

# HEART RATE RESERVE AT VENTILATORY THRESHOLDS, MAXIMAL LACTATE STEADY STATE AND MAXIMAL AEROBIC POWER IN WELL-TRAINED CYCLISTS: TRAINING APPLICATION

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## ABSTRACT

**Introduction:** Several physiological tests have been developed to predict cycling performance. However, the high costs and expertise needs to perform these tests detracts coaches and athletes from using them habitually. The aim of this study is to provide the equivalence between these physiological assessments and heart rate reserve (HRR) to facilitate training advice to cyclists. **Materials and Methods:** Thirty three aerobically-trained male cyclists ( $\dot{V}O_{2max}$   $62.1 \pm 4.6$  ml·kg<sup>-1</sup>·min<sup>-1</sup>) performed two graded exercise tests (GXT; 50 W warm-up followed by 25 W·min<sup>-1</sup>) to exhaustion.  $\dot{V}O_2$  and  $\dot{V}CO_2$  data were collected throughout GXT and several continuous tests were performed to detect maximal lactate steady state workload (MLSS). **Results:**  $VT_1$ ,  $VT_2$  and  $\dot{V}O_{2max}$  were achieved at power outputs of  $184 \pm 36$ ,  $298 \pm 36$  and  $390 \pm 34$  W, respectively corresponding with 66±9, 88±6 and 100% of HRR. MLSS (n=14), occurred at  $256 \pm 31$  W. These HRR defined five training zones; 53-62% HRR (zone R0), 62-71% HRR (zone R1), 74-86% HRR (zone R2), 86-99% HRR (zone R3) and 100% HRR (zone R3+). **Discussion:** We found the HRR correspondence to ventilatory aerobic and anaerobic thresholds (i.e.,  $VT_1$  and  $VT_2$ ) MLSS and  $\dot{V}O_{2max}$ . Those HRR defined 5 distinguishable training zones corresponding to those physiological events that could be used for optimizing training.

**Key Words:** ventilatory threshold, heart rate, heart rate reserve, maximal lactate steady state, cycling

# FRECUENCIA CARDIACA DE RESERVA A UMBRALES VENTILATORIOS, MÁXIMO ESTADO ESTABLE Y POTENCIA AERÓBICA MÁXIMA EN CICLISTAS ENTRENADOS: APLICACIONES AL ENTRENAMIENTO

## RESUMEN

**Introducción:** Un gran número test se han desarrollado para tratar de predecir el rendimiento en ciclismo. Sin embargo, los altos costes y la formación necesaria para poder realizar estas pruebas aleja habitualmente este tipo de valoraciones de entrenadores y atletas. El objetivo de este estudio es proporcionar una equivalencia entre estas valoraciones fisiológicas y la frecuencia cardiaca de reserva (HRR) para facilitar el proceso de entrenamiento en ciclistas. **Materiales y Métodos:** Treinta y tres ciclistas varones bien entrenados aeróbicamente ( $\dot{V}O_{2max}$   $62.1 \pm 4.6$  ml·kg<sup>-1</sup>·min<sup>-1</sup>) realizaron dos test incrementales máximos en rampa (GXT; 50 W calentamiento, seguido de 25 W·min<sup>-1</sup>).  $\dot{V}O_2$  y  $\dot{V}CO_2$  fueron registrados durante el GXT, además varios test fueron llevados a cabo para detectar el máximo estado estable de lactato (MLSS). **Resultados:**  $VT_1$ ,  $VT_2$  y  $\dot{V}O_{2max}$  fueron alcanzados a  $184 \pm 36$ ,  $298 \pm 36$  and  $390 \pm 34$  vatios respectivamente, equivalentes al 66±9%, 88±6% y 100% de la HRR. MLSS (n=14), fue localizado a  $256 \pm 31$  vatios. Se definieron cinco zonas de entrenamiento; 53-62% HRR (zona R0), 62-71% HRR (zona R1), 74-86% HRR (zona R2), 86-99% HRR (zona R3) and 100% HRR (zona R3+). **Discusión:** Se encontró relación entre la HRR y los umbrales aeróbico y anaeróbico ( $VT_1$  y  $VT_2$ ), MLSS y  $\dot{V}O_{2max}$ . La HRR sirvió para definir 5 zonas de entrenamiento

correspondientes a los eventos fisiológicos y que pueden ser utilizadas para optimizar el entrenamiento.

**Palabras clave:** umbrales ventilatorios, frecuencia cardiaca, frecuencia cardiaca de reserva, máximo estado estable, ciclismo

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## INTRODUCTION

Maximal oxygen consumption (Foster, 1983), aerobic-anaerobic transition (Skinner and McLellan, 1980; Beneke and von Duvillard, 1996) metabolic efficiency or economy of movement (Cavanagh and Kram, 1985) and the anaerobic power (Paavolainen et al., 2000; Paavolainen et al., 1999; Noakes, 1988; Bulbulian et al., 1986) have been described as the main physiological markers related to endurance performance. However, the importance of each of these physiological markers during training is based on the capacity of each one of them to explain the performance during the event. While maximum oxygen consumption may predict up to 91% of performance in a marathon race, the speed at lactate threshold explains until 98% of variability in performance (Farrell et al., 1979). In turn, the ventilatory thresholds can accurately track improvements in the performance subtle of elite endurance cyclists can get for a full season (Lucia et al., 2000).

Ventilatory thresholds are the manifestation of and underlying metabolic events where homeostasis is lost. For instance,  $VT_1$  is the intensity at which ventilation and  $\dot{V}CO_2$  increase in parallel. The increase expired  $CO_2$  is generated by the  $HCO_3^-$  buffering of lactic acid that reaches the blood (Del Coso et al., 2009). Second ventilatory threshold (i.e., RCP (Wasserman et al., 1973) in turn, represents a work intensity at which blood lactate accumulation rises considerable and there is hyperventilation to buffer acidosis (i.e., ventilatory compensation). Thus,  $VT_2$  represents the highest metabolic rate at which the system is able to maintain an elevated but stable metabolic acidosis. Exercise above these thresholds results in accumulation of fatigue inducing metabolites (Jones et al., 2008), rapid increases in intramuscular and arterial lactic acid, hydrogen concentration and changes in motor unit recruitment (Copp et al., 2010). Training at workloads that target the above describe thresholds will elicit adaptations to delay fatigue and improve performance (Esteve-Lanao et al., 2007; García-Pallarés et al., 2009; García-Pallarés et al., 2010).

In addition, the correct identification of these physiological markers is critical to guide training and adaptations. In this regard, training and competition intensities for  $\dot{V}O_{2max}$  induces mainly peripheral adaptations such as increases in muscle glycogen stores, capillary and mitochondrial density as well as an increase of oxidative enzymes (García-Pallares et al., 2010; García-Pallarés and Izquierdo., 2011; Helgerud et al., 2007). In contrast, adaptations to low and moderate aerobic training intensity, commonly related with improvements at the aerobic threshold level (Seiler and Tønnessen, 2009), induce mainly efficiency improvements and central cardiorespiratory adaptations such as pulmonary diffusion and haemoglobin affinity, as well as increases in blood volume and cardiac output (Helgerud et al., 2007; García-Pallarés et al., 2009; García-Pallarés et al., 2010;. García-Pallarés and Izquierdo,

2011; Docherty and Sporer, 2000; MacDougall and Sale, 1981). Supramaximal training intensities (higher to  $\dot{V}O_{2max}$ ) causes peripheral adaptations such as including an increased resting glycogen content, a reduced rate of glycogen utilization and lactate production during matched-work exercise, an increased capacity for whole-body and skeletal muscle lipid oxidation, peripheral enhanced vascular structure and function, exercise performance improved measured by time-to-exhaustion test or time trials and increased maximal oxygen uptake (Burgomaster et al., 2005, 2008; Gibala et al., 2006; Gibala et al., 2012; Rakobowchuk et al., 2008).

The methods known as gold standard for the identification of these training intensities (higher to  $\dot{V}O_{2max}$ ), aerobic and anaerobic threshold, maximal lactate steady state) have a high cost, and need of reliable metabolic carts which are expensive (approx. 30,000 \$) and thus are a limited resource for many coaches and athletes.

Herefore, the aim of this study was to determine at which heart rate reserve (HRR) correspond the ventilatory thresholds, maximum lactate steady state, and  $\dot{V}O_{2max}$  of trained cyclists. With this description of correspondence between physiological events and the more accessible HRR we hope to provide a valid and objective information that will allow cyclists to optimize training process creating more accurate working ranges based on the main variables used by exercise scientist.

## METHOD

### *Participants*

Thirty three well and highly trained-men cyclists volunteered to participate in this study (age  $20.5 \pm 7.5$  yr, body mass  $66.1 \pm 6.6$  kg, height  $174.8 \pm 4.9$  cm,  $\dot{V}O_{2max}$   $62.1 \pm 4.6$  ml·kg·min<sup>-1</sup>, endurance training experience  $7.3 \pm 4.6$  yr). Cyclist underwent a complete medical examination (including ECG) that showed all were in good health. The study, which was conducted according to the declaration of Helsinki, was approved by the Bioethics Commission of the University of Murcia. Written informed consent was obtained from all subjects prior to participation. No physical limitations or musculoskeletal injuries that could affect training were reported.

### *Experimental design*

Following a familiarization GXT, participants rested for 48 hours to ensure adequate recovery. Participants visited the lab 3-4 times separated by at least 2 days. In the first sessions, cyclists performed a maximal graded exercise test (GXT) to establish the average power output (W) associated to aerobic-anaerobic events based on ventilatory gas exchange. Thereafter, fourteen of this thirty subjects participants visited the lab 2-3 more times to determine the

workload associated with the maximal lactate steady state (MLSS). All trials were performed between 15:00 h - 19:00 h to control the circadian rhythms effects (Mora-Rodríguez et al., 2015), under similar environmental conditions (21-24°C and 45-55% relative humidity). In all trials subjects were ventilated at a wind velocity of 2.55 m·s<sup>-1</sup> with a fan positioned 1.5 m from the subject's chest.

#### *Maximal graded exercise tests*

Participants performed all the experimental trials on the same cycle ergometer (Ergoselect 200, Ergoline, Germany), with a warm-up of 10 min at 50 W, starting immediately after the ramp protocol with increments of 25 W·min<sup>-1</sup> until exhaustion. During GTX participants were monitored by standard 12 lead ECG (Quark T12, Cosmed, Italy) and Oxygen consumption ( $\dot{V}O_2$ ) and carbon dioxide production ( $\dot{V}CO_2$ ) were recorded using breath-by-breath indirect calorimetry (Quark B<sup>2</sup>, Cosmed, Italy). GXT warm-up was preceded by three 5-min steady state stages at 45%, 55%, and 65% of the peak power output, being the three intensities below the second ventilatory threshold (VT<sub>2</sub>). After 10 minutes of passive recovery each participant ingested 200-250 ml of water to ensure adequate hydration status. Following, participants performed the GXT according to a modification of the protocol described by Lucía et al., (2000). According to the preliminary peak power output attained for all participants (GTX<sub>PRE</sub>), the initial load (50 W) and load increments per minute (25 W·min<sup>-1</sup>) of the GXT were established to ensure that the testing protocol had a duration between 13.5 and 15.0 min, avoiding local acidosis that could impair the attainment of maximum cardiorespiratory performance. Heart rate was continuously monitored (RS400, Polar, Finland), gas exchange was recorded breath by breath using indirect calorimetry. Each participant indicated their rate of perceived exertion every two minutes using the Rate of Perceived Exertion scale (RPE) 6-20, where 6 is defined as an effort "very very light" and one 20 "Maximum, strenuous" effort (Borg, 1998). Indirect calorimetry device was calibrated before each test.

#### *Maximal lactate steady state test*

Several 30 min constant load pedaling were performed to identify the highest load (i.e. W) which elicited increment less than 1 mMol between 10 and 30 min of exercise (Beneke 1995; Beneke and von Duvillard 1996). After 7 days from the second GXT, fourteen participants performed the first MLSS trial at the individual load associated to their respective lactate threshold (LT) determined during the GXT. Depending on the result of the first MLSS test, the load of the second and following MLSS tests increased or decreased 0.2 W·Kg<sup>-1</sup> (~ 15 W),

until criteria was fulfilled. Between 2 and 3 tests were necessary to determine the load (i.e. W) associated MLSS for each cyclist.

#### *$\dot{V}O_{2max}$ and ventilatory thresholds determinations during the GXT*

$VT_1$  was determined using the criteria of an increase in both  $\dot{V}_E/\dot{V}O_2$  and  $P_{ET}O_2$  with no concomitant increase in  $\dot{V}_E/\dot{V}CO_2$ .  $VT_2$  was determined using the criteria of an increase in both the  $\dot{V}_E/\dot{V}O_2$  and  $\dot{V}_E/\dot{V}CO_2$  and a decrease in  $P_{ET}CO_2$  (Lucía et al. 2000). Maximal oxygen uptake (i.e.,  $\dot{V}O_{2max}$ ) was defined as the highest plateau (two successive maximal readings within 0.15 L/min) reached.

#### *Body composition*

Fat-free mass and fat mass were assessed by X-ray absorptiometry dual energy (DXA) (Hologic Discovery, Hologic Corp., Waltham, MA, USA). Participant's height and weight were assessed in a stadiometer (Seca 202, Seca Ltd., Hamburg, Germany) and body mass index was calculated.

#### *Statistical analysis*

The  $\dot{V}O_{2max}$  of the subjects averaged  $61.4 \pm 7.6$  mL·kg·min<sup>-1</sup>.  $VT_1$ ,  $VT_2$  and MLSS were unequivocally determined in 100% of the cases. According to Lucía et al. (2000), both independent researchers were in agreement for  $VT_1$  and  $VT_2$  detection in 30 (91%) of the tests. In those three cases where the opinion of a third observer was assessed for  $VT_1$  and/or  $VT_2$  detection, there always existed agreement with one of the two other researchers.

## RESULTS

Table 1 shows descriptive statistics of the two groups. Only significant differences were found in CAIT score between groups.

TABLE 1  
Average values of several physiological markers, power output (W),  $VO_2$  (ml/min) and heart rate (bpm).

|                                   | Power (W) | $VO_2$ (ml/min) | HR (bpm) |
|-----------------------------------|-----------|-----------------|----------|
| <b><math>VT_1</math> (LT)</b>     | 184 ± 36  | 2254 ± 365      | 143 ± 15 |
| <b>MLSS (LT+0.5)</b>              | 253 ± 31  | -               | -        |
| <b><math>VT_2</math> (LT+2.0)</b> | 298 ± 36  | 3332 ± 321      | 176 ± 15 |
| <b><math>VO_{2max}</math></b>     | 390 ± 34  | 4024 ± 348      | 194 ± 12 |

*$VT_1$  Ventilatory threshold 1,  $VT_2$  Ventilatory threshold 2,  
MLSS Maximal lactate steady state,  $VO_{2max}$  Maximal oxygen consumption.*

TABLE 2  
95% confidence interval for selected variables (C.I. 95%).

|                          | MAP (%)    | VO <sub>2max</sub> (%) | HR <sub>Max</sub> (%) | HRR (%)   | RPE (6-20) |
|--------------------------|------------|------------------------|-----------------------|-----------|------------|
| <b>VT<sub>1</sub></b>    | 50% - 55%  | 54% - 60%              | 71% - 78%             | 62% - 71% | 10 - 11    |
| <b>MLSS</b>              | 63% - 68%  | -                      | 81% - 85%             | 76% - 84% | 12 - 14    |
| <b>VT<sub>2</sub></b>    | 75% - 80%  | 82% - 88%              | 87% - 92%             | 83% - 89% | 15 - 16    |
| <b>VO<sub>2max</sub></b> | 95% - 100% | 95% - 100%             | 100%                  | 100%      | 17 - 19    |

*HR<sub>Max</sub> Maximal heart rate, HRR Heart rate reserve, RPE rate of perceived exertion*

Average values of VT<sub>1</sub> occurred at an intensity of  $184 \pm 36$  of power output (W), at a  $\dot{V}O_2$  of  $2254 \pm 365$  ml/min and an average heart rate of  $143 \pm 15$  bpm which corresponded with 50% - 55% of MAP, associated with a 54% - 60% of  $\dot{V}O_{2max}$ , maximal heart rate 71% - 78% (% HR<sub>max</sub>) and 62% and 71% of HRR. MLSS, measured in fourteen of the thirty-three subjects occurred at  $256 \pm 31$  W and an average heart rate of  $166 \pm 14$  bpm in a range of 63% - 68% of MAP, associated with a 82% - 88% of  $\dot{V}O_{2max}$ , maximal heart rate 81% - 95% (% HR<sub>max</sub>) and 76% and 84% of HRR. VT<sub>2</sub> occurred at a workload of  $298 \pm 36$  W at a  $\dot{V}O_2$  of  $3332 \pm 321$  ml/min, heart rate of  $176 \pm 15$  bpm corresponding to 75% - 80% of MAP, 82% - 88% of  $\dot{V}O_{2max}$ , 87% - 92% HR<sub>max</sub> and 83% - 89% HRR.  $\dot{V}O_{2max}$  was reached at  $390 \pm 34$  W at  $\dot{V}O_2$  of  $4024 \pm 348$  ml/min, average heart rate of  $194 \pm 12$  (bpm).

#### DISCUSSION AND CONCLUSIONS

The aim of our study was to describe the correspondence between habitually measured physiological markers of performance (VT<sub>1</sub>, MLSS, VT<sub>2</sub> and  $\dot{V}O_{2max}$ ) and HRR for a moderately large sample (n=33) of well-trained cyclists. After identification of the HRR corresponding to each of the physiological determination (i.e., in order of intensity VT<sub>1</sub>, MLSS, VT<sub>2</sub> and  $\dot{V}O_{2max}$ ) we propose a training zone model based on these objective parameters. We hope that this information will allow cyclists to optimize training processes by providing a precise HR to develop adaptations in a determined physiological zone (i.e., aerobic threshold, anaerobic threshold, maximal aerobic power).

To delimit training zones for cyclist or other endurance athletes it is required to assess the workload at the aerobic and anaerobic thresholds. The most accurate mode of assessment of these thresholds is the identification of VT<sub>1</sub> and VT<sub>2</sub> by indirect calorimetry. Ventilatory thresholds have been shown to accurately track the improvements in endurance performance of elite (Lucía et al., 2000) and well trained endurance cyclist (Amann et al., 2006). Besides considering the ventilatory threshold 1 and 2 as gold standart of aerobic-anaerobic transition (Skinner and McLellan, 1980), several authors have also found high reliability of this markers in well-trained cyclists (Weston and

Gabbett, 2001; Aunola and Rusko, 1984; Prud'Homme et al., 1984). In addition, the HR values corresponding to several physiological markers of performance (LT,  $VT_1$ , and  $VT_2$ ) remains stable despite significant training-induced adaptations (i.e., shifts in LT,  $VT_1$ , and  $VT_2$  toward higher workloads; Lucia et al. (2000)) which suggests that HR is besides a cheap means of control of workload an easy and accurate mean.

To reach a high level of training and performance, load control training very strict and precise is necessary (Mujika and Padilla, 2001; Lucia et al., 1998). Cyclists of all levels have great confidence in heart rate when monitoring the intensity during training sessions and competition (Lucia et al., 1999), but usually the proposed training zones followed by amateur cyclists are generic and do not provide the correct intensity distribution. As explained in Lounana et al. (2007), the ACSM in 1990 established the recommendation for large populations of 55%, 62%, 70%, 85% and 90% of  $HR_{max}$  to attain respectively 40%, 50%, 60%, 80% and 85%  $\dot{V}O_{2max}$ . In 1998, it adjusted these percentages to 35%, 55%, 70% and 90% of  $HR_{max}$  to the recommendations work 20%, 40%, 60% and 85% of HRR or  $\dot{V}O_2$  reserve (considered comparable). In our study, performed only with well-trained cyclists, the percentages compared to those proposed in the previous paragraph gave back more than 10% of difference to establish the same recommendations for cyclists, which implemented on training process, can cause different adaptations to which we think are associated with the intensities proposals. This fact makes us think about the importance of this type of research for better understanding and optimization of the training process in each sport.

With the objective of applying our findings to training and competition, we developed Table 3. In Table 3 training zones are presented with their correspondent percent of  $HR_{max}$ , HRR, MAP,  $\dot{V}O_2$  and RPE showing the upper and lower 95% confidence interval.

TABLE 3  
Personal author's approach for exercise prescription (training zones).

| Percentage  | Zone | MAP (%)    | VO <sub>2max</sub> (%) | HR <sub>Max</sub> (%) | HRR (%)    | RPE     |
|---|------|------------|------------------------|-----------------------|------------|---------|
| 70% - 90% VT <sub>1</sub> or LT <sup>(1)</sup>      | R0   | 37% - 47%  | 40% - 51%              | 52% - 67%             | 53% - 62%  | 8 - 9   |
| 90% - 110% VT <sub>1</sub> or LT <sup>(1)</sup>     | R1   | 47% - 58%  | 51% - 63%              | 67% - 82%             | 62% - 71%  | 10 - 11 |
| 90% - 100% MLSS or LT+0.5 <sup>(1)</sup>            | R2   | 58% - 70%  | -                      | 82% - 87%             | 71% - 85%  | 12 - 14 |
| 95% - 105% VT <sub>2</sub> or LT+2.0 <sup>(1)</sup> | R3   | 74% - 81%  | 81% - 89%              | 87% - 95%             | 85% - 94%  | 15 - 16 |
| 95% - 105% VO <sub>2max</sub>                       | R3+  | 95% - 105% | 95% - 105%             | 95% - 100%            | 95% - 100% | 17 - 19 |

MAP, Maximal aerobic power, HR<sub>Max</sub> Maximal heart rate, HRR Heart rate reserve, RPE rate of perceived exertion.

<sup>(1)</sup>According to Pallarés et al., 2016. Validity and reliability of ventilatory and blood lactate thresholds in well-trained cyclist. *PLoS One*. In press.

In conclusion, coaches and athletes with similar characteristics to the subjects in this study, that only have access to monitoring heart rate could locate the intensities of VT<sub>1</sub>, MLSS and VT<sub>2</sub> accurately. We hope that this will allow athletes and coaches to undergo training at intensities that induce different metabolic adaptations while only needing measurement of HR<sub>max</sub>, HRR or RPE.

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