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Aim. Lactate minimum test (LMT) has become popular in running evaluation. This study analysed the influence of different stage lengths and determination methods on lactate minimum swimming speed (LMS) and its validity for maximal lactate steady-state speed (MLSS-S) assessment.

Methods. Twelve male swimmers (19.7±1.6 years, 70.3±8.7 kg, 181.4±7.9 cm) randomly underwent 4-5 evaluations in a 2-week period. LMS was accessed by simple visualisation (SV) and spline function (SF) methods during 200 and 300 m stages LMT (LMT200 and LMT300, respectively), and MLSS-S was determined during constant speed 2000 m efforts.

Results. Respectively, SV and SF provided LMS during LMT200 (1.31±0.12 m.s⁻¹ and 1.32±0.10 m.s⁻¹) and LMT300 (1.28±0.11 m.s⁻¹ and 1.28±0.10 m.s⁻¹) which were not significantly different (p>0.05) from each other. However, LMS accessed during LMT200 were significantly greater (p<0.05) than MLSS-S (1.25±0.06 m.s⁻¹). In addition, significant relationships (r=0.79 to 0.98; p<0.05) were found between all studied speeds and lactate minimum values during LMT300 were not significantly different (p>0.05) from those found during LMT200 (5.4±2.2 and 5.5±2.2 mM vs 6.8±2.5 and 7.0±2.6 mM, respectively for SV and SF).

Conclusions. Our results suggest that LMS is not affected by different stage lengths and determination methods. However, LMT300 results seems to provide a more accurate MLSS-S prediction, being accurate for swimmers evaluation.

Key words: Anaerobic threshold - Swimming - Research design.

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Among the protocols used to access the aerobic-anaerobic transition during exercise, or anaerobic threshold, a lactate minimum test (LMT) has received special attention during the past 2 years. This test consists of an incremental exercise session after acidosis induction, and since blood lactate shows an "U" shaped response during the graded phase, its lowest level theoretically represents the maximal exercise intensity in which a balance exists between the rate of appearance of lactate in the blood and its rate of removal from the blood, or maximal lactate steady-state, which in turn is the "gold standard" in anaerobic threshold assessment.

Due to its objectivity and independence of previous nutritional status, LMT has become a popular method of athletic evaluation. However, lactate minimum speed (LMS) during running can be affected by different protocol manipulations, including the initial speed and stage length during the graded phase of LMT.
TABLE I.—Subjects characteristics (n=12).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Age (years)</th>
<th>Body mass (kg)</th>
<th>Height (cm)</th>
<th>Body fat (%)</th>
<th>Years of training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean±SD</td>
<td>19.7±1.6</td>
<td>70.3±8.7</td>
<td>181.4±7.9</td>
<td>10.3±3.3</td>
<td>7.2±1.8</td>
</tr>
</tbody>
</table>

In addition, controversial results have been presented concerning the validity of LMT for maximal lactate steady-state speed (MLSS-S) prediction.\(^2,\)\(^6,\)\(^7\)

Different methods have been employed for LMS determination. While most authors choose to fit the lactate-exercise intensity data to a spline function,\(^2,\)\(^4,\)\(^6\) others used no mathematical adjustment and simply considered the lowest blood lactate concentration attained during the test.\(^5,\)\(^7\) Although previous papers suggested that lactate minimum intensity can be influenced by the mathematical procedure employed for its determination,\(^3,\)\(^4,\)\(^7\) no study has compared these two methods.

In swimming, as in other cyclic activities, anaerobic threshold has been used for prescribing and evaluating training programs and for performance prediction.\(^12\) However, in spite of the increasing interest in running LMT, no paper was found dealing with swimming LMT.

In this context, the aims of this study were to analyse: 1) the effect of stage length (200 vs 300 m) during the graded phase of LMT on the LMS; 2) the influence of the determination method (mathematical vs non-mathematical) on LMS and 3) the validity of LMT for MLSS-S assessment during swimming.

**Materials and methods**

**Subjects**

After having the possible benefits and risks of participation in the experimental protocol fully explained to them, 12 Brazilian male trained swimmers of national level gave their written consent and volunteered to take part in this study, which was approved by the São Carlos Federal University Ethics Committee. Subjects characteristics are presented in Table I.

**Experimental procedures**

Within 2 weeks in preseason period, all swimmers underwent 4 or 5 exercise sessions separated by at least 48 hours each other. Two lactate minimum tests and 2 or 3 constant speed 2000 m swims were performed in a random order in a 25 m swimming pool (26-27°C water temperature) in a 2 hours postprandial state. Individual warm-up regimens were employed before each test and caffeine ingestion and hard physical activity were avoided in the 24 hours preceding them. The crawl stroke was the only swimming style evaluated.

**Lactate minimum tests**

Lactate minimum speeds were determined in 2 different lactate minimum tests: LMT200 and LMT300, which were identical except for the stage length used during the graded phase. Initially, 2 maximal 50 m sprints with 1 min rest interval were performed for high blood lactate accumulation. Following 8 min of passive recovery, 200 (for LMT200) or 300 m (for LMT300) stage length incremental series were performed, with initial speeds ranging individually from 1.05 to 1.25 m·sec\(^{-1}\), and increments of 0.05 m·sec\(^{-1}\) each step until the swimmers could not keep the pace. Initial speeds were chosen in a way that the athletes could perform at least 5 repetitions until fatigue occurs and were kept constant for a single subject in both tests. Swimming speeds were controlled by visual signals each 25 m. Different signals were used to ask the athletes to swim faster, slower or keep the pace in order to perform each turn in pre-determined times. Blood samples were taken at rest, 7 min after the second maximal 50 m sprint and during 45 sec intervals between each graded effort for posterior analysis of blood lactate concentration.

Lactate minimum swimming speeds were accessed in both tests by the lowest blood lactate value directly obtained during the graded phase, or simple visualisation (SV) method, and by a cubic spline function fitting the swimming speed-blood lactate data (MATLAB Student's Version), or spline function (SF) method (Figure 1).

**Maximal lactate steady-state**

For MLSS-S determination, the athletes underwent 2 or 3 constant speed 2000 m with 45 sec rest each 400 m
for blood sampling. MLSS-S was considered the maximal swimming speed which elicited no more than 1 mM blood lactate increase between 800 and 2000 m. Depending on the results of prior session, swimming speeds were increased or decreased by 0.05 m.s⁻¹ for the next 2000 m effort, in a way that each swimmer performed at least one supra MLSS-S effort. Initial speeds were chosen by each athlete from a table containing 100 m split times for speeds ranging from 1.0 to 1.8 m.s⁻¹ with 0.05 m.s⁻¹ steps. Swimmers were instructed to select the maximal speed that could be maintained during continuous 2000 m swim. Swimming speeds were continuously controlled thorough the tests by visual signals each 25 m. Blood lactate concentration at MLSS-S ([lac]ss) was considered the mean value of blood lactate concentrations obtained from 800 to 2000 m during MLSS-S effort.

**Blood analysis**

Twenty-five μl blood samples were taken in calibrated capillaries from athlete’s earlobes and immediately placed and iced in 1.5 ml Eppendors containing 50 μl NaF 1% solution for posterior electrochemical blood lactate analysis (YSI 2700 STAT analyser, Yellow Springs Co., USA).

**Statistics**

Mean and standard deviation (SD) values were calculated for all data and Pearson Product Moment correlation coefficients were employed to evaluate relationships between swimming speeds. Two-way ANOVA was used for comparisons between different lactate minimum speeds and lactate minimum concentrations during LMT (method vs distance), and blood lactate

**Table II.**—Swimming speeds and blood lactate concentrations assessed in different evaluations (n=12).

<table>
<thead>
<tr>
<th>Athlete</th>
<th>LMS (m.s⁻¹)</th>
<th>[lac] (mM)</th>
<th>LMS (m.s⁻¹)</th>
<th>[lac] (mM)</th>
<th>LMS (m.s⁻¹)</th>
<th>[lac] (mM)</th>
<th>MLSS-S (m.s⁻¹)</th>
<th>[lac] (μM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.40</td>
<td>3.5</td>
<td>1.38</td>
<td>3.6</td>
<td>1.35</td>
<td>4.1</td>
<td>1.36</td>
<td>4.0</td>
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<tr>
<td>B</td>
<td>1.45</td>
<td>7.9</td>
<td>1.46</td>
<td>7.8</td>
<td>1.40</td>
<td>5.3</td>
<td>1.42</td>
<td>5.7</td>
</tr>
<tr>
<td>C</td>
<td>1.45</td>
<td>8.6</td>
<td>1.44</td>
<td>8.7</td>
<td>1.40</td>
<td>6.5</td>
<td>1.36</td>
<td>6.8</td>
</tr>
<tr>
<td>D</td>
<td>1.40</td>
<td>10.9</td>
<td>1.36</td>
<td>11.2</td>
<td>1.35</td>
<td>8.1</td>
<td>1.35</td>
<td>8.1</td>
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<tr>
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<td>8.7</td>
<td>1.45</td>
<td>9.0</td>
<td>1.40</td>
<td>5.8</td>
<td>1.40</td>
<td>6.3</td>
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<tr>
<td>F</td>
<td>1.25</td>
<td>6.9</td>
<td>1.27</td>
<td>7.5</td>
<td>1.25</td>
<td>5.1</td>
<td>1.25</td>
<td>5.1</td>
</tr>
<tr>
<td>G</td>
<td>1.35</td>
<td>6.7</td>
<td>1.34</td>
<td>6.7</td>
<td>1.24</td>
<td>4.3</td>
<td>1.28</td>
<td>4.8</td>
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<td>H</td>
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<td>9.8</td>
<td>1.28</td>
<td>10.1</td>
<td>1.30</td>
<td>10.4</td>
<td>1.27</td>
<td>10.4</td>
</tr>
<tr>
<td>I</td>
<td>1.20</td>
<td>6.9</td>
<td>1.24</td>
<td>6.9</td>
<td>1.24</td>
<td>5.1</td>
<td>1.24</td>
<td>5.2</td>
</tr>
<tr>
<td>J</td>
<td>1.25</td>
<td>4.3</td>
<td>1.26</td>
<td>4.3</td>
<td>1.20</td>
<td>4.3</td>
<td>1.20</td>
<td>4.4</td>
</tr>
<tr>
<td>K</td>
<td>1.20</td>
<td>4.9</td>
<td>1.19</td>
<td>4.8</td>
<td>1.10</td>
<td>3.9</td>
<td>1.12</td>
<td>3.8</td>
</tr>
<tr>
<td>L</td>
<td>1.15</td>
<td>2.8</td>
<td>1.14</td>
<td>3.0</td>
<td>1.10</td>
<td>1.6</td>
<td>1.10</td>
<td>1.7</td>
</tr>
</tbody>
</table>

| Mean    | 1.31        | 6.8        | 1.32        | 7.0        | 1.28        | 5.4        | 1.28           | 5.5        |
| SD      | 0.12        | 2.5        | 0.10        | 2.6        | 0.11        | 2.2        | 0.10           | 2.2        |

LMT200=lactate minimum test with 200 m stages; LMT300=lactate minimum test with 300 m stages; MLSS=maximal lactate steady-state test; SV=simple visualisation method; SF=spline function method; LMS=lactate minimum speed; [lac]=minimum blood lactate concentration; MLSS-S=maximal lactate steady-state speed; [lac]ss=blood lactate concentration at MLSS-S. *p<0.05 from MLSS-S; **p<0.05 from [lac]ss.
Table III.—Correlation coefficients between studied speeds (n=12).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LMS-SF (LMT200)</th>
<th>LMS-SV (LMT300)</th>
<th>LMS-SF (LMT300)</th>
<th>MLSS-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMS-SV (LMT200)</td>
<td>0.96*</td>
<td>0.87*</td>
<td>0.91*</td>
<td>0.80*</td>
</tr>
<tr>
<td>LMS-SF (LMT200)</td>
<td>—</td>
<td>0.95*</td>
<td>0.97*</td>
<td>0.79*</td>
</tr>
<tr>
<td>LMS-SV (LMT300)</td>
<td>—</td>
<td>—</td>
<td>0.98*</td>
<td>0.80*</td>
</tr>
<tr>
<td>LMS-SF (LMT300)</td>
<td>—</td>
<td>—</td>
<td>0.82*</td>
<td></td>
</tr>
</tbody>
</table>

LMS-SV = lactate minimum speed by simple visualization method; LMS-SF = lactate minimum speed by spline function method; MLSS-S = maximal lactate steady-state speed; LMT200 = lactate minimum test with 200 m stages; LMT300 = lactate minimum test with 300 m stages; *p<0.05.

Values during 2000 m efforts (effort vs time). Scheffe’s posthoc test was used when significant differences were found. Student’s "t"-test for paired samples was employed for other comparisons and statistical significance was set at p<0.05 in all cases.

Results

Student’s “t”-test showed no significant differences (p>0.05) between LMT200 and LMT300 for rest (1.1±0.2 vs 1.1±0.3 mM) and peak blood lactate concentrations after 50 m efforts (11.3±2.8 vs 10.4±3.8 mM). In spite of a tendency to performance decrease in the second maximal 50 m both in LMT200 (27.5±2.0 vs 28.7±1.9 sec) and LMT300 (27.6±2.1 vs 29.1±2.2 sec), according to 2-way ANOVA (effort vs LMT), no significant differences (p>0.05) were found between sprint performances.

Table II shows LMS to be not significantly affected (p>0.05) by different stage length or determination method. In addition, “t”-test showed that both SV and SF methods provided lactate minimum speeds during LMT300 which were not significantly different (p>0.05) from MLSS-S, which in turn was significantly lower (p<0.05) than lactate minimum speeds accessed during LMT200. Significant correlations (p<0.05) were found between all studied speeds and are shown in Table III.

Multiple comparison statistics also showed no significant differences (p>0.05) between minimum blood lactate concentrations attained during different lactate minimum tests by SV and SF methods, although it was found a tendency to reduction with greater stage length. On the other hand, “t”-test showed lactate minimum concentrations attained during LMT200 to be significantly greater (p<0.05) than [lac]ss, which in turn was not significantly different (p>0.05) from minimum blood lactate during LMT300 (Table II).

Figure 2 shows blood lactate behaviour during constant speed efforts. While a relatively constant blood lactate concentration was observed from 800 to 2000 m during MLSS-S trial (0.10±0.5 mM blood lactate decrease), a continuous increase occurred over this distance for 10 athletes during supra MLSS-S trial (2.6±0.9 mM). One swimmer could not go on with supra MLSS-S effort after 1200 m (3.2 mM blood lactate increase) and another one after 1600 m (2.7 mM blood lactate increase). Significant differences (p<0.05) were found between MLSS-S and supra MLSS-S efforts for blood lactate from 1200 to 2000 m.

Discussion and conclusions

In spite of its controversial physiological basis,1, 13, 14 anaerobic threshold has been widely used in cyclic activities for clinical or sports purposes.15 However,
the traditional criterion for anaerobic threshold assessment, like fixed blood lactate concentration \(10, 19, 20\) or visual breakpoint thresholds \(3, 4, 18\) have been criticised for different reasons. While the later seems to be subjective and have a poor inter-reviewer reliability, \(19, 20\) the former does not consider individual blood lactate kinetics \(21\) and its results can be affected by previous muscle glycogen content. \(16, 22\)

In recent years, maximal lactate steady-state has been increasingly accepted as the gold standard evaluation in anaerobic threshold assessment. \(6, 8\) However, direct MLSS-S determination is a lengthy evaluation, requiring various prolonged exercise sessions in different days. \(8\) In this context, LMT has become popular in athletic evaluation due to its objectivity, rapidity and independence of previous nutritional status. \(2, 5, 7\) However, LMS during running seems to be affected by different factors. \(2, 4\) Once its well-known that stage length can influence blood lactate response to graded exercise, \(17, 23, 25\) Tegtbøur et al. \(2\) tested this hypothesis for LMT and showed LMS during 800 m stages \((4.49\pm0.17 \text{ m.secm}^{-1})\) to be not significantly different from that found during 1200 m runs \((4.44\pm0.18 \text{ m.secm}^{-1})\). However, both speeds were significantly lower than LMS during 400 m stages \((4.96\pm0.35 \text{ m.secm}^{-1})\).

Carter et al. \(4\) found lower initial speeds during the graded phase of LMT to elicit lower LMS, being to with the time to reach lactate minimum concentration relatively constant. In addition, the same research group \(3\) showed LMS to be not changed after 6 weeks of aerobic training in 16 students, in spite significant increases in VO\(_2\)max and other lactate related parameters. Together, these results suggest that LMS depends on blood lactate kinetics during LMT, which in turn depends not only on exercise intensity, but time \(2, 4\) and blood lactate values. \(3\)

In above cited studies, a cubic spline function fitting blood lactate - exercise intensity data (SF method) \(3, 4\) was employed for LMS determination. On the other hand, Simões et al. \(5\) and Bacon and Kern \(7\) used a simplified method for LMS assessment during track and treadmill running, respectively. These authors considered only the blood lactate for each step during LMT, without any mathematical adjustment. In the present study this procedure was named simple visualisation (SV) method.

In SV method, blood lactate values are considered only for exercise intensities performed during the test. This means that LMS was determined with an error lower than 0.05 m.secm\(^{-1}\) by SV in the present work. On the other hand, SF method provides prediction of blood lactate concentrations for non-performed swimming speeds through cubic spline interpolation. Once we considered 2 decimal places for swimming speeds values, spline function method lowered error to less than 0.01 m.secm\(^{-1}\).

Looking for a possible explanation for lower LMS in relation to lactate threshold (LT) speed when starting speeds of LMT where 2-3 km.h\(^{-1}\) below LT, Carter et al. \(4\) argued that lower initial speeds could result in fast blood lactate fall before rising again close to LT. According to the authors, in this situation SF method provides a LMS that is between the fall and new increase in blood lactate concentration.

Mathematical adjustment could also partly explain the non-sensitivity of LMS to training. Once identical LMT were employed in pre- and post-training situations, initial speeds after training could result in lower relative intensities, which in turn could lead to faster blood lactate decreases and lower LMS due to the spline function methods. \(4\) Thus, the authors stated that the mathematical procedure employed for LMS determination may not be sufficiently sensitive to changes in fitness in this situation. Theoretically, 3 possible situations could occur when comparing SF and SV methods. Depending on the shape of blood lactate response to LMT, LMS by SF method could be grater, lower or equal to LMS by SV method. However, no study has analyzed this question.

With respect to LMT validity for MLSS-S assessment, controversial results have been found. \(2, 3, 6, 7\) Although they did not present the criterion used for MLSS-S determination, Tegtbøur et al. \(2\) found LMS to be sustained during an 8 km run with elevated but constant blood lactate levels, while 0.2 m.secm\(^{-1}\) speed increase caused blood lactate to elevate continuously throughout the run, leading many subjects to stop running before 8 km.

While Jones and Doust \(6\) and Carter et al. \(3\) found LMS to underestimate MLSS-S for male distance runners and sport science students, respectively, Bacon and Kern \(7\) showed no significant differences between these speeds for 10 active women. These controversial results could be partially explained by different MLSS-S definitions employed in these studies, \(i.e.,\) no more than 1 \(3, 6, 7\) vs 0.5 \(7\) mM blood lactate increase during constant load exercise, but several factors may have also contributed to these discrepancies, including different experimental designs, exercise protocols, subjects and LMS determination methods.
Although much attention have been devoted to running LMT, this is not true for swimming. According to Pyne et al., the paucity of studies with swimming reflects the relative easy use of laboratory ergometry compared with pool side metabolic measures. Thus, in order to answer questions about swimming LMT, in the present study we employed direct MLSS-S assessment and LMT200 and LMT300 protocols, with LMS being determined both by SV and SF methods.

Very similar results and high significant relationships were found between LMS accessed by different methods in the same test (maximal differences of 6.7% for LMT200 and 3.2% for LMT300). Although a more mathematical approach is beyond the scope of this study, these results suggest that depending on the shape of the blood lactate response to LMT, LMS can be affected by the method employed. However, the magnitude of this alteration seems to be small, leading to close values. No study was found dealing with this question, so it is not possible to compare ours and others results.

Although a tendency to reduction with great stage length protocol, no significant differences and high significant relationships were found between LMS in LMT200 and LMT300 (maximal differences of 8.3% for SV and 5.9% for SF). These results are in agreement to Teghtsir’s et al., findings for endurance runners when comparing 800 and 1200 m stages. However, these authors do not mention the stage duration attained by their subjects for the different stage lengths employed. Thus, we cannot state that the stage length influence on LMS depends on the exercise type performed. Once no significant differences were found between our protocols in relation to maximal 50 m efforts and peak blood lactate levels, the possible influence of these variables on LMS determination can be excluded.

No study was found in the international literature dealing with maximal lactate steady state determination during swimming. Studying the blood lactate response of 8 male trained swimmers to 3 series of 4x400 m repetitions at respectively 98%, 100% and 102% of the critical velocity, Wakayoshi et al. found blood lactate to remain at a steady-state level (3.2 mM) at 100% of critical velocity (1.43±0.02 m.sec'). Evaluating 59 German top class swimmers, Obrecht et al. found 4.01±0.05 mM blood lactate after a 30 min maximal swim (1.36±0.05 m.sec'). However, these authors did not directly accessed MLSS-S. Thus, we designed a protocol trying to reproduce, as close as possible, sampling intervals and criteria recently suggested for maximal lactate steady state assessment in different cyclic activities, i.e., blood sampling each 5 min and lower than 1 mM blood lactate increase between 10 and 30 min of effort. Swimming speeds choose by our swimmers (from 1.15 to 1.40 m.sec') provided real swimming times from approximately 24 to 29 min, with swimming times between each blood sampling varying from approximately 5 to 6 min.

As in other field and laboratory studies, in which earlobe blood sampling is not possible during continuous exercise, brief pauses at regular distances were employed in the present work. Obrecht et al. suggested that a higher swimming speed for a given blood lactate level is possible during intermittent vs continuous exercise. In this context, MLSS-S could be over-estimated by the protocol employed in the present study. However, to our knowledge no study was conducted to analyse the influence of brief pauses for blood sampling on MLSS-S or maximal blood lactate stability.

Due to the lack of literature about direct maximal lactate steady-state evaluation during swimming, it is not possible to compare our results. In spite of limitations related to different protocols and exercise types, blood lactate at MLSS-S found in the present study was close to those recently reported by others for different cyclic activities.

LMS during LMT200 overestimated MLSS-S (mean differences of 5.3% for SV and 5.7% for SF). On the other hand, MLSS-S was not statistically different from LMS during LMT300 (mean differences of 2.5% for SV and 2.6% for SF). The significant relationships found between all LMS and MLSS-S (r=0.79 to 0.83) are greater than that reported previously by Jones and Doust for runners (r=0.61). Probably, this discrepancy could be explained by the fact that we employed a more heterogeneous group. Interesting, we found the highest relationship to occur between LMS determined by SF method during LMT300 and MLSS-S (r=0.83).

Once the main lactate production and clearance sites are located in different parts of the body during exercise, only when equally distributed in body fluids blood lactate concentration represents an equilibrium between its production and removal. Due to lactate diffusion kinetics across cellular membranes and blood
too short stages during an incremental test could lead to lactate values that don’t represent the real metabolic demand for a given exercise intensity. Thus, Tegtbier et al., suggest that LMS only represents the steady-state condition when LMT stages are not too short.

For the swimming speeds used in this study (1.05 to 1.55 m/sec') stages duration ranged from 129 to 190 sec for LMT200 and 193 to 286 sec for LMT300. Thus, we suggest that 3 min or greater stages are more adequate when one’s objective is to access maximal lactate steady-state.

This is supported by the tendency for greater lactate minimum values during LMT200 when compared to LMT300 and blood lactate at MLSS-S. Greater stage length protocols may provide additional time at each exercise level for lactate output and clearance processes to attain an steady-state condition.

Comparison with other’s results in relation to swimming LMT are not possible due to lack of literature. However, lactate minimum speeds and MLSS-S values found in the present study are close to those reported by others using different anaerobic threshold assessment methods for elite swimmers.

Our results suggest that LMS is not significantly affected by different stage length and determination method during swimming. However, 300 m steps test may provide a more accurate MLSS-S prediction. Once SF method requires complex mathematical adjustment, SV seems to offer some advantage over it. In addition, more studies are needed to better understand the factors that influence lactate minimum intensity determination in field and laboratory conditions and the validity of LMT for maximal lactate steady-state determination.

References

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