Relationship Between Running Velocity of 2 Distances and Various Lactate Parameters

Charilaos Papadopoulos, J. Andrew Doyle, and Brian D. LaBudde

Purpose: The purpose of this study was to determine the relationship between various lactate-threshold (LT) definitions and the average running velocity during a 10-km and a 21.1-km time trial (TT). Methods: Thirteen well-trained runners completed an incremental maximal exercise test, a 10-km TT, and a 21.1-km TT on a motorized treadmill. Blood samples were collected through a venous catheter placed in an antecubital vein. Pearson’s correlation coefficients were used to determine the relationship between the running velocity at the different LT definitions and the average running velocity during each TT. A dependent t test was used to determine statistical differences for the mean lactate response between the 2 running distances. Results: The LTDmax, the point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the 2 endpoints, was the LT definition with the highest correlation for both 10-km (r = .844) and 21.1-km TTs (r = .783). The velocity at the LTDmax was not, however, the velocity closest to the performance velocity for either distance. The mean running velocity at each LT was significantly different and tended to overestimate the mean TT performance velocities. The mean lactate concentration during the 10-km TT (3.52 ± 1.58 mmol) was significantly higher than during the 21.1-km TT (1.86 ± 0.90 mmol). Conclusion: These results indicate that a single LT point cannot be reliably associated with different running distances. Furthermore, these data suggest that a different methodology for estimating the LT that considers individual responses might be required for different running distances. Key Words: blood lactate, time trials, correlation, Dmax

The lactate threshold (LT) is commonly used to predict endurance-exercise performance,1-3 to prescribe exercise-training intensity,4 and to monitor training adaptations.5 By definition, then, the LT should occur at a single exercise intensity, either a power output or a velocity. Over the last 3 decades, however, a number of different criteria have been used to identify the LT,6 resulting in inconsistent determinations.
In the 1970s and early 1980s, the LT was defined as the oxygen consumption or running velocity at which blood lactate increased above resting or baseline \(^7,8\) or as the point \(1.0\) mmol above baseline.\(^1\) A visual determination was used to specify the breakpoint, a procedure that was subsequently criticized for its lack of objectivity.\(^9\) Others proposed a fixed blood-lactate model with criterion values of \(2.2\) mmol,\(^4\) \(2.5\) mmol,\(^10\) or \(4.0\) mmol.\(^3,9\) The use of fixed values was also criticized, however, because it does not allow for intersubject variability.\(^11\) A number of mathematical models were subsequently generated, including the log-log transformation model\(^12\) and the Dmax model.\(^11\)

Although all these LT models are independently supported by published studies that provide evidence that the “point” determined by each method correlates significantly with either performance over a specific distance (eg, \(10\) km, marathon)\(^10,13\) or an array of distances (eg, \(400\) m to marathon),\(^1,4\) there is no consensus as to which model best predicts endurance performance. Indeed, it is possible that different LT definitions will predict performance over different distances.

The many attempts to determine the LT criterion that relates best to actual running events have produced conflicting results.\(^8,13,14\) All of these studies have attempted to correlate several definitions of the LT, as determined by using an incremental exercise protocol, with a specific distance. During prolonged exercise, however, blood-lactate responses are not always the same as predicted from an incremental protocol.\(^15,16\) The question then arises, “How can a single point on the lactate-response curve predict performance at different distances?” As distance or duration vary, so too will the exercise intensity, and with it the lactate response. Although there are published reports of the relationship between the different lactate definitions and the running performance of a single distance,\(^13,14\) few studies have attempted to report the lactate responses during actual running events or laboratory time trials and to compare these values with those obtained during the LT tests.\(^17,18\)

Therefore, the purpose of this study was to determine the relationship and the magnitude of the difference between the velocity as determined by various LT definitions and the average running velocity of common road-race distances (\(10\) km and \(21.1\) km). In addition, the aim of this study was to compare the lactate responses between the 2 distances and the extent of subject variability in lactate responses.

**Methods**

**Subjects**

Thirteen well-trained endurance runners completed the study. Physical characteristics of the subjects are presented in Table 1. Each subject had a minimum of 3 years involvement in endurance running events and in the preceding year had completed at least one \(10\)-km race in a time less than \(40\) minutes, as well as either a half-marathon or a marathon. No subject had more than 1 major risk factor as established by the American College of Sports Medicine,\(^19\) indicating they were at low risk for coronary artery disease. Each subject completed a health history and a running-history form, was fully informed of the procedures and potential risks associated with participation, and signed the written consent form, implying
willingness to comply with the testing protocols. The study was approved by the Institutional Review Board at Georgia State University.

Maximal Exercise Test

All subjects were instructed to avoid exercise and maintain a food diary for 2 days before maximal exercise testing. The food diaries were analyzed for total calories and percentage of carbohydrate, fat, and protein. Each subject completed an incremental maximal exercise test on a motorized treadmill (Quinton Instruments Q65, Seattle, Wash) to volitional exhaustion. The testing protocol was a modification of the protocols used by Pfitzinger and Freedson20 and Martin and Coe.21 It was preceded by a 5-minute warm-up at a speed 5 km/h slower than each individual’s 10-km-race pace. The testing protocol consisted of 4-minute stages, the first stage starting at 4.0 km/h slower than the 10-km-race pace, with speed increasing by 1.0 km/h for each successive stage until the subject reached 10-km-race pace for the fifth stage. After the completion of the fifth stage, speed was held constant and the treadmill grade increased by 2% every 2 minutes until the subject reached volitional exhaustion. The same verbal encouragement was given to all subjects.

Oxygen consumption (VO$_2$) and carbon-dioxide production (VCO$_2$) were measured continuously throughout the test using a mixing-chamber metabolic measurement system (ParvoMedics True Max 2400, Salt Lake City, Utah). Gas analyzers and the pneumotachometer were calibrated according to the manufacturer’s specifications before each test to ensure accuracy. Resting and exercising heart rates were measured every minute using a 5-lead electrocardiogram (TM Q4500 Stress Test Monitor/Controller, Quinton Instrument Co). Blood samples were collected at rest, after the warm-up, during the last 30 seconds of each exercise stage, at maximal exercise, and at minutes 1, 3, 5, and 10 of recovery.

Experimental Trials

Each subject performed a 10-km (6.2 miles) time trial and a 21.1-km (13.1 miles) time trial on a treadmill in the laboratory. All subjects performed the maximal
exercise test first, followed by the 10-km time trial and then the 21.1-km time trial, each 2 separated by 1 week. The same treadmill was used for all trials and was calibrated before each trial. The subjects controlled the speed with a programmable controller (Quinton 645 programmable controller, Quinton Instrument Co). Heart rate was monitored using a telemetric system (Polar Vantage XL, Polar Electro Inc, Woodbury, NY) and recorded every 1.6 km. Oxygen consumption was measured at 3 and 8 km during the 10-km time trial and at 8 and 18 km during the 21.1-km time trial. Blood samples were collected at each 1.6 km during the 10-km time trial and every 3.2 km during the 21.1-km time trial. Running time was recorded at each 1.6 km in both trials.

In an attempt to control for variables known to influence blood-lactate measurements, subjects were given very specific pretest instructions. To reduce variations in preexercise glycogen storage, the subjects were instructed to consume the same diet 2 days before each trial and to report for testing at least 4 hours postprandial. In addition, subjects were instructed to refrain from ingesting caffeine or caffeinated beverages for at least 8 hours before testing and to perform an easy 40-minute run 2 days before testing and a 20-minute run 1 day before testing. To minimize variations in hydration, subjects were instructed to consume at least 2000 mL of nondiuretic fluids per day for the 2 days before testing and consume 500 mL (~2 cups) of water during the 3 hours before testing. To control for variations resulting from circadian rhythm, each time trial was conducted within 1 hour of the time of day that the maximal exercise test had been conducted. Furthermore, subjects were instructed to wear the same pair of shoes and running shorts for each test.

**Blood Samples**

Blood samples were collected via a catheter (BD Angiocath™ Autoguard™, BD Medical Systems Inc, Sandy, Utah) placed in an antecubital vein and attached to a 48-in-long collection tube and stopcock. To prevent clotting, a saline solution (0.9% sodium-chloride injection USP, Baxter Healthcare Corp, Deerfield, Ill) was used to fill the catheter and collection tube after each blood-sample removal. All blood samples were collected with the subjects in the upright position to minimize any effect of blood-volume shifts. Five mL of blood per blood draw were collected into a sterile syringe (Becton Dickinson & Co, Franklin Lakes, NJ). One hundred microliters of blood were immediately diluted into 300 μl of lysing agent (YSI 1515 Cell Lysing Agent, Yellow Springs, Ohio).

**Blood Analysis**

All blood samples were analyzed within 24 hours after the completion of the test. Blood lactic-acid concentration in hemolyzed whole blood was determined using an electroenzymatic lactate analyzer (YSI 2300 Stat Plus, Yellow Springs, Ohio).

**Lactate-Threshold Determination**

From the incremental maximal exercise test, a blood-lactate profile was obtained for each subject. Plots of lactic-acid concentration versus running velocity were constructed. LTs were determined according to 7 previously published “definitions” as follows: (1) LTbpt, the running velocity at the point of departure of lactic-acid
concentration from the resting or baseline values as identified by 3 independent raters; (2) LT_{b+1}, the running velocity that was associated with a 1-mmol increase above baseline as identified by the same independent raters; (3) LT_{2.2}, the running velocity at which blood-lactate concentration reached a value of 2.2 mmol; (4) LT_{2.5}, the running velocity at which blood lactate concentration reached a value of 2.5 mmol; (5) LT_{4.0}, the running velocity at which blood lactate concentration reached a value of 4.0 mmol; (6) LT_{Dmax}, the LT calculated by the Dmax method and identified as the point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the 2 endpoints; and (7) LT_{log}, the LT calculated by a statistical method for determining the intersection of 2 lines.

Statistical Analysis

The relationship between the running velocity at each LT (defined by LT_{b+1}, LT_{b+1}, LT_{2.2}, LT_{2.5}, LT_{Dmax}, and LT_{log}) and the mean running velocity for the 10-km and 21.1-km time trials was determined using the Pearson correlation coefficient (r). In this study, the mean running velocity was used as the indicator of performance. A dependent t test was used to determine differences in mean lactate concentration between the 2 running distances. A 2-way repeated-measures ANOVA was used to determine differences in lactate concentration at corresponding distances between the 2 running distances. If statistical significance was found, a Tukey post hoc test was used to identify where those differences occurred. For all statistical comparisons, the level of significance was set at P < .05. Values presented are expressed as mean ± SD.

Results

Pretest controls were successful in standardizing conditions before each experimental trial. Average preexercise body weight was 70.5 ± 6.4 kg and was not significantly different (P = .958) between the incremental maximal exercise test and the time trials. Resting heart rates were 60.8 ± 10.9, 57.2 ± 10.1, and 56.5 ± 11.5 beats/min for the maximal exercise test and 10-km and 21.1-km time trials, respectively. Resting heart rate was not significantly different (P = .245) among testing trials. Average resting lactate concentration was 0.87 ± 0.3 mmol and was not significantly different (P = .108) among experimental trials. Nutritional analysis showed that the subjects consumed an average of 3198 ± 455, 3209 ± 432, and 3235 ± 423 kilocalories during the 2 days before the maximal exercise test and 10-km and 21.1-km time trials, respectively. Carbohydrate intake made up 54% of their diet, whereas 29% was fat and 17% was protein. Statistical analysis indicated that there was no significant difference for total calories (P = .65) or percentage of carbohydrate (P = .78), fat (P = .45), or protein (P = .60) intake among trials.

The mean time for the 10-km time trial was 36.2 ± 2.2 minutes, and the mean velocity was 16.6 ± 1.1 km/h. The mean time for the 21.1-km time trial was 82.4 ± 6.5 minutes, and the mean velocity was 15.5 ± 1.2 km/h. The VO2 assessments revealed that subjects performed at 83% of their V02max during the 10-km time trial and at 76.5% of their V02max during the 21.1-km time trial. Their individual
performance times during the time trials in the laboratory were within 8% of their personal-record times for the same distance over the preceding year.

The running velocities at each of the LT definitions were significantly correlated with the average speed of running during the 10-km time trial \( (r \geq .611, P < .05) \) and the 21.1-km time trial \( (r \geq .59, P < .05; \text{Table 2}) \). The LT definition with the highest correlation coefficient for both the 10-km and the 21.1-km time-trial running velocities was the LT\(_{D_{\text{max}}} \) (Table 2). Other definitions had smaller mean differences in running velocities, for example, LT\(_{2.2} \) for 10 km and LT\(_{\log} \) for 21.1 km (Table 3). A further examination of individual results revealed that the LT\(_{D_{\text{max}}} \) method did not always result in the most accurate determination of time-trial running velocity (Table 4). The velocity identified by the LT\(_{D_{\text{max}}} \) method had the least difference from the average time-trial running velocity for only 6 of the 13 subjects during the 10-km time trial and only 2 of the subjects for the 21.1-km time trial (Table 4). On the other hand, for 8 of the 13 subjects, the velocity determined by the LT\(_{\log} \) method was the least different from the average running velocity during the 21.1-km time trial (Table 4).

The mean lactate concentrations during the time trials (without including the immediate post value, which was affected by the final sprint) were significantly different \( (P = .012) \), 3.52 ± 1.58 and 1.86 ± 0.90 mmol for the 10-km and the 21.1-km time trials, respectively. The pattern of blood-lactate response over the course of the 2 time trials is depicted in Figure 1. Blood lactate rose continuously throughout the 10-km time trial (an increase of 2.6 mmol), whereas it remained at a steady state during the 21.1-km time trial until after the final sprint (no time point more than 0.5 mmol above baseline). The 2-way repeated-measures ANOVA revealed a

### Table 2: Relationship Between the Velocity at Each Lactate-Threshold Definition and Mean Time-Trial Velocity*

<table>
<thead>
<tr>
<th>Definition</th>
<th>10-km time trial</th>
<th>21.1-km time trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT(_{bpt} )</td>
<td>.74</td>
<td>.69</td>
</tr>
<tr>
<td>LT(_{b+1} )</td>
<td>.76</td>
<td>.74</td>
</tr>
<tr>
<td>LT(_{2.2} )</td>
<td>.68</td>
<td>.69</td>
</tr>
<tr>
<td>LT(_{2.5} )</td>
<td>.61</td>
<td>.62</td>
</tr>
<tr>
<td>LT(_{4} )</td>
<td>.64</td>
<td>.60</td>
</tr>
<tr>
<td>LT(<em>{D</em>{\text{max}}} )</td>
<td>.84</td>
<td>.78</td>
</tr>
<tr>
<td>LT(_{\log} )</td>
<td>.75</td>
<td>.77</td>
</tr>
</tbody>
</table>

*LT\(_{bpt} \) indicates the running velocity at the point of departure of lactic-acid concentration from the resting, baseline, values as identified by 3 independent raters; LT\(_{b+1} \), the running velocity that was associated with 1 mmol increase above baseline as identified by the same independent raters; LT\(_{2.2} \), the running velocity at which blood-lactate concentration reached a value of 2.2 mmol; LT\(_{2.5} \), the running velocity at which blood-lactate concentration reached a value of 2.5 mmol; LT\(_{4} \), the running velocity at which blood-lactate concentration reached a value of 4.0 mmol; LT\(_{D_{\text{max}}} \), the lactate threshold calculated by the Dmax method and identified as the point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the 2 endpoints; and LT\(_{\log} \), the lactate threshold calculated by a statistical method for determining the breakpoint of 2 lines. \( P < .05 \) for all values.
Table 3  Mean Running Velocity at the Various Lactate-Threshold Definitions and the Mean Difference in Running Velocity From the 10-km and 21.1-km Time-Trial (TT) Velocities*

<table>
<thead>
<tr>
<th></th>
<th>Running velocity (km/h)</th>
<th>Difference from 10-km TT velocity (km/h)</th>
<th>Difference from 21.1-km TT velocity (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT_{bpt}</td>
<td>14.9 ± 1.3†</td>
<td>−1.7 ± 0.9</td>
<td>−0.5 ± 1.0</td>
</tr>
<tr>
<td>LT_{b+1}</td>
<td>16.4 ± 1.1‡</td>
<td>−0.2 ± 0.7</td>
<td>0.9 ± 0.8</td>
</tr>
<tr>
<td>LT_{2.2}</td>
<td>16.7 ± 1.1‡</td>
<td>0.05 ± 0.9</td>
<td>1.2 ± 0.9</td>
</tr>
<tr>
<td>LT_{2.5}</td>
<td>17.1 ± 1.1‡</td>
<td>0.5 ± 0.9</td>
<td>1.6 ± 1.0</td>
</tr>
<tr>
<td>LT_{4}</td>
<td>18.6 ± 1.2‡</td>
<td>2.0 ± 0.9</td>
<td>3.2 ± 1.1</td>
</tr>
<tr>
<td>LT_{Dmax}</td>
<td>16.8 ± 1.1‡</td>
<td>0.2 ± 0.6</td>
<td>1.3 ± 0.8</td>
</tr>
<tr>
<td>LT_{log}</td>
<td>15.3 ± 1.1†</td>
<td>−1.4 ± 0.8</td>
<td>−0.2 ± 0.8</td>
</tr>
</tbody>
</table>

LT_{bpt} indicates the running velocity at the point of departure of lactic-acid concentration from the resting, baseline, values as identified by 3 independent raters; LT_{b+1}, the running velocity that was associated with 1 mmol increase above baseline as identified by the same independent raters; LT_{2.2}, the running velocity at which blood-lactate concentration reached a value of 2.2 mmol; LT_{2.5}, the running velocity at which blood-lactate concentration reached a value of 2.5 mmol; LT_{4}, the running velocity at which blood-lactate concentration reached a value of 4.0 mmol; LT_{Dmax}, the lactate threshold calculated by the Dmax method and identified as the point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the 2 endpoints; and LT_{log}, the lactate threshold calculated by a statistical method for determining the intersection of 2 lines. Values are mean ± SD.

†Significantly different from 10-km TT, \( P < .05 \) (mean running velocity: 16.6 ± 1.1 km/h).
‡Significantly different from 21.1-km TT, \( P < .05 \) (mean running velocity: 15.5 ± 1.2 km/h).

Discussion

The aim of this study was to determine the relationship between the average running velocity of 2 common road-race distances (10 km and 21.1 km) and the running velocities as determined by various LT methodologies. The major finding of this study is that even though the running velocity determined by the Dmax method had the highest correlation with both the 10-km (\( r = .84 \); Table 2) and 21.1-km (\( r = .78 \); Table 2) distances, it was not the velocity with the smallest mean difference for either one. In addition, this study revealed significant differences in running velocities and lactate responses between the 2 distances and a considerable variability in the relationship between the velocity at which each individual performed and the velocity as determined by the various LT definitions.

Although previous studies have investigated the relationship between either several LT definitions and a single running distance^{13,14} or 1 LT definition and a
Table 4  Lactate-Threshold Definition That Resulted in the Least Difference Between Lactate-Threshold Running Velocity and the Mean Running Velocity During the 10-km and 21.1-km Time Trials for Each Subject*

<table>
<thead>
<tr>
<th>Subject</th>
<th>10-km time trial</th>
<th>21.1-km time trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\text{LT}_{\text{bpt}}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>2</td>
<td>$\text{LT}_{2.5}$</td>
<td>$\text{LT}<em>{\text{Dmax}}$, $\text{LT}</em>{2.2}$</td>
</tr>
<tr>
<td>3</td>
<td>$\text{LT}_{2.5}$</td>
<td>$\text{LT}_{b+1}$</td>
</tr>
<tr>
<td>4</td>
<td>$\text{LT}<em>{\text{Dmax}}$, $\text{LT}</em>{2.5}$</td>
<td>$\text{LT}_{\text{bpt}}$</td>
</tr>
<tr>
<td>5</td>
<td>$\text{LT}_{b+1}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>6</td>
<td>$\text{LT}_{\text{Dmax}}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>7</td>
<td>$\text{LT}_{2.2}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>8</td>
<td>$\text{LT}_{b+1}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>9</td>
<td>$\text{LT}_{\text{Dmax}}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>10</td>
<td>$\text{LT}_{\text{Dmax}}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>11</td>
<td>$\text{LT}_{\text{Dmax}}$</td>
<td>$\text{LT}_{\text{log}}$</td>
</tr>
<tr>
<td>12</td>
<td>$\text{LT}<em>{\text{Dmax}}$, $\text{LT}</em>{b+1}$</td>
<td>$\text{LT}_{\text{bpt}}$</td>
</tr>
<tr>
<td>13</td>
<td>$\text{LT}_{4.0}$</td>
<td>$\text{LT}_{\text{Dmax}}$</td>
</tr>
</tbody>
</table>

*LT$_{\text{bpt}}$ indicates the running velocity at the point of departure of lactic-acid concentration from the resting, baseline, values as identified by 3 independent raters; LT$_{\text{log}}$, the lactate threshold calculated by a statistical method for determining the intersection of 2 lines; LT$_{2.5}$, the running velocity at which blood-lactate concentration reached a value of 2.5 mmol; LT$_{\text{Dmax}}$, the lactate threshold calculated by the Dmax method and identified as the point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the 2 endpoints; LT$_{b+1}$, the running velocity at which blood-lactate concentration reached a value of 2.2 mmol; LT$b+1$, the running velocity that was associated with 1 mmol increase above baseline as identified by the same independent raters; and LT$4.0$, the running velocity at which blood-lactate concentration reached a value of 4.0 mmol. Values are mean ± SD.

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single distance or a range of distances, this study is to our knowledge the only one that has investigated the relationship between several LT definitions and 2 running distances. The results of this study are in agreement with those of Nicholson and Sleivert and Tokmakidis et al. All 3 studies have shown a significant correlation between the different LT definitions and the running velocity of a certain distance. Nicholson and Sleivert investigated the relationship between various LT definitions and mean 10-km running velocity and found that the LT$_{\text{Dmax}}$ had the strongest correlation ($r = .86$). The present study showed the highest correlation between the LT$_{\text{Dmax}}$ and the average running velocities of both the 10-km and 21.1-km. Despite this high correlation, the mean difference between the velocity at the LT$_{\text{Dmax}}$ and the average running velocity for each distance was not the least. Our results show that the velocity determined by the Dmax method was not significantly different from the velocity during the 10-km time trial but was significantly different from
Figure 1 — Group mean (± SD, n = 13) blood-lactate responses during the 10-km and 21.1-km time trials. Mean lactate concentration during the 10-km time trial (3.52 ± 1.58 mmol) was significantly higher \((P < .05)\) than during the 21.1-km time trial (1.86 ± 0.90 mmol). Mean lactate concentrations during the time trials do not include the immediate post value, which was affected by the final sprint. *Significant difference between trials \((P < .05)\).

Figure 2 — Group mean (± SD, n = 13) running velocity (km/h) during the 10-km and 21.1-km trials. Mean running velocity during the 10-km time trial (16.6 ± 1.1 km/h) was significantly greater than during the 21.1-km time trial (15.5 ± 1.2 km/h; \(P < .05\)). *Significantly different from 21.1-km. #Significantly different from 21.1-km. +Significantly different from 10-km.
the velocity during the 21.1-km time trial (Table 3). These results in conjunction with the results of previous studies\(^6,14\) indicate that the running velocity determined by the Dmax method might be more appropriate to determine the running velocity for shorter distances (e.g., 10 km).

The fixed blood-lactate concentration of 4 mmol has been used extensively to predict performance.\(^3,9\) Sjödin and Jacobs\(^3\) found that the velocity at the onset of blood-lactate accumulation (defined as the fixed lactate concentration of 4.0 mmol) accounted for 92% \((r = .96)\) of the variance for marathon running velocity. In our study, we found a small but significant correlation \((r = .59)\) between the running velocity at LT\(_{4.0}\) and the running velocity during the half-marathon, which in this case accounts for only 35% of the variance. Our results are in agreement with those of Nicholson and Sleivert,\(^14\) who found that the mean velocity at LT\(_{4.0}\) was higher than the mean velocity determined using the other LT definitions and the average running velocity during the time trials (Table 3). These results indicate that the velocity determined by the fixed lactate value of 4 mmol is higher than the average sustained velocity by the subjects during the time trials. Therefore, this fixed lactate value cannot be used to accurately predict prolonged running performance from 10-km to half-marathon distances.

Other laboratories have investigated the relationship between 1 LT definition and various distances. Farrell et al\(^1\) found a high correlation \((r \geq .91)\) between the running velocity that was associated with 1 mmol increase above baseline (LT\(_{b+1}\)) and treadmill velocity for 3.2-km, 9.7-km, 15-km, 19.3-km, and 42.2-km distances, whereas LaFontaine et al\(^4\) found a significant correlation \((r \geq .84)\) between the fixed value of 2.2 mmol and the running velocity for 402.3-m, 3.22-km, 8.05-km, 16.09-km, and 20-km distances. In this study, the correlation coefficients between those 2 LT definitions and the running velocity during 10 km and 21.1 km were lower than the correlations reported by the previous studies. A possible reason for the difference is that the other 2 studies used protocols that had 10-minute stages, whereas in our study we used 4-minute stages. It is possible that the shorter stage duration might have not allowed for steady-state blood-lactate responses during an incremental test, which might have caused a greater variability among subjects, thus resulting in lower correlations. Even though the correlations reported in this study were lower than those in other studies, the difference between the mean running velocity at these LT definitions and the mean running velocity for the 10-km time trial was the lowest (Table 3), but not for the 21.1-km time trial. These results indicate that these 2 LT definitions might be appropriate for shorter rather than longer distances.

Finally, Yoshida et al\(^23\) found that the LT calculated by a statistical method for determining the interception of 2 lines (LT\(_{log}\)) was highly correlated \((r \geq .65)\) with running performance over the range of distances from 1500 m to 3000 m. Our results found similar correlations between this LT definition and the 10-km and 21.1-km time trials. However, the average velocity at LT\(_{log}\) was significantly different from the 10-km time-trial velocity but not significantly different from the 21.1-km velocity (Table 3). These results suggest that the velocity determined by the log-log transformation model might be related to longer distances.

Another major finding of this study was the large variability among subjects. For the entire group the difference between the velocity determined by the fixed
LT definition of 2.2 mmol and the average velocity for the 10-km time trial was the smallest (Table 3). Nonetheless, individual results indicated that the velocity determined by this definition had the least difference for only 1 individual during the 10-km time trial (Table 4). For 6 of the 13 subjects tested, the average running velocity during the 10-km was the closest to the velocity determined by the Dmax method (Table 4). On the other hand, the velocity determined by the $LT_{\log}$ method was the velocity closest to the average velocity during the 21.1-km time trial. In addition, for most of the subjects (8 of 13; Table 4) this velocity was the one that resulted in the least difference from the mean velocity during the 21.1-km time trial. For the rest of the subjects, the velocity determined from other definitions had the least difference from the 10-km and 21.1-km distances. Several factors have been identified that might explain why different subjects have different LTs and different blood-lactate responses during exercise. These factors include muscle-fiber type, training state, epinephrine levels, and different rates of lactate removal. It is not the purpose of this study, however, to determine lactate kinetics or the physiological mechanisms behind the LT.

Various laboratories use different types of testing to determine the LT, and most studies have used an incremental test. Although this type of testing requires fewer visits to the laboratory, is convenient, and has been shown to be reliable, there is a question of the extent to which the velocity and the lactate responses associated with the LT are representative of what would occur during prolonged exercise. Mognoni et al found that most of their subjects (20 of 34) could not finish 60 minutes of cycling at the power output that corresponded to the blood-lactate threshold (defined as the power output that elicited a blood-lactate concentration of 4 mmol during an incremental exercise). It is noteworthy that the blood-lactate concentration of those subjects for as long as they exercised exceeded the 4-mmol LT. Mognoni et al concluded that physiological variables at fixed lactate concentration “give a poor prediction of their trends” during prolonged steady-state exercise. Similarly, Oyono-Enguelle et al compared blood-lactate concentrations during prolonged exercise on a cycle ergometer at intensities that corresponded to the aerobic threshold (defined as the power output that elicited a blood-lactate value of 2 mmol), the anaerobic threshold (defined as the power output corresponded to blood-lactate concentration of 4 mmol), and a work rate between the 2 thresholds. They found that the subjects could exercise for 45 minutes at the intensities corresponding to the aerobic threshold and the intermediate workload, but none of the subjects could exercise longer than 30 minutes at the power output corresponding to the anaerobic threshold.

Our results showed that subjects, on average, maintained a relatively constant speed throughout the trials until the final sprint (Figure 2), but blood-lactate responses were not similarly constant between time-trial distances (Figure 1). In the present study, for most of each time trial until the final sprint, blood-lactate responses during the 21.1-km were at “steady state” except for the immediate postexercise lactate response, because of sprinting at the end (Figure 1). O’Brien et al showed similar blood-lactate response during the marathon. On the other hand, during the 10-km time trial, blood lactate was not at a steady state but was continuously increasing. Ramsbottom et al found a similar lactate response during a 5-km time trial. During cycling, studies have shown blood-lactate concentration in excess of 4.0 mmol for 1 hour. In the present study, mean blood lactate during the 10-km time trial was $3.52 \pm 1.58$ mmol and during the 21.1-km
was 1.86 ± 0.90 mmol. Possible reasons for the difference between studies might be blood handling, blood-sampling site, number of blood samples, and mode of exercise (running vs cycling).

**Practical Applications**

These results indicate that the methodologies used to determine the various LT definitions from each individual’s lactate curve can be used as a performance indicator, especially if one concentrates on the subject population as a group. There was no single subject in this study, however, whose performance velocities during both running distances were equally related to a single point or definition. These results indicate that the current LT definitions are associated with either a short or a long running distance. It is apparent that the $LT_{D_{max}}$ method correlated best with short distances (eg, 10 km), whereas the $LT_{log}$ method was related more with longer distances (eg, 21.1 km). Therefore, sport scientists should be wary of using the velocity determined by a single LT method to predict performances at various distances. On the other hand, coaches and athletes should consider individual responses and use an LT definition to monitor training adaptations depending on athletes’ running distance.

**Conclusions**

In conclusion, this study showed that the Dmax method had the highest correlation with the average velocity for the 10-km and 21.1-km time trials. Based on individual results, however, the $LT_{D_{max}}$ was not the velocity closest to the performance velocity for either distance, and none of the LT “definitions” were the same for both distances for each subject. In addition, blood-lactate concentration over the 21.1-km time trial showed a “steady state” response, whereas over the 10-km time trial it was continuously increasing. These results suggest that for runners, maximal lactate steady state occurs at an intensity required somewhere between the 2 distances and that a single point or definition on the lactate curve is not the best single descriptor of endurance-exercise performance. Therefore, according to these results a different definition or methodology might be required (ie, percent of maximum lactate concentration or 1 mmol above or below $LT_{D_{max}}$); this definition might be related to different distances and take into consideration individual lactate responses.

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