determined by incremental testing underestimate steady-state HR and RR. For this reason, monitoring wattage during steady-state exercise may be more appropriate than monitoring HR and RR.

Key Words maximal oxygen consumption, anaerobic threshold, ventilatory equivalent

Introduction

Multisport endurance competition, such as triathlons and duathlons, are a relatively recent phenomenon. The first recorded triathlon was held in San Diego, Calif, in 1978 and had a mere 12 participants (www.usatriathlon.org). Today, there are literally hundreds of multisport events listed on the United States Triathlon Association Web site, including rules and regulations, training and racing tips, available coaches, and membership information.

This exponential increase in participation has also resulted in increased demand for assistance in planning training programs. There are excellent texts available (13,16) that will assist the athlete in planning year-round training programs. However, the basis of the training programs is knowledge of one's anaerobic threshold (AT). Although a field test has been developed that assists athletes in identifying their AT heart rate (HR) (10), both the reliability (8) and the validity (6) of this method have been contested. Although the "gold standard" in AT assessment is maximal lactate steady state (2), AT assessment by ventilatory parameters (ventilatory breakpoint, V-slope, ventilatory equivalent for oxygen) have been validated and are more commonly used. For a thorough discussion of ventilatory parameters used to assess AT, see Wasserman et al. (24).

Because multisport participation includes more than one sport, the question arises as to the validity of using AT assessed in one sport in training for another. Although physiological

Address correspondence to Daniel G. Carey, dgcarey@stthomas.edu.

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responses to treadmill (TM) and cycle ergometer (CE) testing have been compared (11,12, 15,18,19,23), these results are confounded by type of subject (trained vs. untrained) and training specificity (cyclists vs. runners). Research using triathletes as subjects has produced conflicting results. Bassett and Boulay (3,4) found no significant difference between HRs for a given percentage of maximal oxygen consumption ($\dot{V}O_2$max) on TM and CE tests in triathletes and have concluded that a single test will provide them with training data for both modes of exercise. In contrast, Schneider et al. (20) observed significantly greater $\dot{V}O_2$max and AT for TM compared with CE testing, concluding that AT is highly specific to the mode of testing.

Table 1. Racing and training history ($N = 16$).

Racing				
Total	Sprint	Olympic	Half	Full
10.3 ± 6.2	4.0 ± 1.7	1.9 ± 1.1	1.4 ± 0.3	3.0 ± 2.7
Training (h·wk^{-1})				
Total	Run	Cycle	Swim	Other
13.2 ± 6.1	4.0 ± 1.4	5.1 ± 2.2	3.0 ± 2.1	1.1 ± 0.6

The purpose of this study is to 1) compare physiological responses from TM and CE testing in triathletes, 2) compare AT assessed from incremental testing with mean values attained during a 30-minute time trial (TT) on CE, and 3) compare AT assessed by a breakpoint in respiratory rate (RR) with AT assessed by breakpoint in $\dot{V}E/\dot{V}O_2$. In addition to their application to triathletes, these results may be of value to those individuals who are tested in one mode of exercise but do their training in another mode. For example, it is very common for individuals participating in the increasingly popular "spinning" classes to have been tested on TMs and to use the TM training zone guidelines for the spin class.

Methods

Experimental Approach to the Problem

This study is designed to compare physiological responses to incremental TM and CE exercise to exhaustion. Variables of interest are $\dot{V}O_2$max, maximum HR, AT HR, and AT watts. Mean watts and mean HR during the 30-minute TT will allow comparison with AT HR and AT watts to assess the validity of incremental testing to predict steady-state exercise.

Subjects

Subjects ($N = 16$; 10 men, 6 women) were recruited through an advertisement placed on a popular local Web site frequented by triathletes. Participation in a minimum of 2 triathlons during the past year was the criterion for inclusion. A summary of racing and training history for these subjects is presented in Table 1.

Before data collection, approval for this study was granted by the institutional review board of the University of St. Thomas. Subjects read and signed consent forms before the initial test.

Subjects reported to the lab on 3 separate occasions in the postabsorptive state without having trained the previous 24 hours. Order of testing (TM and CE) was randomized. All testing was completed for each subject within a 2-week period, with a minimum of 48 hours between tests. The 30-minute TT was always conducted on the third visit. On the day of CE testing, subjects were tested for percent fat using hydrostatic weighing, and they also were measured for anaerobic power with the Wingate Anaerobic Power Test. A minimum of 1 hour was allowed between the end of CE testing and the beginning of the Wingate test.

Procedures

All CE testing was performed on the Lode Excalibur Sport (Electramed Corporation, the Netherlands). Subjects adjusted seat height and handlebar distance to their specifications before testing. The $\dot{V}O_2$max test began at 25 W and progressed 25 W·min^{-1} until the subject could no longer maintain a cadence of 50 rpm. Subjects were instructed to maintain a cadence of 90–100 rpm. Each subject's HR was recorded each minute and at exhaustion from a Polar Vantage XL Heart Rate Monitor (Polar Electro, Woodbury, NY).

The Wingate Anaerobic Power Test was performed on the Lode Excalibur Sport CE. After a 5-minute warm-up at 100 W, resistance was instantaneously applied according to manufacturer instructions (0.8 and 0.77 torque factors for men and women, respectively). Subjects were instructed to obtain the greatest power output possible, and fatigue was part of the evaluation. Verbal encouragement was given throughout the test.

The 30-minute TT was also performed on the Lode ergometer. After a 5-minute warm-up at 100 W, subjects self-selected the highest watt output they could maintain for 30 minutes. They could increase or decrease wattage at any time during the test. Subjects' HRs were recorded every minute using the Polar Vantage XL Heart Rate Monitor. Subjects were unaware of either wattage or HR throughout the test. Gas analysis (see description below) was performed for 1 minute at 5-minute increments during TT.

TABLE 2. Descriptive data of subjects.

	Age	Height (cm)	Weight (kg)	% Fat	Lean mass (kg)	Fat mass (kg)
Men (*n* = 10)	33.2 ± 7.3	183.9 ± 7.1	81.6 ± 9.1	14.3 ± 5.7	71.6 ± 6.5	12.1 ± 5.0
Women (*n* = 6)	35.0 ± 5.1	168.9 ± 3.9	61.1 ± 6.2	13.8 ± 5.6	54.1 ± 4.9	8.8 ± 4.0
Total (*n* = 16)	33.9 ± 6.4	178.3 ± 9.7	74.4 ± 12.3	14.1 ± 5.4	65.4 ± 10.4	10.9 ± 4.8

All TM testing was conducted on the Quinton Q55XT motor-driven TM following a modified Bruce protocol. Each subject's HR was recorded via the Polar Vantage XL Monitor every minute and at exhaustion.

Gas analysis was performed with the Medical Graphics VO_{2000} Metabolic Measurement System using 30-second averaging. The system has been previously validated (5). Each subject's $\dot{V}O_2$max was taken as the highest $\dot{V}O_2$ achieved during any 30-second increment. Each subject's AT was assessed using software to detect the breakpoint of the $\dot{V}E/\dot{V}O_2$ (ventilatory equivalent method) and RR by least squared errors. Both the $\dot{V}E/\dot{V}O_2$ method (25) and RR method (9) have been previously validated.

Underwater weighing was performed in a swimming pool. Subjects sat in a chair suspended from a load cell in water that was approximately chin level. Each subject was instructed to lower his or her head underwater, exhale maximally, and hold for 3 seconds before raising out of the water. The procedure was repeated 3 more times or until the final 2 measurements differed by no more than 0.1 kg. The 2 highest recordings were then averaged. Residual volume was estimated according to Weidman et al. (26).

Statistical Analyses

Matched paired *t*-tests were conducted to determine differences in physiological measurements for CE and TM. Paired *t*-tests were also used to assess differences in TT HR and TT RR with AT HR and AT RR during incremental testing. Alpha was set at $p \leq 0.05$ to determine significant differences.

RESULTS

Maximal Tests

Table 2 contains descriptive statistics of subjects participating in this study. The 14.3% fat of the men is attributable to a probable overestimation of 24.0% in one subject who had difficulty in expelling air underwater. Excluding this subject results in mean percent fat values of 11.7 and 13.8% for men and women, respectively, placing them at approximately the 85th and 95th percentiles for individuals of the same age and sex (1). These values are typical of values reported for elite competitive triathletes (27).

Table 3 is a comparison of maximal and AT values from TM and CE testing. Our mean $\dot{V}O_2$max of 68.4 and 69.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for CE and TM, respectively, are comparable with values of subelite and elite triathletes reported in the literature (3,20,21). The 1.0-bpm and 0.6-$ml \cdot kg^{-1} \cdot min^{-1}$ differences for maximal HR (max HR) and $\dot{V}O_2$max were extremely small and insignificant. When comparisons of max HR and $\dot{V}O_2$max were made by sex, no significant differences

TABLE 3. Anaerobic threshold and maximal data.

Measurement	Cycle ergometer	Treadmill	Correlation	t Value	p Value
Max HR (bpm)	177.1 ± 6.1	178.1 ± 7.4	0.551	0.62	0.548
% Max HR	100.0 ± 19.9	96.1 ± 3.5	−0.044	−0.78	0.449
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	68.4 ± 11.1	69.0 ± 13.2	0.817	0.32	0.756
$\dot{V}E$max ($L \cdot min^{-1}$) (BTPS)	157.5 ± 29.4	145.7 ± 27.5	0.817	−2.73	0.016
RRmax (bpm)	51.7 ± 29.4	48.3 ± 5.7	0.443	−2.06	0.057
TVmax (ml per breath)	3196.0 ± 468.0	3179 ± 505	0.917	−0.33	0.749
RQmax	1.093 ± 0.07	1.080 ± 0.08	0.719	−0.89	0.386
AT $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) ($\dot{V}E/\dot{V}O_2$ method)	43.8 ± 13.0	50.4 ± 9.9	0.237	1.83	0.088
AT $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) (RR method)	49.3 ± 5.8	47.8 ± 22.1	0.396	−0.29	0.775
AT HR (bpm) ($\dot{V}E/\dot{V}O_2$ method)	153.9 ± 10.5	157.0 ± 9.5	0.321	1.05	0.310
AT HR (bpm) (RR method)	158.4 ± 10.0	142.6 ± 56.3	0.077	−1.12	0.280

HR = heart rate; RRmax = maximum respiratory rate; RQmax = maximal CO_2/O_2 ratio; TVmax = maximum tidal volume; AT = anaerobic threshold.

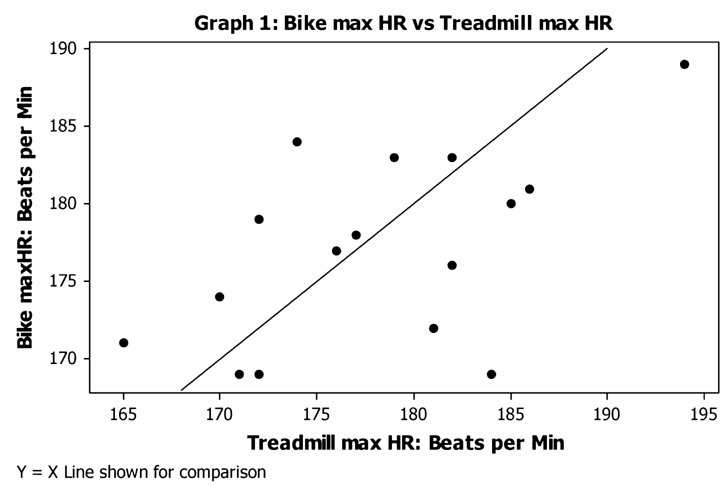

Figure 1. Bike maximum heart rate (max HR) vs. treadmill max HR. Y = X line shown for comparison.

were observed for $\dot{V}O_2max$ (men's CE $\dot{V}O_2max = 69.5$ vs. TM $\dot{V}O_2max = 72.0$ ml·kg^{-1}·min^{-1}, $t = -0.94$, $p = 0.373$; women's CE $\dot{V}O_2max = 66.4$ vs. TM $\dot{V}O_2max = 63.9$ ml·kg^{-1}·min^{-1}, $t = -1.16$, $p = 0.298$) or max HR (men's CE max HR = 176.7 vs. TM max HR = 178.0 bpm, $t = 0.62$, $p = 0.548$; women's CE max HR = 177.8 vs. TM max HR = 178.3 bpm, $t = 0.18$, $p = 0.867$) between the 2 modes of testing. Subsequent discussion will refer to aggregate data. Figures 1 and 2 display these relationships.

Ventilatory parameters demonstrated a significantly greater $\dot{V}Emax$ for CE. The 3.4-breath-per-minute-greater RR for CE approached significance ($p = 0.057$), whereas maximal tidal volume differences were not significant. Figures 3–5 compare ventilatory parameters from the 2 tests. Insignificant differences in RQmax (maximal CO_2/O_2 ratio) indicate maximal effort during both tests.

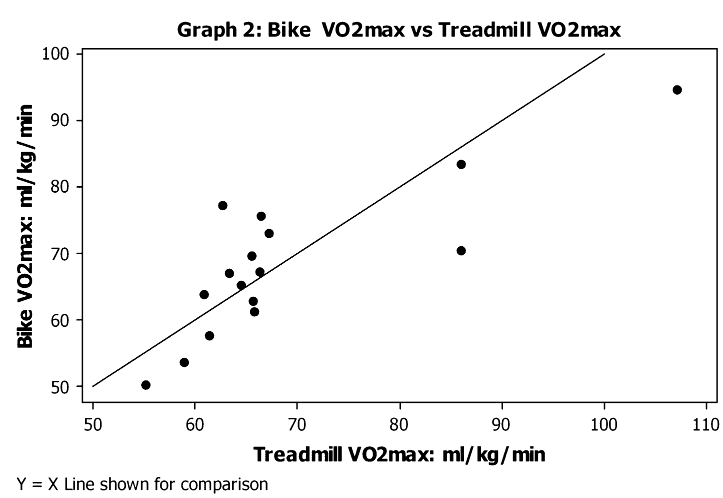

Figure 2. Bike $\dot{V}O_2max$ vs. treadmill [odot]Vo_2max. Y = X line shown for comparison.

Anaerobic Threshold

The AT HR assessed by the $\dot{V}E/\dot{V}O_2$ was not significantly different between CE (153.9 ± 10.5 bpm) and TM (157.0 ± 9.5 bpm; $t = -1.05$, $p = 0.310$) (Figure 6). However, a TE of 12.1 bpm is relatively large and of little practical value to the athlete.

Validation of Respiratory Rate Method of Anaerobic Threshold Assessment

Table 4 contains a comparison of anaerobic threshold measurements between the respiratory rate method (RR) and the ventilatory equivalent method ($\dot{V}E/\dot{V}O_2$). The AT HR assessed by the RR method (158.4 ± 10.0 bpm) was significantly greater than the AT HR assessed by the $\dot{V}E/\dot{V}O_2$ method (153.9 ± 10.5 bpm; $t = 2.87$, $p = 0.012$) for CE. Similarly, AT HR by the RR method (162.9 ± 9.1 bpm) was significantly greater than AT HR assessed by the $\dot{V}E/\dot{V}O_2$ method (156.2 ± 9.8 bpm; $t = 2.89$, $p = 0.013$) for TM.

When AT HR was assessed by the RR and $\dot{V}E/\dot{V}O_2$ methods by sex, AT HR by the RR method was not significantly different for either CE (154.8 ± 8.6 vs. 150.4 ± 10.0 bpm, $t = 1.97$, $p = 0.081$) or TM (161.1 ± 9.9 vs. 153.6 ± 12.1 bpm; $t = 2.01$, $p = 0.065$) for men. Similarly, differences in the 2 methods of AT assessment for women showed no differences in AT HR for either CE (164.3 ± 9.8 vs. 159.8 ± 9.2 bpm, $t = 1.47$, $p = 0.102$) or TM (165.8 ± 9.9 vs. 162.7 ± 10.3 bpm, $t = 1.13$, $p = 0.374$).

The fact that the 2 methods were significantly different when all subjects were compared, but were not significantly different by sex, probably reflects the difficulty in reaching statistical significance with small sample sizes (10 men, 6 women).

Time Trial

Table 5 is a comparison of AT data obtained during maximal testing (CE) and TT data. The

Table 4. Assessment of the validity of the respiratory rate (RR) method.

	Mean ± *SD*	Correlation coefficient	*t* Value	*p* Value	*SEE*	ME	TE
Cycle ergometer							
AT $\dot{V}O_2$ ($\dot{V}E/\dot{V}O_2$)	43.8 ± 13.0						
AT $\dot{V}O_2$ (RR)	49.3 ± 5.8	.214	−1.69	0.112	12.7	5.5	18.2
AT HR ($\dot{V}E/\dot{V}O_2$)	153.9 ± 10.5						
AT HR (RR)	158.4 ± 10.0	0.905	2.87	0.012	4.5	4.5	9.0
AT watts ($\dot{V}E/\dot{V}O_2$)	240.6 ± 71.1						
AT watts (RR)	279.7 ± 39.0	0.138	1.82	0.088	69.7	39.1	108.8
Treadmill							
AT $\dot{V}O_2$ ($\dot{V}E/\dot{V}O_2$)	50.4 ± 9.9						
AT $\dot{V}O_2$ (RR)	47.8 ± 22.1	0.396	−0.50	0.625	9.1	2.6	11.7
AT HR ($\dot{V}E/\dot{V}O_2$)	157.0 ± 9.5						
AT HR (RR)	142.6 ± 56.3	0.141	−0.99	0.338	9.4	14.4	23.8

ME = mean error; TE = total error; AT = anaerobic threshold; HR = heart rate.

purpose of this comparison is to assess the validity of using data obtained during incremental testing and to apply it to high-intensity, long-duration exercise. Although HR is generally accepted as the practical method of monitoring exercise intensity, the RR was included in this analysis because of its potential as another method of monitoring exercise intensity. The TT produced significantly ($p < 0.05$) higher HRs and RRs than the same measurements at AT for the CE test. However, the 8.5-W difference was small and not significant ($p > 0.05$). Analysis of variance with regression comparing changes in both HR and RR over time was performed to determine whether there was significant drift of these variables. Because subjects were free to change wattage at any time during the test, only those subjects who maintained the same wattage for a minimum of the final 20 minutes of the 30-minute TT were included in this analysis. Of the 16 triathletes, 10 met the criteria and were included in the analysis. Regression with analysis of variance indicated that all 10 triathletes (100.0%) demonstrated a significant ($p < 0.05$) upward drift of HR over time at the same wattage. Of these 10 triathletes, 7 (70.0%) show significant drift of the RR, with 3 demonstrating no significant change ($p > 0.05$) over time. The mean increase in HR was 10.2 ± 4.3 bpm (6.5 ± 2.7%) over a mean time of 23.4 ± 2.1 minutes. One subject demonstrated a 19-bpm increase in HR during 24 minutes of identical wattage. The mean increase in RR was 7.6 ± 7.5 breaths per minute (21.5 ± 20.2%). The large standard deviation demonstrates the large variability in the response of the RR over time. One subject increased his RR by 25.5 breaths per minute at the same wattage, whereas 2 other subjects showed virtually no change in RR (increases of 0.7 and 0.2 breaths per minute).

By the end of the TT, subjects had attained a max HR (169.2 ± 9.3 bpm) that was 90.2% of the max HR achieved during the CE $\dot{V}O_2$max test (177.1 ± 6.1 bpm). Likewise, the RR at the end of the TT (43.6 ± 8.3 breaths per minute) was 84.0% of the max RR (51.9 ± 6.7 breaths per minute) achieved during CE $\dot{V}O_2$max.

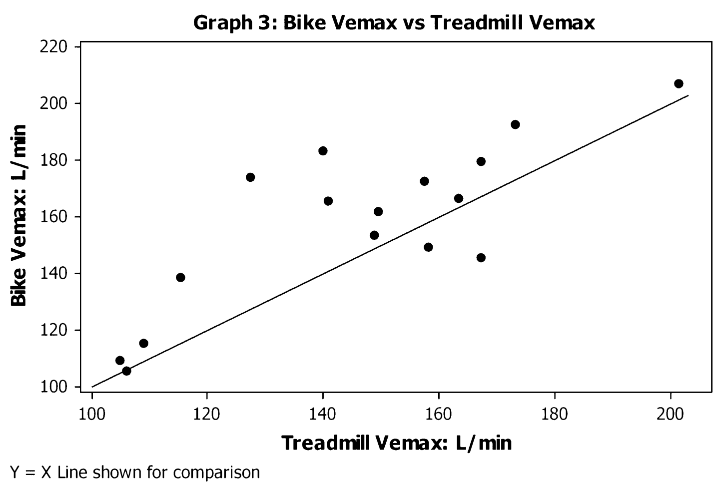

Figure 3. Bike $\dot{V}E$max vs. treadmill $\dot{V}E$max. Y = X line shown for comparison.

Discussion

When examining all studies comparing $\dot{V}O_2$max on CE vs. TM, most results have

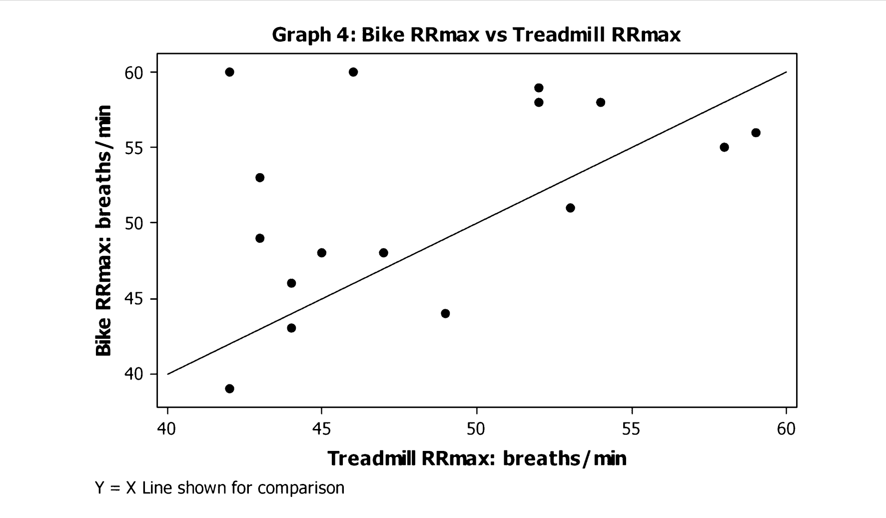

Figure 4. Bike maximum respiratory rate (RRmax) vs. treadmill RRmax. Y = X line shown for comparison.

indicated higher $\dot{V}O_2$max values for TM (3,12,15,20,23). However, these studies are confounded by subjects tested (untrained, trained, triathletes) and study design (untrained on both CE and TM, cyclists on CE vs. runners on TM, runners on both CE and TM, cyclists on both CE and TM). In general, runners have produced higher $\dot{V}O_2$max values on TM, whereas cyclists have produced higher $\dot{V}O_2$max values on CE, thus supporting the specificity principle (18,23). Untrained subjects will produce higher $\dot{V}O_2$max values on TM (12,15), probably because of the recruitment of a greater total muscle mass to perform TM vs. CE.

Our comparisons will focus on those studies using triathletes as subjects. Our finding of no significant difference in $\dot{V}O_2$max for CE and TM is similar to that of Zhou (28), who reported a difference of 0.18 L·min^{-1} for CE and TM to be insignificant ($p > 0.05$). In contrast to these results, others (3,4,20) have found significantly greater $\dot{V}O_2$max values for TM in triathletes. To the best of our knowledge, no study has reported a significantly greater $\dot{V}O_2$max for CE than TM in triathletes. Conflicting results for max HR have also been found, with some authors finding significantly greater max HR for TM (3,4,22), whereas others have reported insignificant differences (20,28). No study has reported higher max HR for CE.

Our finding of significantly higher $\dot{V}E$max for CE than TM is supported by Schneider et al. (20) but refuted by others (3,28), who found no difference in $\dot{V}E$max for CE and TM. None of these studies of triathletes reported tidal volume or RR maximum values.

The ventilatory threshold (AT) has been shown to be a predictor of performance in triathletes (21,22). However, this relationship may not be as strong as performance in individual events such as running, cycling, or swimming, because of many confounding factors in the triathlon, such as hydration, carbohydrate depletion, swimming and cycling economy, and stage transition. Because training programs designed for triathletes are based on AT HR, results demonstrating no difference in AT HR for CE and TM would support the interchangeability of cycle and run training guidelines and eliminate the need for sport-specific testing. Although AT HR was not statistically different for CE and TM, a large TE (12.1 bpm) would indicate the need for sport-specific testing to assess AT HR.

From informal discussions with endurance athletes, most have indicated a minimal requirement of a discrepancy of no greater than 4–5 bpm for both identifying AT HR and transferring these HR guidelines between modes of training. The TE of 12.1 bpm exceeds this requirement of 4–

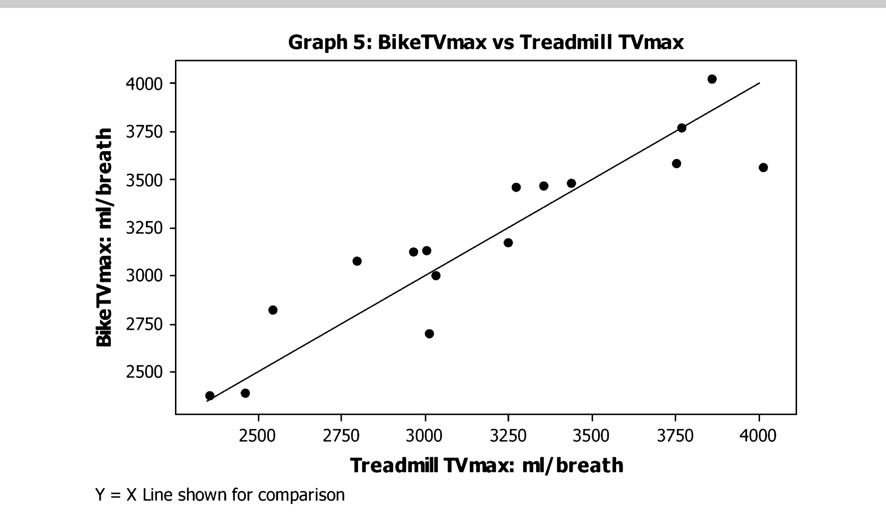

Figure 5. Bike maximal tidal volume (TVmax) vs. treadmill TVmax. Y = X line shown for comparison.

TABLE 5. Comparison of maximal cycle ergometer (CE) testing and time trial (TT) data.

	Mean ± *SD*	Correlation coefficient	*t* Value	*p* Value
AT HR	153.9 ± 10.5	0.534	2.44	0.028
TT HR	159.4 ± 8.9			
AT RR	32.4 ± 3.2	0.529	−4.28	0.001
TT RR	37.8 ± 6.0			
AT watts	240.6 ± 71.1	0.294	0.32	0.754
TT watts	249.1 ± 47.8			

AT = anaerobic threshold; HR = heart rate; TT = time trial.

5 bpm. Examination of individual comparisons reveals that only 5 of the 16 triathletes (31.3%) met this criteria. The mean absolute difference in AT HR was 9.8 ± 7.0 bpm. These results would indicate that most triathletes would opt for sport-specific testing for identification of AT HR. It is the belief of these authors that failure to report TE can be misleading to the athlete or coaches of these athletes, who may assume that training HR guidelines are interchangeable because of 1) nonsignificant differences from a paired *t*-test and/or 2) a significant correlation coefficient. None of these previous studies (3,4,20,22) reported TE.

Previous research by these authors (8,9) and others (17) has determined that an RR breakpoint during incremental testing occurs simultaneously with the ventilatory equivalent ($\dot{V}E/\dot{V}O_2$) breakpoint. However, a relatively high *SEM* and coefficient of variability (CV) observed on repeat testing in the same individuals for the RR method may preclude its use as a method of measuring change in fitness, particularly in highly fit subjects (8). In the present study comparing the RR method with the traditional $\dot{V}E/\dot{V}O_2$ method of AT assessment, significant mean differences, combined with a relatively large TE (9.0 bpm), would indicate that the RR method may not be of practical value to the athlete who requires a rather small error in the training program (4–5 bpm).

As reported previously, mean TT HR was significantly greater than AT HR because of an upward drift of 10.2 ± 4.3 bpm during the 30-minute TT. This is very similar to the results of Heaps et al. (14), who found an increase in HR of 10.0 ± 2.0 bpm with dehydration. The increase in HR was directly related to the degree of dehydration. Likewise, mean TT RR was also significantly greater than AT RR because of an upward drift of 7.6 ± 7.5 breaths per minute, precluding its use as a method of monitoring exercise intensity during constant-load exercise. A higher RR during constant-load exercise than the RR at AT has been previously reported (17). Because endurance events are generally longer than 30 minutes, it would be expected that a larger drift would be seen during competition as dehydration increases. It has been demonstrated that even passive whole-body heating elevates ventilation, probably because of the body's attempt to maintain normal brain temperature (7). Although every effort was made to minimize the effect of heat (air conditioning, high-powered fan), subjects were sweating profusely by the end of TT. However, this may not be unlike what is experienced in competition in hot climates. Although this "drift" of both HR and RR during steady-state exercise may not necessarily indicate to the triathlete that he or she has exceeded the AT, monitoring of this "drift" may be wise to counter the effects of dehydration on performance.

In contrast to HR and RR, no significant difference (p = 0.754) was obtained between AT watts and mean watts during the 30-minute TT. This result will be of practical significance because of the availability of watt meters

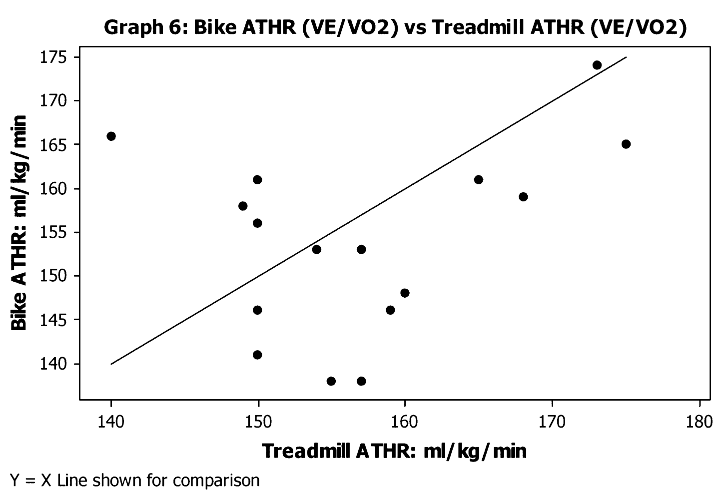

Figure 6. Bike anaerobic threshold heart rate (AT HR; $\dot{V}E/\dot{V}O_2$) vs. treadmill AT HR ($\dot{V}E/\dot{V}O_2$). Y = X line shown for comparison.

currently in use by some competitive cyclists and triathletes. An additional benefit to a watt meter compared with the use of HR monitors is the stability of watts over different weather and terrain conditions. In addition, these results would indicate that endurance cyclists and/or triathletes may assess their AT watts on their own CEs by maintaining maximal watts for 30 minutes.

Practical Applications

Our finding of no difference in max HR and $\dot{V}O_2$max between CE and TM indicates that either mode of testing may be used to assess maximal capacity. Although no differences in CE or TM AT were observed, whether measured as $\dot{V}O_2$ or HR, TE for $\dot{V}O_2$ (19.2 $ml \cdot kg^{-1} \cdot min^{-1}$) and HR (12.1 bpm) were too large to be of practical significance. It is recommended that triathletes undergo both modes of testing if they wish to apply the results to their training programs.

The RR method of AT assessment was not validated in this study. The relatively large TE (9.0 bpm) exceeds the maximum error of prediction acceptable to endurance athletes (4–5 bpm). It is recommended that AT be assessed by $\dot{V}E/\dot{V}O_2$ breakpoint.

Finally, the "cardiovascular drift" of 10.2 bpm during an approximately 20-minute period of steady-state exercise may lead endurance athletes to reduce their HR and, therefore, pace, under the assumption that they are exceeding their AT HR. However, it may also be argued that this "drift" is related to dehydration, which may also hinder subsequent performance. Because no significant difference in AT watts and mean TT watts was observed, it may be wise for the endurance athlete to monitor effort by a watt meter instead of HR. These watt meters are now commercially available.

References

1. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription*. Philadelphia: Lippincott Williams and Wilkins, 2005.
2. Aunola, S and Rusko, H. Does anaerobic threshold correlate with maximal lactate steady state? *J Sports Sci* 10: 309–323, 1992.
3. Basset, F and Boulay, M. Specificity of treadmill and cycle ergometer tests in triathletes, runners and cyclists. *Eur J Appl Physiol* 81: 214–221, 2000.
4. Basset, F and Boulay, M. Treadmill and cycle ergometer tests are interchangeable to monitor triathletes annual training. *J Sports Sci Med* 2: 110–116, 2003.
5. Bayard, A and Dengel, D. Determining the precision of the MedGraphics VO_{2000} when measuring Bayard $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$. *Med Sci Sports Exerc* 30: 122–124, 1998.
6. Bourgois, J and Vrijens, J. Validity of the heart rate deflection point as a predictor of lactate threshold concepts during cycling. *J Strength Cond Res* 18: 498–503, 2007.
7. Cabanac, M and White, M. Core temperature thresholds for hypernea during passive hyperthermia in humans. *Eur J Appl Physiol* 71: 71–76, 1995.
8. Carey, D, Raymond, R, and Duoos, B. Intra- and inter-observer reliaibility in selection of the heart rate deflection point during incremental exercise: comparison to computer-generated deflection point. *J Sports Sci Med* 1: 115–121, 2002.
9. Carey, D, Schwarz, L, Pliego, G, and Raymond, R. Respiratory rate is a valid and reliable marker for the anerobic threshold: implications for measuring change in fitness. *J Sports Sci Med* 4: 483–489, 2005.
10. Conconi, F, Ferrari, M, Ziglio, P, Droghetti, P, and Codeca, L. Determination of the anaerobic threshold by a noninvasive field test in runners. *J Appl Physiol* 52: 869–873, 1982.
11. Costa, M, Russo, A, Picarro, I, Neto, T, Silva, A, and Tarasantchi, J. Oxygen consumption and ventilation during constant load exercise in runners and cyclists. *J Sports Med Phys Fitness* 29: 36–45, 1989.
12. Fairshter, R, Walters, J, Salness, K, Fox, M, Minh, V, and Wilson, A. A comparison of incremental exercise tests during cycle and treadmill ergometry. *Med Sci Sports Exerc* 15: 549–554, 1983.
13. Friel, J. *The Cyclist's Training Bible*. Boulder: VeloPress, 1996.
14. Heaps, C, Gonzalez-Alonso, J, and Coyle, E. Hypohydration causes cardiovascular drift without reducing blood volume. *Int J Sports Med* 15: 74–79, 1994.
15. Hermansen, L and Saltin, B. Oxygen uptake during maximal treadmill and bicycle exercise. *J Appl Physiol* 26: 31–37, 1969.
16. Janssen, P. *Lactate Threshold Training*. Champaign: Human Kinetics, 2001.
17. Neary, J, Bhambhani, Y, and Quinney, H. Validity of breathing frequency to monitor exercise intensity in trained cyclists. *Int J Sports Med* 16: 255–259, 1995.
18. Ricci, J and Leger, L. $\dot{V}O_2$max of cyclists from treadmill, bicycle ergometer and Velodrome tests. *Eur J Appl Physiol* 50: 283–289, 1983.
19. Roecker, K, Striegel, H, and Dickhuth, H. Heart rate recommendations: transfer between running and cycling exercise? *Int J Sports Med* 24: 173–178, 2003.
20. Schneider, D, Lacroix, K, Atkinson, G, Troped, P, and Pollack, J. Ventilatory threshold and maximal oxygen uptake during cycling and running in triathletes. *Med Sci Sports Exerc* 22: 257–264, 1990.
21. Sleivert, G and Rowlands, D. Physical and physiological factors associated with success in the triathlon. *Sports Med* 22: 8–18, 1996.
22. Van Schuylenbergh, R, Vanden Eynde, B, and Hespel, P. Prediction of sprint triathlon performance from laboratory tests. *Eur J Appl Physiol* 91: 94–99, 2004.
23. Verstappen, F, Huppertz, R, and Snoeckx, L. Effect of training specificity on maximal treadmill and bicycle ergometer exercise. *Int J Sports Med* 3: 43–46, 1982.
24. Wasserman, K, Hansen, J, Sue, D, Casaburi, R, and Whipp, B. *Principles of Exercise Testing and Interpretation*. Baltimore: Lippincott Williams and Wilkins, 1999.
25. Wasserman, K, Whipp, B, Koyal, S, and Beaver, W. Anaerobic threshold and respiratory gas exchange during exercise. *J Appl Physiol* 35: 236–243, 1973.
26. Weidman, D, Tesch, J, and Wilson, P. A formula for the prediction of residual volume. *Med Sci Sports Exerc* 19: S31, 1987.
27. Wilmore, J and Costill, D. *Physiology of Sport and Exercise*. Champaign: Human Kinetics, 2004.
28. Zhou, S, Robson, S, King, M, and Davie, A. Correlations between short-course triathlon performance and physiological variables determined in laboratory cycle and treadmill tests. *J Sports Med Phys Fitness* 37: 122–130, 1997.