

**JEPonline****Editor-in-Chief**

Tommy Boone, PhD, MBA

Review Board

Todd Astorino, PhD

Julien Baker, PhD

Steve Brock, PhD

Lance Dalleck, PhD

Eric Goulet, PhD

Robert Gotshall, PhD

Alexander Hutchison, PhD

M. Knight-Maloney, PhD

Len Kravitz, PhD

James Laskin, PhD

Yit Aun Lim, PhD

Lonnie Lowery, PhD

Derek Marks, PhD

Cristine Mermier, PhD

Robert Robergs, PhD

Chantal Vella, PhD

Dale Wagner, PhD

Frank Wyatt, PhD

Ben Zhou, PhD

Official Research Journal
of the American Society of
Exercise Physiologists

ISSN 1097-9751

Individual Glucose Threshold and Maximal Lactate Steady State Coincidence Analysis

THIAGO TEIXEIRA MENDES^{1,2}, CRISTIANO LINO M. DE BARROS^{1,3}, LUCAS DE ÁVILA C. F. MORTIMER¹, GUILHERME MORAIS PUGA, GUILHERME PASSOS RAMOS¹, LUCIANO SALES PRADO¹, EMERSON SILAMI-GARCIA¹

¹Laboratory of Exercise Physiology, School of Physical Education, Physical Therapy and Occupational Therapy, Federal University of Minas Gerais. ²Department of Environmental, Biological and Health Sciences. University Center of Belo Horizonte – UNI-BH. ³College of Health Sciences, University Center of Patos de Minas – UNIPAM.

ABSTRACT

Mendes TT, Barros CLM, Mortimer LACF, Puga GM, Ramos GP, Prado LS, Silami-Garcia E. Individual Glucose Threshold and Maximal Lactate Steady State Coincidence Analysis. **JEPonline** 2011;14(2):27-35. The purpose of the present study was to analyze the association between the individual glucose threshold (IGT) and the maximal lactate steady state (MLSS). Eight physically active men performed an incremental exercise test to identify the IGT, and three to five 30 min submaximal exercise bouts to evaluate the MLSS on a cycle ergometer. Blood samples were collected from the earlobe at the end of each stage of the incremental exercise tests and every 5 min during the submaximal tests to determine blood lactate ($[La^-]$) and blood glucose concentration. Heart rate (HR) was continuously measured during all tests. We were not able to identify the IGT in two subjects. Power output and VO_2 identified by the IGT were not different to those identified by MLSS (165 ± 9 and 180 ± 11 W; 31.88 ± 1.89 and 34.81 ± 1.83 mL·kg⁻¹·min⁻¹, respectively). HR and $[La^-]$ were lower in the IGT compared to MLSS (154 ± 7 and 168 ± 3 bpm; 3.93 ± 0.87 and 5.60 ± 0.26 mM, respectively; $p < 0.05$). The agreement correlation coefficients between IGT and MLSS for power output (-0.13), HR (0.13) and VO_2 (-0.42) were not statistically significant ($p > 0.05$). The results indicate that the IGT method does not represent a valid estimate of the MLSS.

Key Words: Anaerobic Threshold, Blood Lactate, Exercise, Cycling

INTRODUCTION

The blood lactate response $[La^-]$ during incremental exercise is commonly used to evaluate and prescribe exercise training (4,10,12) as well as to predict the maximal lactate steady state (MLSS) (11,27). The MLSS is considered to be the gold standard for aerobic fitness evaluation and is taken as a measure of the exercise intensity that can be maintained for a long duration without continuous lactate accumulation (3,11). The procedure for determining the MLSS is accurate, but it is time consuming and not very practical for use with athletes.

A number of different methods have been proposed for the estimation of the MLSS from a single incremental exercise test, such as, the fixed 4mM $[La^-]$ (11), ventilatory responses (21,28), hormonal responses (7,19), heart rate (HR) responses (8), salivary lactate concentration (18), and blood glucose response (23). Simões et al. (23) observed an “U” shaped on blood glucose concentration $[bGlu]$ during an incremental running test. The rise on $[bGlu]$ with concomitant increase in exercise intensity above the AT occurs in the same fashion as the $[La^-]$ response during incremental exercises. Both the heart rate and the running velocity corresponding to the lowest glucose concentration were not different from exercise intensities identified by the lactate response. Simões et al. (23) proposed the individual glucose threshold (IGT) as a valid and reliable method to identify the anaerobic threshold (AT) during an incremental exercise test, showing no difference from the individual anaerobic threshold (IAT) as proposed by Stegmann et al. (26).

During progressive exercise, adrenaline is increased in an exponential pattern that leads to enhanced hepatic glucogenolysis and, therefore, higher blood glucose concentrations (16). For this reason, the increase in exercise intensity goes along with higher blood glucose concentrations after a reduction of these concentrations at the onset of exercise, which, in turn, is a consequence of a higher glucose uptake at the initial intensity stages. Additionally, at a given exercise intensity, glucose uptake by the muscles become limited due to the decrease in intracellular hexokinase activity (29). Consequently, during progressive exercise, blood glucose concentrations may increase after reaching a concentration minimum which may coincide with the anaerobic or lactate threshold. This point may be defined as the individual glucose threshold (23). Various studies have examined the possibility of IGT in the identification and/or prediction of AT (2,6,20,22,25) or MLSS (24). Interestingly, these studies used a treadmill to exercise the subjects. The purpose of the present study was to analyze the association between IGT and MLSS during exercise on a cycle ergometer. Our hypothesis was that the IGT would be able to predict the MLSS.

METHODS

Subjects

Eight physically active male university students not participating in any aerobic training took part in this study (Table 1).

Table 1. Subject characteristics. Values are presented as Mean \pm SD.

N	Age (years)	Body mass (kg)	Height (cm)	% Body Fat	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
8	23.9 \pm 2.4	75.9 \pm 7.3	178.5 \pm 4.2	15.9 \pm 5.6	47.78 \pm 4.87

Procedures

This study respected all the rules established by the National Health Council (Res. 196/96) for research with humans and was approved by the Ethics Committee from the Federal University of

Minas Gerais (Protocol #355/05). All the subjects signed an informed consent explaining the risks and benefits of the study.

Experimental Design

Subjects performed a maximum incremental exercise test (IT max) to determine maximal oxygen uptake ($\text{VO}_2 \text{ max}$) (1). They also performed an incremental exercise test (IT inc) for IGT identification, and three to five 30-minute continuous submaximal exercise tests (T sub) for the identification of MLSS. All tests were performed between 8:00 am and 12:00 pm in an environmental chamber under a temperate environment of $22 \pm 1^\circ\text{C}$ and $61 \pm 8\%$ relative air humidity (RH). The testing conditions were carried out 5 days apart to minimize the training effect during the study. The subjects were instructed not to ingest alcohol or caffeine and also to refrain from any exercise activity for at least 24 hrs prior to the tests. They were asked to drink 500 mL of water 2 hrs before the tests to guarantee hydration at the beginning of each test (1). Urine density was measured using a portable refractometer (JSCP – Uridens[®], São Paulo, SP, Brazil) before each test. The IT max was performed at a pedaling frequency of 50 rpm. It was started at a power output of 50 W with 25 W increments every 2 min. The IT inc started at 60 W and pedaling frequency of 60 rpm with 15 W increment every 3 minutes. Both tests were performed until voluntary fatigue. Both tests were terminated when either the rate of perceived exertion (RPE) (5) was 20 or the subject voluntarily stopped the test.

Maximal Lactate Steady State Identification

For MLSS identification, three to five 30-minute continuous submaximal exercise tests (T sub) were performed to evaluate the highest exercise intensity at which the $[\text{La}^-]$ did not increase more than 1mM between the 10th and the 30th-minute of constant exercise (3,11). The first intensity was that corresponding to the 3.5 mM lactate as determined previously using the linear interpolation method during the IT. If during the first trial the BLC remained stable or decreased towards the end of the 30 minutes of exercise, the intensity of the following trials was increased until a steady BLC could no longer be maintained. On the other hand, if during the first trial BLC increased continuously over the 30 minutes or exercise was interrupted due to fatigue, the intensity of the following trials was reduced. The intensity of the subsequent MLSS trials was adjusted by 15 or 30 W.

Individual Glucose Threshold Identification

The IGT was considered to be the exercise intensity at which the lowest $[\text{bGlu}]$ occurred followed by one increase during the IT (23), as shown in Figure 1.

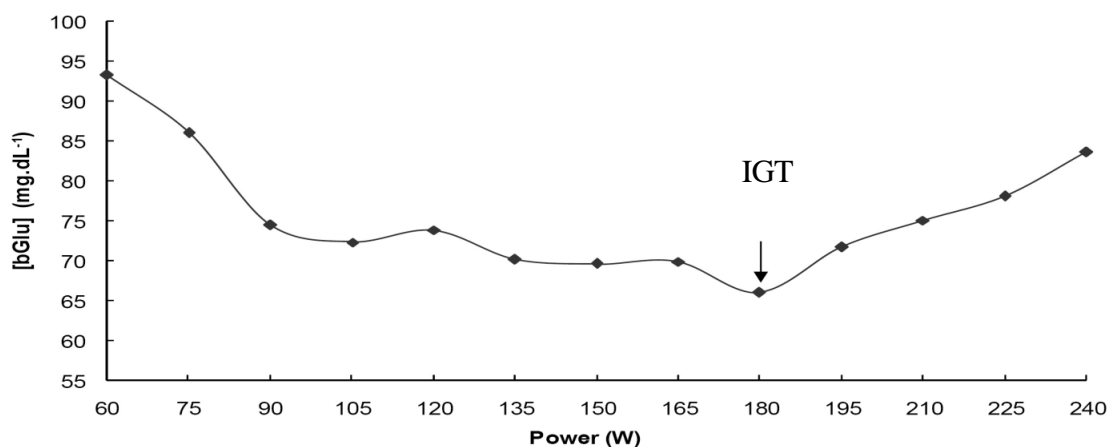


Figure 1. Blood glucose concentration ($[\text{bglu}]$) during and incremental exercise test; an example of identification of the individual glucose threshold (IGT) in one subject from this study.

Blood lactate and Glucose Analysis

A 25 μL sample of capillary blood was taken from the earlobe and deposited into Eppendorf tubes containing 50 μL of 1% NaCl for blood lactate and glucose analysis (YSI 2300 STAT, Yellow Spring Instruments, OH, USA). The samples were collected 10 minutes before the experiments (rest), during the last fifteen seconds of each stage, and at every 5-minute interval of the T sub test.

Respiratory and heart rate analysis

During all tests the respiratory variables were measured breath by breath through a previously calibrated gas analyzer (BIOPAC System®, GasSys2, EUA). The heart rate (HR) was monitored continuously every minute using a Polar heart rate monitor S810i® (Polar Electro, Kempele, Finland).

Statistical Analyses

All results are shown as mean \pm standard error. A paired t-test was used to compare the workload, HR, VO_2 and $[\text{La}^-]$ values identified by IGT and MLSS. The agreement between the workload, HR and VO_2 identified by the IGT and MLSS were tested by the agreement correlation coefficient (ACC) (13-15). This coefficient is used to verify if the regression line of the data coincided with the line of perfect agreement (45°). The ACC does this by joining one precision component (Pearson correlation coefficient, r) and one exact component (C_b). The significance level was set at $p < 0.05$.

RESULTS

Workload, HR, VO_2 and $[\text{La}^-]$ results are shown in Table 2. It was not possible to identify the IGT in two subjects due to a lack of a minimum value followed by an increased response in the $[\text{bGlu}]$. There was no difference between IGT and MLSS in six subjects at the corresponding workload and VO_2 .

Table 2. Workload, heart rate (HR) and blood lactate concentration $[\text{La}^-]$ values identified from the maximum lactate steady state test (MLSS) and individual glucose threshold test (IGT).

Conditions	MLSS	IGT
Workload (W)	185 \pm 12	165 \pm 9
HR (bpm)	169 \pm 2	154 \pm 7*
$[\text{La}^-]$ (mM)	5.63 \pm 0.29	3.93 \pm 0.87

* $p < 0.05$ compared to MLSS.

TABLE 3. Agreement correlation coefficient (ACC), precision (p) and accuracy (C_b) components of the workload, heart rate, and oxygen uptake identified by the individual glucose threshold and the maximal lactate steady state.

	Workload	HR	VO_2
ACC (r_c)	-0.13	0.10	-0.42
Precision (p)	-0.18	0.27	-0.68
Accuracy (C_b)	0.69	0.39	0.62

Table 3 shows the correlation coefficients between the workload, HR and VO_2 identified from IGT and MLSS. No significant ACC was observed between the workload, HR and VO_2 (Figure 2) identified from both IGT and MLSS ($p > 0.05$). The dotted lines represent perfect agreement, and the solid line is line of best fit (correlation line).

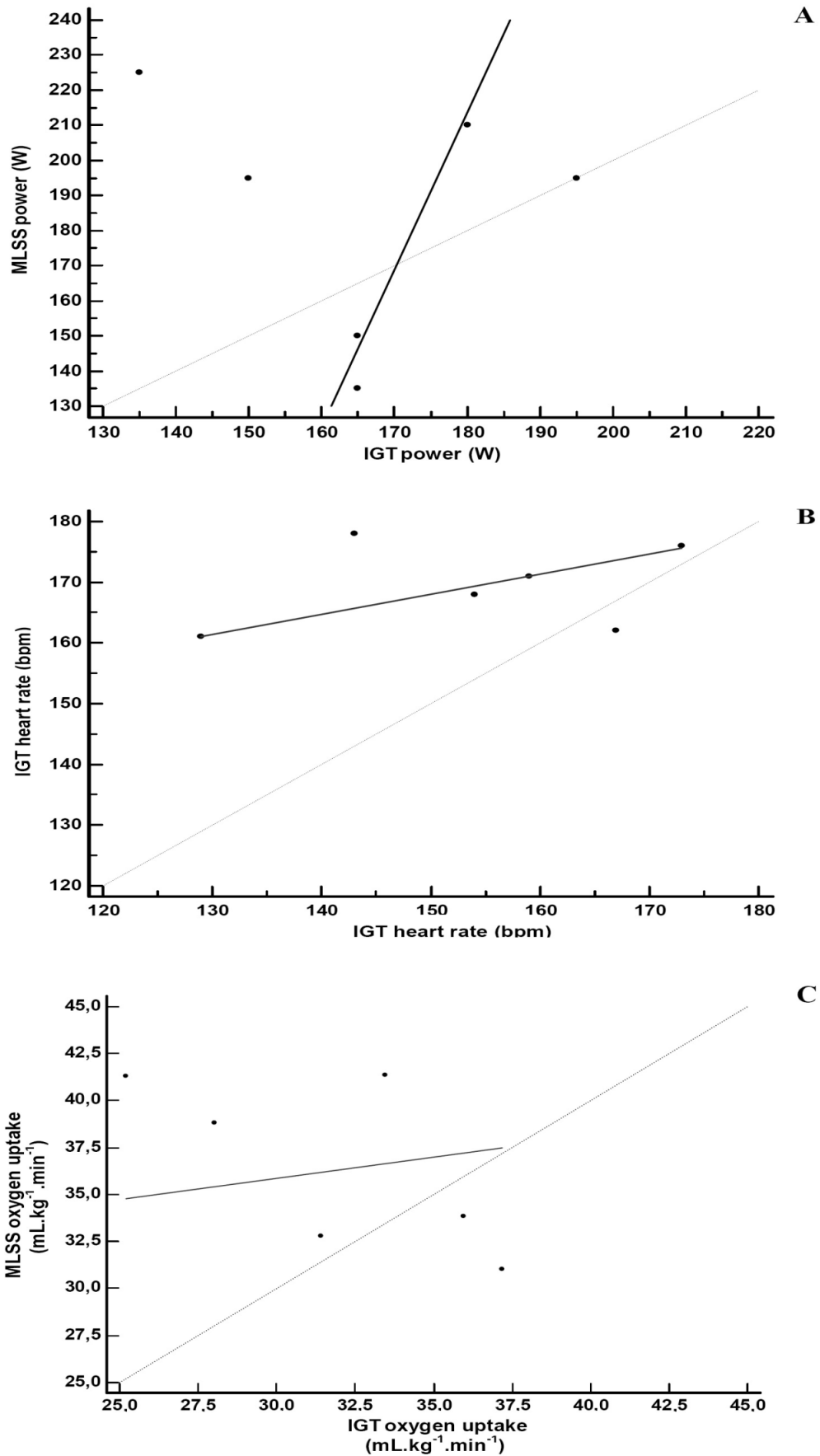


Figure 2. Agreement between (A) power output, (B) heart rate, and (C) oxygen uptake evaluated by the individual glucose threshold (IGT) and the maximal lactate steady state (MLSS).

DISCUSSION

The present study analyzed the possibility of using the IGT to identify the MLSS intensity on a cycle ergometer with one single exercise bout through the [bGlu] responses. No differences were found for power output between IGT and MLSS, but HR was lower in IGT when compared to MLSS. However no significant correlation was found between these methods.

The exercise intensity corresponding to MLSS is considered to be the gold-standard among the protocols that identify aerobic fitness using blood lactate responses. However, its use is not practical due to the number of trials necessary to directly determine the intensity. For this reason, different methods have been proposed to identify MLSS with a single test. The validity of some of the methods was not verified to identify the intensity, and there may have been some use of inadequate statistical procedure to do this verification (9).

Lin (13-15), proposed the ACC to assess the agreement between two methods, and showed that using only the Student t-test, variance analysis or Pearson correlation was not suitable to verify the agreement between two methods. The Pearson correlation coefficient measures a linear relationship but fails to detect any departure from the 45° line, and the paired t-test fails to detect poor agreement in pairs of data. Combining the above two methods also cannot detect poor agreement in pairs of data (14). In the present study, although the IGT showed similar values to MLSS intensity for workload and VO_2 , there was no significant ACC between the workload, HR and VO_2 between the MLSS and IGT intensities. Moreover, it was not possible to identify IGT in two subjects. This result means that the IGT did not individually estimate the workload (Figure 2A) or the VO_2 (Figure 2C) corresponding to the MLSS, even though similar mean values were found. Thus, the use of IGT to estimate MLSS workload or HR for training prescription and control must be done with caution.

However, Sotero et al. (24) analyzed if the running speed corresponding to IGT could predict the MLSS and evaluated 13 physically active men in field tests. No differences between running speeds associated to the IGT and MLSS, with a high correlation between IGT and MLSS ($r = 0.947$; $p < 0.01$). Moreira et al. (17) identified the IGT in sedentary and active type 2 diabetic subjects, and found no significant differences compared to the AT identified by the ventilatory and $[La^-]$ responses on a cycle ergometer. Moreover, these authors suggested the use of IGT for aerobic exercise prescription in type 2 diabetes subjects. As in the previous studies, they did not compare the IGT with the MLSS.

In the present study, there was no “U” shape in the [bGlu] response in any of the subjects. Similar results were found by Ribeiro et al. (20), which identified an inconsistent [bGlu] response in some subjects, although they could identify the IGT in all subjects. The [bGlu] identified at the IGT intensity ranged from 48.93 to 72.22 $mg \cdot dL^{-1}$ and were similar to the results of other studies (20,22,23).

CONCLUSIONS

Our results indicate that the IGT identified by an incremental exercise test on a cycle ergometer did not estimate the MLSS of physically active subjects.

ACKNOWLEDGMENTS

We would like to thank the FAPEMIG, CAPES and CNPq for the financial support.

Address for correspondence: Emerson Silami-Garcia, PhD, Laboratory of Exercise Physiology, School of Physical Education, Physical Therapy and Occupational Therapy, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil, 31270-901. +55 (31) 3409.2350; +55 (31) 3409.2325; Email: silami@ufmg.br

REFERENCES

1. Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC Jr, Sherman WM. American College of Sports Medicine Position Stand: Exercise and fluid replacement. *Med Sci Sports Exerc* 1996; 28: i-vii
2. Balikian PJ, Neiva CM, Denadai BS. Effect of an acute beta-adrenergic blockade on the blood glucose response during lactate minimum test. *J Sci Med Sport* 2001;4:257-265.
3. Beneke R, Hutler M, Leithauser RM. Maximal lactate-steady-state independent of performance. *Med Sci Sports Exerc* 2000;32:1135-1139.
4. Billat VL, Sirvent P, PY G, Koralsztein JP, Mercier J. The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. *Sports Med* 2003; 33:407-426.
5. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982;14:377-381.
6. Campbell CSG, Simões HG, Denadai BS. Influence of glucose and caffeine administration on identification of maximal lactate steady state. *Med Sci Sports Exerc* 1998;30:S327.
7. Chumura J, Nazar K, Kaciuba-Uscilko H. Choice reaction time during graded exercise in relation to blood lactate and plasma catecholamine thresholds. *Int J Sports Med* 1994;15: 172-176.
8. Conconi F, Grazi G, Casoni I, Guglielmini C, Borsetto C, Ballarin E, Mazzoni G, Patracchini M, Manfredini F. The Conconi test: methodology after 12 years of application. *Int J Sports Med* 1996;17:509-519.
9. Faude O, Kindermann W, Meyer T. Lactate threshold concepts: How valid are they? *Sports Med* 2009;39:469-490.
10. Ferreira JC, Rolim NP, Bartholomeu JB, Gobatto CA, Kokubun E, Brum PC. Maximal lactate steady state in running mice: effect of exercise training. *Clin Exp Pharmacol Physiol* 2007; 34:760-765.
11. Heck H, Mader A, Hëss G, Mucke S, Muller R, Hollmann W. Justification of the 4mmol/l lactate threshold. *Int J Sports Med* 1985;6:117-130.

12. Kindermann W, Simon G, Keul J. The significance of the aerobic-anaerobic transition for the determination of work load intensities during endurance training. *Eur J Appl Physiol Occup Physiol* 1979;42:25-34.
13. Lin LI. Assay validation using the concordance correlation coefficient. *Biometrics* 1992;48: 599-504.
14. Lin LI. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 1989;45: 255-268.
15. Lin LI. A note on the concordance correlation coefficient. *Biometrics* 2000;56: 324-328.
16. Mazzeo RS, Marshall P. Influence of plasma catecholamine on the lactate threshold during graded exercise. *J Appl Physiol* 1989;67:1319-22.
17. Moreira SR, Simões GC, Hiyane WC, Campbell CSG, Simões HG. Identification of the anaerobic threshold in sedentary and physically active individuals with type 2 diabetes. *Rev Bra Fisioter* 2007;4:253-259.
18. Perez M, Lucia A, Carvajal A, Pardo J, Chicharro JL. Determination of the maximum steady state of lactate (MLSS) in saliva: an alternative to blood lactate determination. *Jpn J Physiol* 1999;49:395-400.
19. Port K. Serum and saliva cortisol responses and blood lactate accumulation during incremental exercise testing. *Int J Sports Med* 1991;12:490-494.
20. Ribeiro FP, Baldissera V, Balakian P, Soares AR. Limiar anaeróbio em natação: comparação entre diferentes protocolos. *Rev bras Educ Fís Esp* 2004;18:201-212.
21. Ribeiro JP, Yang J, Adams RP, Kuca B, Knutten HG. Effect of different incremental exercise protocols on the determination of lactate and ventilatory thresholds. *Braz J Med Biol Res* 1986;19:109-117.
22. Simões HG, Campbell CS, Kushnick MR, Nakamura A, Katsanos CS, Baldissera V, Moffatt RJ. Blood glucose threshold and the metabolic responses to incremental exercise tests with and without prior lactic acidosis induction. *Eur J Appl Physiol* 2003;89:603-611.
23. Simões HG, Grubert Campbell CS, Kokubun E, Denadai BS, BALDISSERA V. Blood glucose responses in humans mirror lactate responses for individual anaerobic threshold and for lactate minimum in track tests. *Eur J Appl Physiol Occup Physiol* 1999;80:34-40.
24. Sotero RC, Pardono E, Landwehr R, Campbell CS, Simões HG. Blood glucose minimum predicts maximal lactate steady state on running. *Int J Sports Med* 2009; 30:643-646.
25. Souza TNT, Yamaguti SAL, Campbell CSG, Simões HG. Identificação do lactato mínimo e glicose mínima em indivíduos fisicamente ativos. *Rev Bras Cien Mov* 2003;11:71-75.
26. Stegmann H, Kindermann W, Schnabel A. Lactate kinetics and individual anaerobic threshold. *Int J Sports Med* 1981;2:160-165.

27. Van Schuylenbergh R, Vanden Eynde B, Hespel P. Correlations between lactate and ventilatory thresholds and the maximal lactate steady state in elite cyclists. *Int J Sports Med* 2004;25:403-408.
28. Wasserman K, Hansen JE, Sue DY, Whipp BJ. *Principles of Exercise Testing and Interpretation*. Philadelphia: Lea & Febiger, 1986.
29. Watt MJ, Hargreaves M. Effect of adrenaline on glucose disposal during exercise in humans: role of muscle glycogen. *Am J Physiol Endocrinol Metab* 2002;283:578-583.

Disclaimer

The opinions expressed in **JEPonline** are those of the authors and are not attributable to **JEPonline**, the editorial staff or the ASEP organization.