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ORIGINAL

CALCULATION OF THE INTERVENTILATORY THRESHOLD AREA: A METHOD FOR EXAMINING THE AEROBIC-ANAEROBIC TRANSITION

CÁLCULO DEL ÁREA ENTRE UMBRALES VENTILATORIOS: UN MÉTODO PARA EXAMINAR LA TRANSICIÓN AERÓBICA-ANAERÓBICA

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RESUMEN

El objetivo fue determinar la relación entre el área interumbrales (ITA) [la zona comprendida entre el primer y el segundo umbral ventilatorio (VT_1 y VT_2) en la función VO_2/V_E, Carga/VO_2 y Carga/V_E] y las variables ergoespirométricas. Treinta y tres hombres realizaron un test incremental. El ITA se calculó: 1) como la integral definida por el área entre VT_1 y VT_2 bajo las curvas de VO_2/V_E, Carga/VO_2 y Carga/V_E y 2) como la suma de las áreas descritas por el triángulo y rectángulo entre los mismos puntos. El ITA para la función Carga/V_E se correlacionó positivamente ($p<0,01$) con la carga en VT_2 ($r = 0,831$) y la ventilación en VT_2 ($r = 0,799$). El ITA para la función VO_2/V_E fue significativamente mayor en los ciclistas que en los estudiantes. La determinación del ITA es un método simple para evaluar la transición aeróbica-anaeróbica durante las pruebas de esfuerzo incremental.

PALABRAS CLAVES: Umbral anaeróbico, transición aeróbica-anaeróbica, umbral ventilatorio, consumo de oxígeno.

ABSTRACT

The aim was to determine the relationship between the interthreshold area (ITA) [the area between the first and second ventilatory threshold (VT_1 and VT_2) for the function VO_2/V_E, load/VO_2 and load/V_E] and the traditional variables measured. Thirty-three men underwent an incremental test. The ITA was calculated: 1) as the integral defined by the area between VT_1 and VT_2 under the curves for the functions VO_2/V_E, load/VO_2 and load/V_E and 2) as the simple sum of the areas described by the triangle and rectangle between the same points. The mean ITA for the function load/V_E was positively correlated ($p<0.01$) with load at VT_2 ($r=0.831$) and ventilation at VT_2 ($r=0.799$). The mean ITA for the function VO_2/V_E was significantly greater in the cyclists than in the students. The ITA for the function load/V_E differed between March and July as training progressed. The determination of the ITA is a simple method of assessing the aerobic-anaerobic transition process during incremental exercise tests.

KEYWORDS: Anaerobic threshold, aerobic-anaerobic transition, ventilatory threshold, oxygen uptake.

INTRODUCTION

The aerobic-anaerobic transition has been given many definitions, being mainly the transition from aerobic to anaerobic metabolism, which has often been used for performance diagnosis and intensity prescriptions in endurance sports (1-10). The reason for such diversity may be largely due to the different methods employed in its determination. According to Skinner and McLellan (11) the exercise to the first ventilatory threshold is primarily aerobic. The exercise phase between two ventilatory thresholds encompasses an aerobic anaerobic transition. Finally, the exercise above the second ventilatory threshold is primarily anaerobic. However, it is not always technically easy to identify the two thresholds, the relationships between the thresholds and the energy production mechanisms, due to the different methodologies employed. Therefore, the physiological bases of the different procedures used to calculate these thresholds have been the subject of debate (1, 2, 4) and some studies have demonstrated a dissociation between ventilatory and lactate thresholds, and have questioned the relationship between these two methods to assess aerobic-anaerobic transition (12). In the present study, the thresholds are identified using ventilatory parameters. The first threshold will be referred to as ventilatory threshold 1 (VT_1**)** and the second as ventilatory threshold 2 (VT_2).

Several studies have provided descriptive data for VT_1 and VT_2 in different groups of athletes (13-19), but the relationship between these thresholds is unclear. Some authors reported on the behaviour of the aerobic-anaerobic transition with training over one (14, 18, 19) or more the sporting seasons (8, 20, 21). However, the results obtained on the variation in VT_1 and VT_2 over these periods have been contradictory.

It is assumed that VT_1 and VT_2 are influenced by changes in the concentration of lactate in the blood (10, 22-24). Ideally, the ventilatory thresholds, as they mark the boundaries of the aerobic-anaerobic transition, should be as close as possible to maximum oxygen consumption (VO_{2max}), so that the body can work under aerobic conditions for as long as possible. Blood acidosis is more pronounced when VT_2 is surpassed, and at that stage compensatory hyperventilation facilitates the continuation of exercise as blood lactate builds up.

Assuming that from VT_1 to VT_2 isocapnic hyperpnea is produced, and that VT_2 coincided with and caused by the onset of blood lactate exponential accumulation, it would be important to establish a single variable to study the relationship between the two ventilatory thresholds. Therefore, we propose that the aerobic-anaerobic transition can be examined via the determination of the interthreshold area (ITA) between VT_1 and VT_2 with respect to the functions VO_2/V_E (oxygen uptake/ventilation), load/VO_2 or load/V_E, bringing new on the topic of aerobic-anaerobic transition. The aim of the present study was to determine the relationship between the IAT and the ergospirometric variables measured. We also examine the differences in the ITA between elite athletes and students of physical education, together with the changes in the ITA over a sporting season. We hypothesized that the IAT is strongly associated with VT_2 and the new approach reflects the training adaptations.

MATERIALS AND METHODS

SUBJECTS

The study subjects were 33 healthy men, 18 of whom were amateur elite cyclists (20 ± 2 years; 177.5 ± 7.3 cm; 69.7 ± 8.5 kg), and 15 of whom were physical education students (21 ± 3 years; 174.4 ± 6.3 cm, 73.2 ± 6.3 kg) who practised the physical activity required by their studies but who were not dedicated cyclists and were not endurance trained. All subjects were informed of the nature of the study and gave their signed consent to be included in accordance with the norms set out by the Declaration of Helsinki regarding research involving human subjects (25). All procedures described in the present investigation were approved by the Local Ethics Committee of the Technical University of Madrid.

PROTOCOL

All participants underwent an incremental ramp exercise test (5 W every 12 s [25 $W \cdot min^{-1}$]) until exhaustion using a Jaeger ER800 cycloergometer with an electromagnetic break (Erich Jaeger, Germany). During testing, all expired gases were analysed using a Jaeger Oxicon Pro® apparatus (Erich Jaeger, Germany), and a full range of ergospirometric variables was recorded using a breath by breath method. Heart rate (HR) was continuously recorded each 15 s using a heart rate monitor (Polar Electro Oy, Kempele, Finland) coordinated with the gas analyzer. The ventilatory thresholds were determined (2, 26) and the VO_{2max} obtained (27). Eight of the cyclists were followed over a period of one year, repeating the test in December (pre-season period), March (pre-competition period) and July (competition period). All tests were performed under similar atmospheric conditions (temperature 22.8 ± 0.6°C; relative humidity 62.5 ± 4.4%; atmospheric pressure 703.54 ± 7.41 mmHg). All the test were considered as maximum, and fulfilled at least two of the following criteria: respiratory exchange ratio (RER) higher that 1.10, a plateau in VO_2 (variations lower than 100 $mL \cdot min^{-1}$) despite load increase, and maximum heart rate (HR_{max}) calculated as 220 – age (28). VO_{2max} was determined as the mean of the two highest values recorded at the maximum load reached by each subject (29), and VT_1 and VT_2 were set at the point of maximum agreement of the most common methods of assessment. Briefly, VT_1 was calculated 1) according to the V-Slope method (30), 2) as the first exponential increment in ventilation (V_E) (11) and 3) as the first rise in function V_E/VO_2 without increments in the function V_E/VCO_2 (carbon dioxide production) (31). VT_2 was determined as the second rise in ventilation (11), and as the intensity which caused a second rise in the function V_E/VO_2 with a concurrent rise in the function V_E/VCO_2 (31).

CALCULATION OF THE INTERTHRESHOLD AREA (ITA)

The relationship between VT_1 and VT_2 was investigated by determining the area under the curve – the ITA – for the functions VO_2/V_E ($L^2 \cdot min^2$), load/VO_2

(W·L·min^2) and load/V_E (W·L·min^2).This was determined for each subject in two ways:

1) As the integral defined between VT_1 and VT_2 for the above functions, calculated using Matlab v.7.8.0 software.

2) As the simple sum of the areas of the triangle and rectangle described between the same points under the same curves (see Fig. 1). Thus, by way of example, the mathematical expression for the calculation of the ITA for the function VO_2/V_E would be:

Area of the triangle for the function VO_2/V_E (Equation 1)

$$ÁREA = \frac{(VO_{2\_VT2} - VO_{2\_VT1})x(V_{E\_VT2} - V_{E\_VT1})}{2}$$

PLUS

Area of the rectangle for the function VO_2/V_E (Equation 2)

$$AREA = (VO_{2\_VT2} - VO_{2\_VT1})xV_{E\_VT1}$$

The results obtained with both procedures were compared using the Student *t* test for paired samples. Pearson correlation coefficients were also calculated. No significant differences were found between the results and all correlations were >0.9. Thus, the results provided by the second procedure, the simple sum of the areas of the triangle and rectangle, were used in all other statistical analysis.

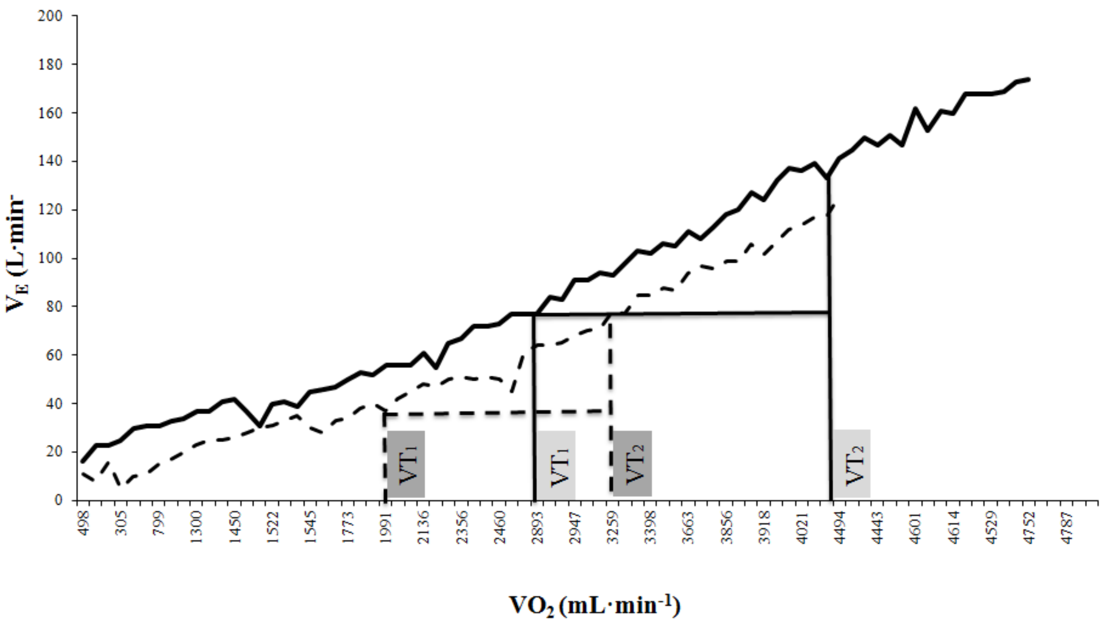

Figure. 1 Procedure for calculating the ITA (sum of the areas of the triangle and rectangle described between VT_1 and VT_2 under the curve), in this case for the function VO_2/V_E. Cyclist (continuous lines) vs. student (discontinuous lines)

STATISTICAL ANALYSIS

After determining distributions to be normal, Pearson correlation coefficients were calculated to examine the relationship between the areas calculated and the values of the ergospirometric variables recorded. Differences between the results of ergospirometric and ITA variables of the two groups of subjects were compared using the Student *t* test. One-way ANOVA was used to determine differences in the ITA of the eight cyclists at different times during the study period. When differences were detected, a *post hoc* Scheffé analysis was performed. All calculations were performed using SPSS software 13.0 for Windows® (SPSS, Chicago, IL). Significance was set at $\alpha < 0.05$.

RESULTS

Table 1 shows the correlation coefficients obtained between the ergospirometric variables recorded and the ITA calculated for the different functions (VO_2/V_E, load/VO_2 and load/V_E) for all subjects as a whole (n=33). The VO_{2max} showed evidence of a statistically significant association (r>0.6, p<0.01) with the ITAs determined for each function; the correlation with the ITA for VO_2/V_E was the strongest (r=0.716; p<0.01). There was no evidence of a statistically significant association between the variables referring to VT_1 and the ITA for any of the functions. However, the variables $load_{VT2}$, VO_{2_VT2}, VCO_{2_VT2} and V_{E_VT2} showed evidence of a statistically significant association with the ITAs for all functions ($p<0.01$).

Table 1. Correlations between the ITA and the ergospirometric variables recorded for all subjects as a whole

	VO_2/V_E	$load/VO_2$	$load/V_E$
VO_{2max}	0.716**	0.652**	0.676**
$Load_{VT1}$	0.403*	0.433*	0.574**
HR_{VT1}	0.066	0.001	-0.003
VO_{2_VT1}	0.438*	0.416*	0.555**
VCO_{2_VT1}	0.346*	0.346*	0.509**
RER_{VT1}	-0.298	-0.251	-0.136
V_{E_VT1}	0.317	0.284	0.505**
$\%VO_{2\_VT1}$	0.071	0.089	0.284
$Load_{VT2}$	0.673**	0.763**	0.831**
HR_{VT2}	0.413*	0.429*	0.399*
VO_{2_VT2}	0.803**	0.754**	0.758**
VCO_{2_VT2}	0.775**	0.774**	0.784**
RER_{VT2}	-0.319	-0.191	-0.167
V_{E_VT2}	0.691**	0.640**	0.799**
$\%VO_{2\_VT2}$	0.467**	0.470**	0.417*
VO_2/V_E		0.872**	0.752**
$load/VO_2$	0.872**		0.869**
$load/V_E$	0.752**	0.869**	

*$p<0.05$. **$p<0.01$. $Load_{VT1}$: load at ventilatory threshold 1; FC_{VT1}: heart rate at VT_1; VO_{2_VT1}: oxygen consumption at VT_1; VCO_{2_VT1}: production of carbon dioxide at VT_1; RER_{VT1}: respiratory quotient at VT_1; V_{E_VT1}: ventilation at VT_1; $\%VO_{2\_VT1}$: percentage of maximum oxygen consumption at VT_1; $Load_{VT2}$: load at ventilatory threshold 2; HR_{VT2}: heart rate at VT_2; VO_{2_VT2}: oxygen consumption at VT_2; VCO_{2_VT2}: carbon dioxide production at VT_2; RER_{VT2}: respiratory quotient at VT_2; V_{E_VT2}: ventilation at VT_2; $\%VO_{2\_VT2}$: percentage oxygen consumption at VT_2.

Table 2 shows that significant differences were detected between the two groups of subjects with respect to the majority of variables studied (Table 2). The ITAs for all three functions were significantly greater for the cyclists (VO_2/V_E 120 ± 34 vs. 86 ± 40 $L^2 \cdot min^2$; $load/VO_2$ 434 ± 130 vs. 300 ± 120 $W \cdot L \cdot min^2$; $load/V_E$ 10862 ± 2196 vs. 7367 ± 2753 $W \cdot L \cdot min^2$). The ventilatory thresholds, expressed as a percentage of VO_{2max}, were closer to VO_{2max} for the cyclists (63

± 7% for the cyclists and 48 ± 8% for the students with respect to VT_1, and 88 ± 5% for the cyclists and 81 ± 8% for the students with respect to VT_2).

Table 2. Comparison of variables recorded for cyclists (n=18) and students (n=15)

	Cyclists	Students
VO_{2max} ($mL\cdot min^{-1}$)	5027 ± 498	4020 ± 746*
$Load_{VT1}$ (W)	245 ± 35	142 ± 34*
HR_{VT1} ($beats\cdot min^{-1}$)	146 ± 32	130 ± 15
VO_{2_VT1} ($mL\cdot min^{-1}$)	3183 ± 460	1912 ± 443*
VCO_{2_VT1} ($mL\cdot min^{-1}$)	2722 ± 429	1663 ± 445*
RER_{VT1}	0.86 ± 0.07	0.86 ± 0.06
V_{E_VT1} ($L\cdot min^{-1}$)	72 ± 13	42 ± 11*
$\%VO_{2\_VT1}$	63 ± 7	48 ± 8*
$Load_{VT2}$ (W)	355 ± 37	258 ± 40*
HR_{VT2} ($beats\cdot min^{-1}$)	180 ± 9	171 ± 12*
VO_{2_VT2} ($mL\cdot min^{-1}$)	4413 ± 507	3240 ± 612*
VCO_{2_VT2} ($mL\cdot min^{-1}$)	4291 ± 528	3366 ± 612*
RER_{VT2}	0.97 ± 0.07	1.04 ± 0.05*
V_{E_VT2} ($L\cdot min^{-1}$)	119 ± 14	86 ± 19*
$\%VO_{2\_VT2}$	88 ± 5	81 ± 8*
VO_2/V_E ($L^2\cdot min^2$)	120 ± 34	86 ± 40*
load/VO_2 ($W\cdot L\cdot min^2$)	434 ± 130	300 ± 120*
load/V_E ($W\cdot L\cdot min^2$)	10862 ± 2196	7367 ± 2753*

* Significantly different compared to the cyclists. Data are means ± standard deviation.

Table 3 shows the results obtained for the different variables in the cyclists at different moments of the year (December, March and July). While the ITA for the VO_2/V_E function did not change significantly, the ITA for the load/VO_2 fell significantly in March while that for the function load/V_E increased significantly to fall again in July, at which time it reached December levels. The VT_2, expressed as a percentage of the VO_{2max}, showed no significant variation over the season, but VT_1 was significantly higher in March and July than in December.

Table 3. Change in ITA over the sporting season (n=8 cyclists)

	December	March	July
VO_2/V_E ($L^2 \cdot min^2$)	132 ± 32	171 ± 54	160 ± 42
load/VO_2 ($W \cdot L \cdot min^2$)	371 ± 107	228 ± 76*	310 ± 84
load/V_E ($W \cdot L \cdot min^2$)	12118 ± 2697	12322 ± 5888*	11676 ± 3428#
$\%VO_{2\_VT1}$	51 ± 6	61 ± 3*	59 ± 5*
$\%VO_{2\_VT2}$	84 ± 4	85 ± 2	89 ± 5

* Significantly different with respect to December. Significantly different with respect to March. Data are means ± standard deviation.

DISCUSSION

The main finding of the present study was that VO_{2max} and VT_2 were strong related with ITA. This variable was greater for the cyclists and changed significantly along season in the cyclists group. This work proposes a simple way of relating the ventilatory thresholds during the aerobic-anaerobic transition. A statistically significant association was found between ITAs calculated for all three functions examined (VO_2/V_E, load/VO_2 and load/V_E), VO_{2max}, and the variables associated with VT_2. Since the area calculated as the simple sum of the areas of the triangle and rectangle between the two ventilatory thresholds showed a strong correlation with the defined integral between the same points, we propose this simple method for calculate ITA. To our knowledge, this is the first work to express the aerobic-anaerobic transition in terms of a single variable – ITA – between VT_1 and VT_2.

Several authors have indicated that the thresholds change with training (19, 32). Thus, if the functions VO_2/V_E, load/VO_2 and load/V_E are modified, ITAs will increase or decrease based on the characteristics of training. We propose an increase in ITA in endurance sports as the result of displacement towards VO_{2max} of each threshold. A higher ITA could be the result of a greater capacity to undertake endurance exercise, and shows that the subject is able to compensate for his/her acid load. There is a strong correlation between the lactate thresholds and the ventilatory thresholds (2, 22, 24, 33). After VT_2 is reached, plasma lactate concentration increases markedly, a reflection of its increased production (10, 34). The relationships between ITA for the function VO_2/V_E and the VT_2–associated ergospirometric variables seen in the present work are explained by the fact that the higher VT_2 the larger ITA.

The positions of VT_1 and VT_2 in the cyclists in the present investigation are similar to those reported in other studies (14, 15, 17, 19, 35). The ITA of the cyclists was greater than that of the students for both VO_2/V_E, load/VO_2 and load/V_E. The greater ITAs of the cyclists are explained by the greater ventilation during the test (63 vs. 42 L/min at VT_1 and 88 vs. 81 L/min at VT_2). The displacement to the right of the thresholds in the cyclists is a consequence of their greater respiratory efficiency through the development of a better breathing pattern (36), in turn a consequence of their degree of training (37, 38).

ITA changes significantly in the cyclists over the sporting season. ITA for the function load/V_E was significantly different between March and July, while the VT_2 (expressed as a percentage of the VO_{2max}) did not change. These differences might be explained by a better peripheral adaptation, allowing greater workloads to be undertaken. The relationship between the position of the ventilatory thresholds and the stage of training is controversial (14, 16, 35, 39, 40). The degree of adaptation of VT_2 over three seasons showed no significant differences at two points in the season (March and July), although the adaptation achieved at either of these moments was greater than in pre-season (December) (14, 19). In some studies performed over one year (18, 19), VT_1, expressed as a percentage of the VO_{2max}, varied between 0.5% and 22%. However, others (14) report the percentage increase between different moments to be <3% in professional cyclists, and <4% in amateur cyclists (19), in agreement with the results of the present study. In contrast, Baumgartl found notable differences over an eight-year study period (20). Depending on the time of assessment over one year, differences between 0 and 15.5% were recorded for elite athletes, and between 1.3 and 30% for amateurs. The differences found by these authors could be explained by the methodologic difficulties to determine the aerobic-anaerobic transition by means of ventilatory methods.

We do not know whether this approach is more useful than the classical assessment of ventilatory or lactate thresholds. Probably, to be able to state that this were indeed the case it would be necessary to perform a randomized controlled trial of two different groups of athletes matched for a large variety of aerobic, anthropometric, physiological and physical variables, and trained using either this novel variable, or the classical thresholds. Probably, the power of the study would be such that this study would never be carried out, especially given the reluctance of athletes to enter randomized trials.

In summary, the determination of ITA is a simple method of assessing the aerobic-anaerobic transition given the statistically significant association with VO_{2max} and the variables associated with VT_2. ITA can be easily calculated by summing the triangle and square between VT_1 and VT_2 under the curves for the functions VO_2/V_E, load/VO_2 or load/V_E. Therefore, coaches and practitioners could easily use this new approach. We suggest that, as the present study is the first investigation that proposes and evaluates this new methodology, it is necessary to perform more investigation to confirm its actual usefulness. In the present work, ITA was greater for the cyclists irrespective of the function used. For these cyclists, and with respect to the function load/V_E and load/VO_2, ITA changed significantly at different moments of the sporting season.

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