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Aerobic Endurance Measurement by Respiratory Exchange Ratio during a Cycle Ergometer Graded Exercise Test

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ABSTRACT

Zagatto AM, Miyagi WE, Sakugawa RL, Kaminagakura ET, Papoti M. Aerobic Endurance Measurement by Respiratory Exchange Ratio during a Cycle Ergometer Graded Exercise Test. **JEPonline** 2012;15(5):49-56. The purpose of this study was to verify that the use of intensity at the respiratory exchange rate (RER) value of 1.00 (iRER=1.00) can be used to estimate aerobic endurance during a cycle ergometer graded exercise test. The iRER=1.00 of 25 active males (22±1 yrs) was compared with respiratory compensation point (RCP), anaerobic threshold of abrupt lactate increase (AnT_{LAC}), and the intensity of blood lactate concentration at 3.5 mmol·L^{-1} ($OBLA_{3.5}$). Respiratory and blood lactate responses were measured during a maximal cycle ergometer graded exercise test (GXT) to determine iRER=1.00, RCP, AnT_{LAC} and $OBLA_{3.5}$. In addition, the heart rate (HR) and rate of perceived exertion (RPE) were measured during the GXT. iRER=1.00 (123.8±5.6 W) did not differ with RCP (126.8±6.5 W), AnT_{LAC} (129.5±5.3 W), and $OBLA_{3.5}$ (120.8±6.5 W) intensities; whereas, iRER=1.00 was significantly correlated with RCP (r = 0.94), $OBLA_{3.5}$ (r = 0.86), and AnT_{LAC} (r = 0.74), and iRER=1.00 shown good agreement with other intensities. Similar results were found with VO_2, HR, blood lactate, and RPE at these intensities. We conclude that iRER=1.00 can be used to estimate aerobic endurance intensity in cycle ergometer exercise.

Key Words: Anaerobic Threshold, Respiratory Compensation Point, Oxygen Uptake, Aerobic Endurance

INTRODUCTION

The maximal lactate steady state (MLSS) is considered the “gold standard” procedure in the assessment of aerobic endurance (2,3). However, there are some disadvantages to the assessment of MLSS in sports teams. Aside from the cost of the test, there is the requirement for individuals to complete 3 to 6 constant-load exercise bouts on separate days. Thus, MLSS has been used to validate other procedures of endurance capacity assessment (1,5,7,13). Researchers have validated procedures that estimate MLSS intensity using only a single exercise session. Between these procedures, blood lactate responses (e.g., lactate threshold, lactate minimum test, and others) (2,5,13) and pulmonary parameters such as respiratory compensation point (RCP) and ventilatory threshold (2,11,14,17) have been used. Although the blood lactate response is effective in estimating MLSS intensity, the use of non-invasive procedures is generally better received by the volunteers.

The exercise intensities below and at RCP represents a physiological steady state (17). It is important to point out that the RCP represents the highest exercise intensity in which the respiratory system maintains a physiological steady state (17). In this exercise intensity, the value of the respiratory exchange ratio (RER) is approximately 1.00. Thus, exercises performed at intensities above the RCP (i.e., RER > 1.00) leads to hyperventilation and a higher production of carbon dioxide (VCO_2). These responses occur due to the buffering of excess hydrogen released by the muscle during anaerobic metabolism. This process is possible due to the bicarbonate buffering system. In this system, carbon dioxide (CO_2) combines with water to form carbonic acid (H_2CO_3), which in turn dissociates to form hydrogen ion and bicarbonate (HCO_3^-) as shown in the reactions below:

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO_3^- + H^+$$

Dickstein and colleagues (4) reported that the intensity corresponding to the RER (iRER)=1.00 could be use to predict anaerobic threshold (17), thus indicating the onset of lactic acidosis. In addition, Solberg et al. (16) found that iRER=1.00 could be used as a good predictor of the exercise intensity in which blood lactate concentration was 1.5 $mmol \cdot L^{-1}$ above the mean blood lactate between the rest and the first load. However, both Dickstein et al. (4) and Solberg et al. (16) compared the iRER=1.00 with the onset lactic acidosis point (classified as the first increase of the blood lactate concentration (11) and characterized as the aerobic threshold intensity) that does not represent the intensity of aerobic endurance.

Laplaud and Menier (9) verified that the iRER=1.00 presented reproducibility in a cycle ergometer ram test. They did not find significant differences comparing this intensity with the intensity corresponding to the second ventilatory threshold (VT_2) and with the intensity corresponding to the blood lactate concentration of 4.0 $mmol \cdot L^{-1}$. However, the correlation coefficients between these parameters were not presented in the mentioned study (9). In subsequent studies, the same research group observed that iRER=1.00 was sensitive to systematic training in basketball players (8) and was able to estimate the MLSS intensity (7).

The use of iRER=1.00 seems to be a fast and non-invasive procedure that allows for the estimation of aerobic endurance using a single exercise session. To better understand this thinking, it is necessary to compare the iRER=1.00 with other procedures that estimate aerobic endurance intensity using blood lactate and respiratory responses in single exercise sessions. In addition, to validating the iRER=1.00 as an aerobic endurance parameter, the use of analysis of association and agreement are necessary. Thus, the purpose of this study was to verify that the use of intensity at the respiratory exchange rate (RER) value of 1.00 (iRER=1.00) can be used to estimate aerobic endurance during a cycle ergometer graded exercise test. The steps towards verification depend on: (a) comparing the

iRER=1.00 value with anaerobic threshold at the abrupt lactate increase and the onset blood lactate accumulation; and (b) determining the correlation and agreement of the iRER=1.00 with these procedures.

METHODS

Subjects

Twenty-five healthy and moderately active male subjects (age 22±1 yrs; height 176.2±0.9 cm; body weight of 78.1±2.9 kg) volunteered to participate in this study. The sample size resulted in a statistical power of 100% to analyze comparisons between means. All subjects were verbally informed of the risks and benefits of the study procedures and signed an informed consent before their inclusion in the study. All procedures were approved by the Ethics Committee of the Federal University of Mato Grosso do Sul/Brazil, and were conducted in accordance with the Declaration of Helsinki.

Procedures

To determine the iRER=1.00, RCP, anaerobic threshold at abrupt lactate increase, and anaerobic threshold corresponding to 3.5 $mmol \cdot L^{-1}$ lactate concentration, the subjects performed a maximal graded exercise test (GXT) on a mechanically braked cycle ergometer (Biotec 2100, Cefise, Brazil). Prior to testing, the subjects performed a warm-up lasting 8 min at an intensity corresponding to 70 W at a cadence of 70 rpm. The cadence of 70 rpm was also used in the GXT, which was started 5 min after the warm-up. The GXT consisted of 70 W of initial workload that was increased by 17.5 W at each stage of 2 min until voluntary exhaustion or inability to keep pace with the cadence for over 5 sec even after substantial verbal encouragement.

Oxygen consumption (VO_2), VCO_2, RER, and ventilation (V_E) were collected-by-breath using an automatic gas analyzer True-One 2400 (ParvoMedics, East Sandy, Utah, USA) during the GXT. Heart rate (HR) was measured concomitantly to respiratory measures coupled to an HR belt transmitter (T31, Polar Electro, Kempele, Finland). The gas analyzer was calibrated immediately before each test using known gas samples (3.98% CO_2 and 16.02% O_2, Air gas Puritan Medical, USA), while the spirometer was calibrated by a 3-liter syringe (Hans Rudolf, Kansas City, USA). The data collected by the gas analyzer were smoothed to remove the outliers (12) and subsequently interpolated in every 1 sec interval. For analysis of respiratory and ventilatory data at each stage of exercise, the last 20 sec of each effort stage was averaged. An electrochemical analyzer (YSI, Yellow Springs Instruments, Ohio, USA) was used to collect blood samples from the earlobe (25 microliters) immediately after each stage of exercise (without interrupting the test) and at the 5th min and the 7th min at the end of the test to determine blood lactate ([La]). Rate of perceived exertion (RPE) was also measured after each effort stage using the Borg 6-20 scale.

Maximal oxygen consumption (VO_2 max) corresponded to the highest average VO_2 over the last 20 sec of the GXT test. The following criteria were also used to determine VO_2 max: Blood lactate ≥8.0 $mmol \cdot L^{-1}$; HR ≥90% age-predicted HR maximal (220-age); RER ≥1.10; and VO_2 plateau (VO_2 changes ≤2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ between the last two exercise stages), while the maximal aerobic power (MAP) corresponded to the highest power attained in the complete stage during GXT. If the subjects were unable to end the stage, the MAP was calculated using the equation suggested by Kuipers and colleagues (6): [MAP= intensity of the previous stage + ((time of exercise/120)*increment)]

The iRER=1.00 corresponded to the intensity in which RER was equal to 1.00, RCP corresponded to the intensity in which an increase of both ventilatory equivalents of oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2) was observed, anaerobic threshold corresponding to the lactate abrupt increase (AnT_{LAC}) was determined using a bi-segmented linear regression, and the intensity of onset blood

lactate accumulation ($OBLA_{3.5}$) corresponded to the intensity of 3.5 mmol·L^{-1} blood lactate. After these measures, the values of VO_2, HR, [La], and RPE at iRER=1.00, RCP, $OBLA_{3.5}$ and AnT_{LAC} were also determined.

Statistical Analyses

The data are shown in mean ± standard error of mean. Initially, the Shapiro-Wilk's test was applied and the normality of the data was confirmed. One-way repeated measures analysis of variance was used to compare the iRER=1.00 with RCP, AnT_{LAC} and $OBLA_{3,5}$ and to compare the VO_2, HR, [La], and RPE correspondents at these intensities. In addition, Mauchly's sphericity test was applied to the data and sphericity was assumed when the F test was significant. In case of violation of sphericity, the Greenhouse-Geisser Epsilion correction was used. Analysis was completed by using Bonferroni's multiple comparison tests. The Pearson product-moment correlation coefficient was used to verify the relationship between each parameter and the Bland-Altman plot was used to verify the agreement of the data. In addition to the significance level (P=0.05), the correlation coefficients were classified as very weak to negligible (0.0 to 0.2), weak (0.2 to 0.4), moderate (0.4 to 0.7), strong (0.7 to 0.9), and very strong (0.9 to 1.0) (15). In all cases, statistical significance was set at P=0.05.

RESULTS

The subjects' VO_2 max and MAP measured during the GXT were 43.0±1.3 ml·kg^{-1}·min^{-1} and 182.7±6.2 W, respectively. Table 1 shows the intensities of iRER = 1.00, $OBLA_{3.5}$, AnT_{LAC} and RCP, and the VO_2, VO_2 at VO_2 max, HR, HR at HR max, RER, [La], and RPE at these intensities. There were no significant differences for almost all variables, except to RER at AnT_{LAC} that was higher than the RER values at $OBLA_{3,5}$ and RCP.

Table 1. Values of iRER=1.00, $OBLA_{3.5}$, AnT_{LAC} and RCP and Metabolic and Respiratory Parameters Corresponding to these Intensities.

	iRER=1.00	$OBLA_{3.5}$	AnT_{LAC}	RCP	P-value
Intensity (W)	123.8±5.6	120.8±6.5	129.5±5.3	126.8±6.5	0.09
Intensity at MAP (%)	67.8±1.9	65.7±2.2	71.1±1.8	69.2±2.2	0.07
VO_2 (ml·kg^{-1}·min^{-1})	29.7±1.3	30.5±1.4	31.5±1.0	30.7±1.4	0.09
VO_2 at VO_2 max (%)	68.7±1.6	68.9±2.1	73.7±1.8	71.2±1.8	0.05
HR (beats·min^{-1})	155.8±2.8	153.6±3.2	159.8±2.8	157.6±3.3	0.33
HR at HR max (%)	82.8±1.0	81.9±1.4	85.0±1.2	83.7±1.3	0.10
RER	—	0.98±0.01*	1.02±0.01	0.99±0.01*	0.02
[La] (mmol·L^{-1})	4.0±0.2	—	4.3±0.3	4.2±0.3	0.64
RPE	11.6±0.5	11.3±0.6	12.0±0.6	11.6±0.5	0.37

MAP = maximal aerobic power; VO_2 = oxygen uptake; HR = heart rate; RER=respiratory exchange ratio; [La] = blood lactate response; RPE = rate of perceived exertion. *P=0.05 in relation to AnT_{LAC}.

The iRER=1.00 was strong and statistically correlated with AnT_{LAC} and $OBLA_{3.5}$, whereas the correlation with RCP intensity was significant and very strong. In addition, the VO_2 and RPE at iRER=1.00 were statistically correlated with the same parameters at RCP, AnT_{LAC} and $OBLA_{3.5}$ intensities. In respect to the correlation coefficients, AnT_{LAC} versus intensity at MAP, HR at HR max, and lactate did not present significant correlations.

Table 2. Correlation Coefficients among the Physiological Parameters and the Rate of Perceived Exertion Relatives to iRER=1.00 with the Same Parameters at $OBLA_{3.5}$, AnT_{LAC} e RCP (*P=0.05)

RER=1.00	$OBLA_{3.5}$	AnT_{LAC}	RCP
Intensity	0.86*	0.74*	0.92*
Intensity at MAP	0.59*	0.26	0.76*
VO_2	0.79*	0.68*	0.90*
VO_2 at VO_2 max	0.48*	0.09	0.66*
HR	0.66*	0.62*	0.86*
HR at HR max	0.51*	0.33	0.75*
Lactate	—	0.33	0.69*
RPE	0.74*	0.58*	0.84*

Figure 1 showns the Bland-Altman plots of iRER=1.00 with RCP (Figure 1A), AnT_{LAC} (Figure 1B), and $OBLA_{3.5}$ (Figure 1C) intensities. Low bias (residual value of average of difference) and moderate random errors (lower and upper limits) were found, showing good absolute agreement of the iRER=1.00 with RCP, AnT_{LAC} and $OBLA_{3.5}$ intensities.

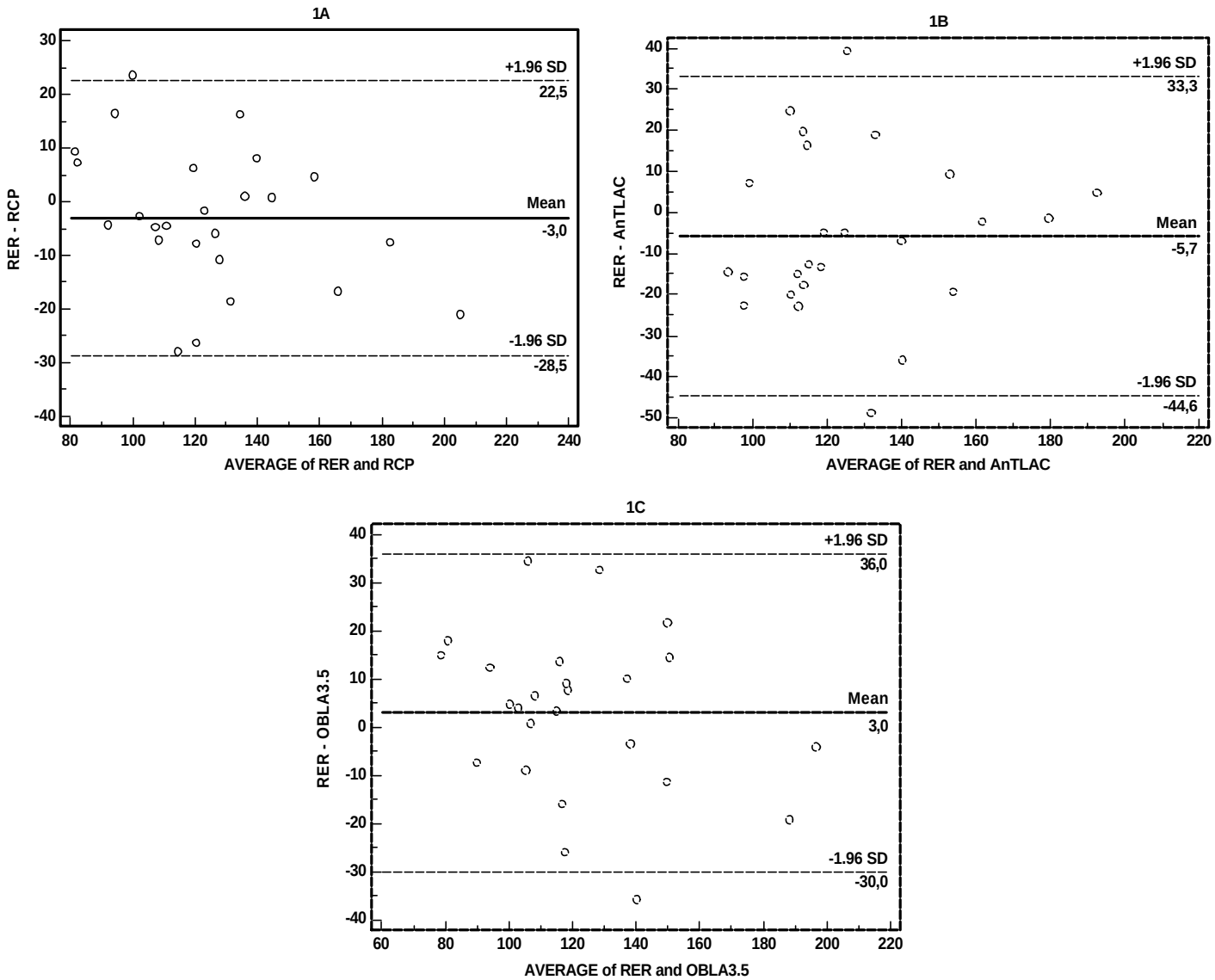

Figure 1. Analysis of agreement between intensities RER=1.00 with RCP (1A), AnT_{LAC} (1B) and $OBLA_{3.5}$ (1C) (standard deviation = SD).

DISCUSSION

The main findings of this study were the similar values between the iRER=1.00, RCP, $OBLA_{3.5}$ and AnT_{LAC} intensities as well as between the other parameters at these intensities (VO_2, HR, HR at maximal, RER, [La], and RPE). In addition, our results showed the good agreement of iRER=1.00 with RCP, $OBLA_{3.5}$ and AnT_{LAC} intensities analyzed by Bland-Altman plots and the significant correlations of iRER=1.00 with $OBLA_{3.5}$, AnT_{LAC} and RCP intensities and other parameters at these intensities.

The aerobic endurance intensity is widely used to measure the aerobic conditioning in sedentary and trained subjects, and it is used for exercise prescription. Therefore, the development of a procedure that allows for measuring this intensity using a fast and non-invasive test is necessary. Anaerobic threshold intensity is the most common parameter used to measure the aerobic endurance, and it can be estimated by the abrupt increase of the blood lactate (11), by fixed blood lactate values (5,13), and by ventilatory and respiratory responses (RCP) (11,17). However, it is important to point out that in the present study anaerobic threshold was assumed as the same physiological phenomena as the maximal lactate steady state intensity. In the literature, there are several authors using anaerobic threshold to describe different physiological phenomena (17). Therefore, we compared the iRER=1.00 with RCP, AnT_{LAC} and $OBLA_{3.5}$, which theoretically corresponds to the same physiological phenomena (11).

Our findings are in agreement with Laplaud and colleagues (7,8,9) who reported similar values for iRER=1.00 with RCP, AnT_{LAC} and $OBLA_{3.5}$ intensities. In the Bland-Altman plots, low average of differences (bias) were observed for iRER=1.00 and RCP (-3.0 W; -1.6%), AnT_{LAC} (-5.7 W; -4.9%) and $OBLA_{3.5}$ (3.0 W; 3.4%). The absolute agreement of the Bland-Altman plot was verified by the mean of difference between two values and values near to zero and represents the higher agreement between two parameters. The acceptation of RER=1.00 as a good procedure to estimate the aerobic endurance is supported by the similar values observed for MAP, VO_2, VO_2 relative to VO_2 max, HR, HR at HR max, [La], and RPE correspondents to iRER=1.00, RCP, $OBLA_{3.5}$ and Ant_{LAC}. In addition, to these findings, the RER at RCP was 0.99±001, 1.02±001 at AnT_{LAC} and 0.98±0.01 at OBLA3.5, where only the RER at AnT_{LAC} was statistically higher than the other values (Table 1). Laplaud et al. (8) observed in basketball players a significant increase in iRER = 1.00 value after 4.7 months of training, showing that the iRER=1.00 is also sensitive to aerobic adaptations that occur with systematic training.

It is important to point out that iRER=1.00 corresponds to the intensity that 100% of the energy source is glucose ($C_6H_{12}O_6 + 6O_2$? $6H_2O + 6CO_2$; RER = $6CO_2/6O_2$ = 1.00) showing the aerobic predominance during this exercise intensity. However, at exercise intensities higher than iRER at 1.00, hyperventilation occurs due to the buffering of excessive H^+ (17). The intensity at which hyperventilation occurs indicates that the respiratory effort is not efficient and that a physiological steady state is not attained (17).

The agreement of the iRER=1.00 as an aerobic endurance procedure is supported by the work of Leti and colleagues (10). They reported that the speed at RER=1.00 did not differ from the speed at MLSS, and both were statistically correlated (r = 0.79). In addition, the VO_2 at RER=1.00 did not differ with the VO_2 at MLSS and VO_2 at VT2. The RER at VT2 corresponded to 1.00±0.05, which was equal to iRER=1.00. However, despite the good absolute agreement between iRER=1.00 with the other procedures, moderate values of upper and lower limits were found. The random error (lower and upper limits) observed by Bland-Altman plots of iRER=1.00 can result in modifications around -28.5 to

22.5 W for RCP, -44.6 to 33.3 W to AnT_{LAC} and -30.0 to 36.0 W to $OBLA_{3.5}$. That is, despite of similar values and significant correlations, individual variations can occur in the aerobic endurance measurement.

The interpretation of an evaluation procedure using only tests that analyze the difference between means and tests of the correlation coefficient can hide a lack of agreement between two or more procedures and, therefore, fail to allow for a robust validity for a new procedure. The inclusion of the agreement analysis (e.g., Bland-Altman plot) represents additional information that confirms the validity of an evaluation procedure, both to absolute agreement (i.e., bias) as well as to individual agreement (i.e., random error).

CONCLUSION

The findings from this study indicate that iRER=1.00 can be used to estimate aerobic endurance intensity in cycle ergometer exercise.

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