Indices of lactate threshold and their relationship with 10-km running velocity

ROBERT M. NICHOLSON and GORDON G. SLEIVERT

School of Physical Education, University of Otago, P.O. Box 56, Dunedin, NEW ZEALAND

ABSTRACT

NICHOLSON, R. M. and G. G. SLEIVERT. Indices of lactate threshold and their relationship with 10-km running velocity. Med Sci Sports Exerc., Vol. 33, No. 2, 2001, pp. 339–342. Purpose: The object of this study was to determine the relationship of three measures of running velocity at lactate threshold (LT) with 10-km running velocity. The methods used to determine LT velocity (m.s⁻¹) during submaximal treadmill running were: 1) LT₁, the velocity preceding two consecutive increases in blood lactate ≥ 1 mmol.L⁻¹; 2) LT₂, the velocity associated with the maximum perpendicular distance between the nonlinear regression line and the straight line formed by the two end data points of the blood lactate profile; and 3) LT₃, the velocity corresponding to a blood lactate concentration of 4 mmol.L⁻¹. Methods: Thirty competitive and recreational runners (11 female and 19 male) undertook two 10-km time trials (7 d apart), three treadmill familiarization sessions over the following 21 d, and then completed an incremental submaximal treadmill run. From blood lactate samples taken during the submaximal run, mean LT velocity (± SD) at LT₁ (3.76 ± 0.57), LT₂ (3.73 ± 0.58), and LT₃ (4.11 ± 0.64) was determined. Pearson product moment correlation analysis revealed a strong relationship between all mean LT speeds and mean 10-km running velocity (3.77 ± 0.57), with the strongest relationship observed for LT₁ (r = 0.86, P < 0.001). Correlations by gender between LT₁ and 10-km velocity were r = 0.84 (female) and r = 0.78 (male). Male subjects had significantly higher LT velocities than female subjects using all methods (P < 0.001), and velocity at LT₃ was significantly faster than 10-km velocity and velocity at LT₁ and LT₂ (P < 0.001). Conclusion: Of the methods measured, LT₁ appears to be the most sensitive and valid measure of LT velocity and may be of benefit in monitoring the training program of 10-km distance runners. Key Words: LACTATE THRESHOLD, DISTANCE RUNNING, PERFORMANCE, VALIDITY, TRAINING

Despite debate within the scientific community about the determination of lactate threshold (LT), many sport scientists use this parameter to assess the physiological capacity of athletes and to establish training intensity. The use of this concept appears to be based on scientific findings that LT running velocity is highly predictive of distance running performance, including the 10,000 m and marathon (1.5–8). These findings appear to hold regardless of gender and training status (2.9,10,17,19).

Numerous methodological approaches have been suggested as providing the best measure of LT, but little work has been undertaken to ascertain the relative robustness and sensitivity of various measures of LT. Three commonly utilized LT methods are the focus of this paper. Thoden (18) suggested that LT is best represented by the running velocity that precedes workloads resulting in consecutive increases in blood lactate ≥ 1 mmol.L⁻¹. Another recommended method is to use the running velocity associated with a blood lactate concentration of 4 mmol.L⁻¹ (11). More recently, the Dmax method has been suggested as an effective means of measuring AT (4). The Dmax method calculates LT as being the point associated with the maximum perpendicular distance between the nonlinear regression line and the straight line formed by the end two data points of a blood lactate profile. Although these methods have been compared for female cyclists (3), direct comparisons of these LT indices for distance runners have not been reported in the literature. Consequently, the purpose of this paper was to determine the relationship of LT calculated using three different methods of 10-km running velocity in a mixed gender sample of recreational and competitive runners.

METHODS

Ethical approval was obtained from the Southern Regional Health Authority, and each participant provided written informed consent before the study was undertaken. Before undertaking the test protocols, all participants were provided with dietary and hydration advice to promote maximal performance and to guard against the potential negative impact of glycogen depletion upon lactate values (13).

Protocol. Thirty participants who were actively engaged in running undertook two 10-km time trials on an
Table 1. Descriptive characteristics of subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Whole Group (N = 30)</th>
<th>Female (N = 11)</th>
<th>Male (N = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>55.1</td>
<td>8.8</td>
<td>47.6*</td>
</tr>
<tr>
<td>Age</td>
<td>23.7</td>
<td>7.3</td>
<td>21.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.6</td>
<td>8.8</td>
<td>165.9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.5</td>
<td>11.1</td>
<td>59.3</td>
</tr>
</tbody>
</table>

* Significantly greater than female values (P = 0.001).

indoor 400-m track (Table 1). The trials were 7 d apart, began at 7 a.m., and each was preceded by a self-determined warm-up of 10 min. Analysis of the 10-km trial data revealed a coefficient of variance of 3.7%. The best 10-km time for each individual was used for statistical analysis. The male runners had significantly higher VO₂max values, were significantly heavier and taller, and were also older than the female runners (Table 1).

During the next 21 d, each participant was required to undertake three treadmill running familiarization sessions each of 15 min duration on a motorized treadmill (Quinton Series 90 Q65, Seattle, WA) to ensure full treadmill accommodation (16). Twenty-one days after their second 10-km time trial, each subject completed an incremental treadmill running test to determine their blood lactate-running velocity profile. The protocol required that each subject begin the test at a running velocity 2 km·h⁻¹ below their mean 10-km running velocity. Workload was increased by an increment of 1 km·h⁻¹ per work period and a work:rest ratio of 5:1 min was employed. The test continued until volitional exhaustion. During each rest period, a blood sample was taken from the right earlobe and immediately analyzed for blood lactate using an automated blood lactate analyzer (YSI 1500, Yellow Springs, OH) previously calibrated using standard lactate concentrations of 5 and 15 mmol·L⁻¹.

Two days before the submaximal test, all participants undertook a VO₂max test. This timing of the VO₂max test with respect to the 10-km time trials was to enable subjects who were being prepared for another experimental time to become accommodated to running on a treadmill. A 5-min warm-up preceded the maximal aerobic power test, which was undertaken on the same motorized treadmill used for the submaximal test. For each participant, the initial testing velocity was the same as used in the submaximal test. Each workload was maintained for 2 min and each subsequent workload velocity increased by 1 km·h⁻¹. After 6 min, the treadmill velocity remained constant, but the gradient was raised by 2% upon completion of every additional minute of work. Cessation of the test was at the discretion of the tester or by the runner’s personal volition. Before each test, the O₂ and CO₂ gas analyzers were calibrated with known gas concentrations and the volume transducer with a 3-L syringe. For both the maximal and submaximal VO₂ tests, oxygen cost was measured during each work period using open-circuit spirometry (SensorMedics 2900, Yorba Linda, CA).

From this protocol, a running velocity-blood lactate profile was obtained for each subject. Lactate threshold velocity at 1 mmol·L⁻¹ (LT₁) was determined by finding the velocity at which blood lactate initially increased by an amount ≥ 1 mmol·L⁻¹ for consecutive workloads (18). A nonlinear function (continuous exponential plus constant) described by Hughson et al. (12) was then fitted to the blood-lactate-running velocity profile using Automated Curve Fitting Software (Table Curve 2D, Jandel, U.S.). Applying the technique described by Cheng et al. (4), a straight line was drawn between the minimum and maximum lactate points (see Cheng et al.’s Fig. 4). The velocity associated with the widest point between the curve and this line was designated the D_max LT velocity (LT₃). Interpolation of the nonlinear function enabled the prediction of LT velocity at 4 mmol·L⁻¹ (LT₄). The determination of LT velocity using the three methods described is illustrated in Figure 1.

**Data analysis.** The relationship between running velocity at LT defined by LT₃, LT₁, and LT₄, as well as the relationship between these variables, and 10-km running velocity was determined using Pearson product moment correlation analysis. To ascertain the applicability of the results to other sample populations, 95% confidence inter-
TABLE 2. Mean value and standard deviation for velocity (m·s⁻¹) at LT by method and 10-km running velocity.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Population (N = 30)</th>
<th>Female (N = 11)</th>
<th>Male (N = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>LT₅₀</td>
<td>3.76 (0.58)</td>
<td>3.32 (0.73)</td>
<td>4.05 (0.54)</td>
</tr>
<tr>
<td>LT₁₀</td>
<td>3.67 (0.57)</td>
<td>3.36 (0.19)</td>
<td>4.01 (0.58)</td>
</tr>
<tr>
<td>LT₄</td>
<td>4.11 (0.64)</td>
<td>3.60 (0.27)</td>
<td>4.40 (0.57)</td>
</tr>
<tr>
<td>10-Km</td>
<td>3.77 (0.57)</td>
<td>3.26 (0.39)</td>
<td>4.07 (0.44)</td>
</tr>
</tbody>
</table>

* Represents significant difference from 4 mmol·L⁻¹, P < 0.001.
† Represents significant difference by gender, P < 0.001.

vals were determined. A two-way analysis of variance (ANOVA) was used to test for gender and method (repeated measures) effects. Greenhouse-Geisser adjustment for degree of freedom was applied to guard against violation of the sphericity assumption. Test analysis (independent and paired sample) was undertaken to determine where any significant differences between methods or gender existed. The Bonferroni adjustment was applied to the post hoc analysis with values of P < 0.008 being used to test significance.

RESULTS

Two-way ANOVA revealed that velocity at LT was significantly different depending upon the method used to determine LT (F(1,48, 44.1) = 19.389, P < 0.001) and also significantly different between the genders (F(1,525, 14.7) = 21.25, P < 0.001) (Table 2). Post hoc analysis by independent t-tests indicated that male subjects had significantly higher LT velocities than female subjects for all methods (P < 0.001). Paired sample t-tests also revealed that the mean predicted LT₄ velocity was significantly greater than the other LT velocities and greater than the 10-km velocity for the whole population, and for male and female subjects analyzed separately (P < 0.001) (Table 2).

Correlation analysis revealed the existence of a significant relationship between LT velocity calculated using all methods and 10-km running velocity for the whole group (Table 3). The strongest relationship was found to exist between LT₄ and 10-km running velocity. Confidence intervals for all methods were narrow, especially for the LT₄ and the LT₅₀ methods. A similar pattern regarding correlation coefficients and confidence intervals was revealed for the male participants (Table 3). For the female group, a significant relationship was found to exist between LT₄ and 10-km velocity but not LT₅₀, LT₄ and 10-km velocity (Table 3).

DISCUSSION

Key requirements in choosing an LT index to be used as a monitoring tool are that it must be sensitive to small changes, it must be objectively determined, and it must be robust enough to be used for different populations. Of all the LT methods used, LT₄ was the most highly correlated with 10-km velocity, regardless of gender. This finding concurs with the results described for female cyclists exercising for 60 min (3).

All of the methods of determining LT velocity in this study were significantly correlated with 10-km velocity, but mean LT₄ velocity was significantly higher than the mean velocity at LT calculated using the other LT methods, regardless of gender. Consequently, it is likely that LT₄ may be in excess of maximal steady-state lactate velocity. The use of the 4 mmol·L⁻¹ method to determine LT has been questioned on the basis that at that fixed level of blood lactate concentration muscle lactate levels can vary widely (9). These variations in lactate levels may be induced by factors including nutrition, prior stress, and muscle fiber distribution (15). Furthermore, Coyle (9) argues against the implication that 4 mmol·L⁻¹ is the maximal steady-state blood lactate concentration at which people can exercise for long periods, indicating that athletes are capable of exercising for 60 min with blood lactate concentrations of 6-10 mmol·L⁻¹. Consequently, it may be more effective to develop a performance-diagnostic tool derived from lactate kinetics than from absolute values (15).

Similarly, the LT₁₀ method may lack sensitivity in measuring LT because no between workload interpolation of running velocity is used with this method. This possible lack of sensitivity inherent in the LT₁₀ method could explain the lower correlation of this parameter with 10-km velocity. Furthermore, it could lead to the under- or over-estimation of LT intensity, thereby reducing the utility of accurately setting training paces based on this index, or the ability of

TABLE 3. Correlation of lactate threshold running velocities with 10-km running velocity for the whole group and by gender.

<table>
<thead>
<tr>
<th>Method</th>
<th>Whole Population (N = 30)</th>
<th>Female (N = 11)</th>
<th>Male (N = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95%</td>
<td>Confidence Interval</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>r</td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>LT₅₀</td>
<td>0.86*</td>
<td>0.93</td>
<td>0.72</td>
</tr>
<tr>
<td>LT₁₀</td>
<td>0.78*</td>
<td>0.89</td>
<td>0.58</td>
</tr>
<tr>
<td>LT₄</td>
<td>0.63*</td>
<td>0.92</td>
<td>0.67</td>
</tr>
</tbody>
</table>

* Significant at P < 0.001 (two-tailed).
this method to detect small changes in LT over time. The velocity at LT is probably more useful as a monitoring tool to track aerobic status than as a tool to help set training pace, because a variety of training paces are generally used by endurance athletes (14).

In conclusion, LT_D was not significantly different from mean 10-km velocity and was more strongly correlated to 10-km velocity than either LT_4 or LT_1. LT_D, therefore, provides a relatively sensitive, simple, and objective means of estimating a running velocity that can be sustained for 30–40 min.

This study was supported by Sport Science New Zealand. Address for correspondence: Robert M. Nicholson, School of Physical Education, University of Otago, P.O. Box 56, Dunedin, New Zealand; E-mail: micholson@pooka.otago.ac.nz.

REFERENCES