Physiological Parameters Determined at OBLA vs. a Fixed Heart Rate of 175 beats · min⁻¹ in an Incremental Test Performed by Amateur and Professional Cyclists

José L. CHICHARRO^{*,†}, Alfredo CARVAJAL^{*}, Javier PARDO^{*},
Margarita PÉREZ[‡], and Alejandro LUCÍA[‡]

^{*}Universidad Complutense, Madrid, Spain;

[†]Escuela de Enfermería, Fisioterapia y Podología, Madrid, Spain; and

[‡]Departamento de Ciencias Morfológicas y Fisiología, Universidad Europea de Madrid, Spain

Abstract: A blood lactate concentration of 4 mmol · l⁻¹ (OBLA) is frequently used as an indicator of the maximal steady state of lactate (MLSS) for workload planning in training programs. The aim of the present investigation was to compare several metabolic parameters determined at OBLA and at a fixed heart rate of 175 beats · min⁻¹ (HR175) in amateur cyclists (AC) and professional cyclists (PC). Sixteen AC and 22 PC performed an exercise test on a cycle ergometer following a ramp protocol (25 W · min⁻¹, 70–80 rpm) to exhaustion. Gaseous exchange was monitored throughout the test. $\dot{V}O_2$, % $\dot{V}O_{2\max}$, and power output (W) corresponding to

OBLA and HR175 were determined and mean values compared using a Student's *t*-test. Findings indicated higher $\dot{V}O_{2\max}$ and W in general in PC ($p < 0.01$), and higher $\dot{V}O_2$ and W at OBLA and HR175 in PC ($p < 0.01$). No significant difference was found between values determined at OBLA and HR175 in the AC group, while in the PC group, $\dot{V}O_2$, % $\dot{V}O_{2\max}$, and W were higher at OBLA. These observations suggest the possible use of a fixed, reference HR of 175 beats · min⁻¹ to determine the exercise intensity corresponding to OBLA in amateur cyclists. This was not the case for the professional cyclists. [Japanese Journal of Physiology, 49, 63–69, 1999]

Key words: OBLA, lactate, training, heart rate, cyclist.

The determination of blood lactate concentration during exercise is important for the estimation of workload intensity in training exercise [1]. The highest blood lactate level, which results in a lactate steady state during constant workload, is called the maximal lactate steady state (MLSS). MLSS represents the highest level of exercise that can be performed by oxidative energy metabolism [2, 3] and reflects the highest attainable equilibrium between lactate appearance and disappearance during prolonged constant workload [4]. The MLSS of a subject can be determined during several constant workloads on different days [5].

Mader *et al.*, 1976 [6], described the aerobic-anaerobic threshold as follows: "The rise in lactic acid concentration to 4 mmol · l⁻¹ in peripheral blood during

gradual increases in workloads can be considered as the criterion for the establishment of the aerobic-anaerobic threshold in spiroergometric testing." This value of 4 mmol · l⁻¹ was later termed the "anaerobic threshold" by Kindermann *et al.* [7] and the "onset of blood lactate accumulation" (OBLA) by Sjödín and Jacobs [8]. Due to the complex and time-consuming technique required for the accurate determination of the MLSS, several researchers suggest the use of the OBLA as a reference value [7–10].

The use of the OBLA obviously does not take into account inter-individual variability as shown by Stegmann *et al.* [11], who reported that the individual anaerobic threshold can range from lactate concentrations of 2.0 to 7.5 mmol · l⁻¹. Despite these limitations, several authors have suggested that the intensity

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Correspondence should be addressed to: José L. Chicharro, Escuela de Enfermería, Fisioterapia y Podología, Facultad de Medicina, 3^a Planta, Universidad Complutense de Madrid, 28040 Madrid, Spain. Fax: +34-1-394-1539, E-mail: jlchicharro@enf.ucm.es

of exercise which induces an optimum qualitative stimulus such that endurance changes are achieved during training, should elicit a steady-state lactate concentration of approximately $4 \text{ mmol} \cdot \text{l}^{-1}$ [7, 12, 13]. Furthermore, the exercise intensity (i.e., running velocity) at which the OBLA occurs has been adopted by trainers all over the world as a useful marker of training status and form.

Despite the ease of using heart rate as an indicator of exercise intensity during training, to date no previous study has explored the possibility of using a fixed heart rate as an indirect indicator of the workload corresponding to the OBLA. The aim of this investigation was therefore to determine if a fixed heart rate (i.e., $175 \text{ beats} \cdot \text{min}^{-1}$) is a valid method to detect the exercise intensity at which the OBLA occurs. The value of $175 \text{ beats} \cdot \text{min}^{-1}$ was chosen based on previous research by Heck *et al.* [14], which quoted a mean heart rate of $\sim 175 \text{ beats} \cdot \text{min}^{-1}$ during continuous exercise at the OBLA. We compared several metabolic parameters which indicate the intensity of exercise determined at the OBLA with those obtained at a fixed heart rate of $175 \text{ beats} \cdot \text{min}^{-1}$ during a ramp bicycle protocol performed by amateur and professional cyclists.

MATERIALS AND METHODS

Study protocol. Sixteen male, amateur road cyclists (AC) and twenty-two male, professional road cyclists (PC) were selected for the study. All the subjects were in good health as determined by a normal physical examination (including ECG) within the previous year. Informed consent was obtained from each subject in accordance with the regulations of the *Complutense* University. Prior to each exercise testing session, subjects were familiarized with the equipment and procedures to be used. They were also instructed to refrain from intense training during the day before testing.

Each subject performed a single exercise test on a bicycle ergometer (Ergometrics 900; Ergo-line; Barcelona, Spain) following a ramp protocol until exhaustion. Starting at 0 watts (W), the power output was increased by $25 \text{ W} \cdot \text{min}^{-1}$. Pedalling cadence was kept constant at 70–80 rpm. The test was terminated either 1) voluntarily by the subject; 2) when pedalling cadence could not be maintained at 70 rpm; or 3) when the established criteria of test termination were met [15]. Each test was performed under similar environmental conditions ($21\text{--}24^\circ\text{C}$; 45–55% relative humidity).

During the test, gas exchange data were monitored

using an automated breath-by-breath system (CPX; Medical Graphics; St. Paul, Minn, USA) based on methodology described elsewhere [16]. The measuring instruments were calibrated before each test and the necessary environmental adjustments made. Oxygen consumption ($\dot{V}\text{O}_2$) and respiratory exchange ratio (RER) were also determined during the test.

Definition of OBLA. Capillary blood samples were taken from fingertips ($25 \mu\text{l}$) every 2 min during the test and immediately after the termination of exercise. Blood lactate concentration was measured using an electro-enzymatic analyser (YSI 1500; Yellow Springs Instruments; Yellow Springs, Ohio, USA).

Individual lactate concentration values were plotted against the workload. The OBLA was defined by interpolation across the $4 \text{ mmol} \cdot \text{l}^{-1}$ line as the workload at the point of section [8] and expressed in terms of power output (W), $\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $\% \dot{V}\text{O}_{2\text{max}}$, and heart rate (HR, in $\text{beats} \cdot \text{min}^{-1}$).

Definition of HR175. Each subject's HR was continuously monitored during the test from modified 12-lead ECG tracings (EK56; Hellige; Freiburg, Germany). The workload corresponding to a fixed HR of $175 \text{ beats} \cdot \text{min}^{-1}$ (HR175) was determined by interpolation of the HR recorded in the incremental exercise test at $175 \text{ beats} \cdot \text{min}^{-1}$. The HR175 was then expressed in terms of power output (W), $\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $\% \dot{V}\text{O}_{2\text{max}}$, and blood lactate concentration ($\text{mmol} \cdot \text{l}^{-1}$).

Statistics. The results were expressed as means $\pm$ SD. Once the Kolmogorov-Smirnov test was applied to data to confirm a Gaussian distribution, a Student's *t*-test for paired data was used to compare mean $\dot{V}\text{O}_2$, $\% \dot{V}\text{O}_{2\text{max}}$, and power output (W) values at OBLA and HR175 in AC and PC. In addition, a Student's *t*-test for unpaired data was used to compare mean $\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $\% \dot{V}\text{O}_{2\text{max}}$, lactate ($\text{mmol} \cdot \text{l}^{-1}$), power output (W), and HR values at maximal exercise intensity, OBLA and HR175 in AC and PC.

For a further analysis of validity of the HR175 method, a comparison of both methods (OBLA vs. HR175) was also accomplished by applying the techniques suggested by Bland and Altman [17]. For this analysis, the mean differences (bias) and standard deviation (SD) of the differences of the values of $\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $\% \dot{V}\text{O}_{2\text{max}}$, and power output (W) for the two methods were calculated. The data were presented graphically comparing the difference between the methods versus their average value for $\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $\% \dot{V}\text{O}_{2\text{max}}$, and power output (W). The mean difference $\pm 2\text{SD}$ (limits of agreement) was indicated in the graph. In this way, the bias and precision of the HR175 method could be calculated for

Table 1. Subject physical characteristics and maximal physiological parameters.

	AC (n=16)	PC (n=22)	p value
Age (year)	23±4	25±2	NS
Height (cm)	177.2±3.8	179.4±5.2	NS
Mass (kg)	68.8±6.8	71.7±4.9	NS
$\dot{V}O_{2\max}$ (ml · kg ⁻¹ · min ⁻¹)	63.9±6.4	72.0±5.4	<0.001
Power output (W)	383.7±47.4	499.8±37.0	<0.001
RER	1.16±0.13	1.17±0.15	NS
HR (beats · min ⁻¹)	191±9	194±9	NS
Blood lactate (mmol · l ⁻¹)	10.1±1.9	8.08±1.8	<0.01

All values are expressed as means±SD. NS, no significant difference; $\dot{V}O_{2\max}$, maximal oxygen consumption; RER, respiratory exchange ratio; HR, heart rate.

Table 2. Comparisons between AC and PC.

	AC (n=16)	PC (n=22)	p value
OBLA			
$\dot{V}O_2$ (ml · kg ⁻¹ · min ⁻¹)	54.4±7.2	65.2±5.5	<0.001
% $\dot{V}O_{2\max}$	85.0±5.2	90.5±3.3	<0.01
Power output (W)	348.1±50.3	424.5±35.9	<0.001
HR (beats · min ⁻¹)	173±14	180±7	NS
HR175			
$\dot{V}O_2$ (ml · kg ⁻¹ · min ⁻¹)	55.6±6.7	62.6±5.0	<0.001
% $\dot{V}O_{2\max}$	87.1±7.9	86.7±6.5	NS
Power output (W)	340.0±52.3	396.0±53.8	<0.01
Blood lactate (mmol · l ⁻¹)	4.0±1.7	3.0±1.3	<0.05

All values are expressed as means±SD. NS, no significant difference; $\dot{V}O_2$, oxygen consumption; $\dot{V}O_{2\max}$, maximal oxygen consumption; HR, heart rate.

both AC and PC. Finally, correlation coefficients between values of $\dot{V}O_2$ (ml · kg⁻¹ · min⁻¹) corresponding to OBLA and HR175 were calculated for the two groups of subjects.

RESULTS

Subject characteristics and maximal physiological parameter values

Maximal $\dot{V}O_2$, power output, RER, HR, blood lactate values, and the demographical characteristics of the subjects are shown in Table 1. No significant differences were found between the subject groups with the exception of higher power output ($p<0.001$) and $\dot{V}O_{2\max}$ (ml · kg⁻¹ · min⁻¹) ($p<0.01$) in PC and higher blood lactate levels in AC ($p<0.01$).

Physiological parameters at OBLA and HR 175: AC vs. PC

The values of $\dot{V}O_2$, % $\dot{V}O_{2\max}$, power output, and HR at the exercise intensity corresponding to the OBLA are shown in Table 2. Significant differences between the groups were found in $\dot{V}O_2$ ($p<0.001$), % $\dot{V}O_{2\max}$

($p<0.01$), and power output ($p<0.001$) values at the OBLA. Higher values were shown each time in PC. No difference was detected in HR.

The values of $\dot{V}O_2$, % $\dot{V}O_{2\max}$, power output, and blood lactate at the exercise intensity corresponding to HR175 are also shown in Table 2. Significant differences were found between the groups in $\dot{V}O_2$ ($p<0.001$) and power output ($p<0.01$) values at HR175, with higher values recorded in PC. The blood lactate concentration at this HR was higher in AC ($p<0.05$). No significant difference was detected between the groups with respect to % $\dot{V}O_{2\max}$.

Physiological parameters in PC and AC: OBLA vs. HR175

In the PC group, significant differences were found in power output ($p<0.01$), $\dot{V}O_2$ ($p<0.05$), and % $\dot{V}O_{2\max}$ ($p<0.05$) values at the OBLA in respect to those recorded at HR175 (Table 3). No significant differences were detected between any of the variables at OBLA and HR175 in the AC group.

Table 3. Comparisons between HR175 and OBLA.

	OBLA	HR175	<i>p</i> value
$\dot{V}O_2$ (ml · kg ⁻¹ · min ⁻¹)			
AC	54.4 ± 7.2	55.6 ± 6.7	NS
PC	65.2 ± 5.9	62.6 ± 5	<0.05
% $\dot{V}O_{2\max}$			
AC	85.0 ± 5.2	87.1 ± 7.9	NS
PC	90.5 ± 3.3	86.7 ± 6.5	<0.05
Power output (W)			
AC	348.1 ± 50.3	340.0 ± 52.3	NS
PC	424.5 ± 35.9	396.0 ± 53.8	<0.01

All values are expressed as means ± SD. NS, no significant difference; $\dot{V}O_2$, oxygen consumption; $\dot{V}O_{2\max}$, maximal oxygen consumption.

Fig. 1. Graphic analysis of agreement between OBLA and HR175, when workload is expressed as $\dot{V}O_2$ (ml · kg⁻¹ · min⁻¹).

Agreement between OBLA and HR175 in AC and PC

Agreement between the exercise intensity ($\dot{V}O_2$, % $\dot{V}O_{2\max}$, power output) at which both OBLA and HR175 occurred was also calculated following the methodology [17] previously described. Data are presented graphically in Figs. 1–3. In the PC group, ~95% of the data points were within the limits of agreement (bias ± 2SD) when exercise intensity was expressed as $\dot{V}O_2$, % $\dot{V}O_{2\max}$, or power output. In the AC group, ~90 and ~95% of the data points were within the limits of agreement when exercise intensity was expressed as $\dot{V}O_2$ or % $\dot{V}O_{2\max}$, and as power output, respectively.

Correlation coefficients

The mean values of $\dot{V}O_2$ (ml · kg⁻¹ · min⁻¹) corresponding to OBLA and HR175 were significantly correlated in both AC ($r=0.73$; $p<0.01$) and PC ($r=$

0.67 ; $p<0.001$).

DISCUSSION

The observations made in the present investigation suggest the validity of using HR175 to determine the intensity of exercise corresponding to OBLA in trained cyclists of the amateur category. However, it seems that the method may not be applied to highly trained athletes such as professional cyclists.

The anaerobic threshold, commonly defined as the performance corresponding to the OBLA during step-wise increasing test procedures, is accepted as a measure for endurance capacity [7, 14, 18–21]. Other authors report that, in a study where blood and muscle lactate samples were simultaneously obtained during different progressive workloads, blood lactate concentrations of about 4 mmol · l⁻¹ are indeed reflective of lactate accumulated within the active muscle [22].

Fig. 2. Graphic analysis of agreement between OBLA and HR175, when workload is expressed as % $\dot{V}O_{2max}$.

Fig. 3. Graphic analysis of agreement between OBLA and HR175, when workload is expressed as power output (W).

This relationship was not observed at higher or lower blood lactate concentrations [23]. Despite these findings and those of other authors who report the validity of the use of a fixed lactate concentration of $4 \text{ mmol} \cdot \text{l}^{-1}$ in functional evaluation and planning of workloads [7, 12, 13], use of the OBLA implies ignoring the individual nature of the value corresponding to the real steady-state of lactate. Thus, when exercise of a steady workload is performed at an intensity which corresponds to the OBLA estimated during an incremental exercise test, the MLSS will only be achieved by certain subjects [22, 24].

In the present study, HR175, which is the mean value originally obtained by Heck *et al.* [14] during a continuous exercise protocol at the OBLA, corre-

sponds to the widely accepted $4 \text{ mmol} \cdot \text{l}^{-1}$ blood lactate threshold. The use of a particular heart rate for all subjects is also a generalization but has the advantage of accessibility and non-invasiveness. The results of this investigation indicated the lack of difference between power output, $\dot{V}O_2$, and % $\dot{V}O_{2max}$ values corresponding to HR175 or OBLA in amateur cyclists. Heitkamp *et al.* [25] reported heart rates of 173 and 194 $\text{beats} \cdot \text{min}^{-1}$ at the OBLA for untrained and trained women, respectively. In our study, both groups of subjects (PC or highly trained athletes and AC or lower level athletes) also exhibited a different response since: 1) the workloads corresponding to HR175 and OBLA were higher in PC than in AC, and 2) the workloads at which HR175 and OBLA oc-

curred differed in PC but were similar in AC. The differences between both groups may be attributed to the higher aerobic performance attained by PC after years of professional training and racing. Indeed, the intensity of exercise corresponding to OBLA has been associated with the composition of muscle fibres and muscular capillary density [8, 9] as well as with the activities of key enzymes [8, 26]. Several authors [11, 27–29] have shown that, at greater aerobic performance, the $4 \text{ mmol} \cdot \text{l}^{-1}$ blood lactate threshold tends to be an overestimation. The present results seem to reflect this in that power output, $\dot{V}\text{O}_2$, and $\% \dot{V}\text{O}_{2\text{max}}$ were only greater at the OBLA with respect to HR175 in professional cyclists (who showed a greater $\dot{V}\text{O}_{2\text{max}}$). This demonstrates a rightward shift of the lactate curve as a function of the intensity of effort or the $\dot{V}\text{O}_2$ obtained during the exercise test, and also to an improvement in the aerobic capacity of the athletes. In fact, in a previous study conducted in our laboratory, we analyzed the main physiological factors that distinguish professional riders from amateur ones [30]. One of the main findings was that professionals exhibit a greater ability to work at high intensities ($\sim 90\% \dot{V}\text{O}_{2\text{max}}$) before lactate accumulation (i.e., OBLA) occurs in the blood.

The results of this study may permit trainers with limited technical resources to use HR175 as an indirect indicator of the intensity of exercise corresponding to the OBLA when they work with athletes of a low-to-moderate level of training. There is no doubt that the use of this parameter neglects the individual degree of training of each subject but this is also true of the use of the $4 \text{ mmol} \cdot \text{l}^{-1}$ blood lactate threshold. The latter is an invasive technique which requires more technical resources for its determination. Indeed, Heitkamp *et al.* [25] stated that training guidance based on heart frequency is to be recommended over guidance based on indicators of speed.

The confirmation of the present results in athletes of other sports such as marathon runners would be of interest as would the application of the HR175 reference to different exercise protocols. On the other hand, the possibility of using other reference heart rates should also be explored in future studies.

In conclusion, the use of a reference heart rate of $175 \text{ beats} \cdot \text{min}^{-1}$ for indirect estimation of the intensity of exercise corresponding to the OBLA is suggested to replace the fixed $4 \text{ mmol} \cdot \text{l}^{-1}$ blood lactate threshold. The validity of the method is, however, questionable for use with athletes of high aerobic potential such as professional cyclists.

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