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## ORIGINAL ARTICLE

# Determining the ventilatory inter-threshold area in individuals with different endurance capacities

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### KEYWORDS

Anaerobic threshold;  
Aerobic–anaerobic  
transition;  
Ventilatory  
thresholds;  
Inter-threshold area

**Abstract** There is a general consensus in the literature regarding the existence of two ventilation break points during incremental exercise, i.e., Ventilatory Threshold 1 (VT<sub>1</sub>) and Ventilatory Threshold 2 (VT<sub>2</sub>), which mark the boundaries of the aerobic–anaerobic transition. The Inter-Threshold Area (ITA) has been defined as a parameter that connects the ventilatory thresholds. The main aim of the present study was to examine the ITA i.e., the expressed area between VT<sub>1</sub> and VT<sub>2</sub> for the function: ventilation ÷ oxygen uptake (VE/VO<sub>2</sub> in L<sup>2</sup> min<sup>-2</sup>) in individuals with various endurance capacities. Six hundred and six men with different levels of endurance completed an incremental exercise test and their ventilatory thresholds were recorded. The ITA is a trapezoid whose area is calculated as the sum of the area of the triangle and rectangle that form it between VT<sub>1</sub> and VT<sub>2</sub> below the VO<sub>2</sub>/V<sub>E</sub> function. The mean ITA for the function VO<sub>2</sub>–V<sub>E</sub> was greater in cyclists, as the main representatives for endurance athletes, than the mean corresponding to physical education students, who averaged a lower endurance level (120 ± 34 vs. 86 ± 40 L<sup>2</sup>/min<sup>2</sup>). The results suggest that the determination of the ITA can reflect metabolic status throughout the aerobic–anaerobic transition during maximal incremental exercise tests. © 2017 Published by Elsevier España, S.L.U. on behalf of FC Barcelona.

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**PALABRAS CLAVE**

Umbral anaeróbico;  
Transición  
aeróbica-anaeróbica;  
Umbral ventilatorio;  
Área interumbral

**Determinación del área ventilatoria interumbral en individuos con diferentes capacidades de resistencia**

**Resumen** Existe un consenso general de que hay dos puntos de ruptura de la ventilación durante el ejercicio incremental, el umbral ventilatorio 1 (VT1) y el umbral ventilatorio 2 (VT2), que marcan los límites de la transición aeróbica-anaeróbica. El área interumbral se ha definido como un parámetro que relaciona los umbrales ventilatorios. El objetivo principal del presente estudio fue examinar el área entre los umbrales (ITA), es decir, el área entre VT1 y VT2 para la función ventilación/absorción de oxígeno. Seiscientos seis varones con diferentes estados de condición física, desarrollaron una prueba de esfuerzo incremental y se registraron los umbrales ventilatorios. EL ITA es un trapecio cuya área se calcula como la suma del área del triángulo y rectángulo que lo forman, tal como se muestra en la figura entre VT1 y VT2 y que permanecen por debajo de la función VO<sub>2</sub>/VE. La media de ITA para la función VO<sub>2</sub>-VE fue mayor en los ciclistas, como representantes de deportistas de resistencia, frente al área correspondiente a los estudiantes de educación física con menores niveles de resistencia ( $120 \pm 34$  vs.  $86 \pm 40$  L<sup>2</sup>/min<sup>2</sup>). Estos resultados sugieren que la determinación del ITA puede reflejar adecuadamente el estado metabólico durante el proceso de transición aeróbica-anaeróbica durante las pruebas de esfuerzo incrementales.

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**Introduction**

The term 'anaerobic threshold' was initially coined by Wasserman and McIlroy (1964) using the respiratory exchange ratio (RER) to detect the beginning of anaerobic metabolism in patients with cardiac problems performing stress tests.<sup>1</sup> Later, Wasserman, Whipp, Koyle and Beaver (1973), defined the anaerobic threshold as: (1) a non-linear increase in ventilation (V<sub>E</sub>), (2) a non-linear increase in the removal of CO<sub>2</sub> (VCO<sub>2</sub>), (3) an increase in the partial pressure of O<sub>2</sub> during a series of breaths (PetO<sub>2</sub>), with no corresponding drop in the partial pressure of CO<sub>2</sub> (PetCO<sub>2</sub>), (4) an increase in the RER, positively correlating to work load (all during an incremental exercise test). In contrast, Skinner and McLellan (1980) developed the triphasic model which uses gaseous exchange (breathing) variables, thus distinguishing the two thresholds: the Ventilatory Threshold 1 (VT<sub>1</sub>) and the Ventilatory Threshold 2 (VT<sub>2</sub>). Unfortunately, in the literature, VT<sub>1</sub> and VT<sub>2</sub> are known by different names which has led to much ambiguity.<sup>2</sup>

It is assumed that VT<sub>1</sub> and VT<sub>2</sub> are influenced by changes in the concentration of lactic acid in the blood.<sup>3-5</sup> Ideally, the ventilatory thresholds (VTs), which mark the boundaries of the aerobic-anaerobic transition, should be as close as possible to the maximum oxygen consumption value (VO<sub>2max</sub>). This is so the body may experience conditions where oxygen can be used efficiently for as long as possible. Acidosis begins when VT<sub>1</sub> is surpassed, and at this stage compensatory hyperventilation facilitates the continuation of exercise as lactic acid builds up.

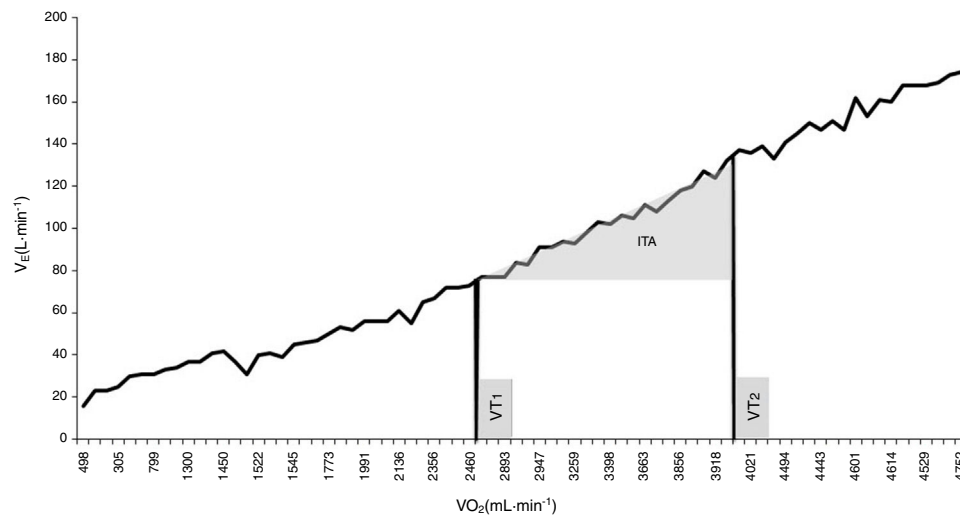
Several studies have provided descriptive data for VT<sub>1</sub> and VT<sub>2</sub> in different groups of athletes<sup>6-11</sup>; however, the literature appears to contain no reports referring to the relationship between these thresholds, nor does it suggest if there is an ideal relationship between the VTs. As suggested in a review article<sup>12</sup> the VT<sub>1</sub> can vary between 0.5%

and 22% in relation to VO<sub>2max</sub>, while the variation of the VT<sub>2</sub> ranges from 2.5% to 12.8%, and with specific reference to this review, these variations occur over one or more competitive seasons. Furthermore, a parameter known as the Inter-Threshold Area (ITA) has been said to connect the VTs.<sup>13</sup> The ITA is expressed as the area between VT<sub>1</sub> and VT<sub>2</sub> for the function: ventilation/oxygen uptake (VE/VO<sub>2</sub> in L<sup>2</sup> min<sup>2</sup>).

According to this rationale, the general aim of this study was to examine the ITA, and to report the values of inter-ventilatory threshold in a large sample of male athletes who specialize in different sports. The data was collected through subject completion of a maximal incremental exercise test until exhaustion. Our investigation followed a verified protocol proposed by Peinado et al. (2014). We hypothesized that athletes who participate in typical endurance-dominant sports, e.g., cycling and athletics (track), will display higher VT<sub>1</sub> and VT<sub>2</sub> values; as well as the ITA being a suitable variable to indicate metabolic status during a maximal incremental exercise test.

**Material and methods****Participants**

606 men completed a maximal incremental exercise test until exhaustion using a cycloergometer (Jaeger ER 800, Germany) or a treadmill (H/P/COSMOS 3PW 4.0, H/P/Cosmos Sports & Medical, Nussdorf-Traunstein, Germany): 251 cyclists, 104 triathletes, 53 swimmers, 51 track athletes, 17 basketball players, 26 football players, 12 gymnasts and 92 physical education (PE) students. All tests were performed under similar atmospheric conditions (temperature  $22.8 \pm 0.6$  °C; relative humidity  $62.5 \pm 4.4$ %; barometric pressure  $703.54 \pm 7.41$  mmHg). All subjects were informed about the nature of the study and gave their signed consent



**Figure 1** Elemental procedure for calculating the ITA for the function  $VO_2/V_E$ .

for participation, in accordance with the norms set out by the Declaration of Helsinki regarding research involving human subjects.<sup>14</sup> All mentioned procedures in the present research were approved by our Local Ethics Committee.

### Instruments and parameters

All participants performed a maximal incremental exercise test to determine their maximal oxygen uptake ( $VO_{2max}$ ) and VTs. Verbal encouragement was provided to ensure that maximal effort was reached. Gas exchange data was continuously collected during each test using an automated breath-by-breath system (Jaeger Oxycon Pro gas analyser, Erich Jaeger, Viasys Healthcare, Germany). The volume signal and gas analysers were calibrated with a syringe of known precision and volume of analyzed gas mixture, respectively. The values were averaged for a 60 s period. A 12-lead electrocardiogram (ECG; Viasys Healthcare, Germany) was continuously recording during the tests to determine the Heart Rate (HR). At least two of the following criteria were required for the attainment of  $VO_{2max}$ : the plateau in  $VO_2$  values despite increasing workload,  $RER \geq 1.1$ , or the attainment of 95% of the maximum theoretical heart rate (HRmax).<sup>7,15</sup> The VTs were determined according to the criteria proposed by Davis (1985) and Siegler, Gaskill and Ruby (2003), whilst  $VO_{2max}$  obtained were determined according to Lucia et al. (2006), and were set in a specific manner in order to achieve the point of maximal agreement between the different methods of assessment. The results from all the tests were evaluated by two researchers in a double blind process. The coefficient of variation between the assessments of these two researchers and those of a highly-experienced expert was 1.3%.

The calculation for ITA as well as the correction (CITA) was performed according to the elementary model proposed by Peinado et al. (2014): the area under the curve (the ITA) for the functions  $VO_2/V_E$  ( $L^2 \text{ min}^{-2}$ ),  $\text{load} \div VO_2$  ( $W L \text{ min}^{-2}$ ) and  $\text{Load}/V_E$  ( $W L \text{ min}^{-2}$ ). It is calculated as the sum of the area of the triangle and the rectangle below the function  $V_E/\text{load}$  (see Fig. 1).<sup>13</sup>

### Statistical analysis

Data were tested for normality, based on skewness ( $-2 < z < 2$ ) and kurtosis ( $-2 < z < 2$ ) using the Kolmogorov–Smirnov test. The Pearson's bivariate correlation analysis was performed to examine the relationship between performance variables,  $VO_2$  and the ITA. Differences between the results of the two subject groups were compared using the Independent Samples Student *t* Test. Effect sizes between the different methods of expressing the VTs were calculated using Cohen's *d*; using the means and the pooled standard deviations of the measurements from the conditions. Cohen's *d* was corrected for dependence among means by using the correlation between the two means. Interpretation of Cohen's *d*: an effect size of less than 0.33 is considered small, while 0.33–0.55 is considered moderate and effect sizes of 0.56–1.2 are considered large. Comparisons were two-tailed. All data were prepared and analyzed using SPSS v15.0<sup>®</sup> (SPSS Worldwide Headquarters, Chicago, IL) software. The significance level for all studies was set at  $p < 0.05$ .

### Results

Table 1 shows the anthropometric variables and  $VO_{2max}$  for the sample, divided into two categories, sports with a high endurance component and sport with a low endurance component. For endurance sports,  $VO_{2max}$  values are relatively higher for cyclists ( $71.89 \pm 8.84 \text{ mL/min/kg}$ ) compared to triathletes ( $65.37 \pm 8.39 \text{ mL/min/kg}$ ), swimmers ( $53.91 \pm 7.54 \text{ mL/min/kg}$ ) and track athletes ( $61.21 \pm 9.07 \text{ mL/min/kg}$ ). In sports with a smaller endurance component, basketball players reported higher  $VO_{2max}$  values ( $58.33 \pm 5.56 \text{ mL/min/kg}$ ) than those obtained by soccer players ( $56.5 \pm 5.03 \text{ mL/min/kg}$ ). PE students and gymnasts expressed the lowest  $VO_{2max}$  values.

Table 2 show the values obtained from the VTs and ITA for the two groups according to the endurance component. In descending order, reported VT<sub>1</sub> values are as follows: track athletes ( $65.0 \pm 8.6\%$ ), triathletes ( $58.6 \pm 9.3\%$ ), cyclists

**Table 1** Anthropometric variables and  $VO_{2max}$  for sportsmen with high and low endurance capacity.

	Endurance athletes				
	Cycling	Triathlon	Swimming	Track and field	Total
Age (years)	22 ± 7	28 ± 6	15 ± 4	31 ± 11	19 ± 6
Weight (kg)	68 ± 7	70 ± 8	58 ± 16	71 ± 9	53 ± 8
Height (cm)	175 ± 6	177 ± 7	167 ± 14	174 ± 6	139 ± 7
$VO_{2max}$ (mL/min)	4846 ± 624	4558 ± 692	3106 ± 908	4280 ± 558	3358 ± 556
$VO_2$ rel (mL/min/kg)	71.89 ± 8.84	65.37 ± 8.39	53.91 ± 7.54	61.21 ± 9.07	50.48 ± 6.27
	Not endurance athletes				
	Physical education students	Basketball	Football	Artistic gymnastics	Total
Age (years)	26 ± 8	17 ± 3	22 ± 4	18 ± 2	17 ± 3
Weight (kg)	75 ± 9	79 ± 12	71 ± 6	65 ± 6	58 ± 6
Height (cm)	177 ± 5	187 ± 9	177 ± 5	168 ± 7	142 ± 5
$VO_{2max}$ (mL/min)	3983 ± 621	4590 ± 674	4016 ± 410	3348 ± 471	3187 ± 435
$VO_2$ rel (mL/min/kg)	53.42 ± 7.91	58.33 ± 5.56	56.5 ± 5.03	52.03 ± 6.59	44.06 ± 5.02

**Table 2** Ventilatory thresholds and inter-ventilatory threshold area for sportsmen with high and low endurance capacity.

	Cyclists	Triathletes	Swimmers	Track and field	Total
$VO_2$ $VT_1$ (mL/min)	2749 ± 535	2672 ± 591	1692 ± 474	2793 ± 525	2476 ± 531
HR $VT_1$ (beats $min^{-1}$ )	144 ± 13	139 ± 15	139 ± 15	149 ± 13	143 ± 14
$VO_{2max}$ $VT_1$ (%)	56.6 ± 7.5	58.6 ± 9.3	55.4 ± 7.7	65 ± 8.6	59 ± 8.3
$VO_2$ $VT_2$ (mL/min)	4116 ± 622	3914 ± 616	2564 ± 735	3808 ± 526	3600 ± 625
HR $VT_2$ (beats $min^{-1}$ )	177 ± 11	170 ± 12	175 ± 12	176 ± 10	174 ± 11
$VO_{2max}$ $VT_2$ (%)	84.9 ± 6.0	86.0 ± 6.4	83.1 ± 7.2	89.1 ± 6.4	85.8 ± 6.5
ITA ( $L^2 min^{-2}$ )	35.75 ± 17.11	31.10 ± 15.86	16.11 ± 12.67	23.07 ± 12.30	26.51 ± 14.48
	Physical education students	Basketball	Football	Artistic gymnastics	Total
$VO_2$ $VT_1$ (mL/min)	2188 ± 530	2967 ± 671	2254 ± 514	1737 ± 427	2287 ± 536
HR $VT_1$ (beats $min^{-1}$ )	137 ± 17	147 ± 18	141 ± 18	129 ± 9	138 ± 16
$VT_1$ $VO_{2max}$ (%)	54.9 ± 10.3	64 ± 10.2	55.8 ± 9.1	51.7 ± 8.0	56.8 ± 9.4
$VO_2$ $VT_2$ (mL/min)	3327 ± 583	4117 ± 654	3416 ± 409	2686 ± 517	3386 ± 541
HR $VT_2$ (beats $min^{-1}$ )	171 ± 12	176 ± 15	174 ± 12	165 ± 12	171 ± 13
$VT_2$ $VO_{2max}$ (%)	83.6 ± 6.8	89.8 ± 6.4	85.1 ± 6.0	79.9 ± 6.0	84.6 ± 6.3
ITA ( $L^2 min^{-2}$ )	25.39 ± 14.64	30.23 ± 13.70	26.91 ± 11.85	17.47 ± 10.65	25.00 ± 12.71

Heart rate (HR), oxygen consumption ( $VO_2$ ). Subscripts max,  $VT_1$  and  $VT_2$  indicate maximum, first ventilatory threshold and second ventilatory threshold respectively. Inter-threshold area (ITA), i.e., the area defined between  $VT_1$  and  $VT_2$  for the function ventilation/oxygen uptake.

(56.0 ± 7.5%), and swimmers (55.4 ± 7.7%). The cyclists displayed the highest ITA values (35.75 ± 17.11  $L^2 min^{-2}$ ) in comparison to triathletes (31.10 ± 15.86  $L^2 min^{-2}$ ), track athletes (23.07 ± 12.30  $L^2 min^{-2}$ ) and swimmers (16.11 ± 12.67  $L^2 min^{-2}$ ). Athletics (track) (65.0 ± 8.6%) and basketball (64.6 ± 10.2%) displayed a higher aerobic threshold (%) in comparison to the other sports. With regards to the different sports and anaerobic threshold percentages, many differences were reported. In addition, basketball players and tracks athletes presented high average ITA values with respect to other sports (30.23 ± 13.70  $L^2 min^{-2}$ , 23.07 ± 11.06  $L^2 min^{-2}$ ) (see Table 2).

The values of the inter-ventilatory threshold area were significantly higher for subjects with a high endurance

capacity, for both the absolute values ( $t_{300} = 3-88$ ,  $p < 0.001$ ,  $d = 0.37$ ) and for the corrected ( $T_{298} = 4.31$ ;  $p < 0.001$ ;  $d = 0.41$ ). Both the  $VT_2$  and  $VT_1$  (in percentages with respect to the  $VO_{2max}$ ) were significantly higher for subjects with a high resistance ( $t_{604} = 1.85$ ;  $p = 0.033$ ,  $d = 0.18$ ) in comparison to those with a low resistance ( $t_{213} = 2.06$ ,  $p = 0.022$ ,  $d = 0.20$ ). The absolute values of  $VT_2$  and  $VT_1$ , too, were significantly higher for subjects with a high endurance in comparison to those with a low endurance ( $T_{198} = 7.37$ ;  $p < 0.001$ ,  $d = 0.70$  and  $T_{604} = 6.07$ ;  $p < 0.001$   $d = 0.58$ ).

Although significant ( $p < 0.001$ ), the study of correlational analysis (Table 3) indicates a very low ITA, in relation to the values of  $VT_1$  and  $VT_2$  expressed in absolute (ml/min) or relative (%) values. Only the correlation between ITA

**Table 3** Correlations for different parameters.

		VO <sub>2</sub> VT <sub>1</sub> (mL/min)	VO <sub>2</sub> VT <sub>2</sub> (mL/min)	VO <sub>2max</sub> VT <sub>1</sub> (%)	VO <sub>2max</sub> VT <sub>2</sub> (%)	ITA (L <sup>2</sup> min <sup>2</sup> )
VO <sub>2</sub> VT <sub>1</sub> (mL/min)	Pearson's correlation	1	0.874**	0.646**	0.386**	0.176**
	Sig. (bilateral)		0.000	0.000	0.000	0.000
	N	606	606	606	606	606
VO <sub>2</sub> VT <sub>2</sub> (mL/min)	Pearson's correlation	0.874**	1	0.277**	0.392**	0.601**
	Sig. (bilateral)	0.000		0.000	0.000	0.000
	N	606	606	606	606	606
VO <sub>2max</sub> VT <sub>1</sub> (%)	Pearson's correlation	0.646**	0.277**	1	0.606**	-0.363**
	Sig. (bilateral)	0.000	0.000		0.000	0.000
	N	606	606	606	606	606
VO <sub>2max</sub> VT <sub>2</sub> (%)	Pearson's correlation	0.386**	0.392**	0.606**	1	0.278**
	Sig. (bilateral)	0.000	0.000	0.000		0.000
	N	606	606	606	606	606
ITA (L <sup>2</sup> min <sup>2</sup> )	Pearson's correlation	0.176**	0.601**	-0.363**	0.278**	1
	Sig. (bilateral)	0.000	0.000	0.000	0.000	
	N	606	606	606	606	606
CITA (L <sup>2</sup> min <sup>2</sup> )	Pearson's correlation	0.273**	0.660**	-0.224**	0.404**	0.985**
	Sig. (bilateral)	0.000	0.000	0.000	0.000	0.000
	N	606	606	606	606	606

ITA, inter-threshold area.

CITA, correct inter-threshold area.

\*\* The correlation is significant at the 0.01 level (bilateral).

and VT<sub>2</sub> (ml/min) can be considered as strong and appropriate ( $r=0.601$ ). Moderate effects were found for the inter-ventilatory threshold area ( $d=0.41$ ) and very low values for the VTs ( $d=0.20$ ), expressed in percentages with respect to VO<sub>2</sub> max. Cohen's  $d$  value was higher for VTs in absolute values (ml/min VO<sub>2</sub>) ( $d=0.58$ ).

## Discussion

The aim of this study was to examine the ITA and, to report the values of inter-ventilatory threshold in a large sample of male athletes who specialize in different sports. We propose that the aerobic-anaerobic transition should be examined through the calculation of the ITA, between VT<sub>1</sub> and VT<sub>2</sub>. To our knowledge, this is the first study to provide evidence of a relationship between the VTs in a large sample of healthy individuals with different levels of physical fitness, specifically referring to endurance capacity.

### The inter-ventilatory threshold area

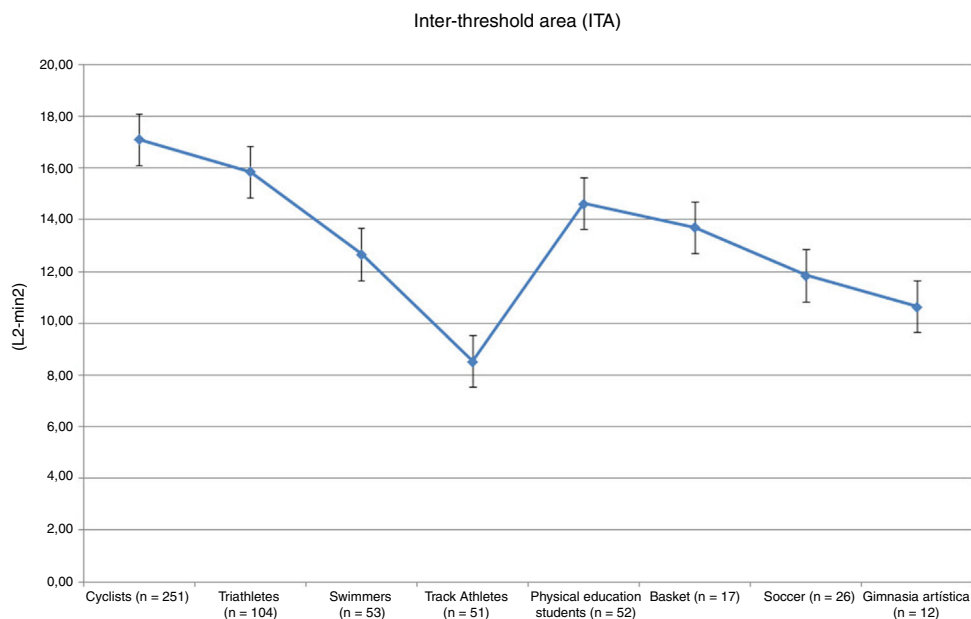
Ideally, the VTs, which mark the boundaries of the aerobic-anaerobic transition, should be as close as possible to the VO<sub>2max</sub>; as such so that the body may experience conditions where oxygen can be used efficiently for as long as possible. During acidosis, which begins when VT<sub>1</sub> is surpassed, compensatory hyperventilation facilitates the continuation of exercise as lactic acid builds up. Therefore, it is plausible to argue that a higher ITA is the result of a greater capacity to undertake endurance tests, and illustrates that the subject is able to compensate for the

increase in the lactic acid. Thus, a strong correlation exists between lactate and VTs.<sup>3-5,16</sup> Once the VT<sub>2</sub> is surpassed, the plasma lactic acid concentration increases markedly. This is the result of increased lactic acid production and a decreased rate of clearance. As a result, our research demonstrates that the highest ITA values are found in cyclists and triathletes; sports where high endurance capacity is vital for high-level performance. However, one cannot simply explain the high value of ITA reported in basketball players, as basketball is not considered as endurance dominant.<sup>17</sup>

The highest ITA values were obtained for cycling, followed by triathlon and basketball. Athletics (track) and basketball reported the highest aerobic threshold values (%) in relation to VO<sub>2max</sub>, above all other sports (see Fig. 2). There is a significant difference between the results of the anaerobic threshold (%) and the peak oxygen consumption between sports.

### The ventilatory thresholds (% in respect to VO<sub>2max</sub>)

Mean values for cyclists' aerobic threshold, expressed in percentages, were  $56.6 \pm 7.5\%$ . Our results are similar to those reported by Zapico et al. (2007): November-December ( $50 \pm 2.4\%$ ), January-February ( $61 \pm 2.1\%$ ) and May-June ( $56 \pm 2\%$ ). However, they are well below the values by Pardo (2001): November-December ( $76.1 \pm 1.3\%$ ), January-February ( $72 \pm 1.5\%$ ) and May-June ( $73.1 \pm 1.3\%$ ); who analyzed the evolution of aerobic-anaerobic transition throughout a competitive season. Our results also differ from those found by Withers et al. (1981) ( $66.3\%$ ), and



**Figure 2** Inter-ventilatory threshold area average values of the different sports.

Simon et al. (1986) (65.8%). The differences may be due to variations in the terminology and methodology used to determine the aerobic-anaerobic transition.<sup>2</sup> The relationships between the ITA for the function  $\text{VO}_2/\text{V}_E$  and the  $\text{VT}_2$  (associated with present ergospirometric variables) are explained by the fact that a higher  $\text{VT}_2$  results in a larger ITA. The positions of  $\text{VT}_1$  and  $\text{VT}_2$  in the cyclists, in the present investigation, are similar to those reported in other studies.<sup>9,11,18–20</sup> Overall, the ITA of the cyclists was higher in comparison to the other sports with lower endurance characteristics.

In our research, the mean values for the triathletes' aerobic and anaerobic thresholds, expressed in percentages, were  $58.6 \pm 9.3\%$  and  $86.0 \pm 6.4\%$ , respectively. Galy et al. (2003) investigated the evolution of the physiological parameters over seasonal parameters, and found an aerobic threshold rate ranging from  $73.8 \pm 0.2\%$  and  $75.6 \pm 0.2\%$ ; and for the anaerobic threshold of  $79 \pm 0.2\%$  and  $88.9 \pm 0.2\%$ . It is plausible to assume that the differences in reported aerobic threshold values, between the investigations, are a result of the method used to determine the aerobic-anaerobic transition. We discovered that the method used was the same as ours.<sup>21</sup> Other studies<sup>22–25</sup> reported large variations in VTs (ranging between 61% and 81%). Again, the differences and variability can be explained by nomenclature used in terms of aerobic-anaerobic transition,<sup>2</sup> the methods for determining the thresholds<sup>21</sup> and the mode of exercise.<sup>26</sup>

For swimming, soccer, gymnastics, athletics (track), and PE, the percentages of the aerobic threshold, with respect to  $\text{VO}_{2\text{max}}$ , were very similar (ranged between 51.7% and 55.8%), but lower than endurance-specific sports. Therefore, the higher values obtained for this parameter in the aerobic-anaerobic transition are for athletics (track) ( $65.0 \pm 8.6\%$ ) and basketball ( $64.6 \pm 10.2\%$ ). The mean percentage of the anaerobic threshold is very similar for all sports (ranging from 80% to 89%). Our results are in

accordance with those reported by Bunc et al. (1987) where a total of 223 highly trained track athletes were studied. In particular, the anaerobic threshold percentage values ranged between 80.5% and 86.6%.<sup>6</sup> Track athletes and basketball players have the highest aerobic threshold percentage values with respect to the  $\text{VO}_{2\text{max}}$ , above all other sports. Between sports, there is a significant difference in reported anaerobic threshold percentages from the peak oxygen consumption.

### Expression of the ventilatory thresholds

In this study, we assessed the degree of association between VTs in the two categories of track athletes studied. We believe that the manner one expresses the VTs can result in significantly different outputs. The calculation of the ITA aims to aid and explain the high values commonly found in endurance track athletes. One would expect that track athletes with a greater endurance component (in both training and competition) would report significantly high relative values. However, no significant differences between groups with a high and low endurance component were reported for both  $\text{VT}_1$  ( $59 \pm 8.3\%$  versus  $56.8 \pm 9.4\%$ ), and  $\text{VT}_2$  ( $85.5 \pm 6.5\%$  versus  $84.6 \pm 6.3\%$ ).

In this study, individuals with a low endurance capacity displayed an average  $\text{VT}_1$  value of  $55.94 \pm 10.3$  and  $\text{VT}_2$  value of  $84.26 \pm 6.9$ , respectively; while individuals with a high endurance capacity had values of  $57.88 \pm 8.5$  and  $85.4 \pm 6.4$ , respectively. When the effect size is calculated, the average athlete with a high endurance capacity would approximately exceed 58% ( $d=0.20$ ; 57.8%) of the sample of athletes with a low endurance capacity. Therefore, it is not convenient to express VTs as a percentage of  $\text{VO}_{2\text{max}}$ . However, the effect size for inter-ventilatory threshold area and VTs expressed in absolute values (ml/min) are appropriate ways to express the aerobic-anaerobic transition.

The effect size for absolute values of  $VT_1$  and  $VT_2$  of athletes with low endurance,  $2253 \pm 606.26$  for ( $VT_1$ ) and  $3381.76 \pm 641.87$  ( $VT_2$ ), means that approximately 71% could have higher values than the corresponding population of athletes with low endurance [ $2614.50 \pm 635.09$  and  $3856.91 \pm 787.02$  for  $VT_1$  and  $VT_2$ , respectively] ( $d=0.50$ , 69.1%). The effect size for the inter-ventilatory threshold area is less ( $d=0.40$ , 65.5%) than  $VT_1$  and  $VT_2$  in absolute values. We believe it is appropriate to express the VTs first as absolute values, and secondly as values in terms of inter-ventilatory threshold area, but never as percentages of  $VO_{2max}$ .

When the obtained effect size is estimated over 58% ( $d=0.20$ ; 57.8%) of the athlete population with a low endurance capacity,  $VT_1$  and  $VT_2$  values will differ from the average athlete sample with high endurance. Therefore, it is not convenient to express the VTs as percentages of  $VO_{2max}$ . However, the effect size of the ITA and VTs expressed in absolute values (ml/min) are appropriate ways to express the aerobic-anaerobic transition. Approximately 66% of the population with low endurance would be higher than the corresponding area of high endurance ( $d=0.40$ ; 65.5%); whilst almost 71% of the ventilatory threshold (ml/min) would be higher in endurance track athletes. Therefore, it seems appropriate to express the VTs first as absolute values, and secondly as values in terms of inter-ventilatory threshold area.

## Conclusion

The ITA is a simple method to assess the relationship between the VTs. The ITA allows one to distinguish between athletes with different endurance capacities. Moreover, it is inconvenient to express the anaerobic thresholds as percentages with respect to  $VO_{2max}$ , as it is routinely done. It is more appropriate to report thresholds as absolute values of oxygen consumption. In relation to expressing the VTs, the results of this study indicate that the ITA does not present superior information in comparison to absolute values of  $VT_1$  and  $VT_2$ .

## Conflict of interests

Authors declare that they don't have any conflict of interests.

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