Software for Calculating Blood Lactate Endurance Markers

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Abstract

Blood lactate markers are used as summary measures of the underlying model of lactate production in athletes. Several markers have appeared in the literature in the last 20 years and papers comparing their performance (i.e. relation to endurance) presented.

A typical lactate curve exhibits a curvilinear pattern but there is no consensus on the true model of lactate production. The main debate concerns whether a lactate curve is comprised of two sections – a linear baseline and a region of rapidly increase lactate production. The intersection of these two sections is thought to represent a breakpoint, or threshold [1,2,3,4,5]. The alternative suggestion is that a lactate curve is simply a smooth monotonicly increasing curve [6]. Given this debate several markers have been suggested. Typically each marker corresponds to a workload in the region of high curvature in the lactate curve.

To date no free software exists that allows the sports scientist to calculate these markers in a consistent manner. In this paper software is introduced for precisely this purpose. The software will calculate a variety of lactate markers for an individual player, a player across different time points (e.g. across a season) and simultaneously for a team.

A concise description of the markers considered is given in addition to the algorithms used to calculate the markers.

Keywords: Lactate Curves, Endurance Markers, Software.

Introduction

The main controversy surrounding blood lactate analysis is whether there is a breakpoint (i.e. threshold) present in the lactate curve or whether lactate increases as a monotonically increasing smooth function. Note the presence of a breakpoint implies a discontinuity in the first derivative of the lactate curve. This assumption does not imply that the lactate curve itself is non continuous, as highlighted by Morton [7].

The breakpoint is considered to represent a workload where lactate production and clearance are equal and is defined as the Lactate Threshold (LT). Improved endurance is associated with prolonging the LT. This proposed change point is thought to represent a switch from one physiological system to another which has been debated in the literature [8,9,10,11,12,13,14,15,16].

The work from Hughson [6] however suggests that during incremental exercise the change in blood lactate is a continuum that does not display a threshold phenomenon. In light of this additional markers have been proposed.

Lactate Markers

1. Assuming a breakpoint exists

If it is assumed that the lactate threshold exists (i.e. a unique point where lactate production switches from an anaerobic to aerobic state) two objective approaches have been suggested to determine this breakpoint.

Traditionally the LT was determined subjectively from plots of the lactate concentration versus workload by identifying the treadmill velocity or workload that best corresponds to a departure from a linear baseline pattern. Lundberg et al. [17] proposed fitting a linear spline where the estimated workload corresponding to the location of the knot is the LT. The location of the knot (i.e. the point of intersection between the two linear splines) and the parameters of the lines are estimated by minimizing the sum of the squared differences between the observed lactate values and the fitted values.

Under this model it is assumed that the relationship between blood lactate *L* and workload *w* for individual *i* is given by

$$L_{1i} = \beta_0 + \beta_1 w_{ij} + \beta_2 (w_{ij} - LT)_+ + \varepsilon_{ij}, \qquad (1.1)$$

for i=1,…,N individuals, j=1,…,n_i workloads

where the error term ε is assumed independently distributed with mean zero and finite variance. Note that the notation $(\ldots)_+$ means the positive part of the argument. This model is an example of a broken stick regression model, with the 'break' occurring at the lactate threshold LT. The value of LT can be estimated using simple linear regression by fitting model 1.1 and identifying the workload *LT*, corresponding to the model with minimum Mean Squared Error.

A log transformation of both the workload and blood lactate concentration has been suggested (LT_{loglog}) in an attempt to gain a better estimate of the lactate threshold [1].

Criticisms of the LT marker include that it may be estimating a feature that does not actually exist; it is using linear regression which is quite sensitive to outliers in small data sets (i.e. there can be a considerable difference in the estimate of the LT following small changes in the recorded lactate); it may not be appropriate to use linear splines if the increase in lactate post LT is curvilinear.

Criticisms of the LT_{loglog} are similar to those highlighted for the LT marker but also include the fact that taking logarithms of both the lactate and workload in some way assumes that the increase in lactate post LT is exponential. Thus assumption may be difficult to justify as the use of an exponential function in the model suggests that somehow the rate of change of lactate depends on the amount of lactate.

2. Assuming a breakpoint does not exists

Several additional lactate markers have been suggested if it is assumed that the lactate curve is a smooth process. There is a tendency in the literature [18] to refer to these markers incorrectly as lactate thresholds rather than endurance markers. The Lactate Threshold is a particular marker referring to the presence of a breakpoint while an endurance marker is a general term used to represent any single summary statistics derived from a sample of blood lactate data.

The markers in this section typically have no physiological interpretation but appear to estimate workloads corresponding to points of curvature on the lactate curve.

2.1 DMax

The workload corresponding to the point that yields the maximum perpendicular from a line L_2, joining the first and last lactate measurements to the estimated lactate curve L_3 [2].

The line L_2 joining the first and last lactate measurements can be estimated using simple linear regression

$$L_{2i} = \beta_0 + \beta_1 w_{ij} + \varepsilon_{ij} \qquad (2.1)$$

for i=1,…,N individuals, j=1, n_i workloads only

An estimate of the true lactate curve is calculated by fitting a polynomial regression model (typically of degree 3)

$$L_{3i} = \beta_0 + \beta_1 w_{ij} + \beta_2 w_{ij}^{\ 2} + \beta_3 w_{ij}^{\ 3} + \varepsilon_{ij} \qquad (2.2)$$

for i=1,…,N individuals, j=1,…,n_i workloads

The point of maximum perpendicular distance from L_2 and L_3 corresponds to the workload w_{DMax} where

$$\frac{dL_2}{dw} = \frac{dL_3}{dw}$$

(i.e. the workload where the first derivative of L_2 and L_3 are equal).

The main criticism of the DMax marker is its dependence on both the initial and final lactate reading. The initial and final workloads where the lactate data are collected will have a direct influence on the value of this marker. If it is assumed that there is no breakpoint then the location of the DMax will depend on the arbitrary choices of the first and last workloads. If however there was a breakpoint in the lactate curve then the DMax would to be less sensitive to these workloads.

2.2 FBLC

The workload corresponding to a fixed blood lactate concentration (FBLC), typically 4mmol [4]. This is calculated using inverse prediction by finding the workload *w* such that the estimated model (2.2)

$$\hat{L}_{3i} = \hat{\beta}_0 + \hat{\beta}_1 w_{ij} + \hat{\beta}_2 w_{ij}^{\ 2} + \hat{\beta}_3 w_{ij}^{\ 3} = \text{FBLC}$$

The FBLC is a marker that represents a ceiling value for lactate. The main criticism of the FBLC marker is the considerable variability present at higher workloads [19].

2.3 FRPB

The workload preceding an increase in lactate concentration of a Fixed Rise Post Baseline (e.g. 1mmol from baseline). Let $L_{baseline}$ represent the lactate reading at baseline. The FRPB marker is calculated by finding the workload *w* corresponding to a selected rise from baseline (e.g. 1mmol)

$$\hat{L}_{3,j} - L_{baseline} = \text{FRPB}$$

The choice of baseline reading is clearly important as is the subjectivity of the choice of lactate rise.

2.4 TEM

The workload preceding an increase in lactate concentration greater than the determined error of measurement of the lactate analyser. This is calculated by finding the minimum workload *w* such that

$$\hat{L}_{3,j+1} - \hat{L}_{3,j} > \text{TEM}$$

for j=1,…,n-1 workloads.

Limitations of this marker include the measurement error estimate of the machine and the subjective choice of TEM value.

2.5 D2LMax

The workload corresponding to the point of maximum acceleration of the estimated underlying lactate curve (i.e. the maximum of the second derivative of the lactate curve).

Smoothing procedures involving polynomial or B-splines are becoming increasing popular alternatives when interest involves estimating the second derivative of a curve constructed with no parametric model assumptions.

Assume that the lactate data for the i^{th} individual can be modelled as a smooth function L_i of the workload w_{ij} as

$$L_{smooth,ij} = L_i(w_{ij}) + \varepsilon_{ij},$$

for i=1,…,N individuals, j=1,…,n_i workloads

It is assumed that L satisfies reasonable continuity conditions on the bounded interval of interest and that derivatives dL/dw of order 2 can be evaluated. The smoothing procedure chosen must also take into account that smooth estimates of the first two derivatives of the lactate curve L_{smooth} are required. Penalised smoothing splines [20] using polynomials of degree 4 are one such choice in order to have a continuous second derivative. Previous research [20] suggests that choosing the smoothing parameter corresponding to n-2 *df* should be adequate.

The workload corresponding to the maximum of the $D^2L_{smooth}(w)$ is calculated as

$$\text{D2LMax} = \max(D^2 L_{smooth}(w)) .$$

The main criticism of this marker is the subjectivity on the choice of smoothing parameter.

A simple approximation of the D2LMax is easily obtained by finite differences of second order by identifying the corresponding workload to the lactate reading where

$$\text{D2LMax}_{\text{discrete}} = \max(L_{w+2} - 2L_{w+1} + L_w)$$

for w=1,…,n-2.

It should be noted that the $\text{D2LMax}_{\text{Discrete}}$ will always correspond to a workload where data were collected.

The Software

Code is available to calculate the various markers described above in the form of an Excel template (Microsoft® Excel 2003) and as a function in R, a freely available statistics package (http://www.cran.r-project.org). Due to the unavailability of smooothiing routines in Excel the current version of the template does not calculate the D2LMax marker while the code provided for R calculates all the markers.

Markers may be calculated for a single athlete (Figures 1 and 2), an athlete across time or collectively for a squad of players. The team analysis allows the sports scientist to calculate the various markers for the complete squad in one batch. A dataset with the results for the complete squad in addition to a report for each player individually is generated. Interpolated estimates of variables such as VO_2 and Rate of Perceived Exertion for example at the lactate markers are available also (Figure 1).

The software is available for download at http://www.nuigalway.ie/maths/jn/Lactate.

Conclusion

Blood lactate endurance markers are statistics representing unique features of a blood lactate curve. These markers are typically used to monitor the training status of athletes and to assist in individualised training programmes. Free software is provided for objective calculation of several of these markers.

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Figure 1. Sample Excel Output for a Single Athlete.

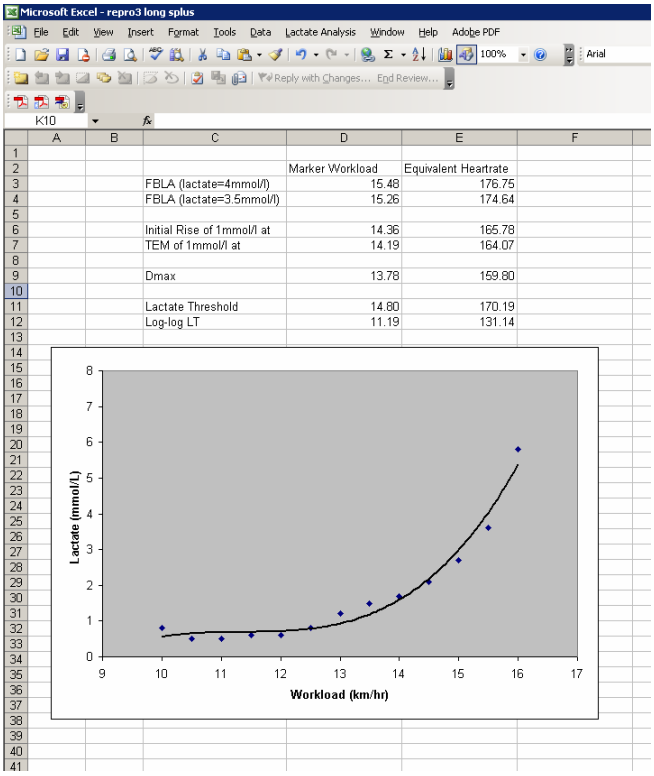

Figure 2. Sample R Output for a Single Athlete

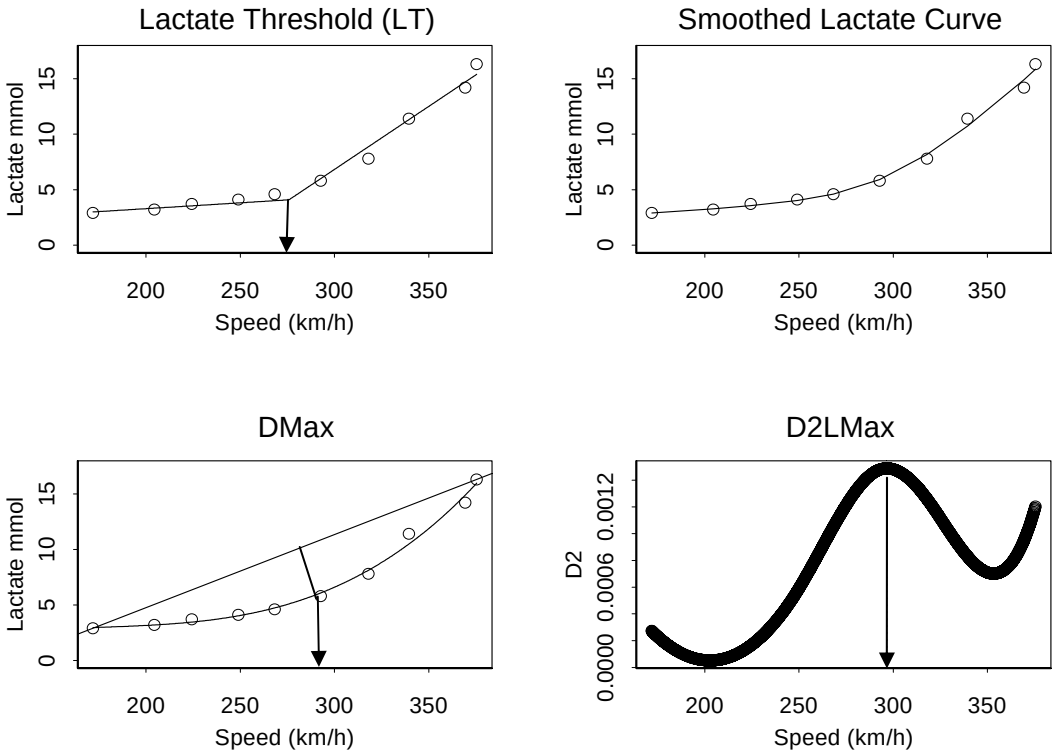

Figure 3. Sample Excel Output for a Single Athlete across Time

	A	B	C	D
1				
2		Player A Oct	Player A Jan	Player A June
3	FBLA (lactate=4mmol/l)	14.03	13.74	13.59
4	FBLA (lactate=3.5mmol/l)	13.72	13.51	13.28
5				
6	Initial Rise of 1.5mmol/l at	13.32	13.30	13.47
7	TEM of 1mmol/l at	12.77	12.99	13.13
8				
9	Dmax	12.49	12.34	12.13
10				
11	Lactate Threshold	13.20	12.30	12.20
12	Log-log LT	12.00	12.09	11.84