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 ([La-]) 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 VOBLA (Test 1), and then another one at the corresponding VOBLA 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). The individual lactate threshold velocity (VTL) and lactate concentration ([La-]) were calculated according to the D-max method. Results: VOBLA and VTL were higher in well-trained runners (P<0.001). [La-] was <4 mmol·L⁻¹ in the well-trained runners (P<0.001), but not in trained runners. Well-trained runners were faster at VBLA than at VTL (P<0.001). Well-trained runners ran a shorter TE than the trained runners (P<0.05). Moreover, well-trained runners presented a higher respiratory rate at 50, 80 and 90% of TE, and VO₂ at 20-100% of TE (P<0.05). TE was inversely correlated (P<0.01) with VOBLA and positively with personal best 10-km performance (P<0.01). VOBLA was positively correlated with the %VO₂max 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: VOBLA may not be accurate for programming running training sessions or for performing an evaluation of aerobic capacity.

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

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. 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). MLSS represents the highest intensity of exercise at which a balance exists between the rate of lactate production and lactate clearance.

The MLSS has been proposed as a useful tool for the evaluation of aerobic capacity, training intensity prescription and the prediction of exercise performance. 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. As a result, several authors have recommended the use of single day tests for the indirect determination of MLSS.

During running exercise, a lactate concentration of 4 mmol·L⁻¹ was reported to be associated with the MLSS and consequently, different researchers have proposed the use of the 4 mmol·L⁻¹ value as a reference value for the MLSS. This value of 4 mmol·L⁻¹, first proposed by Mader et al in 1976, was later termed as the onset of blood lactate accumulation (OBLA). 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, and therefore OBLA exercise intensity has been adopted by coaches all over the world as a useful index of training status and fitness.

However, several researchers are against the utilization of OBLA as an indirect marker for the MLSS, because [La-] corresponding to MLSS may be reduced as a result of aerobic training. In addition, it is acknowledged that the 4 mmol·L⁻¹ value does not take into account inter-individual variability in the MLSS. Thus, use of the OBLA as an 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

Received on 5/15/2012, and approved on 12/7/2012.
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 athlete 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. All subjects performed two maximal running tests: a peak treadmill lactate test (Test 1) and a constant treadmill Vo2 BLA 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·h⁻¹ without previous warm up. The velocity was increased by 1.5 km·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 (VO₂) and respiratory exchange ratio (RER) were continuously measured using the same calibrated gas analyzer system (Ergocard, Medisoft, Sorrines, 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 VO₂max when three of the following criteria were fulfilled: 1) a plateau in VO₂; 2) RER > 1.15; 3) HR within 5 beats·min⁻¹ of theoretical maximal HR (220-age); 4) lactate concentration > 8 mmol·L⁻¹; 5) RPE = 10.

Peak treadmill velocity in km·h⁻¹ (PTV) was calculated as follows taking every second into account:

$$\text{PTV} = \left( \frac{240 \text{ sec}}{\text{seconds at final velocity}} \right) \times 1.5 \text{ km·h}^{-1}$$

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. The individual lactate threshold (LT) was calculated by the D-max method. The reliability of this method has previously been reported. 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.

Constant treadmill Vo2 BLA test (Test 2) - This test involved running on a treadmill at the individual's velocity corresponding to a lactate concentration of 4 mmol·L⁻¹ (Vo2 BLA) until volitional exhaustion with a 1% gradient. Vo2 BLA 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 (TEₜ₂) as suggested by Pires et al. Lactate concentration was sampled immediately ([La⁻]ₜ₂) and 3 minutes ([La⁻]ₜ₃) 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 was utilized 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 VO₂ (absolute and relative to body mass), HR, RER or [La⁻] between both groups.

Vo2 BLA and the velocity at the lactate threshold (Vₜ₁) 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⁻]ₜ₁) was lower in the well-trained runners (P<0.001). Vo2 BLA was faster than Vₜ₁ in the well-trained runners (P<0.001), but not in the trained runners. Similarly, [La⁻]ₜ₁ was <4mmol·L⁻¹ in the well-trained runners (P<0.001), but not in the trained runners.

TEₜ₂ 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 %VO₂max, %PTV, [La⁻]ₜ₂ ([La⁻]ₜ₃) 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 VO₂ (ml·kg⁻¹·min⁻¹) at 20 to 100% of the TEₜ₂ and a higher respiratory rate (RR) at 50, 80 and 90% of the TEₜ₂ than trained runners (P<0.05, figure 1). There were no statistically significant differences in the physiological responses of volume ventilation (VE), carbon dioxide...
Tables 1 to 3 present the results of the maximal treadmill test (Test 1) and VOBLA velocity test (Test 2) for trained and well-trained runners. The data includes anthropometric characteristics, performance indicators, and exertion measures. The tables show significant differences in VO2max, lactate concentration, and time to exhaustion between trained and well-trained runners.

DISCUSSION

The study compared physiological responses at VOBLA to determine if a 4 mmol·L⁻¹ lactate concentration represents the same relative exercise intensity for runners of different abilities. The results indicated that well-trained runners had shorter time to exhaustion at VOBLA and lower lactate concentrations compared to trained runners. This suggests that well-trained runners maintain a higher VO2max and have a greater ability to sustain exercise at a given lactate concentration.
The athletic level of the runners is a determinant factor for the exercise duration at the velocity corresponding to a lactate concentration of 4 mmol·L⁻¹. This idea is corroborated by the finding that VO₂ (ml·kg⁻¹·min⁻¹) and respiratory rate (RR) values during the VOBLA test were higher for well-trained runners at certain points. Respiratory responses are related to the exercise intensity²³, so these results suggest that, although at a consistent VOBLA, the intensity of workload was greater in the well-trained runners.

The key to understanding why the higher level athletes experienced a shorter TE₂ during Test 2 may be explained by differences in the VLT and [La]LT between the trained and the well-trained runners. VOBLA was close to the VLT in trained runners, whereas VLT 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 VOBLA 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·L⁻¹ appears to be influenced by the athletic conditioning of the runners.

This statement is further supported by the positive correlation between %VO₂max in Test 2 and VOBLA. These results suggest that athletes of a higher athletic level (athletes with a higher VOBLA) ran at a higher %VO₂max during Test 2. This finding may imply that the athletic level of the runners is a factor that influences the relative

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**Figure 1.** Physiological parameter responses in trained and well-trained runners during the VOBLA test according to time to exhaustion. VE, volume ventilation (A); VO₂, oxygen uptake (B); VCO₂, carbon dioxide production (C); RER, respiratory exchange ratio (D); %HRmax, percentage of maximum heart rate (E); RR, respiratory rate (F). Statistically significant differences with respect to trained runners are indicated as *P<0.05.
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, %VO₂max 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 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. Lactate exchange is a dynamic process with simultaneous muscle uptake and release at rest and during exercise. 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. 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 VOBLA, volitional exhaustion occurred whilst there was evidence for physiological reserve capacity. Thus, exercise termination at VOBLA may be induced by an integrative homeostatic 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.

In summary, the present study suggests that VOBLA 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 VOBLA. 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.

ACKNOWLEDGEMENTS

This study has been partially supported by the Department of Physical Education and Sport, of the Faculty of Physical Activity and Sport, University of the Basque Country (UPV/EHU). J.S.C. is supported by a predoctoral fellowship from the Basque Government (ref. BFI08.51).

All authors have declared there is not any potential conflict of interests concerning this article.

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