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## ORIGINAL

# CARDIORESPIRATORY RESPONSES AT THE INTENSITY OF THE THRESHOLD. COMPARATIVE STUDY BETWEEN HALF SQUAT AND CYCLOERGOMETER

## RESPUESTAS CARDIORRESPIRATORIAS A INTENSIDAD UMBRAL. ESTUDIO COMPARATIVO ENTRE MEDIA SENTADILLA Y CICLOERGÓMETRO

Domínguez, R.<sup>1</sup>; Garnacho-Castaño, M.V.<sup>2</sup>; San Juan, A.F.<sup>3</sup>; Pérez-Ruiz, M.<sup>4</sup>; García-Fernández, P.<sup>5</sup>; Veiga-Herreros, P.<sup>5</sup> y Maté-Muñoz, J.L.<sup>5</sup>

<sup>1</sup> Health Sciences Faculty, Isabel I University (Spain) [raul.dominguez@ui1.es](mailto:raul.dominguez@ui1.es)

<sup>2</sup> Health Sciences School, Pompeu Fabra University (Spain) [mgarnacho@escs.tecnocampus.cat](mailto:mgarnacho@escs.tecnocampus.cat)

<sup>3</sup> Health Sciences Faculty, Public University of Navarra (Spain) [alejandro.sanjuan@unavarra.es](mailto:alejandro.sanjuan@unavarra.es)

<sup>4</sup> Doctoral School, European University of Madrid (Spain) [margarita.perez@universidadeuropea.es](mailto:margarita.perez@universidadeuropea.es)

<sup>5</sup> Health Sciences Faculty, Alfonso X El Sabio University (Spain) [rdomiher@uax.es](mailto:rdomiher@uax.es), [pablqafe@uax.es](mailto:pablqafe@uax.es), [pveigher@uax.es](mailto:pveigher@uax.es), [jmatmuo@uax.es](mailto:jmatmuo@uax.es)

**Spanish-English translator:** Víctor Gutiérrez Martínez, [victor@idiomasleon.es](mailto:victor@idiomasleon.es).

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### ABSTRACT

**Objective:** To compare respiratory responses, heart rate (HR) and lactate at the intensity of the lactate threshold (LT) between half squat (HS) and cycle ergometer. **Methods:** 24 men (21.5±1.8 years, 180.1 ± 5.2 cm, 81.9±8.7 kg) with experience in resistance performed a progressive incremental test in HS and cycle ergometer to determine LT. During such test, the following parameters were measured: blood lactate concentrations, HR, oxygen consumption (VO<sub>2</sub>),

carbon dioxide production ( $VCO_2$ ), pulmonary ventilation (PV), ventilatory equivalent of oxygen ( $PV \cdot VO_2^{-1}$ ) and ventilatory equivalent of carbon dioxide ( $PV \cdot VCO_2^{-1}$ ). A *t* student evaluated the variables analysed among the two exercise modalities. **Results:** blood lactate concentrations, HR, PV, and  $PV \cdot VO_2^{-1}$  and  $PV \cdot VCO_2^{-1}$  were higher in HS than in cycloergometer ( $p < 0.05$ ). **Conclusions:** LT can be detected in HS exercise. Furthermore, the resistance training sessions to the intensity of LT might be used in training sessions which seek to improve cardiovascular endurance and muscle strength.

**KEYWORDS:** endurance, strength, against-resistance training, anaerobic threshold, aerobic-anaerobic transition

## RESUMEN

**Objetivo:** Comparar las respuestas respiratorias, de frecuencia cardíaca (FC) y lactato a intensidad de umbral láctico (UL) en media sentadilla (MS) vs cicloergómetro. **Métodos:** 24 hombres ( $21,5 \pm 1,8$  años,  $180,1 \pm 5,2$  cm,  $81,9 \pm 8,7$  kg) con experiencia en el entrenamiento de fuerza realizaron un test incremental progresivo en MS y cicloergómetro para determinar el UL. Durante los test se midieron las concentraciones de lactato, FC, consumo de oxígeno ( $VO_2$ ), producción de dióxido de carbono ( $VCO_2$ ), ventilación pulmonar (VE), equivalente ventilatorio del oxígeno ( $VE \cdot VO_2^{-1}$ ) y del dióxido de carbono ( $VE \cdot VCO_2^{-1}$ ). Una *t* student valoró las diferencias entre las dos modalidades de ejercicio. **Resultados:** las concentraciones de lactato, FC, VE,  $VE \cdot VCO_2^{-1}$  y  $VE \cdot VO_2^{-1}$  fueron superiores en MS vs cicloergómetro ( $p < 0,05$ ). **Conclusiones:** el UL puede ser detectado en el ejercicio de MS. Además, la realización de sesiones de entrenamiento contrarresistencia, a intensidad de UL, podrían ser utilizadas para mejorar la resistencia cardiovascular y la fuerza muscular.

**PALABRAS CLAVE:** resistencia, fuerza, entrenamiento contrarresistencia, umbral anaeróbico, transición aeróbica-anaeróbica

## INTRODUCTION

Low levels of cardiorespiratory endurance have been identified as an element of risk in the development of hypertension, diabetes, metabolic syndrome, cancer and death by any cause (1). As a result, the cardiorespiratory endurance training is associated with a decrease in the number of risk factors regarding cardiovascular diseases (2). The maximum oxygen consumption ( $VO_{2max}$ ) - parameter which is able to reflect the top amount of oxygen an organism is able to take up, transport and consume per time unit (3)- is considered to be the best marker of the functional capability of a person (4). Due to the fact that  $VO_{2max}$  detection means the highest effort, with an elevated cardiovascular stress, the research was focused in assessing the endurance ability via sub maximal tests (5), being the lactate threshold (LT) the most employed criteria (6).

As well as the  $VO_{2max}$ , the assessment of the LT requires a progressive incremental test in which, as the workload increases, samples of blood lactate

are taken. The LT has been identified as the *intensity of the exercise from which the concentrations of lactate start to increase in relation to the rest values during a progressive incremental test* (7). Different proposals have tried to link the LT with some fixed concentrations that fluctuate between 2 and 4 mmol·L<sup>-1</sup> of lactate (Bosquet, 2002). However, the lactate concentrations detected as a response to exercise present a wide interindividual range (8), being the composition muscle fibres a decisive factor (9). In a study carried out by De Sousa (10), several methods to determine the LT were analysed. It transpired that, although the visual inspection procedures might be an appropriate form of measurement to determine LT, the algorithmic setting adjustment can be more exact. According to this mathematical method, the LT must be identified as the cut-off point of the two linear regressions in the curve that addresses the lactate concentrations in regard with the exercise intensity so that these methods are more precise in the determination of the LT (11).

It has been suggested that the LT is related, to even a higher extent than VO<sub>2</sub>max, with endurance performance (12), being it able to discriminate the achievement in sport people with a similar level of VO<sub>2</sub>max (13). The exercise calculated to de intensity of LT, besides keeping the blood lactate concentrations stable, matches with the magnitude that precedes a disproportionate increase of pulmonary ventilation (PV) and of the carbon dioxide production (VCO<sub>2</sub>) during a progressive incremental test (7). That incommensurate augmentation of VCO<sub>2</sub> compared to the VO<sub>2</sub> leads to that intensity undertaking an escalation in the respiratory exchange rate (RER) (VCO<sub>2</sub>·VO<sub>2</sub><sup>-1</sup>) (7). Furthermore, the disproportionate increase of the PV compared to the VO<sub>2</sub> causes an analogous power intensification in the ventilatory equivalent of oxygen (PV·VO<sub>2</sub><sup>-1</sup>) without a concomitant growth of the ventilatory equivalent of carbon dioxide (PV·VCO<sub>2</sub><sup>-1</sup>) (14). Previous pulmonary responses, associated to some minimum values in the oxygen pressure at the end of expiration (PeTO<sub>2</sub>) (15), suggest that in the LT there is a larger relative utilisation of oxygen in the VO<sub>2</sub>-related substrate oxidation. Thus, it can be observed a maximum proportion in the contribution of the oxidative metabolism during the stress (16). Regarding the blood glucose kinetics, the values detected to the LT are the lowest throughout a progressive incremental test (17); making such intensity optimum for people who have metabolic disorders such as obesity, diabetes and hypertension (18).

Nowadays, in parallel to the progressive incremental tests employed in cardiorespiratory endurance, a growing number of investigations apply these tests in a discontinuous manner for strength or against-resistance training. Whilst executing this sort of diagnose, the subjects are required to work fixed periods of time with increasing working loads after some recovery time in which samples of blood lactate are retrieved. Afterwards, those blood lactate values are compared to the intensity in a chart. Hence, several studies have assessed the LT in exercises such as the half squat (HS) (19,20,21), bench press (22), leg press (10) or leg extension (23).

Strength training leads to medium and long term adaptations -both from structural and neural origin- raising the hypertrophy, strength and muscular power levels (18). The mentioned adaptations explain why the strength training

-no matter if it is with healthy people or with pathologies- is an effective approach to induce improvements in the cardiorespiratory and cardiometabolic function, reducing the mortality and cardiovascular events risks (24). Additionally, they diminish the chances of developing functional limitations (25). Recently, it has been suggested that strength training performed at a certain intensity of the LT might be optimal practice for triggering adaptations related to muscular function or cardiorespiratory endurance (19, 20, 21). Nevertheless, no research, so far, has compared the metabolic and cardiorespiratory responses that take place at the intensity of the lactate threshold in against-resistance exercises with respect to other activities employed in the development of cardiorespiratory endurance, as might be jogging or the cycloergometer.

## **OBJECTIVE**

The aim of the current research has been to compare the ventilatory, heart rate and lactate responses. They were obtained in a discontinuous protocol of growing workload to the intensity of the LT in the exercise of HS in relation to the results gathered with an incremental load in cycloergometer.

## **MATERIAL AND METHOD**

### **Subjects**

The subjects were 24 men -with an age of  $21.5 \pm 1.8$  years, height of  $180.1 \pm 5.2$  cm and weight of  $81.9 \pm 8.7$  kg. Each sample fulfilled the inclusion criteria set by the researchers. Criteria among which we can find: an age between 18 and 25 years old, having over 6 months experience in against-resistance training -in a frequency of three sessions per week-, being familiarised with the HS exercise and being able to lift, at least, 150 kg in one maximum repetition (1 MR) HS test. The subjects were also required to not have taken any kind of nutritional supplement nor anabolic steroids for no less than the last 6 months and to not show any sort of alterations -of cardiovascular, metabolic, pulmonary or orthopaedic nature- that might hinder the performance during the test. Everyone was gathered in a meeting in which they were informed about the study's procedure, besides providing an informed consent signed by all participants. In the 24 hours before the study and until its end, these men did not perform any complementary exercise. Moreover, they did not smoke, eat or take caffeine beverages nor any other type of stimulants for the 2 hours previous to the test.

This study met the Declaration of Helsinki about human experimentation. It was also approved by the ethics committee of Alfonso X "The Wise" University.

### **Experimental design**

The participants attended a total of 3 assessment sessions in the laboratory at a same time slot ( $\pm 2$  hours). The mentioned gatherings were separated among themselves by 72 hours. In the first session, the subjects undertook a 1 MR HS test. For the second, the men performed a discontinuous progressive

incremental test in HS. In the third one, it was a progressive incremental test in cycloergometer.

### **1 MR HS test**

The session started with a general warm-up routine. It consisted of 5 minutes jogging in a treadmill (Technogym, Gambettola, Forli, Italia) at a speed of 6 km/h<sup>-1</sup> and another 5 minutes of articular mobility drills and dynamic stretching. This was followed by a specific warm-up consisting in a series of 10 HS repetitions with a load which was easily moved by the subjects. Then, after 2 minutes of recovery, the 1 MR test began, following the methodology suggested by Baechle (26). Thus, the subjects started the experiment with a set of 3 routines with a load 20% heavier than the one used in the specific warm-up. Having finished the 2 recovery minutes, the successive sets were reduced to a single repetition, the load was increased by 10% and the recovery time was broadened to 3 or 4 minutes. When the individuals reached the muscle failure, the load was reduced by 5% and they were asked to try once more. The 1 MR was set as the highest weight that the men were able to move through the right procedure. It was deemed that the adequate HS technique was the one in which subjects were capable of completing the full knee extension from a 90° flexion -all this performed with the feet placed at a position which matched the width of the hip and the beam in the rear side of the deltoid (27). The aim of the analysis of 1 MR was to determine the loads for the relative intensities (% of 1 MR) to be employed in the discontinuous progressive incremental test in HS (from 10 to 40% of 1 MR).

### **The discontinuous progressive incremental test in half squat**

The discontinuous progressive incremental test in HS had its aim set in ascertaining the LT in HS. Before this procedure, there was a general warm-up session which was divided in 5 minutes jogging in a treadmill at a speed of 6 km/h<sup>-1</sup> and another 5 minutes of articular mobility drills and dynamic stretching. After that, the individuals were submitted to a specific warm-up consisting in a series of 10 HS repetitions with a 20 kg load. They took a 3 minute break before the test.

The discontinuous progressive incremental test in HS consisted in performing one minute workload series followed by a two minutes passive recuperation. The weights -which were ever increased- matched the 10, 20, 25, 30, 35 and 40% of 1 MR. While affected by each burden, the subjects had to complete the sum of 30 repetitions at an implementation rate of 1 second for the eccentric phase and 1 more second for the concentric phase -set by a metronome. During the first 30 seconds of each recovery time, 5  $\mu\text{l}^{-1}$  samples of capillary blood were retrieved from the soft part of the index finger. It was used for ascertaining blood lactate concentrations by means of the Lactate Pro digital meter analyser (Lactate Pro LT-1710, Arkray Factory Inc., KDK Corporation, Siga, Japan).

The heart rate (HR) was monitored each 5 seconds through all work ranges via a telemetric recorder (RS-800CX, Polar Electro OY; Kempele, Finland). In this exact way some other data were estimated. Information such as the respiratory exchange in relation to PV, VO<sub>2</sub>, VCO<sub>2</sub>, ventilatory equivalent of oxygen (PV·VO<sub>2</sub><sup>-1</sup>), ventilatory equivalent of carbon dioxide (PV·VCO<sub>2</sub><sup>-1</sup>) and the respiratory exchange rate (RER). These were measured by means of an open circuit gas analyser -*breath to breath*- (Vmax spectra 29, Sormedics Corp., Yorba Linda, California, USA®), which had been calibrated before hand.

### **The progressive incremental test in cycloergometer**

This study was performed in a Monark cycloergometer (Ergomedic 828E, Vansbro, Sweden). Before this procedure, there was a warm-up in cycloergometer which consisted in 5 minutes pedalling at a 50 revolutions per minute rate (rev·min<sup>-1</sup>) with a load of 0,5 kilopond (kp) and 5 more minutes of articular mobility drills and dynamic stretching.

The test began with a 50 watt (W) load and the subjects were requested to keep a 50 rev·min<sup>-1</sup> pedalling rate. At 1 minute intervals, the load was increased by 25 W and the men had to keep their pedalling rate steady (50 rev·min<sup>-1</sup>) -the escalation in the load was of 0,5 kp. As happened in the discontinuous progressive incremental test in HS, besides analysing the blood lactate concentrations each 2 minutes, the HR was measured throughout the test via telemetry and the respiratory variables by means of an open circuit gas analyser -*breath to breath*-.

### **The establishment of the lactate threshold**

The LT was set, both in HS and cycloergometer, as the exercise intensity -% of 1MR in HS and % of VO<sub>2peak</sub> in cycloergometer- from which the lactate concentrations began to increase exponentially (10). To this effect, it was established, through a mathematical model, that the LT matched the intersection point where the blood lactate concentrations corresponded to a stipulated relative strength. This was monitored via a computer controlled linear regression of both segments (11). The data processing was conducted by the computer software Matlab version 7.4 (MathWorks, Natick, MA, USA).

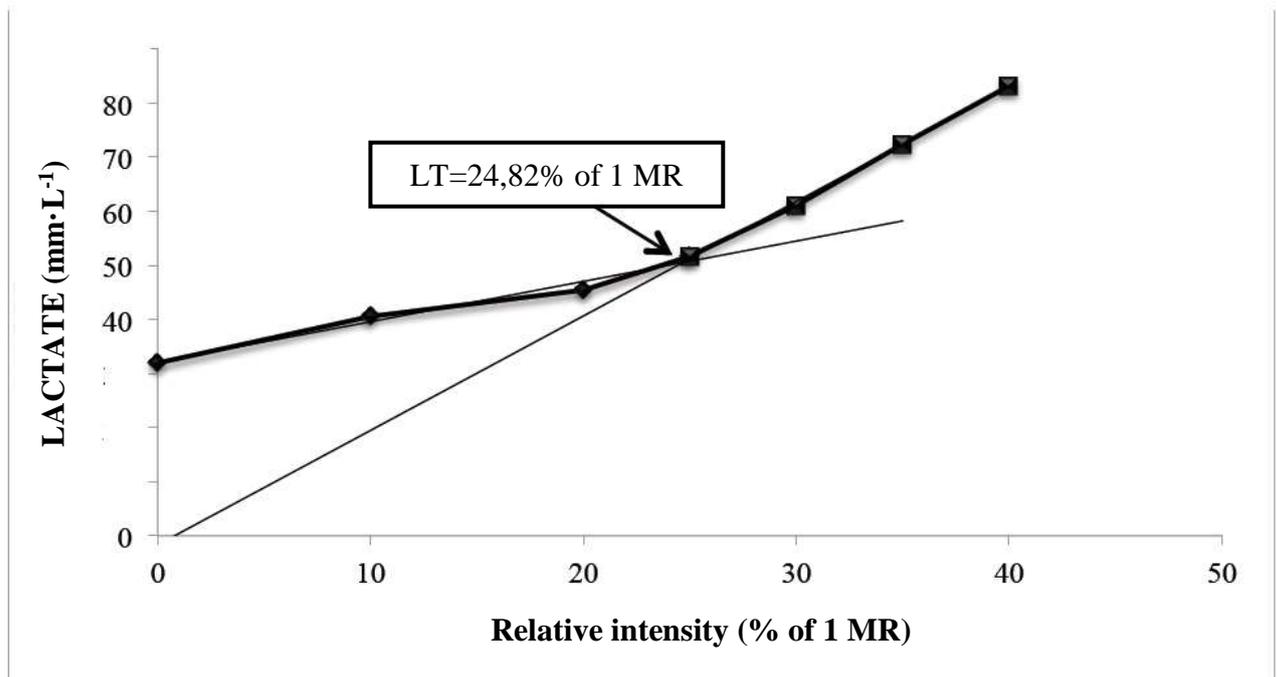
### **Statistical analysis**

The Saphiro-Wilk test was the way through which the data were analysed for normality. Once normality was confirmed, the data were presented as half (H) and standard deviation (SD). In order to verify the differences amongst the variables to lactate threshold intensity, a *t* student was employed for related samples. The statistical significance level was *p* < 0,05. The statistical analysis was performed by the SPSS software version 18.0 (SPSS, Chicago, IL, USA).

## **RESULTS**

The LT in HS was obtained with a load of 24,82 ± 4,8% of 1 MR (49,9 ± 16,5 kg) -see Figure 1-. In cycloergometer it corresponded to 44,58 ± 10,84 %

$VO_{2peak}$  ( $134,8 \pm 26,88$  W) -see Figure 2-. As it can be appreciated in Figure 3, at a certain LT intensity, the blood lactate concentrations were higher ( $4,58 \pm 1,5$  mmol·L<sup>-1</sup>) in HS than in cycloergometer ( $2,06 \pm 0,63$  mmol·L<sup>-1</sup>) ( $p < 0,001$ ). That same behaviour could be observed in the HR, significantly higher values were found in the HS ( $144,1 \pm 16,27$  bpm) with regard to the cycloergometer ( $123,7 \pm 16,71$  bpm) ( $p < 0,001$ ) -see Figure 4-. Table 1 shows the values of the respiratory variables taken at a LT intensity in HS and cycloergometer. Statistically superior values were witnessed in the parameters PV, RER,  $PV \cdot VO_2^{-1}$  and  $PV \cdot VCO_2^{-1}$  in the HS exercise versus the cycloergometer ( $p < 0,05$ ).



**Figure 1.** Identification of the lactate threshold as % of 1 MR in half squat.

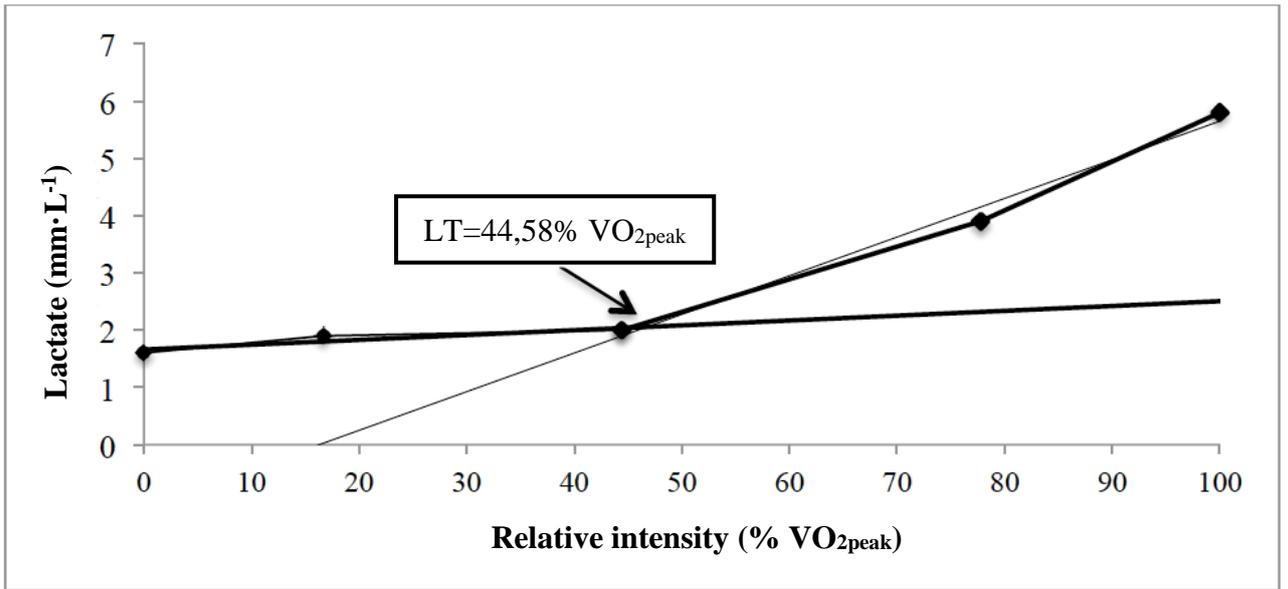
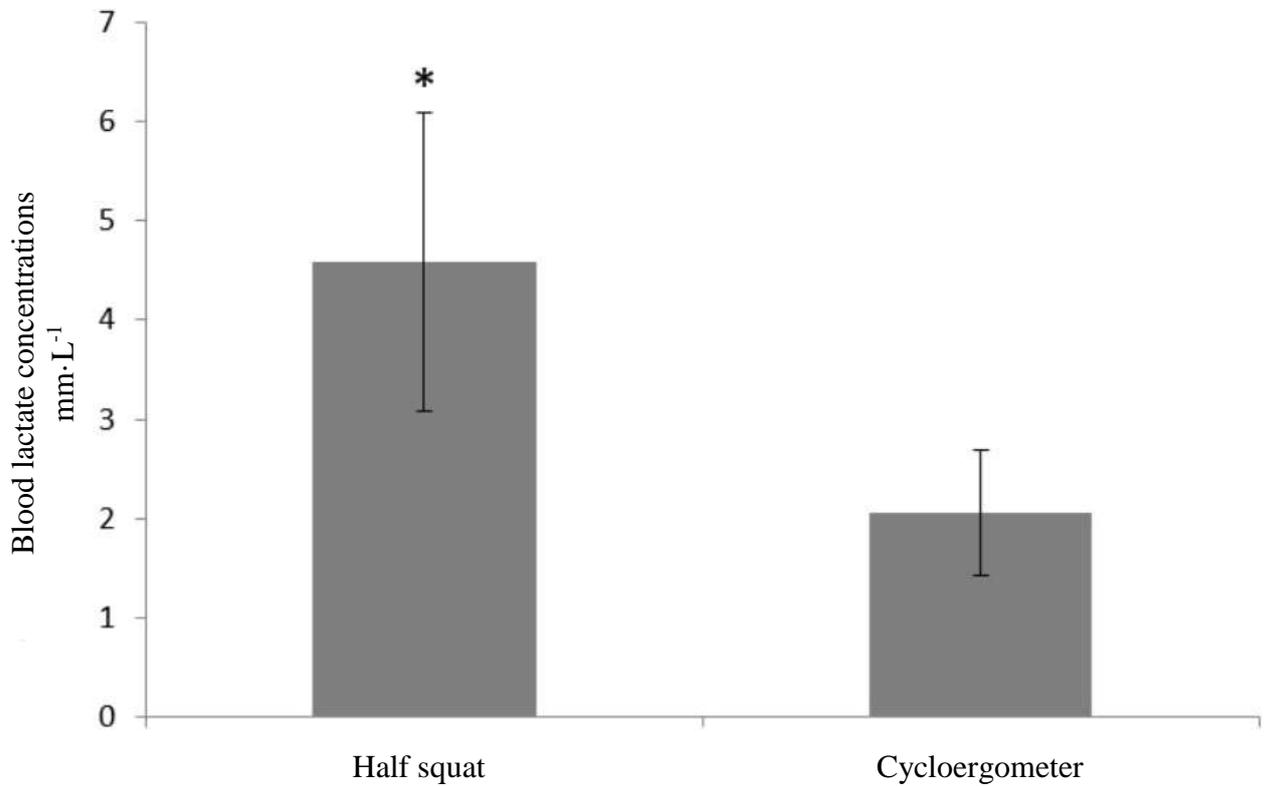
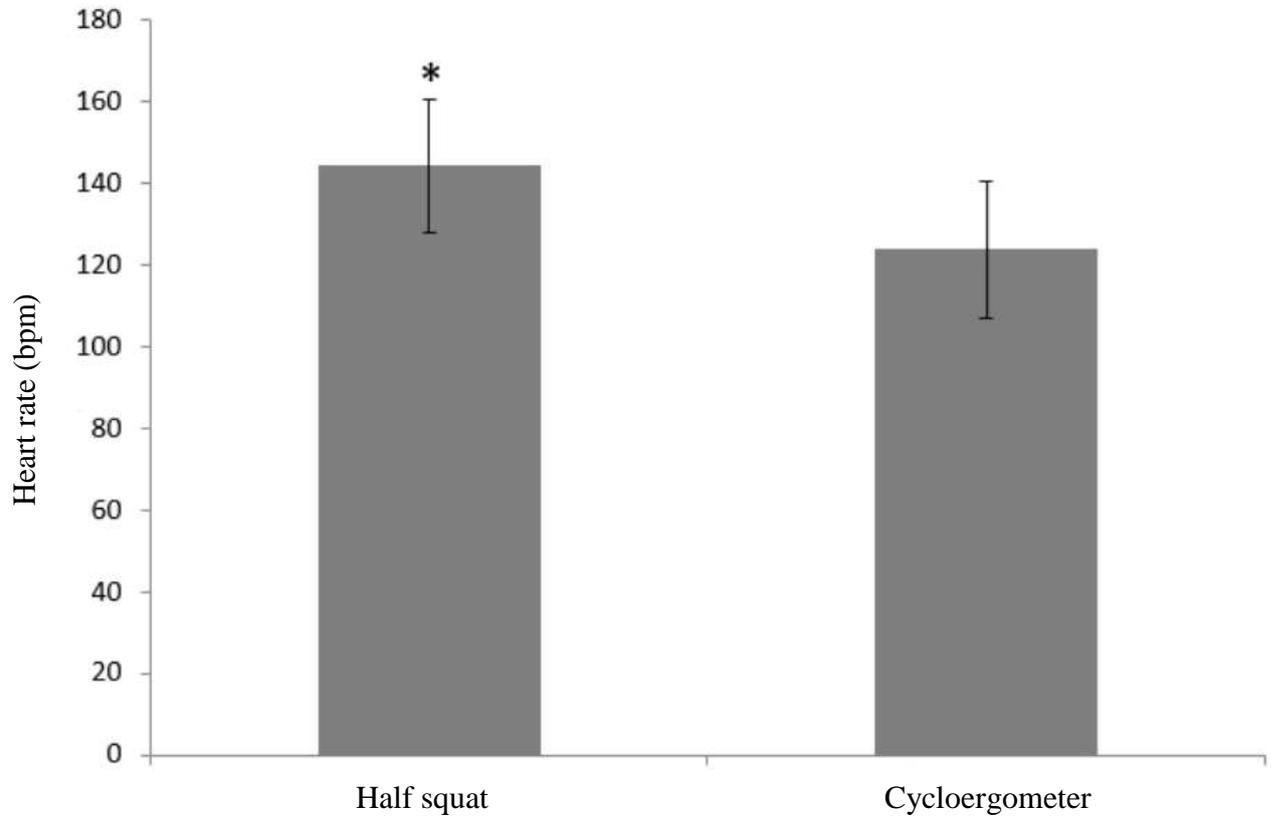


Figure 2. Identification of the lactate threshold as % of VO<sub>2peak</sub>



**Figure 3.** Average blood lactate concentrations (mmol·L<sup>-1</sup>) at the intensity of the lactate threshold in half squat and cycloergometer.



\* Statistically significant differences between groups ( $p < 0,05$ )

**Figure 4.** The average values of the heart rate (bpm) at a certain lactate threshold intensity in half squat and cycloergometer

\* Statistically significant differences between groups ( $p < 0,05$ )

bpm: beats per minute

**Table 1.** Data from the respiratory variables at a certain lactate threshold intensity in half squat and cycloergometer

Variables	Half squat LT	Cycloergometer LT	Mean difference	<i>t</i>	<i>P</i>
VO <sub>2</sub> (L·min <sup>-1</sup> )	2,05 ± 0,34	1,97 ± 0,37	0,08 ± 0,5	0,82	0,421
VCO <sub>2</sub> (L·min <sup>-1</sup> )	1,83 ± 0,34	1,70 ± 0,39	0,13 ± 0,5	1,35	0,189
PV (L·min <sup>-1</sup> )	52,72 ± 11,94 *	41,62 ± 8,54	11,1 ± 13,2	4,11	0,000
RER	0,91 ± 0,07 *	0,86 ± 0,06	0,06 ± 0,1	3,42	0,002
PV·VO <sub>2</sub> (L·min <sup>-1</sup> )	25,98 ± 2,83 *	21,23 ± 1,42	4,75 ± 2,8	8,26	0,000
PV·VCO <sub>2</sub> (L·min <sup>-1</sup> )	28,56 ± 1,81 *	24,60 ± 1,84	3,96 ± 2,5	7,81	0,000

\* Statistically significant differences between groups

HR: Heart rate; BPM: Beats per minute; RER: Respiratory exchange rate; LT: Lactate threshold; VO<sub>2</sub>: oxygen consumption; VCO<sub>2</sub>: carbon dioxide production; PV: pulmonary ventilation; PV·VO<sub>2</sub><sup>-1</sup>: ventilatory equivalent of oxygen; PV·VCO<sub>2</sub><sup>-1</sup>: ventilatory equivalent of carbon dioxide

## DISCUSSION

The assessment of the LT in HS that was found (24,82 ± 4,8% of 1 MR) matches with previous researches that had determined the LT in such exercise in intensities of 23-25% of 1 MR (18, 19, 20, 23). However, it has been ascertained that blood lactate concentrations at LT intensity are statistically higher in HS in comparison to cycloergometer. The lactate concentrations found in cycloergometer (2,06 ± 0,63 mmol·L<sup>-1</sup>) are similar to the ones detected in other studies performed also in cycloergometer (1,9-2,5 mmol·L<sup>-1</sup>) (28,29). Nevertheless, the blood lactate concentrations identified in HS (4,58 ± 1,5 mmol·L<sup>-1</sup>) point that the detection methodologies of the LT based in lactate concentration close to 2,0 mmol·L<sup>-1</sup> might not be extrapolated to other exercises as the HS.

In literature, it has been described that a number of elements affect the blood lactate response to exercises. Elements such as the dietary glycogen availability and the carbohydrate intake (8) or the individual variability (8). Some

other relevant factors might be the muscle fibres composition, the lipolytic or glycolytic enzyme activity of the mentioned or the capillary and mitochondrial volume (9). Our results suggest that the procedure for the exercise could be another detail to influence the lactate responses to exercise.

In regard with the HR, it has been proved that it is higher in HS than in cycloergometer. The mentioned behaviour possesses some similarities with running vs cycloergometer (31). The elevated HR response may have its origin in the involvement of larger active muscular mass during the performance of HS in the different neuromuscular recruitment pattern in both training modalities.

The raised PV -found in in HS-, taking into account the same levels of  $\text{VO}_2$  and  $\text{VCO}_2$ , provokes the raising of the ventilatory equivalents -both oxygen ( $\text{PV}\cdot\text{VO}_2^{-1}$ ) and carbon dioxide ( $\text{PV}\cdot\text{VCO}_2^{-1}$ )-. The  $\text{PV}\cdot\text{VCO}_2^{-1}$  is a tracer of the oxygen consumption efficiency at pulmonary level and an uplift in  $\text{PV}\cdot\text{VO}_2^{-1}$  and  $\text{PV}\cdot\text{VCO}_2^{-1}$  would point to a pulmonary gasses exchange decrease (32) while performing HS. Several studies have tested a strong correlation among blood lactate levels as an answer to exercise and  $\text{PV}\cdot\text{VO}_2^{-1}$  and  $\text{PV}\cdot\text{VCO}_2^{-1}$  concentrations (33).

The increased levels in HR, blood lactate,  $\text{PV}\cdot\text{VO}_2^{-1}$  and  $\text{PV}\cdot\text{VCO}_2^{-1}$  in HS could be due to the exercise modality. When executing strength training routines, capillary collapse is likely to be induced as the drill time escalates. The mentioned collapse reduces oxygen availability in the muscle stimulates anaerobic glucose (34) and boosts lactate concentration and the rest of previously mentioned parameters. Moreover, more elevated strength requirements during the HS incremental test and, thus, higher type II quick muscle fibres in each one of HS repetitions might be the product in each one of the turnings of the pedal performed in the cycloergometer incremented test. Lucía (35) noticed the same physiologic reactions in professional cyclist in a constant test at the same power (350 w) but different pedalling paces. So, at  $60 \text{ rev}\cdot\text{min}^{-1}$ , the strength per pedal turning required was higher than at 80 and  $100 \text{ rev}\cdot\text{min}^{-1}$ . This heightened substantially the recruitment of type II motor units measured via surface EMG (electromyography), such as  $\text{VO}_2$ , HR, lactate concentration and the subjective perception of effort. Consequently, it is possible that the exercises applied to strength training have an anaerobic nature that entails stimulating non oxidative metabolic pathways. Nevertheless, we should take into consideration that different researches have confirmed the fact that including recuperation periods of time in the performance of endeavours with strength training exercises at a LT intensity (1:2 work/rest ratio) allows us to keep stability conditions in the several ventilatory factors, HR and blood lactate concentrations. We mean, of course, after the initial surge (20, 21).

After realising that HS is an effective method to induce a  $\text{VO}_2$  response similar to the one in a cycloergometer at LT intensity and considering studies confirming the metabolic and respiratory answers during the HS at LT intensity in endurance training, we judge that it might be an optimum adaptations stimulation manner over muscular and cardiorespiratory functions. This implementation could prove useful for communities looking to reduce

cardiovascular risk elements or improve their health condition and, in whose goal, cardiovascular endurance and muscle strength ought to be found.

## CONCLUSIONS

LT can be detected in exercises used in strength endurance. Furthermore, the against-resistance training sessions at LT intensity might be employed in training drills looking to improve cardiovascular endurance and muscle strength concomitantly.

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