LACTATE MINIMUM, ANAEROBIC THRESHOLD AND CRITICAL SWIMMING SPEED IN BOYS

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ABSTRACT

The aim of this study was to compare the lactate minimum speed (S_{Lacmin}), the anaerobic threshold speed (S_{AT}) and the critical swimming speed (CSS) of 10 swimmer boys (14.8 ± 0.6 years) involved in national competitions. The tests to determine S_{Lacmin}, S_{AT} and CSS were done in a 25 m swimming pool and consisted of 7 or 8 evaluations separated by 24-48 h intervals. There was no significant difference between the S_{Lacmin} and S_{AT} (1.28 ± 0.05 vs. 1.29 ± 0.04 m.s⁻¹, p>0.01), the S_{Lacmin} and CSS (1.28 ± 0.05 vs. 1.29 ± 0.05 m.s⁻¹, p>0.01), or the S_{AT} and CSS (1.29 ± 0.04 vs. 1.29 ± 0.05 m.s⁻¹, p>0.01). The correlation was high and significant between the S_{Lacmin} and S_{AT} (r = 0.94, p<0.01), the S_{Lacmin} and CSS (r = 0.93, p<0.01), or the S_{AT} and CSS (r = 0.85, p<0.01). Based on these findings, we suggest that the S_{Lacmin}, S_{AT} and CSS should be used by trainers and coaches to evaluate the aerobic capacity of young swimmers.

Keywords: Lactate Minimum, Anaerobic Threshold, Critical Speed, Aerobic Capacity, Swimmers Boys.

INTRODUCTION

The maximal lactate steady state (MLSS) is defined as the highest blood lactate concentration and work load that can be maintained for a prolonged time without a continuous accumulation of blood lactate (2). However, assessing the MLSS is costly because of the time required to determine this value since the subject must undergo many tests. In addition, the need to collect blood samples means that determining this parameter is impractical for studies involving children and adolescents (1). Thus, some authors have utilized the anaerobic threshold (AT) to predict MLSS indirectly (10,13).

Some researchers have suggested that the AT may be determined using fixed lactate concentrations during tests of progressive intensity (13). However, this approach has been criticized because the methods involved do not consider the lactate kinetics individually (23), and because the results are influenced by the muscle glycogen content (17). Heck et al. (10) showed that the blood lactate concentration used to determine the intensity corresponding to the AT depended on the duration of the stage. On the other hand, Tegtbur et al. (25) suggested the use of the minimum lactate test (Lac_{min}), which provides an individual assessment of the AT; this test is easy to do and the results are unaffected by prior depletion of glycogen. However, the stage duration during the graded phase and the initial intensity of the Lac_{min} test may influence the Lac_{min} intensity (25,4). This influence could partly explain the controversy surrounding the validity of Lac_{min} for identifying the MLSS (12). Despite this limitation, swimming studies have shown that the Lac_{min} speed does indeed correspond to the MLSS (18, 22). Similar findings have been reported by De Araujo et al. (5) in swimming protocol for rats.

It is not always possible to determine the AT from the blood lactate level, particularly in children and adolescents, and this has led to the use of indirect methods to assess this parameter. In the early 1990s, Wakayoshi et al. (27) broadened the concept of critical power proposed by Monod and Scherrer (14) for swimming, and proposed the term critical swimming speed (CSS), which is the swimming speed that theoretically can be maintained for a long period of time without exhaustion. In subsequent studies using swimming athletes, these investigators also found highly significant correlations between the CSS and the AT speed (r=0.86 and r=0.91, respectively), and that the CSS corresponded to the MLSS (28, 29).

The use of the CSS model in young swimmers has received increasing attention because of its simplicity and the fact that no blood collection is required. Hill et al. (11) suggested the use of the CSS to evaluate the aerobic performance of young swimmers (8-18 years old). Subsequent studies involving young swimmers have confirmed the validity of this method for assessing the anaerobic threshold, independently of the level of performance (6), gender (8, 26) and chronological age (9, 26).

In swimming, athletes begin their evaluations and intensive training programs very early, hence the availability of a simple and rapid means for determining the AT in order to predict performance, prescribe the correct intensity of training and adequately assess the effects of training in young swimmers is desirable.
However, so far, there has been no systematic comparison of the $\text{Lac}_{\text{min}}$ intensity with other criteria for determining the blood lactate response, particularly in young individuals involved in competitive swimming. Thus, the aim of the present study was to compare the lactate minimum speed ($S_{\text{Lac\text{min}}}$), the anaerobic threshold speed ($S_{\text{AT}}$) and the critical swimming speed (CSS) in young swimmers.

**MATERIAL AND METHODS**

**Subjects**

The subjects consisted of ten male Brazilian swimmers (14.8 ± 0.6 years, 64.4 ± 8.2 kg, 174.1 ± 8.3 cm), with 6-7 years of experience in competitive swimming at a national level. Six subjects specialized in the freestyle stroke (four in short and middle distance competitions, and two in long distance competitions), three in the backstroke (short and middle distance) and one in the breaststroke (short and middle distance). All were involved in a training program that consisted of six sessions a week with a weekly median training distance of 30,000 m. During the evaluation period, all of the swimmers were training in the polishing phase.

Before participating in the study, the procedures were explained to the athletes and to their parents or guardians. After obtaining their verbal consent, their parents or guardians provided voluntary written informed consent to participate in the study. The study was approved by the Ethics Committee of the Faculty of Medical Sciences of the State University of Campinas.

**Maturational evaluation**

The degree of sexual maturation was assessed based on the stages of genital (GD1 to GD5) and pubic hair (PH2 to PH5) development (24). The developmental stages were ascertained through a self-assessment in which, after detailed explanations on the use of the "boards with photographs", the subjects identified the maturational stages that they most closely matched (19).

**Experimental procedures**

The tests applied in this study were aimed at determining the $S_{\text{Lac\text{min}}}$, $S_{\text{AT}}$ and CSS. All of the tests were done in a 25 m swimming pool with a water temperature of 26-27°C, and with the subjects always using the freestyle stroke. The subjects participated in 7 or 8 test sessions separated by 24-48 h intervals. A warm-up was done before each test session and consisted of swimming at a constant speed for 5 min. In all of the tests, the swimmers received visual instruction every 25 m so that the pre-established speeds were maintained.

The test sessions occurred at the same time throughout the study, and a pilot study was used to familiarize the swimmers with the protocols and the equipment used.

**Determination of the lactate minimum speed**

To determine the $S_{\text{Lac\text{min}}}$, the swimmers initially did two 50 m sprints at maximum speed with a 1 min rest between sprints in order to produce a high accumulation of blood lactate. Following a passive recovery of 8 min, 300 m stage-length incremental series were done, with initial speeds ranging from 1.10 to 1.25 m.s⁻¹, and increments of 0.05 m.s⁻¹ per step until the swimmers could not keep the pace (18). The initial speeds were chosen so that the athletes could perform at least six repetitions before fatigue occurred. Twenty-five microliters of arterial blood for the determination of blood lactate was collected from the ear lobe with a heparinized capillary 7 min after the second 50 m sprint and during 30 sec intervals between each graded effort. The $S_{\text{Lac\text{min}}}$ was determined using a simple visualization method and was defined as the lowest blood lactate value measured during the graded phase of the test (18).

**Determination of the anaerobic threshold speed**

The $S_{\text{AT}}$ was determined using the protocol proposed by Mader et al. (13) with a fixed lactate blood concentration of 3.5 mM (10). The participants swam 200 m at 85% and 95% of the maximum speed for the distance (determined previously during the training sessions). A rest of more than 20 min was allowed between the two tests. One, three and five minutes after each swim, 25 µl of arterial blood was collected from the ear lobe using a heparinized capillary and stored until the blood lactate could be measured. Linear interpolation was used to determine the speed corresponding to a blood lactate concentration of 3.5 mM (9).

**Determination of the critical swimming speed**

To determine the CSS, the athletes were instructed to swim distances of 50, 100, 200, and 400 m as quickly as possible. The exit of the swim was given inside the swimming pool, close to border and the time taken to swim each distance was recorded using a manual digital chronometer (SEIKO S140, JAPAN). During the training sessions, the participants swam one event per day in random order. The CSS was determined using the slope of the linear regression between the swimming distances and the time taken to swim them, as described by Wakayoshi et al. (27). The athletes were evaluated in groups in order to motivate them to do their best.

**Blood analysis**

The blood samples collected for the lactate measurements were immediately transferred to microcentrifuge tubes containing 50 µl of 1% NaF and then frozen at -70°C. Blood collection took approximately 30 sec. The lactate concentrations were determined using an electrochemical blood lactate analyzer (YSI 2300 STAT, Yellow Spring, OH).

**Statistical analysis**

The results were expressed as the mean ± SD. First, it was calculated the power of the sample based in
the critical swimming speed. The statistic power of the sample was 80%. After testing the data for normality and homogeneity using the Shapiro-Wilk and Levene tests, respectively, the mean values for the $S_{\text{Lacmin}}$, $S_{\text{AT}}$ and CSS were compared using analysis of variance (ANOVA) for repeated measures followed by the Scheffé test when necessary. The correlation between the $S_{\text{Lacmin}}$, $S_{\text{AT}}$ and the CSS was examined using the Pearson product moment correlation coefficient. The level of significance was set at p<0.01.

RESULTS
Based on the evaluation of sexual maturation, all of the boys were classified as stages GD4 and PH4.

The time required to swim 50, 100, 200 and 400 m and the mean speeds at which this was done are shown in table 1. The mean speed decreased significantly as the distance swum increased (p<0.01). There were also significant differences in all of the comparisons after modifications in the time required to do the tests (p<0.01).

<table>
<thead>
<tr>
<th></th>
<th>50 m</th>
<th>100 m</th>
<th>200 m</th>
<th>400 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>28.8 ± 1.0</td>
<td>62.7 ± 2.4*</td>
<td>140.3 ± 5.3†</td>
<td>299.1 ± 11.0‡</td>
</tr>
<tr>
<td>Speed (m.s$^{-1}$)</td>
<td>1.74 ± 0.06</td>
<td>1.60 ± 0.06*</td>
<td>1.43 ± 0.05†</td>
<td>1.34 ± 0.05‡</td>
</tr>
</tbody>
</table>

The values are the mean±SD (n = 10). *p<0.01 compared to 50 m, †p<0.01 compared to 50 and 100 m, and ‡p<0.01 compared to 50, 100 and 200 m.

There were no significant differences among the values for $S_{\text{Lacmin}}$ (1.28 ± 0.05 m.s$^{-1}$), $S_{\text{AT}}$ (1.29 ± 0.04 m.s$^{-1}$), and CSS (1.29 ± 0.05 m.s$^{-1}$) (p>0.01). The Figure 1 shows that there were highly significant correlations between $S_{\text{Lacmin}}$, $S_{\text{AT}}$ and CSS (p<0.01). In the test to determine $S_{\text{Lacmin}}$, the mean blood lactate concentration 7 min after the induction of acidosis and the lowest mean lactate level measured during the lactate minimum test were 10.79 ± 1.65 mM and 3.90 ± 1.06 mM, respectively. Figure 2 shows the changes in blood lactate during one of the tests to determine $S_{\text{Lacmin}}$.

Figure 1. Correlation between the lactate minimum speed ($S_{\text{Lacmin}}$) and anaerobic threshold speed ($S_{\text{AT}}$) (A), $S_{\text{Lacmin}}$ and the critical swimming speed (CSS) (B), and critical swimming speed (CSS) and anaerobic threshold speed ($S_{\text{AT}}$) (C).
DISCUSSION

The aim of the present study was to compare the lactate minimum speed (S_{lacmin}), the anaerobic threshold speed (S_{AT}) and the critical swimming speed (CSS) in young swimmers.

A few studies of swimming have used the Lac_{min} test to determine the AT, especially in adolescents. Ribeiro et al. (18) reported that the S_{lacmin} and MLSS were similar (1.28 ± 0.11 vs. 1.25 ± 0.06 m.s^{-1}, respectively) in 12 national level swimmers 19.7 ± 1.6 years old who independently chose their own starting intensity in stages 300 m long. However, in this same study, the S_{lacmin} was significantly higher than the MLSS (1.31 ± 0.12 vs. 1.25 ± 0.06 m.s^{-1}, respectively) when determined in 200 m stages, which suggested that the use of 200 m stages (but not 300 m) and allowing the individuals to independently choose their initial intensity of activity resulted in an overestimation of MLSS.

Simões et al. (22) investigated the relationship between S_{lacmin} and MLSS in swimmers of both sexes (16.0 ± 0.8 years old) but found no significant differences between these parameters (65.3 ± 5.6 vs. 64.3 ± 4.2 m.min^{-1}, respectively), although there was a significant correlation between S_{lacmin} and MLSS (r=0.93). Based on these results, these authors suggested that the Lac_{min} should be used to determine the aerobic capacity of young swimmers. Similar findings have been reported in swimming protocol for rats (5).

In the present study, there was also no significant difference between S_{lacmin} and S_{AT}, a finding that agreed with Simões et al. (20) who observed similar values between the intensity of exercise corresponding to the AT and the Lac_{min} (288.9 ± 20.1 vs. 285.2 ± 19.7 m.min^{-1}, respectively) in 12 runners involved in 5,000 m and 10,000 m competitions. In this study, the AT was determined for a lactate concentration of 4 mM starting with two submaximal race series of 1,200 m that provided stages of approximately 4 min. In addition, these authors also reported similar values for Lac_{min} and the individual anaerobic threshold (which considers individual variations in the blood lactate kinetics) in 15 trained runners exercised under similar intensities (284.7 ± 20.8 vs. 282.6 ± 18.8 m.min^{-1}, respectively) (21). The use of a fixed lactate concentration of 3.5 mM in this investigation, based on the fact that in incremental and continuous protocols with stage durations of <5 min, the literature suggest a lactate concentration of 3.5 mM instead of 4 mM since the latter value can overestimate the intensity of AT (10).

Since in swimming it is not always possible to determine the AT from the lactate response, some studies have have suggested that the CSS is one of the best indirect methods for assessing aerobic performance and for predicting the AT in adult (27, 28, 29) and young (8-18) years old (11) swimmers, independently of the level of performance (6), gender (8, 26) and chronological age (9, 26).

There was no significant difference between S_{lacmin} and CSS in our subjects. In contrast, Pardone et al. (15) reported that the CSS values determined after short distance exercises in cyclists significantly overestimated S_{lacmin}. In contrast, when long distance exercises were used, the CSS values were closer to S_{lacmin}. This finding has been confirmed by others who have shown that the use of shorter distances to predict CSS results in significantly higher values for this parameter (9). Hence, the short distances (50, 100, 200, 400 m) used to determine the CSS here were decisive in producing similarities among the swimming speeds. To date, no studies have compared the Lac_{min} protocol and AT

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**Figure 2.** Changes in the blood lactate concentration during one of the tests to determine S_{lacmin} in one subject.
protocol for a fixed lactate concentration, and the Lac_{min} protocol and CSS in swimming.

The similarity between S_{AT} and CSS in the present study agreed with the findings of Greco et al. (9) who studied 13-15-year-old swimmers, and observed that the CSS estimated for distances of 50, 100 and 200 m were not significantly different from the S_{AT} for 4 mM lactate (1.02 ± 0.14 vs. 1.00 ± 0.11 m.s^{-1}, respectively). More recently, Greco and Denadai (8) analyzed the relationship between the CSS for distances of 100, 200 and 400 m and the swimming speed in a 30 min test (S_{30}) in 13-15-year-old boys and girls, and observed that there was no significant difference between these parameters (boys = 1.10 ± 0.13 vs. 1.07 ± 0.11 m.s^{-1} and girls = 0.93 ± 0.06 vs. 0.91 ± 0.05 m.s^{-1}, respectively). This finding suggested that the CSS could be useful in evaluating the aerobic capacity of young swimmers. It is emphasized that similar findings have been reported by Toubekis et al. (26).

The mean lactate concentration in our subjects after the induction of acidosis was 10.79 ± 1.65 mM and 3.90 ± 1.06 mM at the lactate minimum. The blood lactate concentrations reported for other types of exercise (i.e., running, swimming) after acidosis and at the lactate minimum vary considerably (~6-14 mM and ~2.4-7 mM, respectively) (3, 4, 12, 18, 20, 22, 25), but include the values found here.

According to Carter et al. (4), the lactate concentrations after the induction of acidosis reflect a combination of the maximal effort and the initial intensity of this effort. Other factors that can contribute to these differences include the type of muscle fiber, the capillary density of the exercised muscles, the type and intensity (high or moderate) of training, the site of blood sampling, and the nature of the sample used (plasma or whole blood) (3, 12).

The lowest lactate blood value seen in the S_{Lacmin} was probably related to the developmental stage of the subjects since the boys were in stages GD4 and PH4. According to Tanner (24), there is continuous maturation of each characteristic in the third and fourth developmental stages and, because of the difficulting in assessing these stages, individuals in these stages cannot be considered mature.

Beneke et al. (1) reported that blood lactate concentrations varied from 2.1 mM to 5 mM, depending on the intensity of the MLSS, and recommended that there should be caution in the use of blood lactate levels to evaluate the aerobic capacity of children and adolescents because of the greater inter-individual variability in the concentrations of this metabolite compared to adults. According to Ericksson and Saltin (7) and Williams and Armstrong (30), children and adolescents have less anaerobic metabolism than adults, and this difference is reflected in the lower lactate concentrations in muscle and blood compared to adults. Similarly, the rate of anaerobic glycolysis increases as the activity of oxidative enzymes decreases with aging (7, 16).

CONCLUSION

There were no differences in the anaerobic threshold determined by the AT of fixed lactate concentration of 3.5 mM, Lac_{min} and CSS methods. This finding suggests that either of these methods can be used by trainers and coaches to evaluate the aerobic capacity of young swimmers. Additional studies are required to analyze the validity of these methods for determining the MLSS in young swimmers.

Acknowledgements

The authors thank Dr. Benedito S. Denadai for the blood lactate analyses, and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for post-graduate scholarships. This work was supported financially by CPG-FEF/UNICAMP.

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Received: 20/09/2010
Accepted: 14/10/2010