Using lactate threshold to predict 5-km treadmill running performance in veteran athletes

AUTHORS: Jacky Forsyth, Dean Burt, Fiona Ridley, Christopher Mann

Staffordshire University, Leek Road, Stoke-on-Trent ST4 2DF, England, UK

ABSTRACT: Measuring lactate threshold to predict endurance performance is difficult among veteran athletes, due to age-related decreases in net lactate concentration. The objective of this study was to determine whether lactate threshold, as assessed using the maximal deviation method (D_{max}), which is not dependent on net values of lactate, could be used as a more valid measure of 5-km treadmill running performance than other methods of determining lactate threshold. Veteran runners (18 male and 18 female, aged 47.3±6.7 years) performed an incremental exercise test to establish mean treadmill velocity at lactate threshold using D_{max}, a log-log method, a visual method, and a 4-mmol·L^{-1} method, and, on a separate occasion, completed a 5-km time trial. Mean treadmill velocity at D_{max} was 12.2±1.8 km·h^{-1}, not being significantly different to mean treadmill velocity (12.1±1.8 km·h^{-1}) attained during the 5-km time trial ($p>0.05$); velocities were also significantly correlated ($r=0.92$, $p<0.001$), and limits of agreement narrow (-1.61 to 1.35 km·h^{-1}). Correlations were weaker and limits of agreement wider for the other methods of lactate threshold determination. Using a two-way, mixed-methods ANOVA, there was no significant effect of sex when using the different methods of determining T_{lac} ($F_{4,136}=3.70$, $p=0.15$). Mean treadmill velocity, when using D_{max} for determining lactate threshold, can be used to predict 5-km running performance among male and female veteran athletes.

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Corresponding author:
Jacky Forsyth
Staffordshire University
Leek Road
ST4 2DF Stoke-on-Trent
United Kingdom
E-mail: j.j.forsyth@staffs.ac.uk

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INTRODUCTION

The number of veteran athletes, typically defined as being athletes aged 35 and over, is increasing [1]. In attempting to maintain or improve performance, these veteran athletes have set tremendous world records; for example in 2003, Ed Whitlock became the oldest person, at the age of 73, to run a sub 3-h marathon [2]. Physiological testing of veteran athletes is crucial for understanding age-related declines in performance, how exercise attenuates this decline, and how the veteran athlete responds to training, in order to ensure continued athletic success in this population [3].

Determining lactate threshold (T_{lac}), defined as the point at which blood lactate concentration increases exponentially with increasing exercise intensity, has been used to ascertain endurance capability, measure adaptations to training, and to predict performance potential. In veteran athletes, however, T_{lac}, according to Wiswell et al. [4], is not a good predictor of self-reported running times, since, when T_{lac} is expressed as a percentage of maximal oxygen consumption (VO_2max), it has been found to significantly increase with age. The reason for this phenomenon was claimed to be due to a reduction in VO_2max with age [4,5], which makes it seem that T_{lac} has increased. It is also plausible that there is a reduction in net blood lactate concentration with age, since, when using absolute values of blood lactate concentration, T_{lac} has been found to occur at a higher exercise intensity [6]. Lower values of blood lactate concentration in veteran athletes can be explained by a lower percentage of type II muscle fibres, a reduction in lactate dehydrogenase activity, and an increase in oxidative enzyme activity [6], which decrease lactate production and carbohydrate utilisation, and assist with lactate clearance.

For the veteran athlete, using absolute values of blood lactate concentration to determine T_{lac}, such as the 4-mmol·L^{-1} method ($T_{lac-4mM}$), also termed onset of blood lactate accumulation, are not appropriate, if net lactate concentration is too low for a threshold to be accurately detected and determined [7]. Other methods of determining T_{lac} have been developed, which rely on emphasising the shape of the lactate curve. One such method is the maximal deviation (D_{max}) method, which is defined as the maximal distance between a line of best fit (3rd order polynomial) and the straight line joining two end points (the start and finish) [8]. Although D_{max} has mainly been validated on younger-aged athletes [9], it has been found to be highly correlated and in good agreement with 30-min time trial cycling performance among veteran endurance cyclists (8 male and 1 female) [10], and with 10-km road race performance among recreational, female veteran runners [6]. The D_{max} method of determining T_{lac} among veteran athletes is, therefore, worthy of further investigation, by including both males and females in the sample and by comparing D_{max} with a laboratory-based time trial, rather than a road race (which can be influenced by extraneous variables).

The purpose of the study (which was a comparative analysis by design) was to compare the D_{max} method of determining T_{lac} with 5-km treadmill performance among male and female veteran runners. It was hypothesised that mean treadmill velocity at D_{max} would be correlated and have good agreement with mean treadmill velocity attained during a 5-km treadmill time trial, and that these velocities would not be significantly different. For comparison, other methods of determining T_{lac}, including the log-log method of Beaver [11], a visual method, and $T_{lac\text{-}4mM}$, were also determined. A secondary aim was to examine whether sex altered the results.

MATERIALS AND METHODS

Twenty two male, and 18 female, endurance-trained, veteran runners between the ages of 35 and 62 (mean±SD 47.4±6.6) years volunteered to take part in the study. Subjects were considered veteran athletes if they were ≥35 years, ran ≥15 km per week, were actively competing at club level, and had been running for at least 5 years. Volunteers were excluded from the study if they were injured or not deemed fit to exercise at the time of testing. Subjects signed a consent form, and the study was approved by the University's ethical research committee. The study was conducted in accordance with the ethical standards of the Helsinki Declaration.

Subjects attended the laboratory on two separate occasions, one to complete a 5-km time trial and on the other to complete an incremental exercise test to determine T_{lac}, the order of these tests being counterbalanced and randomised, to account for any training/learning effect of using the treadmill. Tests were separated by a minimum of 48 h, and a maximum period of 2 weeks. To control for circadian rhythm effects, subjects attended the laboratory at the same time of day on both occasions. Subjects were advised to eat a main meal 3 h prior to testing, and to replicate their diet for a 24-h period prior to the second test occasion. They were also required to avoid strenuous activity for 48 h prior to testing, these requirements being stipulated to ensure that subjects came to the laboratory in a glycogen-replete state. Subjects were also encouraged to avoid alcohol and caffeine and to ensure adequate hydration within 48 h preceding each test.

A standardised warm up was completed prior to each test, which consisted of running for 5 min at an exercise intensity equivalent to 2 $km{\cdot}h^{-1}$ below the subjects' current 10-km running velocity. A rest period of 3-4 min was given, to allow for mobilisation and dynamic stretching. A 1% gradient was applied to the treadmill for both tests, to reflect the energy cost of outdoor running [12].

For the incremental exercise test, the starting velocity was the same as that used in the warm-up. Each stage was 4 min in duration, and increased by 0.5-1 $km{\cdot}h^{-1}$ every stage. The aim was to achieve exhaustion between 5 and 9 stages. Subjects continued until they felt they could not complete a further stage in full. At the end of each stage, subjects were required to dismount from the treadmill for the purpose of fingertip capillary blood (5 μl) collection, and lactate was analysed using a pre-calibrated analyser (Lactate Pro, Arkray, KDK Corporation, Kyoto, Japan). For the 5-km time trial, subjects were required to complete 5 km in the quickest time possible. Feedback on distance covered was freely available; however, subjects were not able to view time or treadmill velocity. Subjects were able to adjust the velocity freely.

Methods used to determine T_{lac} included D_{max}, the log-log method ($T_{lac\text{-}log}$), a visual method ($T_{lac\text{-}vis}$), and the $T_{lac\text{-}4mM}$ method. For determining D_{max}, procedures and mathematical calculations, as outlined elsewhere [8,13], were followed. For $T_{lac\text{-}log}$ [11], plots of log lactate against the log of velocity, were drawn. The data points were divided into two segments, and the division point between them was determined visually as the point where the steep portion of the curve begins. Each segment, below and above the division point, was fitted using a linear regression equation, and the solution for the threshold was determined mathematically by the intersection of the two lines. For both $T_{lac\text{-}4mM}$ and $T_{lac\text{-}vis}$, plots of blood lactate concentration against treadmill velocity were drawn. For $T_{lac\text{-}4mM,}$ treadmill velocity was interpolated from the curve using an algebraic equation. $T_{lac\text{-}vis}$ was defined as the highest treadmill velocity before a curvilinear increase in blood lactate concentration occurred. Two observers initially determined $T_{lac\text{-}vis}$ independently, then came together to agree the point, if there were discrepancies.

A Shapiro-Wilk test was used to check normality of all data. To examine whether the different methods of determining T_{lac} were as equally as effective as D_{max} in determining 5-km velocity, a repeated measure analysis of variance (ANOVA) was used, with post-hoc analysis using Tukey's HSD if differences existed. A two-way, mixed-methods ANOVA was used to examine the effect of sex on the different methods of determining T_{lac}. Pearson correlations were used to examine the relationships between treadmill velocity in the 5-km time trial and treadmill velocity at T_{lac} (all methods), and 95% limits of agreement [14] were used to further examine differences. A stepwise, linear regression analysis was used to determine whether T_{lac} indices could be used to predict treadmill velocity in the 5-km time trial. A sample size of 40 was used to give an effect size of 0.059 and a power of 0.76 using an F-ratio in ANOVA [15]. Data are given as mean and SD.

RESULTS

Four male subjects were excluded from the study due to un-related injuries, leaving a total of 18 male subjects (mean age, height and body mass of 49.1±7.0 years, 175.2±6.7 cm, and 72.70±8.54 kg, respectively), and 18 females (mean age, height and body mass of 45.5±7.0 years, 165.4±6.3 cm, and 61.32±6.82 kg, respectively). Parametric assumptions were all met; there were no outliers and the data were normally distributed.

Based on the results of the repeated measures ANOVA, there was a significant difference in mean treadmill velocity for the various

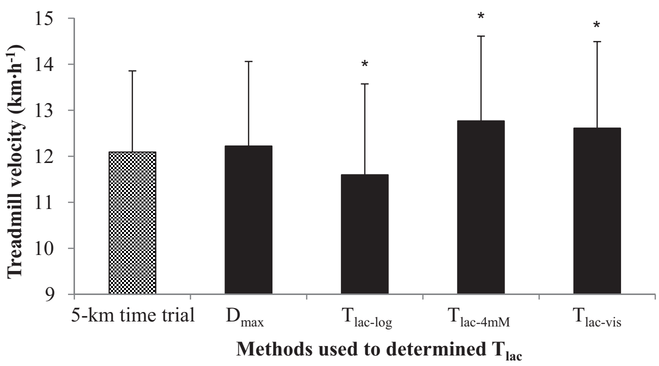

FIG. 1. Mean treadmill velocity in the 5-km time trial and at the different methods of determining lactate threshold (T_{lac}). The asterisk (*) denotes a significant difference between mean 5-km time trial velocity and mean velocity when using the log-log ($T_{lac-log}$) method (p=0.006), the 4-mmol·L^{-1} ($T_{lac-4mM}$) method (p<0.001), and the visual ($T_{lac-vis}$) methods (p<0.001). There was no significant difference between 5-km time trial velocity and mean velocity when using the maximal deviation (D_{max}) method (p=0.30).

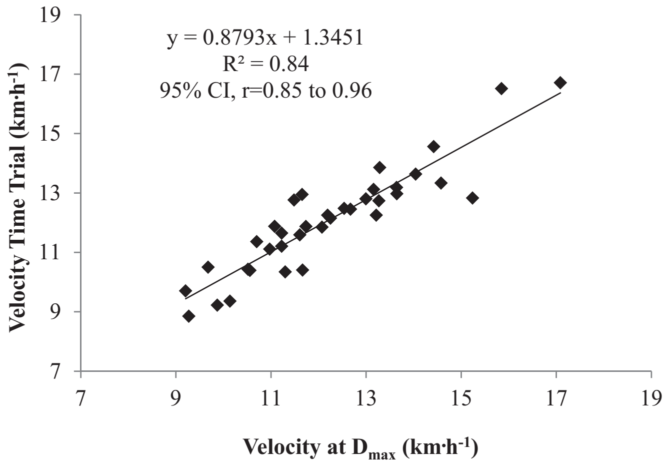

FIG. 2. Correlation between mean treadmill velocity at D_{max} and mean treadmill velocity during the 5-km time trial.
D_{max}: The maximal deviation method of determining lactate threshold.
R^2: Adjusted R-squared from regression analysis.
CI: Confidence interval for correlation.

TABLE 1. Correlation coefficients and limits of agreement between mean treadmill velocity during the 5-km time trial and mean treadmill velocity for all methods of lactate threshold determination

	5-km time trial (r)	Limits of agreement (km·h^{-1})
D_{max}	0.92	-1.6 to +1.4
$T_{lac-log}$	0.86	-1.5 to +2.5
$T_{lac-4mM}$	0.88	-6.1 to +5.5
$T_{lac-vis}$	0.91	-2.1 to +1.0

All correlations are significant at the 0.01 level.
D_{max}: The maximal deviation method of determining lactate threshold.
$T_{lac-log}$: The log-log
$T_{lac-4mM}$: The 4-mmol/L method of determining lactate threshold.
$T_{lac-vis}$: The visual method of determining lactate threshold.

methods used to determine T_{lac} and 5-km time trial ($F_{4,140}$=26.5, p<0.001). Mean treadmill velocity in the 5-km time trial and at the different methods of determining T_{lac} are given in Figure 1, along with results from the post-hoc analysis.

The correlation for mean treadmill velocity at D_{max}, and mean treadmill velocity in the 5-km time trial is given in Figure 2, which also displays the adjusted R^2 from the regression analysis. Entering $T_{lac-log}$, $T_{lac-4mM}$, and $T_{lac-vis}$ into the regression in a stepwise fashion did not significantly alter the strength of the model using D_{max} only (R^2=0.004, p=0.346; R^2=0.008, p=0.204; and R^2=0.003, p=0.452, respectively). Correlations and limits of agreement for all methods of determining T_{lac} are given in Table 1.

Mean treadmill velocity for males on the 5-km time trial and at the various methods of assessing T_{lac} were significantly higher than those for females ($F_{1,34}$=22.39, p<0.001). The interaction between sex and velocity was not significant ($F_{4,136}$=3.70, p=0.15).

DISCUSSION

The main finding of the study was that T_{lac}, when assessed using D_{max}, was highly correlated and was in good agreement with 5-km treadmill performance among veteran male and female runners. Indeed, when compared to other methods of determining T_{lac}, velocity at D_{max} had the highest correlation with mean velocity in the 5-km time trial, the narrowest limits of agreement, and independently explained 84% of the variance in velocity in the 5-km time trial (Table 1, Figure 2). The other methods of T_{lac} determination ($T_{lac-log}$, $T_{lac-4mM}$ and $T_{lac-vis}$) all differed significantly from velocity in the 5-km time trial, whereas D_{max} did not. These findings are in agreement with those of Machado et al. [7], who assessed 13 recreational, female runners aged 35-51 years and found that D_{max} correlated more strongly with running performance in a 10-km road race than other lactate indices ($T_{lac-4mM}$, $T_{lac-vis}$), and presented the narrowest limits of agreement. The findings also support those of Fell [10], who suggested that D_{max} was a good predictor of 30-min time trial performance in well-trained veteran cyclists. The current findings and those of Fell and Machado et al. are important, as they suggest that T_{lac} can be used in veteran athletes to predict performance, contrary to the advice of Wiswell et al. [4], as long as D_{max} is used.

The D_{max} method has been used successfully in a number of other studies [16,17]. For veteran athletes, D_{max} is particularly preferable, since this method does not rely on absolute concentrations of blood lactate, which might be lower or altered in the older athlete. Age-related declines in Type II muscle fibres, lactate dehydrogenase activity, gluconeogenesis, function of monocarboxylate transporters, and increases in oxidative enzyme activity could alter lactate appearance and clearance rates [3,6], having an effect on net concentrations of blood lactate. It is important, therefore, to examine the shape of the lactate curve; in the D_{max} calculation, the shape of the curve is considered. The shape of the curve is also considered when using the $T_{lac-vis}$ method, but when net concentrations of lactate are so low, often it is difficult to determine where $T_{lac-vis}$ occurs; in the current study, there were nine instances where the researchers disagreed as to where $T_{lac-vis}$ occurred. The D_{max} method, because it uses a third-order regression equation, emphasises the shape of the curve, useful for when net lactate is low, and also takes out the subjectively of T_{lac} determination.

The $T_{lac-log}$ method, like the D_{max} method, allows for T_{lac} to be determined mathematically, and also does not rely on absolute concentrations of lactate. The $T_{lac-log}$ method, however, significantly under-predicted performance in the 5-km time trial; this finding has been observed in other research [16,18]. Although the $T_{lac-log}$ method is useful for fitting the data, there is very little research on whether $T_{lac-log}$ relates to performance [19,20]. The $T_{lac-log}$ method also requires the use of an observer to determine the division point subjectively and in this way, is no more sophisticated than the $T_{lac-vis}$ method. In the current study, the $T_{lac-log}$ method was not useful for predicting 5-km treadmill running performance.

For two of the subjects in the current study, lactate values were lower than 4 $mmol \cdot L^{-1}$ in response to the final stage of exercise, despite these subjects being encouraged to complete as many stages as possible. Mean blood lactate concentration at D_{max} was 3.3±2.0 $mmol \cdot L^{-1}$. It is well known that not all individuals are able to reach a lactate concentration steady state at 4 $mmol \cdot L^{-1}$ [21,22], and that modification in glycogen content in the muscle through diet and training state can alter lactate concentration [23,24]. In veteran athletes, net lactate concentration might also be lower as a result of altered metabolism. The D_{max} method is, therefore, suitable for veteran runners, as it does not require a fixed value that must be achieved.

Limits of agreement were used to provide an indicator of how much variation could be expected between T_{lac} indices and 5-km time trial performance, and are advantageous over correlations because systematic bias can be detected [14]. Limits of agreement for mean treadmill velocity at D_{max} and mean treadmill velocity for the 5-km time trial ranged from -1.6 $km \cdot h^{-1}$ to +1.4 $km \cdot h^{-1}$ (Table 1), being only slightly larger than the mean increment used in the protocol. In contrast, limits of agreement for treadmill velocity at $T_{lac-4mM}$ were much greater than the mean increment of the protocol (Table 1). With values being so wide when using $T_{lac-4mM}$, predicting performance (and also setting training intensities) becomes too variable and inconsistent. D_{max}, owing to having the narrowest limits of agreement, is, therefore, the preferred method to use for predicting running performance among veteran runners.

In comparing the four methods of T_{lac} detection, mean treadmill velocity was higher using the $T_{lac-4mM}$ method than when using D_{max} (Figure 1). This is consistent with findings of others [16,25]. The four methods produced slightly different values for T_{lac}, which is indicative of how values are calculated, but also may represent different durations of endurance performance. Although D_{max} was useful in this study for predicting mean treadmill 5-km time, the other methods of T_{lac} determination might be useful for predicting other performance durations. The use of D_{max} for assessing other performance variables among veteran athletes could be investigated.

The current study extends the findings of those done previously by including a wider age range (up to 62 years). Moderate age-related declines have been found to occur up to the age of around 50, with exponential declines thereafter [1,26]. Fifteen subjects (42%) in the current study were aged 50 or older, and therefore might have experienced the more dramatic declines in Type II muscle fibres, which are thought to alter lactate metabolism [6]. Although investigating differences due to age was not an objective of the study, correcting for age in the repeated measures ANOVA did not affect overall findings; there was also no significant interaction effect for age ($F_{4,136}=0.737$, $p=0.568$). The current study included an equal mix of males and females, and used a larger sample size (compared to Machado [7]); there were no sex-related differences in findings.

A limitation of the present study is the lack of ecological validity in terms of using treadmill running, which does not approximate outdoor running particularly well [27]. Using a treadmill, however, has the advantage that extraneous variables that occur with outdoor running, such as changes in environmental conditions, surface variance, and increases in adrenaline that occur in race-like conditions, can be avoided. These extraneous variables might have affected the findings of Machado [7], which was why it was important, in the current study, to compare the velocity at D_{max} with velocity in treadmill running. Using a treadmill also allows for training to be prescribed. The exercise intensity at D_{max}, for instance, can be used to set training intensities on the treadmill. A further limitation, however, is that the current study only considered the use of D_{max} in predicting 5-km running performance, as opposed to using D_{max} to ascertain training intensities and measure adaptations to training. Further research on the use of D_{max} to predict outdoor running performance, and to determine whether D_{max} is sensitive enough to detect changes over time with training in this age group could be carried out.

Practical implications

Using a lactate threshold method that relies on determining the exercise intensity at an absolute value of lactate can be problematic in veteran runners, since lactate values can be too low.

Using visual methods of determining where the lactate threshold occurs can also be a problem as the curve is often 'flat' in veteran runners, and determination subjective.

The maximal deviation method should be the method of choice for determining lactate threshold and predicting 5-km running performance for veteran runners, since this method is objective and relies on the shape of the lactate curve.

CONCLUSIONS

The D_{max} method provides a valid measure of the treadmill velocity that can be maintained during a 5-km treadmill time trial. The D_{max} method can, therefore, be used for predicting 5-km treadmill performance time among veteran runners. The D_{max} method should be used as the T_{lac} method of choice for veteran runners.

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