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Research article

A Simplified Approach for Estimating the Ventilatory and Respiratory Compensation Thresholds

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Abstract
This study aimed to investigate whether ventilatory (VT) and respiratory compensation (RCT) thresholds could be derived from percentages of maximal running speed (Vmax). During the model building phase (1), VT & RCT of 31 competitive level athletes were identified with respiratory gas exchange. During the cross-validation phase (2), 20 subjects performed a treadmill test to identify Vmax and then they performed 30-min runs at velocities 2SE below or above the velocity at VT and RCT derived from (1), with measurement of blood lactate [BL], RPE, heart rate (HR), and speech comfort. Phase (1) revealed that VT and RCT were reached at 67 ± 9% and 84 ± 6% of Vmax. In (2) sustained running 2SE below VT (64% Vmax) was associated with the ability to finish 30-min, with low and constant [BL] (~2.5 $mmol \cdot l^{-1}$), moderate RPE (~3.0-3.5), a small HR drift, and ability to speak comfortably. Conversely, running at 2SE above RCT (86% Vmax) was associated with the inability to finish 30-min (18.5 ± 2.5 min to fatigue), increasing [BL] (end-exercise = 11.9 ± 0.9 $mmol \cdot l^{-1}$), high RPE (end-exercise = 8.9 ± 1.0), large HR drift (end-exercise = 98 ± 3% HRmax), and inability to speak comfortably. Simple percentages of Vmax (≤64% and ≥86%) obtained from a treadmill test without gas exchange, may be useful for prescribing exercise training intensities.

Key words: Running, maximal running speed, maximal lactate steady state.

Introduction

Direct measurement of physiologic thresholds based on respiratory gas exchange (RGE) or blood lactate [La] responses during incremental exercise is a standard technique with competitive athletes, serving to facilitate performance diagnostics and training prescription (Beneke and von Duvillard, 1996; Billat, 1996; Meyer, 2005). However, for the majority of exercise professionals and coaches working with other than elite athletes, direct measurement of physiologic thresholds is not practical. Less technical approaches, such as the Talk Test (Foster et al., 2008; 2009; 2012; Jeans et al., 2011; Recalde et al., 2002) and the Rating of Perceived Exertion (RPE) have been demonstrated to be of value relative to both performance diagnostics and prescription. There is a convincing body of evidence suggesting that the relative distribution of training intensity is regulated more effectively on the basis of the individual metabolic response to training (Billat et al., 1999; 2001; Esteve-Lanao et al., 2007; Seiler, 2010; Sjodin and Svedenhag, 1985; Steinacker, et al., 1998), than by the percent of maximal oxygen uptake (VO_2max) or maximal heart rate (HRmax) concept that has been the dominant model in the fitness-rehabilitation community (Katch et al., 1978; Scharhag-Rosenberger et al., 2010). A variety of simple approaches might be of help in the case where RGE or [La] technology is not available. We have shown that the Talk Test response during incremental exercise testing was useful for prescribing absolute training intensities, both in sedentary (Foster et al., 2009) and well-trained/athletic (Foster et al., 2008; 2012; Jeans et al., 2011; Recalde et al., 2002) individuals. De Koning et al. (2012) observed that ventilatory (VT) and respiratory compensation thresholds (RCT) occurred at ~50 and ~75% of peak cycle power output (PPO), respectively. This finding is similar to observations of the percentages of maximal power output at the gas exchange threshold and critical power made by Burnley, Doust and Vanhatalo (2006) and Vanhatalo, Doust and Burnley (2008). Furthermore, Groslambert et al. (2004) demonstrated that a 30-min perceptive individual time trial allows a partial valid estimation of the power output at the anaerobic threshold in triathletes. These findings, and their implication relative to sustainable exercise, were anticipated a generation ago by Wasserman et al. (1967). Taken together, these findings suggest the question of whether absolute dimensions of exercise intensity (e.g. velocity or power output) available from an incremental exercise test, without RPE, gas exchange or [La] measurement, could be used to predict physiologic markers for guiding exercise training intensity. We already know that peak treadmill running velocity is, like VO_2max and threshold measurements, a very good predictor of running performance (Noakes et al., 1985).

Accordingly, the purpose of this study was to determine if simple percentages of maximal incremental running velocity (Vmax), at which VT and RCT occur, could be used to define training intensity criteria. If successful, we would be able to provide, to a broader range of athletes and to professionals responsible for the conditioning of athletes, a simple and inexpensive technique to define desired training intensities based only on Vmax data.

Methods

Experimental approach to the problem

This study was conducted in two phases. Phase 1 was

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designed to evaluate physiologic thresholds (VT and RCT) as percentages of Vmax during an incremental treadmill running test. Afterward Phase 2 was designed to cross-validate the percentages of Vmax suggested based on the results obtained during Phase 1.

The subjects provided written informed consent to the procedures and the protocol was approved by the University human subjects committee. The protocol conformed to the broad principles of the Declaration of Helsinki.

Subjects

Thirty-one well-trained athletes were recruited to participate in Phase 1. They represented a variety of type and level of athletic accomplishment, including University level runners, soccer players, and basketball players as well as regularly competing recreational runners. Twenty well-trained athletes with similar demographics (Table 1) were recruited to participate in Phase 2. None of the subjects of Phase 1 participated to Phase 2. All subjects were training ≥5 hr·week^{-1} at the time of study.

Table 1. Characteristics of the subjects. Data are means (±SD).

Phase 1	Males (n=16)	Females (n=15)
Age (yr)	22.2 (2.2)	21.8 (2.5)
Height (m)	1.83 (.05)	163 (6)
Body Mass (kg)	81.9 (11.0)	61.8 (8.0)
Vmax (m·s^{-1})	4.6 (.6)	3.9 (.5)
HRmax (bpm)	187 (10)	190 (4)
VO_2max (ml·min^{-1}·kg^{-1})	59.3 (8.0)	50.6 (4.4)
Phase 2	**Males (n=10)**	**Females (n=10)**
Age (yr)	21.8 (2.6)	21.9 (1.8)
Height (m)	1.78 (.06)	1.68 (.06)
Body Mass (kg)	75.7 (10.1)	61.0 (5.3)
Vmax(m.s^{-1})	4.6 (.5)	4.0 (.6)
HRmax (bpm)	189 (8)	191 (5)

Procedures

During Phase 1, each subject performed a maximal incremental treadmill test (1% grade, start @ 1.56 m·s^{-1} for 3 min + 0.22 m·s^{-1} every minute), with measurement of respiratory gas exchange using open circuit spirometry (Parvo Medics, TrueOne 2400 Metabolic Measurement System, Sandy, UT). Measurements were made using a mixing chamber based system, with data integration every 30 s. In stages where the last full minute was not completed, Vmax was interpolated based on proportional time in stage. VT and RCT were determined by visual inspection of the v-slope and ventilatory equivalent for each individual test (Foster and Cotter, 2006). Consequently, the running speed at the determined VT and RCT was identified.

During Phase 2, each subject performed the identical treadmill test as in Phase 1 in order to determine Vmax, although without measurement of respiratory gas exchange. They then performed two steady-state submaximal running bouts on the treadmill, designed to be 30 min in duration, at intensities (64% and 86% Vmax) which were predicted to require ≤VT and ≥RCT (based on the results of Phase 1). [La] was measured at 10, 20 and 30 min (or at the end of the run if the subject could not continue for 30 min) from a fingertip blood sample using dry chemistry (Lactate Plus, Nova Biomedical Corporation, Waltham, MA, USA). Heart rate (HR) was measured at the same time using radiotelemetry (Polar, Kempele, Finland), as was the Rating of Perceived Exertion (RPE) using the Category Ratio scale (Eston, 2012) and Talk Test responses during the steady state runs was measured according to previous studies (Foster et al., 2008; 2009; 2012; Jeans et al., 2011; Recalde et al., 2002).

Statistical analyses

Data are presented as mean ± standard deviation (SD). Alpha level was set at $p < 0.05$. Simple t-tests revealed no differences between male and female subjects for VT & RCT as %Vmax. Accordingly, their data were combined. Target values for ≤VT & ≥RCT were calculated as 2 standard error (SE) of %Vmax below VT and above RCT values from Phase 1. Target velocities for the cross-validation runs in Phase 2 were calculated by taking the lower 95%CI for the ≤VT run (mean %Vmax at VT in Phase 1 minus 2SE) and by taking the upper 95%CI for the ≥RCT run (mean %Vmax at RCT in Phase 1 plus 2SE). In Phase 2, the repeated measures analysis of variance (ANOVA) was conducted to evaluate differences between 10, 20, and 30 min (or at the end of the run if the subject could not continue for 30 min) for heart rate, blood lactate and RPE during ≤VT and ≥RCT runs.

Results

The mean ± SD Vmax in Phase 1 was 4.28 ± 0.58 m·s^{-1}. The mean ± SD running speed at VT (2.81 ± 0.44 m·s^{-1}) and RCT (3.58 ± 0.51 m·s^{-1}) representing 67 ± 9 and 84 ± 6 % of Vmax, respectively. Using the lower and upper 95% confidence intervals for VT and RCT, respectively, <64% and >86% of Vmax was predicted to produce conditions consistent with ≤VT and ≥RCT exercise intensity. Results from Phase 1 are presented in Figure 1.

In Phase 2, during the ≤VT run, all but one subject met criteria for being at less than the intensity of the maximal lactate steady state (MLSS), as [La] increased < 1 mmol·l^{-1} during the final 20 min (Beneke and von Duvillard, 1996; Harnish, et al., 2001; Jeans et al., 2011; Jones and Doust, 1998; Meyer et al., 2005; Swensen et al., 1999). During the ≥RCT run, every subject met > MLSS criteria, as [La] rose more than 1 mmol·l^{-1} over the final 20 min of the exercise bout. The HR, [La] and RPE responses in both steady state runs are presented in Figure 2. Except for blood lactate during the ≤VT run, differences ($p < 0.05$) emerged between 10, 20, and 30 min (or at the end of the run if the subject could not continue for 30 min) for heart rate, blood lactate, and RPE during ≤VT and ≥RCT runs.

All of the subjects successfully finished the ≤VT run, with the HR increasing from 81± 3 to 86 ± 4% HRmax between 10-30 min, with the greatest individual RPE being 5 (hard) and 18 of 20 subjects being able to speak comfortably throughout the run. The other two subjects reported mild difficulty with speech during the final 10 min of the ≤VT run. In the ≥RCT run, none of the subjects could finish the 30 min, with a mean time at the end of the run of 18.5+2.5 min. The HR at 10 min was 93 ± 2% HRmax and increased to 101 ± 2% HRmax at the point the subjects discontinued the run. The RPE by the 10 min point, which was the last common point with all subjects included, was 5.4 ± 1.0. Only 6/20 subjects could speak comfortably at the 10 min point and 0/20 were able to speak comfortably at the conclusion of the study.

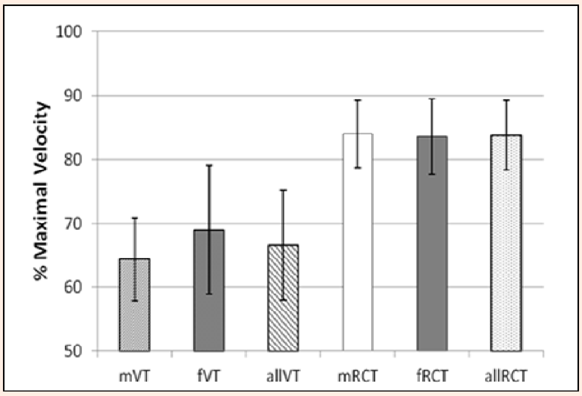

Figure 1. Mean (±SD) values for %Vmax at VT and RCT in Phase 1. Results are presented for m: male, for f: female and (because there was no significant difference between men and women) for the combined group of subjects. From this data, the mean -2SE of the VT intensity was taken as the lower 95% confidence interval for the ≤VT run in Phase 2. The mean +2SE was taken as the upper 95% confidence interval for the ≥RCT run in Phase 2.

Discussion

The major finding of this study was that steady state treadmill running at 64% and 86% of Vmax produced conditions consistent with ≤VT and ≥RCT, respectively. Blood lactate, HR, RPE, and Talk Test responses all supported the concept that the run at 64% Vmax required an intensity ≤VT. Given that 1 subject had blood lactate values that rose during the last 20 min of the run, and that 2/20 subjects were not fully capable of comfortable speech during the ≤VT run, it may be suggested that 64% Vmax is slightly faster than optimal. Given that there is abundant evidence that athletes do the majority of training (e.g. 70-80%) in this intensity zone, it seems reasonable to suggest that this important zone can be identified as a simple percentage of Vmax, the upper border of which is <64% Vmax. While the intensity of the 64% Vmax run was easy enough to satisfy criteria for being <MLSS (Beneke and von Duvillard, 1996; Heck et al., 1985; Jones and Doust, 1998; Jones et al., 2008; Swensen et al., 1999), a lower intensity is probably desirable if athletes wish to be certain that they achieve the <VT training intensity that is widely employed by the majority of systematically training athletes (Billat et al., 1999; 2001; Esteve-Lanao et al., 2007; Seiler, 2010; Sjodin and Svedenhag, 1985; Steinacker et al., 1998). Given that the subjects represented a wide variety of athletes, from systematically trained runners to athletes that only used running training as a conditioning mode for their primary (non-competitive running) sporting activity, we believe that the results may be reasonably generalizable across the sporting community.

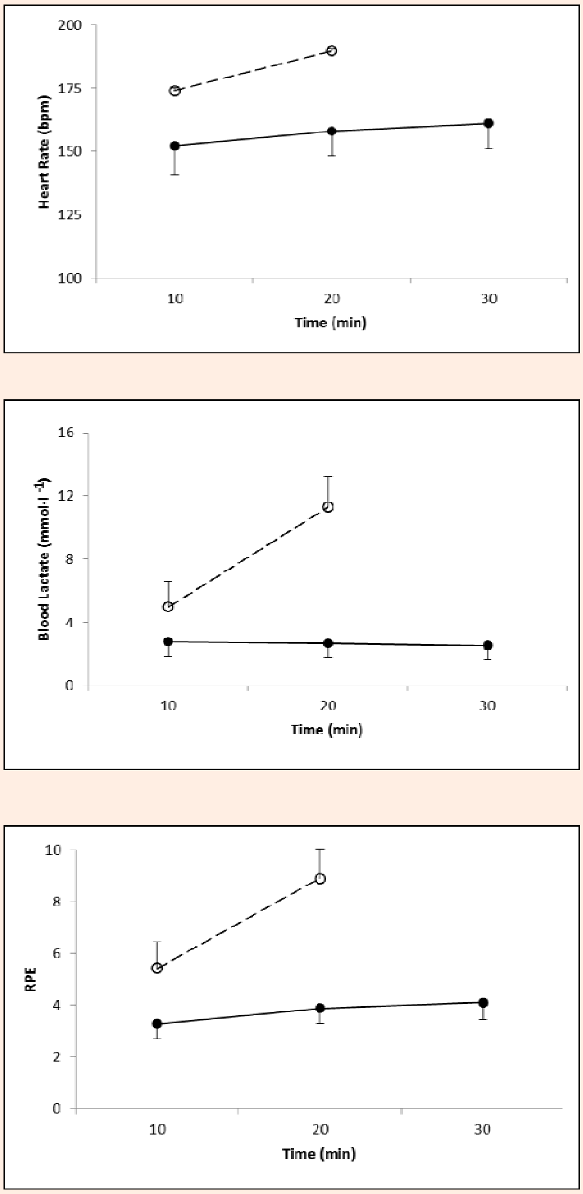

Figure 2. Mean (±SD) for heart rate, blood lactate concentration and RPE during the ≤VT (closed symbols, solid lines) and ≥RCT (open symbols, dashed lines) runs in Phase 2. The ≥RCT runs are plotted using the mean time for the completion of the run. * Denotes significance at $p < 0.05$

In the training distribution model suggested by several authors (Beneke and von Duvillard, 1996; Billat et al., 1999; 2001; Esteve-Lanao et al., 2007; Seiler, 2010; Sjodin and Svedenhag, 1985; Steinacker et al., 1998), approximately 10% of training is normally conducted at higher intensities, typically between the RCT and VO_2max. This practice appears to be based on classical studies suggesting that 3-4 min exercise bouts at intensities that require ~VO_2max might be uniquely valuable for improving oxygen transport capacity (Billat, 1996; Billat et al., 1999; 2001; Esteve-Lanao et al., 2007; Seiler, 2010). The intensity suggested in this data set, >86% of Vmax, appears to satisfy criteria for an intensity that is >RCT but less than VO_2max. It provides a time to failure, e.g. t_{lim}, of 15-20 min, which is meaningfully greater that the t_{lim} of 5-7 min typically associated with the velocity at VO_2max (Billat et al., 1999) but less than the t_{lim} of 30-60 min which is typically associated with RCT or MLSS (Schnabel et al., 1982; Snyder et al., 1994).

The results of the present study are consistent with previous results in the literature. Schnabel et al. (1982) observed essentially constant [La] and a HR drift comparable to that observed in the present data during the last 25 min of a 50 min run, at the velocity of the Individual Anaerobic Threshold (IAT). The relative running velocity at IAT was 69 ± 3% Vmax, which is slightly greater than the 64% Vmax during the ≤VT run in the present data. Given that the IAT is thought to approximate the MLSS, the slightly higher %Vmax seems reasonable. Nevertheless, the subjects in the study of Schnabel et al. (1982) were able to complete a 50 min training bout, which suggests an intensity <MLSS (e.g. <RCT). Snyder et al. (1994) reported a simple HR based method of identifying MLSS. As part of the model construction phase of this study, the MLSS velocity was identified at 86% Vmax, which is the same as the ≥RCT velocity in the present study. In the cross-validation phase of the study by Snyder et al. (1994), the magnitude of HR drift was similar to that observed in the ≥RCT data in this study. More recently, Passelergue et al. (2006) compared responses while running at constant HR and constant velocity. Stable [La] conditions with a small HR drift were observed at 69% Vmax and progressively increasing [La], a large HR drift and inability to complete a 40 min training session were observed at 77% Vmax, similar to the ≤VT and ≥RCT conditions in the present study, respectively. Other studies using cycling (Harnishet al., 2001; Swensen et al., 1999) and speed skating (Foster et al., 1995) have also demonstrated the efficacy of using %Vmax as a predictor of MLSS, further supporting the basic validity of the simple approach used in this study.

It is quite clear that no unique pair of %Vmax velocities is going to perfectly identify VT and RCT velocities during steady state running for all athletes. There is even considerable variation in the ability of respiratory gas exchange and [La] techniques to accurately identify universally appropriate exercise intensities. However, in combination with technology free feedback techniques such as the Talk Test (Foster et al., 2008; 2009; 2012; Jeans et al., 2011; Recalde et al., 2002) and RPE (Eston, 2012; Garcin et al., 1999; Scherr et al., 2013), the simple %Vmax suggested by the current data suggests that desired absolute training velocities can be identified very easily. This may extend the ability to accurately guide training for well-trained athletes into desired training intensity zones.

Conclusion

The results of this study provided indications of how physiologic thresholds (i.e., VT and RCT), can be detected even when sophisticated laboratory resources are not available. Considering that 64% and 86% of the maximal running speed produce conditions consistent with ≤VT and ≥RCT, respectively, training prescription can be better addressed to the improvement of either aerobic or anaerobic capacity. Moreover, the accessibility to treadmills, allowing for measurement of Vmax is, nowadays, much more practicable, giving the possibility of evaluation to almost any professional responsible for the conditioning of athletes. However, the population evaluated in this study should be considered as the reference target since differences for level of training and physiological capacities between recreational athletes and elite runners are evident. Thus, future studies can give a greater insight into the percentages of running speed at VT and RCT for elite runners and evaluate possible difference with recreational athletes.

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Key points

- Simple performance parameters can be used to provide indications of physiologic thresholds.
- 64% and 86% of the maximal running speed produce conditions consistent with ≤VT and ≥RCT.
- The combination of technology free feedback techniques such as the Talk Test and RPE and the simple %Vmax can be used as available and easy methods for the performance evaluation.
- Training prescription can be better addressed to the improvement of the aerobic or anaerobic capacity.

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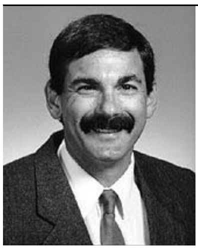

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