

Effect of the aerobic capacity on the validity of the anaerobic threshold for determination of the maximal lactate steady state in cycling

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Abstract

The maximal lactate steady state (MLSS) is the highest blood lactate concentration that can be identified as maintaining a steady state during a prolonged submaximal constant workload. The objective of the present study was to analyze the influence of the aerobic capacity on the validity of anaerobic threshold (AT) to estimate the exercise intensity at MLSS (MLSS intensity) during cycling. Ten untrained males (UC) and 9 male endurance cyclists (EC) matched for age, weight and height performed one incremental maximal load test to determine AT and two to four 30-min constant submaximal load tests on a mechanically braked cycle ergometer to determine MLSS and MLSS intensity. AT was determined as the intensity corresponding to 3.5 mM blood lactate. MLSS intensity was defined as the highest workload at which blood lactate concentration did not increase by more than 1 mM between minutes 10 and 30 of the constant workload. MLSS intensity (EC = 282.1 ± 23.8 W; UC = 180.2 ± 24.5 W) and AT (EC = 274.8 ± 24.9 W; UC = 187.2 ± 28.0 W) were significantly higher in trained group. However, there was no significant difference in MLSS between EC (5.0 ± 1.2 mM) and UC (4.9 ± 1.7 mM). The MLSS intensity and AT were not different and significantly correlated in both groups (EC: $r = 0.77$; UC: $r = 0.81$). We conclude that MLSS and the validity of AT to estimate MLSS intensity during cycling, analyzed in a cross-sectional design (trained x sedentary), do not depend on the aerobic capacity.

Key words

- Anaerobic threshold
- Lactate steady state
- Aerobic capacity
- Cycling

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The maximal lactate steady state (MLSS) is the highest blood lactate concentration (BLC) that can be identified as maintaining a steady state during prolonged submaximal constant workload. The MLSS has been used to determine the highest intensity (MLSS intensity) that can be maintained over time without continuous blood lactate accumula-

tion (1,2). There are many reasons for trying to quantify this intensity of exercise, including assessment of cardiovascular or pulmonary health, evaluation of training programs, prescription of appropriate exercise intensity, and categorization of the intensity of exercise as moderate, heavy or severe (3-5). However, the determination of MLSS inten-

sity requires the subject to perform 4-5 exercise bouts of 30-min duration, preferably on separate days. This procedure is time-consuming and can interfere with the training of the athlete.

In contrast to the latter procedure, some studies have proposed to predict the MLSS intensity within a single incremental load test. Heck et al. (6) showed in a heterogeneous group (endurance runners and active individuals) that the intensity obtained during an incremental test corresponding to 4 mM blood lactate (anaerobic threshold) is valid to indirectly determine MLSS intensity during running. Subsequently, other studies conducted on endurance runners (7) and soccer players (8) confirmed the validity of anaerobic threshold to estimate MLSS intensity during running. However, Beneke (9) showed that the use of the anaerobic threshold overestimated MLSS intensity in rowers with different performance levels. Differences in muscle mass involved in these types of exercise (running x rowing) might explain, in part, these contradictory data. Beneke (10) has proposed that the MLSS depends upon the motor pattern of exercise caused by task-specific interrelationships between power output per unit muscle mass and the specific masses of the primarily engaged muscles. To our knowledge, no studies have compared anaerobic threshold with the directly and independently determined MLSS intensity during cycling.

Some studies have developed the concept of individual anaerobic threshold, which is based on the hypothesis that the BLC at anaerobic threshold may decrease with increasing performance capacity (11,12). However, the physiological mechanisms and experimental proof of this hypothesis are missing. Possible effects of aerobic capacity on the validity of anaerobic threshold for estimating MLSS intensity can only be evaluated by using constant load tests and the direct determination of the MLSS.

The objective of the present study was to

analyze the influence of the aerobic capacity on the validity of anaerobic threshold as an estimate of MLSS intensity during cycling.

Ten untrained males (UC) (22.6 ± 4.1 years, 71.5 ± 12.9 kg, 175.1 ± 4.3 cm), and 9 endurance cyclists (EC) (20.6 ± 2.3 years, 69.1 ± 9.9 kg, 177.5 ± 5.0 cm) volunteered to participate in this study. The subjects gave informed consent and the protocol was approved by the Biosciences Institute Ethics Committee, UNESP, Rio Claro, SP, Brazil.

All subjects performed one incremental maximal load test to determine anaerobic threshold and 2 to 4 constant submaximal load tests on a mechanically braked cycle ergometer (Monark, São Paulo, SP, Brazil) to determine MLSS. The pedaling rate was set at 70 rpm. The interval between the two tests was at least 48 h. The subjects were instructed to arrive at the laboratory in a rested and fully hydrated state, at least 3 h post-prandial, and to avoid strenuous exercise in the 48-h preceding a test session. Each subject was tested at the same time of day ($9:30 \pm 1:00$ h) to minimize the effects of diurnal biological variation.

The incremental load test started with 70 W for the UC and 105 W for the EC and was increased to exhaustion by 35 W by every 3rd minute. The peak workload (PW) was defined as the highest workload maintained at least 1 min. The anaerobic threshold was determined as the intensity corresponding to 3.5 mM blood lactate (6). The constant load tests lasted 30 min. Workload of the first constant load test corresponded to a BLC of 3.5 mM measured during the incremental load test. If during the first constant load test a steady state or a decrease in lactate was observed, further subsequent 30-min constant load tests with 3-7% higher workload intensities were performed on separate days until no BLC steady state could be maintained. If the first constant load test resulted in a clearly identifiable increase of the BLC and/or could not be completed due to exhaustion, further constant workloads were

conducted with subsequently reduced workload intensities. The MLSS intensity was defined as the highest workload at which BLC did not increase by more than 1 mM between minutes 10 and 30 of the constant workload (1). MLSS was calculated as average value of the BLC measured at minutes 10 and 30 of the MLSS intensity (1).

Blood samples (25 μ l) were collected from the ear lobe into microcentrifuge tubes containing 50 μ l NaF (1%) during the final 15 s of every 3rd (incremental load test) or every 5th (constant load test) minute. BLC was determined by an electrochemical method (YSL 2300 STAT, Yellow Springs, OH, USA).

Data are reported as means \pm SD. The paired *t*-test was applied to compare anaerobic threshold and MLSS intensities. The correlations between anaerobic threshold and MLSS intensities were calculated using Pearson Product Moment correlation coefficients. In addition, the bias and limits of agreement between anaerobic threshold and MLSS intensities were calculated (13). Differences between the trained and untrained groups were tested by non-paired *t*-test. Significance was set at $P \leq 0.05$.

The PW, MLSS intensity, and anaerobic threshold reported as absolute as well as relative values related to body mass, and also MLSS intensity as percent of PW (%MLSS intensity) were significantly higher in EC than in UC. However, there was no significant difference in MLSS between EC and UC (Table 1). There were no significant difference between MLSS intensity and anaerobic threshold in both groups (Table 1). MLSS intensity was significantly correlated with anaerobic threshold in both groups (EC: $r = 0.77$; UC: $r = 0.81$). Moreover, the bias \pm 95% limits of agreement for comparisons between MLSS intensity and anaerobic threshold in EC [7.2 (16.4) W], UC [-7.0 (16.4) W] and EC + UC [-0.3 (17.5) W], suggest the validity of anaerobic threshold to estimate MLSS intensity during cycling in

both groups (Figure 1).

The main objective of the present study was to analyze the influence of the aerobic capacity on the validity of anaerobic threshold to estimate MLSS intensity during cycling. In contrast to previously published speculations that higher aerobic capacity reduces the BLC at anaerobic threshold (11,12,14), we showed here that the anaerobic

Table 1. Maximal and submaximal responses obtained in endurance cyclists and untrained subjects.

	Endurance cyclists (N = 9)	Untrained cyclists (N = 10)
Peak workload (W)	355.1 \pm 27.7	267.3 \pm 39.5*
Peak workload (W/kg) - relative	5.2 \pm 0.7	3.7 \pm 0.5*
MLSS (mM)	5.0 \pm 1.2	4.9 \pm 1.7
MLSS intensity (W)	282.1 \pm 23.8	180.2 \pm 24.5*
MLSS intensity (W/kg) - relative	4.1 \pm 0.7	2.5 \pm 0.4*
AT (W)	274.8 \pm 24.9	187.2 \pm 28.0*
AT (W/kg) - relative	4.0 \pm 0.6	2.6 \pm 0.5*
%MLSS intensity (%)	79.5 \pm 4.1	68.0 \pm 9.5*

W, Watts; MLSS, maximal lactate steady state; MLSS intensity, intensities at MLSS; AT, anaerobic threshold; %MLSS intensity, MLSS intensity as percent of peak workload; relative, values related to body mass. Data are reported as means \pm SD.

* $P \leq 0.05$ compared to endurance cyclists (non-paired *t*-test).

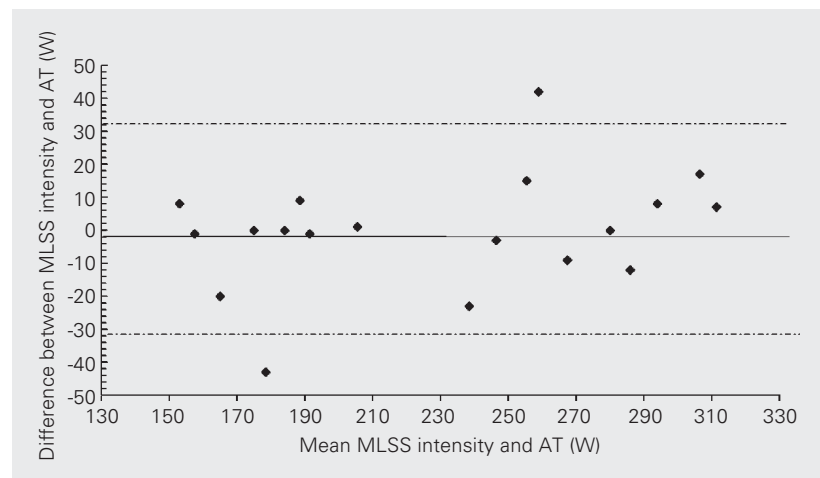


Figure 1. Bland-Altman diagram comparing exercise intensity at anaerobic threshold (AT) and maximal lactate steady state (MLSS intensity) for all subjects (untrained and trained). The solid horizontal line represents the bias between the two measures (i.e., the mean difference between the group means for the two variables). The dashed lines represent the 95% limits of agreement between the two variables, and reflect the extent to which one variable might be expected to differ from another in individual subjects.

threshold presents a good validity for the estimate of MLSS intensity irrespective of aerobic capacity. In agreement with Beneke et al. (15), we also found that the MLSS does not depend on aerobic capacity during cycling.

The PW (W/kg), MLSS intensity and %MLSS intensity values obtained for the EC group were compatible with those reported in the literature for individuals classified as well trained (16). In addition, these values were significantly higher in the EC than in the UC group. As the MLSS intensity is considered the “gold standard” for the assessment of aerobic capacity (4), our objective of comparing groups with different levels of aerobic training (trained x sedentary) was achieved.

Different methods for the identification of MLSS and, consequently, MLSS intensity have been reported in the literature. These methods basically differ with respect to test duration and the period of constant workload selected for the interpretation of the BLC response and the maximally accepted increase of BLC. In the present study, we used a method employed by different research groups (2,10), whose validity has been recently confirmed by Beneke (1). The MLSS values obtained here are similar to those reported in other studies on cycling (1,10,15).

Many investigations have shown that at a given submaximal exercise intensity, expressed as absolute (i.e., km or W) or relative values (i.e., %VO₂max or %PW), the BLC is lower in trained than in sedentary individuals (17). This decline in BLC after a period of training can be observed even in highly trained athletes, and in the absence of any changes in VO₂max (18). The BLC depends on the dynamic equilibrium between lactate appearance in and disappearance from the blood compartment. Bergman et al. (17) showed that mechanisms for dampened arterial lactate concentration after endurance training vary depending on exercise intensity. At the same absolute workload, endur-

ance training decreases whole body and working muscle lactate production and increases clearance by active muscle. However, at similarly high relative exercise intensities, endurance training increases whole body and active muscle lactate clearance, but does not influence whole body or muscle production.

Although these modifications in the lactate response to exercise might exist, the MLSS does not seem to depend on aerobic capacity. Similar to the results of the present study in which the MLSS did not differ between groups (EC = 5.0 ± 1.2 mM vs UC = 4.9 ± 1.7 mM), Beneke et al. (15) reported that MLSS (4.9 ± 1.4 mM) was independent of MLSS intensity (3.4 ± 0.6 W/kg). Thus, factors other than the training status (e.g., exercise type) (10) seem to influence MLSS.

To our knowledge, this paper reports the first study analyzing the influence of the aerobic capacity on the validity of anaerobic threshold to estimate MLSS intensity during cycling. Investigations involving a heterogeneous group (endurance runners and active individuals; 6), endurance athletes (7) and soccer players (8) showed that anaerobic threshold presents good validity in estimating MLSS intensity during running. In the present study, we demonstrated that the validity of anaerobic threshold to estimate MLSS intensity during cycling does not depend on the level of training. In contrast, Urhausen et al. (19) reported that anaerobic threshold is not a valid method to estimate MLSS intensity during cycling, although the cited authors did not directly measure MLSS. In that study, 7 (43%) of 16 athletes did not present a lactate steady state during constant load exercise performed at anaerobic threshold. In contrast, in the present study only 3 (30%) subjects of the UC group and one subject (11%) of the EC group showed intensities corresponding to anaerobic threshold, which were 5% higher than the MLSS intensity. This percentage (5%) was used in the present study, and also by Urhausen et al. (19), to determine differences in intensities

between constant load exercises, i.e., the level of precision that identified the presence or absence of lactate steady state. Differences in the increment rate of the incremental protocol (11.6 x 16.6 W/min) and in the lactate concentration corresponding to anaerobic threshold (3.5 x 4.0 mM) used here and by Urhausen et al. (19), respectively, might explain, in part, these apparently contradicting data. Heck (20) demonstrated an increase of approximately 1.4 W in anaerobic threshold when the increase in workload during incremental load test was increased by 1.0 W/min. In addition, protocols with lower stages (e.g., 3 min) should use 3.5 instead of 4.0 mM to identify anaerobic threshold (6).

Based on the data reported in some studies (11,12,14), it has been proposed (4) that the validity of anaerobic threshold depends on the athlete's level of aerobic training. For example, Mognoni et al. (14) showed that anaerobic threshold (i.e., aerobic fitness) was negatively correlated with the maximum du-

ration of exercise performed at anaerobic threshold intensity (4 mM) during cycling. However, we believe that these data do not demonstrate that the validity of anaerobic threshold to estimate MLSS intensity is compromised in endurance athletes. In fact, the concepts and mechanisms that can influence the MLSS and maximum exercise duration at a given exercise intensity (e.g., at MLSS intensity) may be different, and have not yet been completely established. Thus, our data do not support previously published speculations that higher aerobic capacity reduces the BLC at anaerobic threshold (11,12,14).

We conclude that MLSS and the validity of anaerobic threshold to estimate MLSS intensity during cycling, analyzed in a cross-sectional design (trained x sedentary), do not depend on the aerobic capacity. However, longitudinal studies are necessary to analyze the effects of different training programs (i.e., different intensities and volumes) on MLSS and on the validity of anaerobic threshold to estimate MLSS intensity.

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