Original Article

Perceived exertion threshold predicts the second ventilatory threshold in elite mountain runners

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Abstract:

Gold standards methodologies for accessing physiological transition thresholds (PTT) are expensive or invasive measures, as ventilatory and metabolic analyses. Rating of Perceived exertion (RPE) has been applied with athletes during physical evaluation and/or daily training since it is a simple and low-cost tool which measures the internal load of the athletes. The use of DmaxRPE seems to be a promising methodology to use in training, although, the effectiveness of this methodology has never been previously evaluated. Then, the aim of the present study was to assess the efficacy of Ratings of Perceived Exertion threshold identified by the Dmax method (DmaxRPE) for predicting second physiological transition thresholds in elite mountain runners. Twelve elite male mountain runners' athletes (age 34.08 ± 6.68 years; height, 1.76 ± 7.76 m; weight, 73.65 ± 9.16 kg; $\dot{V}O_{2\max}$, 68.49 ± 5.03 ml·min⁻¹·kg⁻¹) with 10.0 ± 7.1 years of experience in long-distance races underwent an incremental test on a treadmill. There were no differences between DmaxRPE, ventilatory threshold (VT) and heart rate deflection point (HRDP) ($P > 0.05$). However, significant differences were observed between fixed 5.8 RPE score and the DmaxRPE, VT, and HRDP methods ($p < 0.05$). In addition, strong associations were observed between VT and DmaxRPE for HR ($r = 0.79$; $p < 0.05$) and %HR ($r = 0.87$; $p < 0.05$). Bland-Altman plots showed low bias and good agreement between DmaxRPE and VT. The results suggest that DmaxRPE is a valuable tool for predicting VT and should be used in future studies since it is a low-cost and easy-to-apply method.

Keywords: Anaerobic threshold; DmaxRPE; Perception of effort; Athletes; Performance.

Introduction

Physiological transition thresholds (PTT) identified by lactate threshold (LT) and ventilatory threshold (VT) are commonly used to prescribe and evaluate the performance of endurance athletes (Faude, Kindermann, & Meyer, 2009; Bentley, McNaughton, Thompson, Vleck, & Batterham, 2001). These variables allow the identification of zones that delimit intensities (Whipp & Wasserman, 1972) using “gold standard” methods, such as ventilatory and metabolic analyses, which increase the accuracy of training prescription (Gaesser & Poole, 1996; Scherr, et al., 2013). However, recent research has focused on non-invasive, low-cost and alternative measures of PTT. Hemodynamic variables such as a threshold of heart rate variability, heart rate at inflection point and heart rate at deflection point (HRDP) (Cambri, Foza, Nakamura & De-Oliveira, 2008; Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982; Lima & Kiss, 1999), and rating of perceived exertion (RPE) (Fabre et al., 2013; Scherr et al., 2013; Zamunér, et al., 2011) have been addressed as measures to predict PTT.

Heart rate (HR) through HRDP has been widely used to predict the second PTT in athletes since it occurs near the LT and there is a strong association between these thresholds, suggesting that HRDP adequately estimates aerobic capacity (Conconi et al., 1982; Conde, Rubio, Ferreira, & Osieki, 2014). Mikulic et al. (2011) observed strong correlations among physiological variables measured in HRDP and LT ($r = 0.79-0.96$; $P \leq 0.001$) and suggested the use of HRDP to determine the second PTT for performance evaluation and training control, confirming the accuracy of this measure.

The RPE has been widely used for training evaluation and prescription since it measures the internal load of the subjects (Borg & Kaijser, 2006; Fabre et al., 2013; Scherr et al., 2013; Zamunér et al., 2011). Furthermore, some studies suggest the use of fixed RPE scores as a predictor of the second PTT (e.g., fixed 5–6 RPE u.a.) (Scherr et al., 2013; Zamunér et al., 2011; Ferliche, Chicharro, Vaquero, Perez, & Lucia, 1998). Zamunér et al. (2011) showed that the Borg CR-10 Scale was associated with the second PTT and suggested that it is possible to prescribe exercise intensities equal to this threshold using RPE. Scores of 5 or higher could be used

as parameters to evaluate the exercise intensity, i.e., aerobic activity, in active or sedentary women (Zamunér et al., 2011). Nevertheless, the method of fixed scores does not consider individual biological variations.

Within this context, mathematical methods have been investigated using the Dmax method, which was initially proposed to determine LT by Cheng et al. (1992). Recently, Fabre et al. (2013) investigated the use of this method to ascertain RPE threshold to determine PTT (Fabre et al., 2013), as the RPE has a curvilinear response and also to discover the reliability of DmaxRPE method applied with different protocols and populations (Conde et al., 2014; Ferreira et al., 2014). The DmaxRPE method consists of a third-order polynomial fit to all points and other linear fit between the two end points related to lactate/intensity curve (Cheng et al., 1992) or RPE/intensity curve (Fabre et al., 2013) in a graph. The predicted values obtained with these two fits should be subtracted and the highest value corresponds to the RPE threshold (DmaxRPE). Thus, DmaxRPE can be associated with the second PTT (see Figure 3).

Gold standards for assessing PTT, such as blood lactate concentration and ventilation methodologies, are expensive and/or invasive, and are therefore difficult to apply in daily training. In contrast, RPE is a simple, low-cost tool that is easy to apply in different populations. Thus, DmaxRPE seems to be a promising methodology for assessing PTT (Fabre et al., 2013), although further investigation is required to determine the association of RPE with gold standard measures such as ventilatory and hemodynamic thresholds in long-distance runners. Long-distance mountain running usually exposes the athlete's body to numerous environmental conditions such as variations in terrain, temperature and altitude (Kupchak, Kraemer, Hoffman, Phinney, & Volek, 2014), factors that may contribute to early exhaustion and may alter physiological and psychological processes (Vitiello et al., 2015). Evaluation of the efficacy of RPE for predicting PTT in long-distance runners is also logical as pacing is often based on RPE (Millet, 2011). Against this background, the present study aimed to evaluate whether the perceived exertion threshold identified by the DmaxRPE method is effective in predicting the second PTT (measured by VT, HRDP and fixed 5.8 RPE score) in elite long-distance mountain runners.

Method

Participants

Twelve elite male mountain runners' athletes (34.08 ± 6.68 years; 1.76 ± 0.07 m; 73.65 ± 9.16 kg; 68.49 ± 5.03 ml·min⁻¹·kg⁻¹) with experience of 10.0 ± 7.1 years in long-distance races participated in this study. Each participant provided written informed consent according with the Declaration of Helsinki and present study was approved by Ethics Committee (Protocol No. 1.844.721).

Procedures

Participants were instructed to eat light meals up two hours prior to testing, to refrain from alcohol/caffeine-based beverages and to avoid vigorous physical activity during the 24 hours prior to the test. The participants attended one session in the laboratory and anthropometric measurements (body mass, height, and skinfold) were obtained prior to the test. Participants accomplished a maximal incremental test to identify PTT thresholds on an electrical treadmill (Inbramed, Super ATL Model, Inbrasport®). The test was conducted at an initial velocity of 8 km·h⁻¹, with increments of 1 km·h⁻¹ and each stage lasting 1 minute. The participants were verbally encouraged to achieve their maximum performance until exhaustion (Bertuzzi et al., 2013).

Psychophysiological Measures

Ventilatory thresholds and heart rate

Respiratory gas analysis was performed during the test with a PowerLab 4/30 spirometer (ADInstruments®, Bella Vista, Australia). The spirometer was calibrated before the test with ambient air (20.93% O₂/0.03% CO₂) and a gas mixture of known composition (16.04% O₂/4.01% CO₂). The VO₂max was achieved when two or more criteria were met: (1) VO₂ reaching a plateau with increasing work rate; (2) Respiratory exchange ratio above 1.1; (3) Maximum HR (HR_{max}) within 10 bpm of the predicted maximum (i.e., 220-age); (4) and maximal voluntary exhaustion with impossibility to continue the test. HR was checked during the maximal incremental test at each stage using a Polar® Electro Oy HR monitor (Kempele, Finland).

Rating of Perceived Exertion

RPE was recorded over the final 30 seconds of each stage of the incremental test using Borg category-ratio scale (CR-10). CR-10 is a numerical scale that ranges from 0 ("nothing at all") to 10 ("maximal effort"). A value higher than 10 can be obtained, which is considered the "absolute maximum" (Borg, 1982). Before starting the test, each subject received the three following instructions: (a) CR-10 scale familiarization; (b) instructions to combine peripheral muscular and central cardiorespiratory feelings into the total RPE, and; (c) to point how "hard, heavy and strenuous" the exercise was at a given stage.

Data Analysis

Two independent researchers determined in a blinded way the second VT by visual analysis of the breakpoints of ventilatory equivalent (VE) for carbon dioxide (VE/VCO₂), the ventilatory equivalent for oxygen (VE/VO₂) and VE changes over time. Thus, VT was determined by increased ventilation and a concomitant increase in respiratory equivalents of O₂ and CO₂ (VE/VO₂-1 and VE/VCO₂-1, respectively) in relation to the increase in intensity corresponding to the second transition threshold (Cottin et al., 2006).

The DmaxRPE was identified using the method proposed by Fabre et al. (2013) in which RPE was plotted against intensity. Two fits were applied to the RPE curve – a linear fit connecting both extremes (first and last value) and a third-order polynomial fit passing through all points of the curve. The maximal distance observed between the two fits was considered the DmaxRPE.

The intensity associated with the instant RPE achieving the fixed 5.8 score was determined by an interpolation technique (Microsoft Office, Excel®).

Dmax was applied to the HR curve model to determine HRDP, as suggested by Kara et al. (1996). Equivalent to or superior values than 140 bpm were plotted against the intensity. A linear fit connecting both extremes (first and last value) and a third-order polynomial fit passing through all points of the curve were performed. The largest difference observed between the two fits was considered the HRDP.

Statistical Analysis

Descriptive statistics were calculated for all data and reported as mean±SD. Normality was tested by the Shapiro-Wilk test and homogeneity by Levene's test. One-way ANOVA was used to compare the thresholds (VT, DmaxRPE, HRDP, fixed 5.8 RPE score) followed by post-hoc testing (Tukey test) when necessary.

Associations between data sets based on different PTT predictors were tested by Pearson's correlation coefficients, and Bland-Altman plots were used to demonstrate agreement between correlated measures. The difference between values obtained with the two methods was plotted on the y-axis as a function of their measurements on the x-axis, and the limit of agreement was the mean difference between the two methods ± 1.96 SD. Significance was set at p≤0.05. The SPSS 20.0 package was used (SPSS, Inc., New York, USA).

Results

The physiological, perceptual and performance variables (intensity, VO₂, HR, and RPE) identified by the VT, DmaxRPE, fixed 5.8 PE score and HRDP methods are shown in Table 1. There were no significant differences among VT, DmaxRPE, fixed 5.8 score and HRDP thresholds. Nevertheless, significant differences were found: (a) between the VT, DmaxRPE and HRDP methods and the fixed 5.8 RPE score for the variables intensity (INT) and percentage of intensity (%INT) (p<0.05); (b) between DmaxRPE and the fixed 5.8 RPE score for percentage of VO₂ (%VO₂; p<0.05); and (c) between VT and DmaxRPE and the fixed 5.8 RPE score for percentage of HR (%HR; p<0.05).

Table 1. Physiological, perceptual and performance variables corresponding to the VT, DmaxRPE, fixed RPE score and HRDP, Mean ± SD.

	INT. (km·h ⁻¹)	INT. (%)	VO ₂ (%)	HR (bpm)	HR (%)	RPE (u.a.)
VT	15.58 ± 0.90*	80.06 ± 2.82*	85.57 ± 5.49	162.45 ± 7.07	91.10 ± 4.26*	4.29 ± 0.75
DmaxRPE	15.01 ± 1.41*	77.17 ± 7.07*	80.26 ± 9.77*	160.42 ± 9.24	89.67 ± 4.80*	3.71 ± 1.26
Fixed RPE score	17.02 ± 1.06	87.54 ± 5.26	89.79 ± 6.43	169.17 ± 9.65	94.81 ± 4.63	5.8
HRDP	15.61 ± 1.45*	80.15 ± 5.82*	86.45 ± 8.61	162.45 ± 9.20	91.11 ± 5.62	4.58 ± 1.10

*Note: DmaxRPE: perceived exertion threshold obtained by the Dmax method; Fixed RPE score: ratings of perceived exertion fixed in the 5.8 score; HR: heart rate; HRDP: heart rate deflection point; INT: intensity; RPE: rating of perceived exertion; VO₂: oxygen uptake; VT: ventilatory threshold. * Significant difference compared to the fixed 5.8 RPE score method at p < .05.*

Pearson's coefficient showed a strong correlation between VT and DmaxRPE for HR (r=0.790; p<0.05) and %HR (r=0.873; p<0.05), as illustrated in Figure 1 (plots A and B). In addition, the Bland-Altman plots showed concordance and low bias between thresholds for HR and %HR (Figure 1; plots C and D). Therefore, significant correlations were also found for INT (r=0.784) and %INT (r=0.798) with VT; for HR (r=0.903) with VT; for HR (r=0.700) with DmaxRPE, and for HR (r=0.714) and %HR (r=0.587) with HRDP compared to the fixed 5.8 RPE score method. However, the Bland-Altman plots showed no agreement for the cited correlations.

Figure 1. (A) Scatterplot of the relationship between heart rate (HR) corresponding to the ventilatory threshold (VT) and perceived exertion threshold (DmaxRPE). (B) Scatterplot of the relationship between the percent heart rate (%HR) corresponding to VT and DmaxRPE. (C) Bland-Altman plots with estimated mean bias and 95% limits of agreement for the difference in HR, corresponding to DmaxRPE and VT, plotted against the mean. (D) Bland-Altman plots with estimated mean bias and 95% limits of agreement for the difference in %HR, corresponding to DmaxRPE and VT, plotted against the mean.

Discussion

Alternative approaches to PTT identification have been widely used in past research for the evaluation of athlete routines. The present study proposed to contribute information regarding the utility of RPE as a different approach for determining the second PTT in elite long-distance mountain runners. To the best of our knowledge, the present research is the first to investigate these concepts in this population.

RPE has been reported as an attractive tool for controlling and prescribing exercise intensity because of its relationship with physiological indicators, including blood lactate concentrations, HR, and VO₂ (Gaesser & Poole, 1996). There are a few studies that have predicted the second PTT using alternative and non-invasive methods whose results are consistent with the present research (Ferreira et al., 2014; Fabre et al., 2013; Conde et al., 2014). No differences were observed between DmaxRPE and VT for all variables analyzed (Table 2). Moreover, strong correlations were observed between HR corresponding to VT and HR corresponding to DmaxRPE and between %HR corresponding to VT and %HR corresponding to DmaxRPE (Figure 1, plots A and B), as well as low bias, indicating good agreement (Figure 1, plots C and D). These results suggest that DmaxRPE instead of VT can be used, with no significant alteration of its original meaning.

In 2013, Fabre et al. applied the Dmax method to the RPE during a maximal incremental test on a cycle ergometer with physically active subjects. The DmaxRPE method was compared to fixed blood lactate concentrations of 2 and 4 mMol·l⁻¹; to the DmaxLa method proposed by Cheng et al. (1992); to the respiratory compensation point, and to the intensity corresponding to RER of 1.0. Their findings partially agree with our results which showed the lack of significant differences between DmaxRPE and DmaxLa for intensity, VO₂ and HR, and a strong correlation ($r=0.97$) and low bias between the VO₂ values identified by the two methods. In agreement with the present study, Ferreira et al. (2014) manipulated carbohydrate availability in the diet of physically active individuals and found no differences between the physiological variables and RPE scores obtained using LT and DmaxRPE. In addition, the authors reported a significant correlation between the two

thresholds in the control diet group for the intensity of occurrence and it was observed good concordance and low bias between the intensity of the thresholds for the two diets.

To obtain an approximation of the second PTT, some studies have recommended the use of fixed RPE scores of 5 to 6 on the Borg CR-10 Scale, which correspond to “strong” perceived exertion on the scale (Monnier-Benoit, Gros Lambert, & Rouillon, 2009; Zamunér et al., 2011). Furthermore, others have suggested scores of 12 to 13 on the Borg RPE 6–20 Scale (Feriche et al., 1998). Although an apparently promising approach, past analyses from these studies did not consider the individual biological variations among participants such as gender, age, emotional and dietary factors, test protocol, and other specificities. This methodological omission reduced the relevance of this past research. Bias was observed for the concentrations of blood lactate fixed at 2 and 4 mmol·l⁻¹ (Fabre et al., 2013), as also verified in the present study, with the observation of significant differences between INT and %INT of the second PTT identified by the VT, DmaxRPE and HRDP methods, VO₂ identified by DmaxRPE, and %HR identified by VT and DmaxRPE compared to the fixed 5.8 RPE score (Table 2). Despite significant correlations between these methods, there was no evident concordance (Figure 1), a fact that demonstrates misinterpretations in the use of fixed 5.8 RPE values for determining the second PTT.

Understanding the utility of psychophysical scales (e.g., Borg CR-10) that show an exponential increase with increasing the intensity of exercise (Fabre et al., 2013) will allow the application of mathematical models and threshold identification. Studies demonstrate that the RPE is mediated by the integration between peripheral and central brain signals (Borg, 1982). During exercise, the brain receives several feedback signals such as pH, muscular and blood acidosis and circulating catecholamine, as well as external factors such as temperature and altitude. Interpreting these signals, the brain transmits a feedforward response to the organs and active muscles, which may be quantitatively assessed by the athlete's RPE (Noakes, Peltonen, & Rusko, 2001). In this context, the increased sympathetic activity and circulating adrenaline modulate the RPE kinetics, as well as HR, events that may explain why VT and DmaxRPE occur at the same intensity. Thus, the evaluation of RPE is closely related to peripheral metabolic parameters (blood lactate concentrations) and central signals involving HR (Scherr et al., 2013) and ventilation, which act as amplifiers and potentiators of RPE during dynamic exercises. The American College of Sports Medicine (ACSM, 2009) suggests that RPE could add precision to or even replace HR during exercise intensity monitoring. In a cohort study, Scherr et al. (2013) evaluated 2560 individuals who completed incremental tests on a treadmill or cycle ergometer. High correlations were found between RPE scores and HR and blood lactate concentrations. The authors suggested that RPE is a valid and practical tool for monitoring and prescribing exercise intensities for healthy individuals and patients with coronary disease, regardless of gender, age or level of physical activity. Another important result of the present study was the lack of significant differences between DmaxRPE and HRDP, with these methods providing similar results for all variables that correspond to the second threshold. Similarly, Conde et al. (2016) found no significant differences between these methods, supporting the use of DmaxRPE as a predictor of HRDP. In addition, Conde et al. found no differences and strong correlations between DmaxRPE and HRDP when the data were expressed as absolute HR (Conde, Souza, Costa, Novak, & Osiecki, 2016). Hence, DmaxRPE is a reliable alternative method for predicting the second PTT, considering that HRDP is widely used for identifying the transition point. Indeed, the RPE seems to be linked to the metabolic demand evidenced by HR during exercise (Green, McLester, Crews, Wickwire, Pritchett, & Redden, 2005).

Practical Applications

The effectiveness of determinants of the second PTT have been reported to depend on the protocol used as well as on the exercise modality (Fabre et al., 2013). Laboratory data do not reflect the training environment and competitions and further investigation is necessary to understand this mechanism. Although different methodologies exist for determining the second PTT, the results are consistent with the current literature and are of great interest to those seeking to describe both the physiological phenomena and their relationship with RPE scales. The CR-10 Scale is the RPE scale most used in athletes because it does not have a ceiling effect. Moreover, the CR-10 exhibits a non-linear behavior during incremental tests, similar to physiological variables (Borg & Kaijser, 2006). In addition, this type of RPE scale provides sufficient points for the necessary mathematical fitting (Borg, 1982).

Conclusions

The present study demonstrated that DmaxRPE is an accurate and consistent method to predict the second PTT in elite long-distance mountain runners. Indeed, the use of low-cost and non-invasive methods for assessing performance are attractive options for athletes and in future studies. In this regard, perceptual responses are associated with actual performance in long-distance events.

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