EXERCISE AND SPORTS SCIENCES

ORIGINAL ARTICLE

TIME TO EXHAUSTION AT THE ONSET OF BLOOD LACTATE ACCUMULATION IN RUNNERS WITH DIFFERENT ATHLETIC ABILITY

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ABSTRACT

Objective: To characterize the physiological responses of runners of different athletic ability at the velocity at onset of blood lactate (V_{OBLA}) and to determine if 4 mmol·L^{-1} represents the same relative exercise intensity for every runner. Methods: Eleven trained and twelve well-trained runners completed two running tests on a treadmill: first, a maximal incremental lactate test to calculate the V_{OBLA} (Test 1), and then another one at the corresponding V_{OBLA} until exhaustion (Test 2). Gas exchange and heart rate (HR) were continuously measured and plotted as a percentage of time to exhaustion in Test 2 (TE_{T2}). The individual lactate threshold velocity (V_{LT}) and lactate concentration ($[La^{-1}]_{LT}$) were calculated according to the D-max method. Results: V_{OBLA} and V_{LT} were higher in well-trained runners (P<0.001). $[La^{-1}]_{LT}$ was <4 mmol·L^{-1} in the well-trained runners (P<0.001), but not in trained runners. Well-trained runners were faster at V_{OBLA} than at V_{LT} (P<0.001). Well-trained runners ran a shorter TE_{T2} than the trained runners (P<0.05). Moreover, well-trained runners presented a higher respiratory rate at 50, 80 and 90% of TE_{T2} and VO_2 at 20-100% of TE_{T2} (P<0.05). TE_{T2} was inversely correlated (P<0.01) with V_{OBLA} and positively with personal best 10-km performance (P<0.01). V_{OBLA} was positively correlated with the $\%VO_{2max}$ in Test 2 (P<0.01). The standard value (4 mmol·L^{-1}) for the concentration of blood lactate appears to represent a different exercise intensity for runners of different athletic ability. Conclusion: V_{OBLA} may not be accurated for programming running training sessions or for performing an evaluation of aerobic capacity.

Keywords: Athletes, OBLA, fatigue, exercise intensity, performance.

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INTRODUCTION

The determination of blood lactate concentration ([La$^-$]) during exercise has been traditionally used as an important factor for the estimation of workload intensity in training exercise[1]. The maximal exercise intensity which elicits a constant [La$^-$] over time, more specifically a rise lower than 1 mmol·L^{-1} in the last 20 minutes of a constant work rate test of 30 minutes, has been defined as the maximal lactate steady-state (MLSS)[2]. MLSS represents the highest intensity of exercise at which a balance exists between the rate of lactate production and lactate clearance[3,4].

The MLSS has been proposed as a useful tool for the evaluation of aerobic capacity, training intensity prescription and the prediction of exercise performance[1]. However, the technique required for the accurate determination of the MLSS is complex and time--consuming, as 3 to 5 constant work-rate tests have to be performed on different days[5]. As a result, several authors have recommended the use of single day tests for the indirect determination of MLSS[3,6].

During running exercise, a lactate concentration of 4 mmol·L^{-1} was reported to be associated with the MLSS[7] and consequently, different researchers have proposed the use of the 4 mmol·L^{-1} value as a reference value for the MLSS[8,9]. This value of 4 mmol·L^{-1}, first proposed by Mader et al in 1976[10], was later termed as the onset of blood lactate accumulation (OBLA)[11]. Some studies have reported that the exercise intensity which induces an optimum qualitative stimulus should elicit a steady-state [La$^-$] of approximately 4 mmol·L^{-1}[12], and therefore OBLA exercise intensity has been adopted by coaches all over the world as a useful index of training status and fitness3).

However, several researchers are against the utilization of OBLA as an indirect marker for the MLSS[13,14], because [La$^-$] corresponding to MLSS may be reduced as a result of aerobic training[15]. In addition, it is acknowledged that the 4 mmol·L^{-1} value does not take into account inter-individual variability in the MLSS[16]. Thus, use of the OBLA as universal index for accurately estimating aerobic capacity, prescribing training intensity or a predicting performance, may have important limitations.

Currently, it is unclear if relative exercise intensity corresponding to OBLA is similar in athletes of different levels or training status. Thus, the main purpose of this study was to investigate the physiological responses at OBLA exercise intensity and consequently, to ascertain if the 4 mmol·L^{-1} value for lactate concentration represents the same relative exercise intensity in runners of different athletic ability. These results will assist us in determining if the OBLA index could be used to design and program running training sessions independently of the runner's athletic level.

METHODS

Subjects

Twenty-three long distance Caucasian male runners participated in this study: eleven trained (39.9 ± 5.8 years) and twelve well--trained (28.4 ± 6.8 years). Before participation, subjects were medically examined to ensure that they had no signs of cardiovascular, musculoskeletal and metabolic diseases. The Ethics Committee for research on Human subjects at the University of Basque Country (CEISH/GIEB) approved this study. All athletes were informed about all the tests and the possible risks involved and signed a written informed consent prior to testing. For the purpose of this study, athletes were selected according to their recent 10-km personal best time. Inclusion criteria for the trained runners group included a minimum of three days per week of running sessions, current participation in competitions and a 10-km race time between 35-45 minutes. Inclusion criteria in the well-trained athletes group included current participation in international or national level competitions and a 10-km race time below 33.5 minutes.

Procedures

Anthropometry - Height (cm) and body mass (kg) were measured with the use of a precision stadiometer and balance (Seca, Bonn, Germany), and body mass index (BMI) was calculated. Eight skinfold sites (biceps, triceps, subscapular, supraspinale, abdominal, suprailiac, mid-thigh, and medial calf) were determined in duplicate with a skinfold caliper (Holtain, Crymych, UK) by the same researcher and the sum of skinfolds was determined. The body fat percentage was calculated for each athlete, as described elsewhere[17].

All subjects performed two maximal running tests: a peak treadmill lactate test (Test 1) and a constant treadmill V_{OBLA} test (Test 2) with a break of one week between them. 24 hours prior to testing, athletes were encouraged to be well rested and to abstain from a hard training session and competition. All athletes were familiarized with running on the treadmill.

Peak treadmill lactate test (Test 1) - All subjects completed a maximal effort incremental running test on a treadmill with a 1% gradient (ERGelek EG2, Vitoria-Gasteiz, Spain), starting at 9 $km \cdot h^{-1}$ without previous warm up. The velocity was increased by 1.5 $km \cdot h^{-1}$ every 4 minutes until volitional exhaustion, with 1 minute of recovery between each stage. Verbal encouragement was provided to ensure that a maximal effort was reached. During the test, respiratory rate (RR), ventilatory output (VE), oxygen uptake (VO_2) and respiratory exchange ratio (RER) were continuously measured using the same calibrated gas analyzer system (Ergocard, Medisoft, Sorinnes, Belgium), which was calibrated before each session according to the instructions of the manufacturers.

Athletes were considered to have attained their maximal ability, and therefore, reached their VO_{2max}, when three of the following criteria were fulfilled: 1) a plateau in VO_2; 2) RER > 1.15; 3) HR within 5 $beats \cdot min^{-1}$ of theoretical maximal HR (220-age); 4) lactate concentration > 8 $mmol \cdot L^{-1}$; 5) RPE= 10.

Peak treadmill velocity in $km \cdot h^{-1}$ (PTV) was calculated as follows taking every second into account[18]:

PTV= Completed full intensity in $km \cdot h^{-1}$ + [(seconds at final velocity · 240 seg^{-1})·1.5 $km \cdot h^{-1}$]

Immediately after each exercise stage, a 25 µl sample of capillary blood was drawn from the earlobe and analyzed in order to determine the blood lactate concentration (Lactate Pro, Arkray, KDK Corporation, Kyoto, Japan). This system has been validated as an effective analyzer for lactate measurements[19]. The individual lactate threshold (LT) was calculated by the D-max method[20]. The reliability of this method has previously been reported[21]. A third order polynomial regression equation was established on the plasma lactate concentrations versus workloads. The D-max was identified as the point on the polynomial regression curve that yielded the maximal distance to the straight line formed by the two end data points[21].

Constant treadmill V_{OBLA} test (Test 2) - This test involved running on a treadmill at the individual's velocity corresponding to a lactate concentration of 4 $mmol \cdot L^{-1}$ (V_{OBLA}) until volitional exhaustion with a 1% gradient. V_{OBLA} was calculated by interpolation, expressing the collected blood lactate data of each subject in Test 1 as a function of running velocity. A quadratic equation was used to perform the regression of the $[La^-]$ and velocity. During the test, HR and gas exchange were continuously measured and plotted as 10-100% of time to exhaustion (TE_{T2}) as suggested by Pires et al.[22]. Lactate concentration was sampled immediately ($[La^-]_{finalT2}$) and 3 minutes ($[La^-]_{3minT2}$) after the test.

Statistics

All values are expressed as mean ± standard deviation (SD) and the statistical analyses of data were performed using the Statistical Package for the Social Sciences 15.0 software package (StatSoft, USA). Data were screened for normality of distribution and homogeneity of variances using a Shapiro-Wilk normality test and a Levene test respectively. An independent Student t-test for the comparison of the means of both groups was utilized. In cases in which variables were not normal, a Mann-Whitney U-test was utilized. Relationships between variables were evaluated by using linear regressions and Pearson and Spearman correlation analyses. Significance for all analyses was set at $P<0.05$.

RESULTS

Anthropometric characteristics and maximal treadmill test results in trained and well-trained runners are listed in Table 1. Well-trained runners were younger and faster according to their best 10-km time than trained runners ($P<0.001$). There were no differences in height between the two groups. However, well-trained runners were lighter, and presented lower values of BMI, sum of skinfolds and %BF than trained runners ($P<0.01$-0.05). Well-trained runners achieved a higher PTV during Test 1 (table 1, $P<0.001$). Nevertheless, there were no significant differences in any maximum physiological parameter, such as VO_2 (absolute and relative to body mass), HR, RER or $[La^-]$ between both groups.

V_{OBLA} and the velocity at the lactate threshold (V_{LT}) were faster in the well-trained runners when compared to the trained runners ($P<0.001$) (table 2). Further, the blood lactate concentration at the lactate threshold ($[La^-]_{LT}$) was lower in the well-trained runners ($P<0.001$). V_{OBLA} was faster than V_{LT} in the well-trained runners ($P<0.001$), but not in the trained runners. Similarly, $[La^-]_{LT}$ was <4$mmol \cdot L^{-1}$ in the well-trained runners ($P<0.001$), but not in the trained runners.

TE_{T2} was 46.8% shorter ($P<0.05$) in the well-trained runners than in the trained runners (table 3). However, there were no significant differences in $\%VO_{2max}$, %PTV, $[La^-]_{finalT2}$, $[La^-]_{3minT2}$ between both groups (although the values were higher in well-trained runners), neither in distance covered in Test 2.

During Test 2, well-trained runners showed a statistically higher VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) at 20 to 100% of the TE_{T2}, and a higher respiratory rate (RR) at 50, 80 and 90% of the TE_{T2} than trained runners ($P<0.05$, figure 1). There were no statistically significant differences in the physiological responses of volume ventilation (VE), carbon dioxide

Table 1. Anthropometric characteristics and indicators of performance and exertion in the maximal treadmill test (Test 1) results for trained and well-trained runners.

	Trained	Well-trained
	(*n* = 11)	(*n* = 12)
Age (years)	39.9 (5.8)	28.4 (6.8)***
10-km time (min)	39.1 (3.0)	31.8 (1.2)***
Height (cm)	176.4 (7.1)	177.2 (5.1)
Mass (kg)	70.3 (7.1)	64.9 (4.0)*
BMI	22.6 (1.8)	20.7 (1.5)*
∑ 8 skinfold (mm)	72.3 (23.2)	46.6 (12.6)**
%BF	12.2 (2.5)	9.5 (0.9)**
PTV ($km{\cdot}h^{-1}$)	16.5 (1.5)	20.6 (1.1)***
VO_{2max} ($L{\cdot}min^{-1}$)	4.2 (0.4)	4.1 (0.4)
$VO2_{max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	59.4 (7.2)	63.2 (4.3)
HR_{max} ($beats{\cdot}min^{-1}$)	180.6 (11.2)	186.7 (5.8)
RER_{max}	1.19 (0.08)	1.20 (0.06)
$[La\text{-}]_{final\ T1}$ ($mmol{\cdot}L^{-1}$)	9.0 (1.7)	8.5 (1.7)
$[La\text{-}]_{3minT1}$ ($mmol{\cdot}L^{-1}$)	9.5 (1.3)	9.6 (1.8)

n, number of subjects; BMI, Body Mass Index, ∑ 8 skinfold, (biceps, triceps, subscapular, supraspinale, abdominal, suprailiac, mid-thigh, and medial calf); %BF, percentage of body fat; PTV, peak treadmill velocity; VO_{2max}, maximum oxygen uptake rate; HR_{max}, maximum heart rate; RER_{max}, maximum respiratory exchange ratio; $[La^-]_{finalT1}$, final lactate concentration in Test 1; $[La^-]_{3minT1}$, lactate concentration 3 minutes after Test 1. Values are means (SD). Statistically significant differences with respect to trained runners are indicated as *P<0.05; **P<0.01; ***P<0.001.

Table 2. V_{OBLA}, V_{LT} and $[La^-]_{LT}$ in trained and well-trained runners.

	Trained (n=11)				Well-trained (n=12)		
Subjects	V_{OBLA}	V_{LT}	$[La^-]_{LT}$	Subjects	V_{OBLA}	V_{LT}	$[La^-]_{LT}$
T1	13.9	14.0	4.1	WT1	17.0	16.1	2.7
T2	10.8	12.5	6.4	WT2	17.7	17.0	2.5
T3	10.5	12.4	5.5	WT3	19.1	18.1	2.9
T4	14.7	14.3	3.4	WT4	19.0	18.5	3.1
T5	14.6	13.7	3.0	WT5	17.8	17.7	3.5
T6	15.9	15.0	2.7	WT6	18.9	18.2	3.0
T7	13.0	13.5	4.4	WT7	18.1	17.8	3.1
T8	13.5	13.4	3.9	WT8	16.3	16.0	3.7
T9	15.0	14.5	3.4	WT9	17.5	17.0	3.4
T10	15.4	16.0	4.4	WT10	19.8	19.5	3.4
T11	16.1	16.0	3.9	WT11	16.2	16.0	3.7
				WT12	15.0	15.0	4.0
Mean (SD)	13.9 (1.9)	14.1 (1.2)	4.1 (1.1)		17.7 (1.4)***	17.2 (1.3)***†††	3.3 (0.4)*‡

n, number of subjects; V_{OBLA}, velocity corresponding to the Onset of Blood lactate accumulation ($km{\cdot}h^{-1}$); V_{LT}, velocity corresponding to the lactate threshold ($km{\cdot}h^{-1}$), $[La^-]_{LT}$, lactate concentration at lactate threshold ($mmol{\cdot}L^{-1}$). Statistically significant differences with respect to trained runners are indicated as *P<0.05; ***P<0.001. Statistically significant differences with respect to V_{OBLA} are indicated as †††P<0.001. Statistically significant differences with respect to 4 $mmol{\cdot}L^{-1}$ *lactate concentration are indicated as ‡P<0.05.*

production (VCO_2), percentage of maximum heart rate ($\%HR_{max}$) or RER during the V_{OBLA}. The overall trend was a physiological steady state in the last half of the Test 2.

The individual values of the TE_{T2} correlated negatively with the individual V_{OBLA} values (r=0.719, P<0.001, n=23) (figure 2A), as well as positively with the individual best 10-km race time values (r=0.536, P<0.01, n=23) (figure 2B). Further, V_{OBLA} correlated positively with $\%VO_{2max}$ in Test 2 (r=0.604, P<0.001, n=23) (figure 3).

DISCUSSION

This is the first study to compare the physiological responses (measured as a function of % time to exhaustion) at V_{OBLA}, in order to ascertain if a 4 $mmol{\cdot}L^{-1}$ lactate concentration represents the same relative exercise intensity for runners of different athletic ability.

Time to exhaustion is considered a good indicator of the relative exercise intensity[22]. An important finding of this study is that the time to exhaustion at the velocity corresponding to 4 $mmol{\cdot}L^{-1}$ lactate concentration (TE_{T2}) was shorter in well-trained runners compared to trained runners. This result, together with the negative correlation between TE_{T2} and the V_{OBLA}, and the positive correlation between TE_{T2} and the 10-km race time, suggests that the

Table 3. V_{OBLA} velocity test (Test 2) results in trained and well-trained runners.

	Trained	Well-trained
	(n = 11)	(n = 12)
$\%VO_{2máx}$ (%)	84.4 (9.6)	90.0 (7.2)
%PTV	84.0 (5.3)	85.8 (3.5)
TE_{T2} (min)	32.6 (10.9)	22.2 (6.6)*
Distance (km)	7.4 (2.2)	6.4 (1.7)
$[La^-]_{finalT2}$ ($mmol{\cdot}L^{-1}$)	5.8 (2.0)	7.1 (1.5)
$[La^-]_{3minT2}$ ($mmol{\cdot}L^{-1}$)	5.6 (2.3)	7.0 (1.9)

n, number of subjects; V_{OBLA}, velocity corresponding at the Onset of Blood lactate accumulation; $\%VO_{2max}$, percentage of the maximum oxygen uptake, %PTV, percentage of the peak treadmill velocity; TE_{T2}, time to exhaustion at the end of Test 2; $[La^-]_{finalT2}$, blood lactate concentration at the end of the Test 2; $[La^-]_{3minT2}$, blood lactate concentration 3 minutes after Test 2. Values are means (SD). Statistically significant differences with respect to trained runners are indicated as *P<0.05.

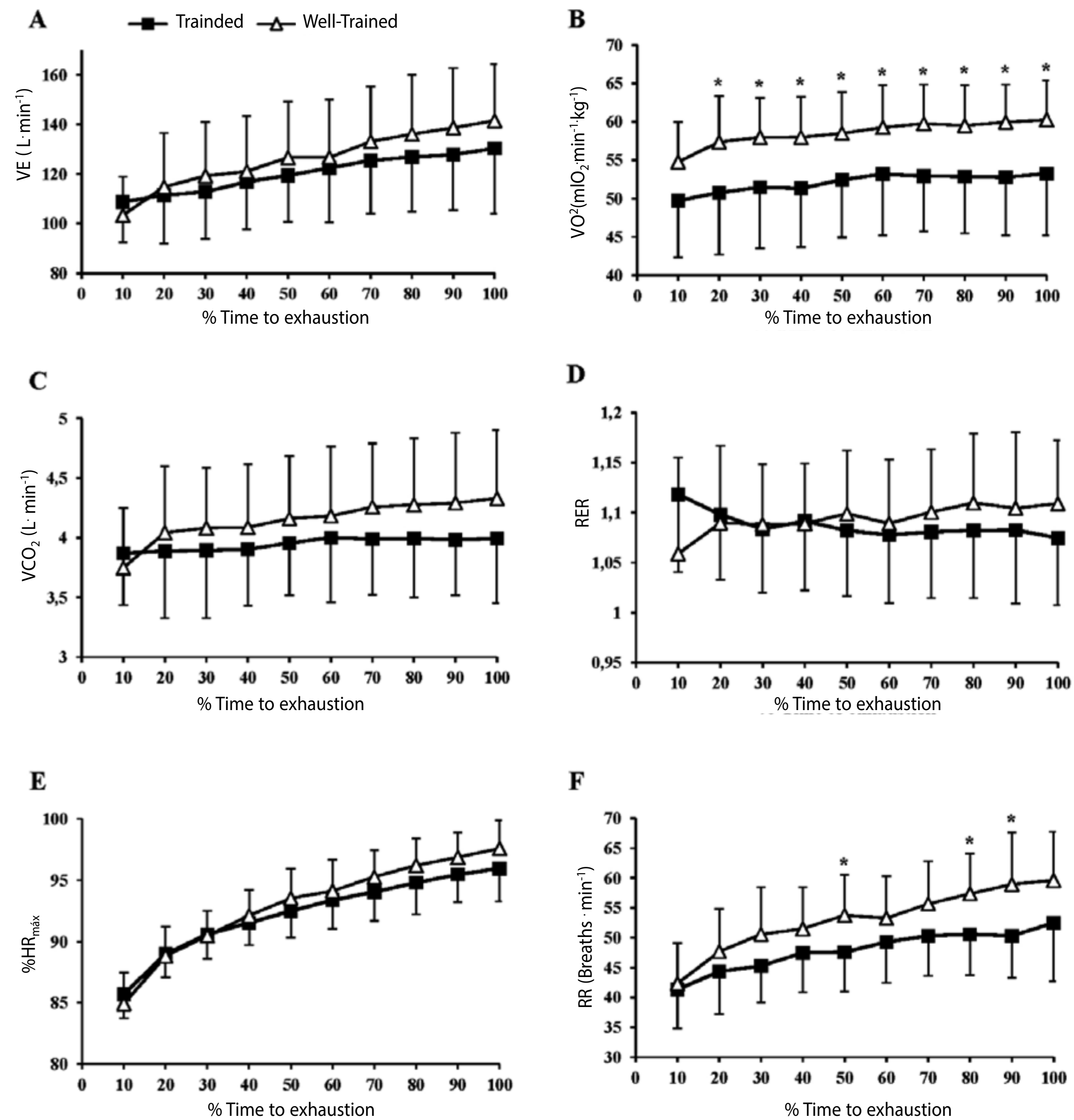

Figure 1. Physiological parameter responses in trained and well-trained runners during the VOBLA test according to time to exhaustion. VE, volume ventilation (A); VO_2, oxygen uptake (B); VCO_2, carbon dioxide production (C); RER, respiratory exchange ratio (D); $\%HR_{max}$, percentage of maximum heart rate (E); RR, respiratory rate (F). Statistically significant differences with respect to trained runners are indicated as $*P<0.05$.

athletic level of the runners is a determinant factor for the exercise duration at the velocity corresponding to a lactate concentration of 4 $mmol \cdot L^{-1}$. This idea is corroborated by the finding that VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) and respiratory rate (RR) values during the V_{OBLA} test were higher for well-trained runners at certain points. Respiratory responses are related to the exercise intensity[23], so these results suggest that, although at a consistent $V_{OBLA,}$ the intensity of workload was greater in the well-trained runners.

The key to understanding why the higher level athletes experienced a shorter TE_{T2} during Test 2 may be explained by differences in the V_{LT} and $[La^-]_{LT}$ between the trained and the well-trained runners. V_{OBLA} was close to the V_{LT} in trained runners, whereas V_{LT} was faster in the well-trained runners. Similarly, the $[La^-]_{LT}$ was not different to OBLA in trained runners and was lower than OBLA in the well-trained runners. These results indicate that V_{OBLA} does not represent the same relative exercise intensity in runners of different athletic ability and that the time to exhaustion at a running velocity corresponding to a lactate concentration of 4 $mmol \cdot L^{-1}$ appears to be influenced by the athletic conditioning of the runners.

This statement is further supported by the positive correlation between $\%VO_{2max}$ in Test 2 and V_{OBLA}. These results suggest that athletes of a higher athletic level (athletes with a higher V_{OBLA}) ran at a higher $\%VO_{2max}$ during Test 2. This finding may imply that the athletic level of the runners is a factor that influences the relative

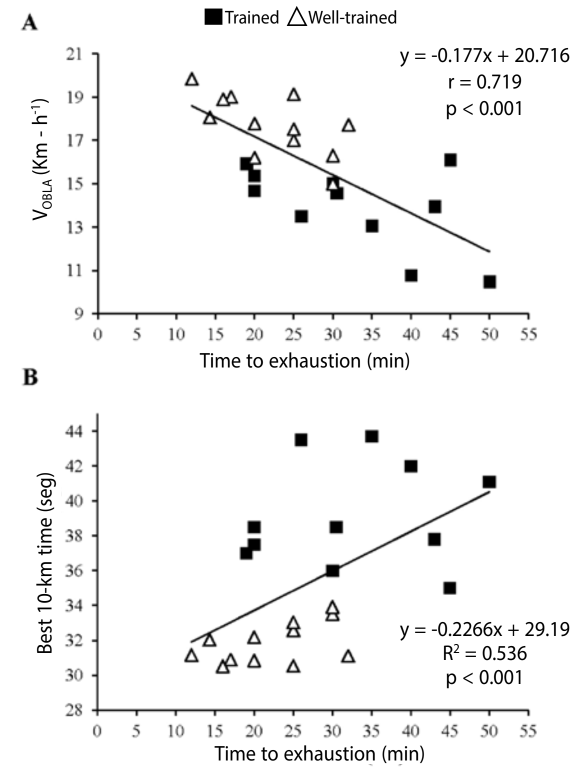

Figure 2. Significant relationships between time to exhaustion in Test 2 and the velocity corresponding to onset of blood lactate accumulation (VOBLA) (A) and running performance according to the best 10-km time (B) in trained and well-trained runners.

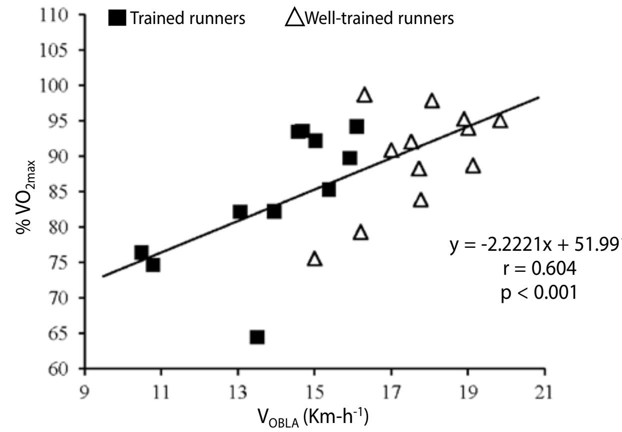

Figure 3. Significant relationship between the velocity corresponding to the onset of blood lactate accumulation (V_{OBLA}) and the percentage of maximum oxygen uptake in Test 2 in trained and well-trained runners.

intensity corresponding to 4 mmol·L^{-1} lactate concentration. Although, the athletes were exercising at a speed set to maintain 4 mmol·L^{-1} blood lactate concentration, $\%VO_{2max}$ differed between athletes. Thus, suggesting the athletes exercised at different relative intensities during Test 2.

Currently, it is known that during prolonged exercise at intensities eliciting the MLSS, glycolytic muscle fibers are producing and releasing lactate[24] into the blood for oxidation by distant tissues as well as conversion to glucose and glycogen, while some lactate may diffuse to adjacent oxidative muscle fibers to be oxidized[25]. Lactate exchange is a dynamic process with simultaneous muscle uptake and release at rest and during exercise[26]. Consequently, lactate values measured in blood are not necessarily indicative of the levels of lactate produced in active muscles. In fact, well-trained runners are likely to have an enhanced lactate clearance capacity[27]. Thus, the 4 mmol·L^{-1} blood lactate concentration may be associated with higher relative exercise intensity in this group of athletes.

During exercise performed at V_{OBLA} volitional exhaustion occurred whilst there was evidence for physiological reserve capacity. Thus, exercise termination at V_{OBLA} may be induced by an integrative homoeostatic control of the central and peripheral physiological system. This is to specifically ensure the maintenance of homeostasis and not a result of the failure of the body to perform work, as proposed by the Central Governor Model[28].

In summary, the present study suggests that V_{OBLA} does not represent the same relative exercise intensity in runners of different competitive level, possibly due to differences in lactate kinetics. Our results demonstrate that the time to exhaustion, which is a good indicator of the relative exercise intensity, is closely related to the level of the athletes when running at V_{OBLA}. Thus, we conclude that this index should not be recommended for programming training sessions, performing an aerobic capacity evaluation or comparing runners of different athletic ability and conditioning.

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