

Characterization of the blood lactate curve and applicability of the Dmax model in a progressive protocol on treadmill

Flávio de Oliveira Pires¹, Adriano Eduardo Lima Silva², João Fernando Laurito Gagliardi¹, Ronaldo Vilela Barros¹ and Maria Augusta Peduti Dal' Molin Kiss¹

ABSTRACT

Purpose: To characterize the blood lactate ([La]) behavior along a progressive protocol on treadmill, and to investigate the applicability of the Dmax model in detecting the lactate threshold (LT) and the sportive performance. **Methods:** Twenty-seven male athletes of regional level performed the Heck *et al.* protocol (1985) incremented every 3 minutes. The sportive output was attained by the mean velocity of the 10 km-test. The first and second LT were determined through visual analysis of the [La] (LTv1 and LTv2) curve, and by interpolation of the velocity related to the 2.0 and 3.5 mmol.l⁻¹ concentrations (LT_{2.0} and LT_{3.5}). The Dmax model has identified the LT in measured values (Dmax_{MED}), and was predicted by the polynomial functions (Dmax_{POL}), the 2-segment linear (Dmax_{SEG}) and the continuous exponential (Dmax_{EXP}). The characteristic of the blood lactate along the incremental test was checked through 2-segment linear adjustments and continuous exponential. **Results:** There was no significant difference between the sums of the square residues of the curve adjustments, but there was a trend for a better continuous exponential adjustment at 70.4% of the sampling. Although there was no significant difference between the Dmax_{MED}, Dmax_{POL}, Dmax_{SEG}, and Dmax_{EXP}, the Dmax methods were higher than the LTv1, lower than the LT_{3.5}, and were not different of the LT_{2.0}. Every Dmax criteria were significantly lower than the mean velocity of the 10 km-test. **Conclusions:** While the [La] trended to an exponential increase along the progressive protocols on treadmill, the Dmax model presented evidences of its applicability to detect the LT, but not for the sportive output.

INTRODUCTION

The analysis of the blood lactate concentrations ([La]) curve has supplied important subsidies to provide an understanding on the phenomena related to the sportive output⁽¹⁾. Along the 80's, Hughson *et al.* (1987)⁽²⁾ and Campbell *et al.* (1989)⁽³⁾, showed an exponential increase in that variable along progressive protocols employing mathematical curve adjustments, differently from prior studies that checked a 3 or 4-segment curvilinear characteristic^(4,5). Nevertheless, Hughson and co-workers⁽²⁾ and Campbell and co-workers⁽³⁾ used ergometric bike protocols, restricting the extrapolation of those results when a treadmill was employed, as the behavior of that variable depends on the motor pattern and the size of the recruited muscular mass^(6,7).

Keywords: Curve adjustments. Progressive protocol. Lactate threshold.

Still, the analysis of the blood lactate concentrations enables the identification of one or two metabolic transition zones that are dependant on the terminology and methodology adopted, and which is commonly denominated lactate threshold (LT)⁽⁵⁾. This point has been investigated due to its properties in detecting the level of the aerobic capability and to predict the sportive output, since it theoretically represents a maximal balance status in the [La] along constant exercising^(8,9). In fact, whenever methodologies to identify the two metabolic transition zones are used, the second point is frequently taken as reference for such intensity⁽¹⁰⁾. In this sense, several methods to allow an objective^(11,12) and practice^(13,14) determination of that spot were proposed, but the major part of them has limitations and methodological implications.

In the 90's, Cheng *et al.* (1992)⁽¹⁵⁾ suggested the Dmax model to determine the LT (figure 1), under the supposition it would allow more individualized identifications instead of using fixed and less subjective concentrations, and less subjectives than visual analysis, since it makes objective calculations of the intensity that considers every value contained in the curve⁽¹⁵⁾. Consequently, the point identified by the Dmax is directly connected to the behavior of every curve of the blood lactate along the incremental test.

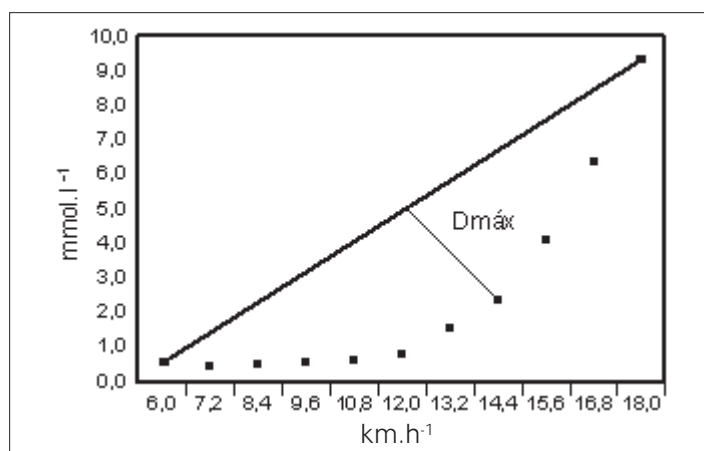


Figure 1 – Velocity of the LT (solid arrow) identified by the Dmax model

Despite the evidences of the validity of this model⁽¹⁶⁻¹⁸⁾, whenever is admitted the existence of two metabolic transition zones, there are gaps related to which of both transition zone is marked by such method.

Therefore, some speculations must be investigated from the above mentioned statements. First, it is unknown in what extent the [La] present an exponential increase along the progressive tests on treadmill, since the previously observed exponential characteristic^(2,3) was not confirmed by that type of ergometric device. Second, considering that the Dmax model is conditioned to the be-

1. Laboratory of Sportive Performance – School of Physical Education and Sports – São Paulo University – São Paulo (SP).

2. Laboratory of Morpho-Functional Researches – Center of Physical Education, Physiotherapy and Sports – Santa Catarina State University – Florianópolis (SC).

Received in 24/11/04. Final version received in 30/7/05. Approved in 3/11/05.

Correspondence to: Flávio de Oliveira Pires, Rua Acalanto de Bartira, 166, Jd. Bonfiglioli, Butantã – 05358160 – São Paulo, SP. Phone: (11) 3731-3071, fax: (11) 3763-2588. E-mail: piresfo@usp.br

havior of every [La] curve, it appears some doubts as to its applicability to determine the LT and the sportive performance, because although some studies applied that method to adjusted data with polynomial regression⁽¹⁹⁾, others employed the continuous exponential function⁽²⁰⁾, suggesting that the use of different mathematical functions can generate distortions in the intensity determined through that model.

Thus, the purpose of this paper was to characterize the blood lactate behavior along the progressive period on treadmill, and to check the applicability and consistency of the Dmax model in detecting the LT and the sportive output from measured and adjusted values by different mathematical functions.

METHODS

Sampling: Twenty-seven male athletes of regional level (triathletes and marathon runners) participated in this study (29.1 ± 5.4 years; 172.3 ± 8.1 cm; 67.2 ± 9.3 kg; 58.5 ± 10.8 ml.kg⁻¹.min⁻¹) after signing an informed consent term. This study was approved by the ethics committee for studies in humans (EEFE-USP).

Progressive protocol: All subjects performed incremental test on a Quinton® model 2472 treadmill with initial velocity of 6.0 km.h⁻¹ and 1.2 km.h⁻¹ increments in each of the 3 minutes phase and with 30 second pause to the blood collection⁽¹³⁾.

Data collection and analysis: During the 30 final seconds of each stage, 25 µl of arterialized blood were collected from the ear lobe (previously prepared with Finalgon®), which was stored in microtubes containing 50 µl of sodium fluoride and stored at 10°C for later analysis in a Yellow Springs® Model 2000 lactate analyzer. The attained [La] had the velocity plotted to identify the LT (expressed in km.h⁻¹).

Identification of the lactate threshold: The 1st and 2nd lactate thresholds (LT1 and LT2) were identified through visual analysis of the blood lactate curve from a mean observation performed by three researchers. While the LT1 was determined at the increase point of the [La] related to the resting values (1st interruption of the curve's linearity), the LT2 was determined by the intensity where the [La] presented a sudden and continuing increase (2nd interruption of the curve's linearity). Whenever necessary, LT1 or LT2 were approximated according to other criteria⁽²¹⁾.

The LT1 and LT2 were also identified by interpolation⁽⁶⁾ of the velocity corresponding to the fixed lactate concentrations of 2.0 and 3.5 mmol.l⁻¹, and they are representatives of the LT1 and LT2, respectively^(10,13). For a better understanding on the terms, the visually attained LT1 and LT2 will be called LTV1 and LTV2, and the LT1 and LT2 attained by the use of fixed concentrations will be called LT_{2.0} and LT_{3.5}.

The LT was also determined at the point where the [La] presented an increase \geq at 1.0 mmol.l⁻¹⁽¹⁹⁾. Such criterion was treated herein as L1.0, and it was used because it allows the identification of only one metabolic transition zone.

At last, the Dmax⁽¹⁵⁾ model has identified the LT at the most distant perpendicular point between the [La] values contained in the curve, and a regression line was traced between the first and the last value of that curve.

Adjustments in the blood lactate curve: The characterization of the blood lactate curve in function of the velocity was verified following the 2-segment linear mathematical functions, and the continuous exponential varying between 7 and 11 points. Later, the Dmax model was calculated in measured data (Dmax_{MED}), and in adjusted data using the 2-segment linear (Dmax_{SEG}), the continuous exponential (Dmax_{EXP}), and the 3rd order polynomial (Dmax_{POL}) functions.

The 2-segment linear adjustment⁽²²⁾ was attained by linear regression equation with an initially unknown intercept calculated from every possible visual intersection points between segments. The intercept that better divided the curve in two theoretically lin-

ear segments was assumed as the higher R² value and the lower sum of the square residues (SRQ). Thus, the curve segments were predicted by the following equations:

$$Y = a + b_1(x_1); \text{ for the 1st segment}$$

$$Y = a + b_2(x_2) + c; \text{ for the 2nd segment}$$

where y is the predicted value for the [La], a is the intercept for both segments, b_1 and b_2 are respectively, the inclination of the 1st and 2nd segments, and c is the tangent between both segments.

The exponential characteristic of the [La] along the progressive tests was tested by the continuous exponential function⁽²⁾, through the following equation:

$$Y = a + b \exp(cx) + e$$

where y is the predicted value for [La], x is the velocity, e is the residual error, a , b , and c are minimized estimates of the SRQ between measured and predicted values for the [La], and $\exp(x)$ is the maximized estimate of the correlation coefficient between variables x and y .

The 3rd order polynomial function was used to attenuate the noises contained in the rough values of the [La], without changing the initial characteristics of the curve, allowing one of the variations for the Dmax model (Dmax_{POL}). The equation generated was the following:

$$Y = b_1(x^3) + b_2(x^2) + b_3(x) + a$$

where y is the predicted value for the [La], b_1 , b_2 , and b_3 are the inclination's constants of the curve; x is the velocity, and a is the intercept.

Sportive output: After a lower than 30 days interval from the progressive protocol, the sampling performed a 10 km-test on a 400-meter race track. The mean time and velocity of the 10 km-test (VM_{10km}) were recorded.

Statistical analysis: After verifying the data distribution (Shapiro-Wilk's) it was attained the significance of the differences between the assessed variables using the Friedman's Anova along with the Wilcoxon (*post hoc*) signalization test for matched pairs. The association between variables was attained using the Spearman Rank test. In every analysis (SPSS version 1.0) it was adopted 5% significance level ($p < 0.05$).

RESULTS

Every calculation used the mean and standard deviation as central trend and dispersion measurements, respectively. For eventual comparisons, a few data related to the 10 km-test and the SRQ between the mathematical functions of adjustment are also presented as mean and standard deviation.

Quality of the curve adjustments

The 3rd order polynomial adjustment was not included in the residual analysis, once it does not have a theoretical basis that justifies its application in the attempt to describe the assessed phenomenon. As to the 2-segment linear adjustment, eight individuals presented the 2nd segment adjusted in only two points. There was no significant difference between the SRQ of the continuous exponential adjustment and the 2-segment linear adjustment's SRQ (0.11 ± 0.18 mmol.l⁻¹ vs. 0.09 ± 0.07 mmol.l⁻¹ – mean and standard deviation values). Upon an individual comparison of the SRQ, 19 out of 27 analyzed individuals (70.4%) presented trend for a better continuous exponential adjustment. The 2-segment linear adjustment presented a trend for improvement in seven individuals (25.9%), while one individual (3.7%) showed an identical residual value between both mathematical functions. The ten first runners in the 10 km-test showed a trend for a better continuous exponential adjustment.

Dmax and different methods to identify the LT

Four individuals did not attain the 2.0 and/or 3.5 mmol.l⁻¹ concentration values along the incremental test. There were no significant differences between variations in the Dmax model, whether applied on measured and/or adjusted values by three different mathematical functions (table 1).

TABLE 1

Velocity of the LT identified by the method of visual analysis [La], fixed [La], ≥ 1,0 mmol.l⁻¹, and by the Dmax model applied on real and adjusted data. The values are presented in mean and standard deviation

LTv1 km.h ⁻¹	LTv2 km.h ⁻¹	LT _{2,0} km.h ⁻¹	LT _{3,5} km.h ⁻¹	L1,0 km.h ⁻¹
11.1 ± 1.3 [†]	13.2 ± 1.0 [†]	13.2 ± 2.0	14.4 ± 1.3 ^{††}	14.4 ± 1.6
	Dmax _{MED} km.h ⁻¹	Dmax _{POL} km.h ⁻¹	Dmax _{SEG} km.h ⁻¹	Dmax _{EXP} km.h ⁻¹
	13.2 ± 1.0	13.2 ± 0.9	13.2 ± 0.9	13.2 ± 1.0

† Different from Dmax_{POL} and Dmax_{SEG}; †† different from Dmax_{MED} and Dmax_{EXP} (p < 0,05); visual analysis (LTv1 e LTv2); [fixed La] (LL_{2,0} and LL_{3,5}); ≥ 1,0 mmol.l⁻¹ (L1,0); Dmax in measured values (Dmax_{MED}) and in adjusted values (Dmax_{POL}, Dmax_{SEG}, Dmax_{EXP}).

Related to the other methods, it was found no significant differences between any Dmax criterion and the LT_{2,0} and LT_{1,0} (p between 0.06 and 0.09). However, while Dmax_{MED} and Dmax_{EXP} were different from LTv2, the same was not observed in the Dmax_{POL} and Dmax_{SEG}. Every Dmax criterion was higher than LTv1 and lower than LT_{3,5} (table 1). Interestingly, LT1 and LT2 attained through fixed concentrations were higher than LT1 and LT2 attained through visual analysis (LT_{2,0} > LTv1 and LT_{3,5} > LTv2).

Dmax_{MED}, Dmax_{SEG}, Dmax_{EXP}, and Dmax_{POL} presented a correlation coefficient that varied between 0.57 and 0.80 (p < 0.01). Table 2 shows the association level between the Dmax criteria and other methods.

Dmax and sportive output

The time of the test and the VM_{10km} were 37.8 ± 3.2 minutes, and 16.0 ± 1.3 km.h⁻¹, respectively.

Every Dmax variation, as well as other identification methods for the LT was significantly lower than the VM_{10km}. On the other hand, only the Dmax_{EXP} were significantly correlated to the VM_{10km} (r = 0.68) (table 2).

TABLE 2

Correlation coefficient between the Dmax model and other different methods to identify the LT, the mean velocity of the 10 km, and the peak velocity on treadmill

	LTv1	LTv2	LT _{2,0}	LT _{3,5}	L1,0	Vel _{10km}	PVE
Dmax _{MED}	0.58**	0.69**	0.40*	0.41*	0.39	0.34	0.48*
Dmax _{POL}	0.57**	0.60**	0.32	0.38	0.58**	0.41	0.64**
Dmax _{SEG}	0.55**	0.66**	0.45*	0.61**	0.65**	0.37	0.64**
Dmax _{EXP}	0.67**	0.77**	0.68**	0.65**	0.72**	0.68**	0.88**

** significant for p < 0,01; * significant for p < 0,05; Dmax in measured values (Dmax_{MED}) and adjusted values (Dmax_{POL}, Dmax_{SEG}, Dmax_{EXP}); visual visual (LTv1 and LTv2); fixed [La] (LL_{2,0} e LL_{3,5}); ≥ 1,0 mmol.l⁻¹ (L1,0); mean v10 km-velocity mean of the 10 km, peak velocity on a treadmill (Vel_{10km}).

DISCUSSION

Historically, conceptual and methodological problems limitate a broadest definition to the phenomena related to the lactate metabolism while exercising. That approach is expressly linked to the different models used to investigate them, and our paper reinforces such premise.

The major contribution this paper supplied was the trend for an exponential increase in the [La] related to the workload observed in 70.4% of the assessed sampling. In that case, the absence of a significant difference between the SRQ of the mathematical functions may be conditioned to some factors.

First, differently from studies verifying a better exponential adjustment in the [La]^(2,3), the protocol employed here has generated a lower amount of points per curve. As the continuous exponential function (figure 2) predicts the blood lactate values with progressive correction minimizing the SRQ maximizing the correlation coefficient between the x and y⁽²⁾ values, such lower amount of points could be one of the reasons for the absence of differences between the mathematical functions.

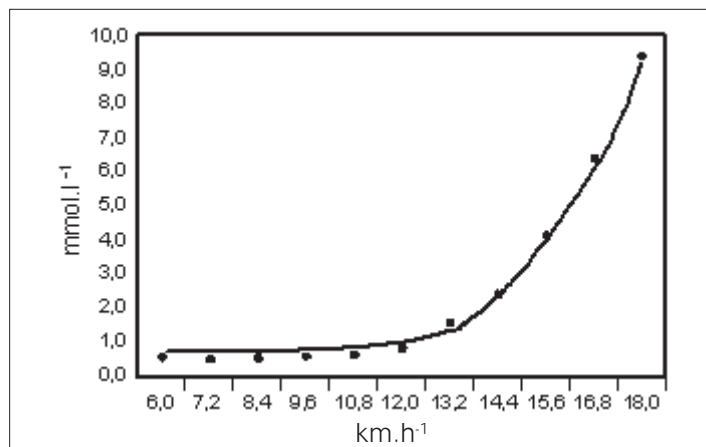


Figure 2 – Blood lactate curve in function of the velocity in an individual with values adjusted according to the continuous exponential function (compact line)

In fact, the duration of the protocol can influence the curve behavior of the [La] in the incremental test⁽²³⁾.

Second, the 2-segment linear adjustment (figure 3) was calculated using four to nine points in the first segment, and two to four points in the second segment. As it is demanded at least seven points to achieve a successful curve adjustment⁽²⁴⁾, this would be a limitation to the present investigation, as that mathematical function splits the curve in two theoretically linear and partially independent segments. Thus, even observing between 7 and 11 points to analyze each total curve, it could there have been a “best” ad-equation of the data to the segmented linear function by the simple division of the curve in two segments. The difficulties in using such mathematical adjustment were previously mentioned⁽²⁵⁾.

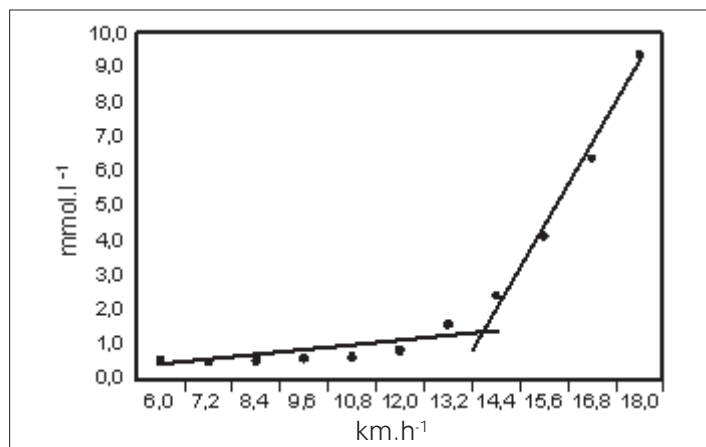


Figure 3 – Blood lactate curve in function of the velocity in an individual with values adjusted according to the 2-segment linear function (compact line)

A descriptive approach helps to understand our results. The features of the blood lactate increase along the progressive protocol must pursue associations with the sportive output, since the best places in a 10 km-test trended to present an exponential increase in the [La].

Such behavior was also observed as to the PVE, with the highest values generated by the majority of individuals with trend for a better continuous exponential adjustment (12 individuals). Although we must be careful, it is reasonable to expect that individuals with a higher aerobic fitness level, also present a higher trend for an exponential increase of the [La] due to the workload⁽²⁶⁾.

The main justification for this suggestion is the changes in the blood lactate accumulation features after a physical training⁽²³⁾. Along with the incremental test, individuals presenting a better aerobic conditioning are successful in keeping themselves during a prolonged period of low [La], thus delaying the beginning of the progressive increase of that variable^(1,8,14,27), and this could generate an exponential increase in the blood lactate curve. This behavior seems to be connected to the higher capability of the tamponage system⁽²⁸⁾, to the better removal^(28,29), and/or a lower lactate production rate⁽³⁰⁾ in individuals performing exercises.

Another important contribution granted by this investigation was the confirmation of the applicability and consistency of the Dmax model in determining the LT both in measured and in adjusted values. On the other hand, even with no significant differences, the points attained by the variations in the Dmax model were not kept away in the same way compared to other methods used.

However, some divergences between methods to identify the LT were previously observed^(16,17,19,20), and these can be related to different methodologies adopted to obtain such intensity⁽³¹⁾.

Unlike prior studies^(19,20), it was observed that the Dmax model was unable to detect the sportive output, because besides the significant difference between the velocities attained through that method and the VM_{10km} , we have noticed low correlation levels between these variables. Our results confirm the supposition that the LT has a higher predictive power in long endurance tests^(8,19,32,33), suggesting that the PVE and the blood lactate peak attained in incremental tests is a more sensitive variable to detect the sportive output in short term tests, with lower or equal to 10 km distances⁽³⁴⁾. Thus, the lack of capability in detecting the sportive output in such type of test should not be conditioned to that specific model, but instead to the physiological phenomenon it represents.

This and other investigations⁽¹⁵⁻¹⁷⁾ allow us to suppose that the Dmax is closest to the L1.0 and away from $LT_{3.5}$ and/or the 4.0 mmol.l⁻¹ threshold. This supposition is justified by the trend to the overestimation of the LT when the fixed [La] is used mainly in

individuals with higher aerobic fitness levels^(12,13), as the individuals assessed in this and other investigations^(16,17) were recreational and/or competitive aerobic athletes.

Additionally, when it is assumed that there is a curvilinear relationship between the [La] and the workload^(4,22), this criterion can be arbitrary and less sensitive to identify such intensity⁽²⁵⁾.

However, considering the existence of two metabolic transition zones^(5,10), it is not possible to conclude to which one the Dmax model is the marker. For instance, although it was noted no difference between any Dmax criterion and the $LT_{2.0}$, the $Dmax_{MED}$ and the $Dmax_{EXP}$ were significantly different from LTV_2 ($p = 0.03$), although the same behavior as to the $Dmax_{POL}$ and $Dmax_{SEG}$ was not observed. This makes difficult to interpret our findings, since theoretically, the $LT_{2.0}$ and the LTV_2 are considered markers for different metabolic transition zones^(5,10).

In fact, the theoretical model suggesting two metabolic transition zones is based on classic studies using visual analysis of the lactate curve^(25,35-37) and/or fixed [La]^(13,25,26,35) in order to obtain the LT. Thus, the identification for two distinct intensities is allowed by the arbitrariness of the fixed [La] method or by the high level of subjectivity and dependence when the researcher is interpreting using the visual method^(11,12). Considering the limitations of these classic methods, it could be suggested the existence of a continuously manifested sole metabolic transition zone⁽²¹⁾.

In fact, a better exponential adjustment in the blood lactate curve observed in prior studies^(2,3), and the trend for a better continuous exponential adjustment observed here would be the evidence for the presence of only one metabolic transition zone.

Despite the limitations of the present study, it was observed trends for an exponential behavior in the blood lactate curve along the progressive protocol on treadmill. On the other hand, it was noted evidences on the applicability and consistency of the Dmax model in determining the LT intensity both in measured and in adjusted values. Nevertheless, this method was not effective in detecting the sportive output on a 10 km-test, suggesting that the exponential characteristic of the [La] curve in that case can be a phenomenon that may help to understand the performance in those tests. Further studies must confirm this suggestion.

THANKFULNESS

We wish to thank to Prof. Doctor Fernando Roberto de Oliveira and Professor Cláudio Romero Marinho for their contributions along the elaboration of the study.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES

1. Mader A. Evaluation of the endurance performance of marathon runners and theoretical analysis of test results. *J Sports Med Phys Fitness* 1991;31:1-19.
2. Hughson R L, Weisiger KH, Swason GD. Blood lactate concentration increases as a continuous function in progressive exercise. *J Appl Physiol* 1987;62:1975-81.
3. Campbell ME, Hughson RL, Green HJ. Continuous increase in blood lactate concentration during different ramp exercise protocols. *J Appl Physiol* 1989;66:1104-7.
4. Kiss MAPDM, Fleishmann E, Cordani LK, Kalinovsk F, Costa R, Oliveira FR, et al. Validade da velocidade do limiar de lactato de 3,5mmol x L⁻¹ identificada através de teste em pista de atletismo. *Rev Paul Educ Fis* 1995;9:16-25.
5. Ribeiro JP. Limiares metabólicos e ventilatórios durante o exercício. *Arq Bras Cardiol* 1995;64:171-81.
6. Beneke R, Von Duvillard PS. Determination of maximal lactate steady state response in selected sports events. *Med Sci Sports Exerc* 1996;28:241-6.
7. Beneke R, Leithäuser RM, Hütler M. Dependence of maximal lactate steady state on the motor pattern of exercise. *Br J Sports Med* 2001;35:192-6.
8. Billat LV. Use of blood lactate measurements for prediction of exercise performance and for control of training. *Sports Med* 1996;22:157-75.
9. Simões HG, Campbell CSG, Kokubun E, Denadai BS, Baldissera V. Determination of maximal lactate steady state velocity coincidence with lower blood glucose. *Med Sci Sports Exerc* 1996;28:S68.
10. Ribeiro JP, Hughes V, Fielding RA, Holden W, Evans W, Knuttgen HG. Metabolic and ventilatory responses to steady state exercise relative to lactate thresholds. *Eur J Appl Physiol* 1986;55:215-21.
11. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. *J Appl Physiol* 1986;60:2020-7.
12. Stegmann H, Kindermann W, Shnabel A. Lactate kinetics and individual anaerobic threshold. *Int J Sports Med* 1981;2:160-5.
13. Heck H, Mader A, Hess G, Mücke S, Müller R, Hollmann W. Justification of the 4-mmol/l lactate threshold. *Int J Sports Med* 1985;6:117-30.
14. Farrell PA, Wilmore JH, Coyle EF, Billing JE, Costill DA. Plasma lactate accumulation and distance running performance. *Med Sci Sports* 1979;11:338-44.

15. Cheng B, Kuipers H, Snyder AC, Jeukendrup A, Hesselink M. A new approach for the determination of ventilatory and lactate thresholds. *Int J Sports Med* 1992; 13:518-22.
16. Baptista RR, Oliveira LG, Figueiredo JB, Oliveira AR. Comparação entre a determinação do limiar de lactato em remadores pelos métodos D_{máx} e limiar de 4,0mmol.l⁻¹. *Rev Bras Med Esporte* 2003;9(Supl 1):S57.
17. Pires FO, Lima Silva AE, Barros RV, Gagliardi JFL, Degaki E, Kiss MAPDM. Estimativa do 2º limiar de lactato pelo modelo D_{máx}. *Rev Bras Med Esporte* 2003;9 (Supl 1):S56.
18. Kara M, Gökbel H, Bediz CS. A combined method for estimating ventilatory threshold. *J Sports Med Phys Fitness* 1999;39:16-9.
19. Bishop D, Jenkins DG, Mackinnon LT. The relationship between plasma lactate parameters, W_{peak} and 1-h cycling performance in women. *Med Sci Sports Exerc* 1998;30:1270-5.
20. Nicholson RM, Sleivert GG. Indices of lactate threshold and their relationship with 10-km running velocity. *Med Sci Sports Exerc* 2001;33:339-42.
21. Pires FO, Lima Silva AE, Barros RV, Gagliardi JFL, Degaki E, Kiss MAPDM. Possibilidade da ocorrência dos 1º e 2º limiares ventilatórios em cargas de trabalho coincidentes, durante protocolos progressivos com incrementos de longa duração. *Rev Bras Ciênc Mov* 2005;13:61-9.
22. Orr GW, Green HJ, Hughson RL, Bennett GW. A computer linear regression model to determine ventilatory anaerobic threshold. *J Appl Physiol Respirat Environ Exerc Physiol* 1982;52:1349-52.
23. Maassen N, Busse MW. The relationship between lactic acid and work load: a measure for endurance capacity or an indicator of carbohydrate deficiency? *Eur J Appl Physiol* 1989;58:728-37.
24. Lima Silva AE, Gagliardi JFL, Lotufo RF, Kiss MAPDM. Ajustes lineares vs quadráticos da curva de consumo de oxigênio durante teste progressivo. *Rev Bras Ciênc Mov* 2003;11:13-8.
25. Gladden LB, Yates JW, Stremel RW, Stamford BA. Gas exchange and lactate anaerobic thresholds: inter- and intraevaluator agreement. *J Appl Physiol* 1985;58: 2082-9.
26. Föhrenbach R, Mader A, Hollmann W. Determination of endurance capacity and prediction of exercise intensities for training and competition in marathon runners. *Int J Sports Med* 1987;8:11-8.
27. Costill DL, Thomason H, Roberts E. Fractional utilization of the aerobic capacity during distance running. *Med Sci Sports* 1973;5:248-52.
28. Monodero J, Donne B. Effect of recovery interventions on lactate removal and subsequent performance. *Int J Sports Med* 2000;21:593-7.
29. Green H, Halestrap A, Mockett C. Increases in muscle MCT are associated with reductions in muscle lactate after a single exercise session in humans. *Am J Physiol* 2002;282:E154-60.
30. MacRae HSH, Dennis SC, Bosch AN, Noakes TD. Effects of training on lactate production and removal during progressive exercise in humans. *J Appl Physiol* 1992;72:1649-56.
31. Meyer K, Hajric R, Westbrook S, Samek L, Lehmann M, Schwaibold M, et al. Ventilatory and lactate threshold determinations in healthy normals and cardiac patients: methodological problems. *Eur J Appl Physiol Occup Physiol* 1996;72:387-93.
32. Kuipers H, Reijtens G, Verstappen F, Shoenmakers H, Hofman G. Effects of stage duration in incremental running tests on physiological variables. *Int J Sports Med* 2003;24:486-91.
33. Fernhall B, Kohrt W, Burkett LN, Walters S. Relationship between the lactate threshold and cross-country run performance in high school male and female runners. *Pediatric Exerc Sci* 1996;8:37-47.
34. Roecker K, Schotte O, Niess AM, Horstmann T, Dickhuth HH. Predicting competition performance in long-distance running by means of a treadmill test. *Med Sci Sports Exerc* 1998;30:1552-7.
35. Moneta JC, Robergs RA, Costill DL, Fink WJ. Threshold for muscle lactate accumulation during progressive exercise. *J Appl Physiol* 1989;66:2710-6.
36. Simon J, Young JL, Gutin B, Blood DK, Case RB. Lactate accumulation relative to the anaerobic and respiratory compensation thresholds. *J Appl Physiol Respirat Environ Exerc Physiol* 1983;54:13-7.
37. Ivy JL, Withers RT, Van Handel PJ, Elger DH, Costill DL. Muscle respiratory capacity and fiber type as determinants of the lactate threshold. *J Appl Physiol Respirat Environ Exerc Physiol* 1980;48:523-7.