A Simplified Strategy for the Estimation of the Exercise Ventilatory Thresholds

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ABSTRACT

NEDER, J. A., and R. STEIN. A Simplified Strategy for the Estimation of the Exercise Ventilatory Thresholds. *Med. Sci. Sports Exerc.*, Vol. 38, No. 5, pp. 1007–1013, 2006. **Purpose:** To analyze the limits of agreement between exercise ventilatory threshold values (VT1 and VT2) estimated from a combination of pulmonary gas exchange and ventilatory variables (cardiopulmonary exercise testing) and those derived from an alternative approach based on the ventilatory response only ($\dot{V}E$, ventilometry). **Methods:** Forty-two nontrained subjects (24 males, aged 18–48, peak $\dot{V}O_2$ = 33.1 ± 8.6 mL·min^{-1}·kg^{-1}) performed a maximum incremental cardiopulmonary exercise testing on an electromagnetically braked cycle ergometer. The participants breathed through a Pitot tube (Cardio$_2$ System™, MGC) and a fixed-resistance ventilometer (Micromed, Brazil), which were connected in series. HR values at the estimated VT (VT_{HR1} and VT_{HR2}) were obtained by the conventional method (ventilatory equivalents, end-expiratory pressures for O_2 and CO_2, and the V-slope procedure) and an experimental approach ($\dot{V}E$ vs time, $\dot{V}E$/time vs time, and breathing frequency vs time). **Results:** There were no significant between-method differences on VT_{HR1}, VT_{HR2}, $VT_{\dot{V}E1}$, $VT_{\dot{V}E2}$, and peak $\dot{V}E$ ($P > 0.05$). After certification of data normality, a Bland–Altman analysis revealed that the mean bias ± 95% confidence interval of the between-method differences were lower for VT_{HR2} than VT_{HR1} (2 ± 9 and 0 ± 17 bpm, respectively). VT_{HR2} according to ventilometry differed more than 10 bpm from the standard procedure in 3 out of 42 subjects (9%). Between-method differences were independent of the level of fitness, as estimated from peak $\dot{V}O_2$ ($P > 0.05$). **Conclusions:** A simplified approach, based on the ventilatory response as a function of time, can provide acceptable estimates of the exercise ventilatory thresholds—especially VT_2—during ramp-incremental cycle ergometry. This new strategy might prove to be useful for exercise training prescription in nontrained adults. **Key Words:** GAS EXCHANGE, VENTILOMETER, CARDIOPULMONARY EXERCISE TESTING, LIMITS OF AGREEMENT

The ventilatory response to rapid-incremental exercise is well characterized by an exponential-like function that is thought to be influenced—or at least temporarily related—by the rate of blood lactate accumulation (25,26). In this context, there seems to exist an early inflection point in the pulmonary ventilation when expressed as a function of the oxygen uptake (i.e., the first ventilatory threshold (VT_1)). This parameter has been found to delimit the upper boundary of "moderate" exercise (26). More importantly, a second threshold (VT_2) has been found to separate a "heavy" from a nonsustainable, "very heavy" intensity domain: VT_2 is thought to be associated with a respiratory compensation point (RCP) to the ongoing metabolic acidosis (9,19). Although the precise mechanism(s) underlying these adjustments is (are) still a source of controversy (7,12,17,20), they provide a physiological framework for the evaluation of human ability to sustain whole-body exercise and, therefore, a guide to endurance exercise prescription (6–9,13–16).

Estimation of the exercise VT, however, depends on a careful evaluation of the dynamic relationships between pulmonary gas exchange and the ventilatory responses (22,23). As a consequence, cardiopulmonary exercise testing (CPET) has evolved as an useful tool for training prescription and evaluation of exercise tolerance in health (16) and disease (14,18). Unfortunately, however, standard CPET relies on cumbersome and expensive gas exchange analyzers; these shortcomings have substantially hampered the application of the test in the clinical and sport arenas. Consequently, it would be interesting to investigate the usefulness of a more practical approach for the estimation of VT with the purpose of defining the appropriate range of exercise intensity for endurance training.

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This prospective study, therefore, aimed to evaluate whether a simplified strategy, based on the pulmonary ventilatory response as a function of time during ramp-incremental exercise, would provide acceptable estimates of the VT in a sample of healthy, but sedentary, males and females. We reasoned that such an investigation would be of special relevance for apparently healthy, nontrained subjects, in whom a lower level of accuracy in the VT estimation is plausibly required as compared with a sporting population.

SUBJECTS AND METHODS

Study Design and Subjects

This was a prospective, cross-sectional study performed in a single clinical laboratory of a tertiary, university-based center. Forty-seven (24 males, aged 18–48 yr) apparently healthy, nontrained subjects (i.e., those reporting no regular physical activity in the past year) were evaluated for study inclusion; subjects were actively recruited from the general population. Subjects who had medical history or physical or laboratory findings of cardiac (2), respiratory (1), metabolic (1), or neuromuscular diseases (1) were excluded from the study, and therefore, 42 subjects comprised the study population. Written informed consent (as approved by the Federal University of Sao Paulo Medical ethics committee) was obtained from all subjects.

Protocol

The participants underwent a single ramp-incremental exercise test on an electromagnetically braked cycle ergometer (Corival™, Lode, NL). Subjects wore a facial neoprene mask and breathed through a low-resistance, turbulent-flow Pitot tube (Pre-Vent Pneumotach™, Medical Graphics Corporation (MGC)) and a fixed-resistance ventilometer (Micromed, Brazil), which were connected in series, with the Pitot tube placed before the ventilometer. This experimental setting was accepted after certification that there were no significant differences on measured volumes when the ventilometer was calibrated with and without this arrangement. Volume-flow data derived from the Pitot tube and the expired fractions of oxygen and carbon dioxide were analyzed in a commercially available cardiopulmonary exercise system. Pilot data have also shown that gas exchange and ventilatory data were not affected by positioning the ventilometer after the Pitot tube. Data from the ventilometer were recorded for comparison with those derived from the cardiopulmonary exercise testing. Determination of the VT according to each method was performed independently, and the investigator remained blinded to the VT value determined by the other procedure.

Measurements

Cardiopulmonary exercise testing. Breath-by-breath gas exchange and ventilatory variables were analyzed by using a calibrated computer-based exercise system (Cardio$_2$ System™, MGC) (2). In this system, a breath is defined as the interval between onset and end of CO_2 washout and O_2 wash-in; respirations with a total volume equal or less than 150 mL are automatically discarded. The CO_2 and O_2 analyzers were calibrated before each test using a two-point measure: a calibration gas (CO_2 5%, O_2 12%, N_2 balance) and a reference gas (room air after ambient temperature and pressure, saturated (ATPS) to standard temperature and pressure, dry (STPD) correction). The Pitot tube was also calibrated with a 3-L syringe using different flow profiles. Periodically, the overall output data system was validated against a respiratory gas exchange simulator, which allows a range of metabolic rates to be established between 0.2 and 5.0 $L{\cdot}min^{-1}$, with a resulting accuracy of ± 2%. During the exercise tests, room temperature and humidity were controlled by air conditioning. All tests were performed in the same laboratory at an altitude of 680 m above sea level (Sao Paulo, Brazil), barometric pressure of 685–699 mm Hg and ambient temperature between 18 and 22°C.

The exercise test consisted of: i) 2 min at rest; ii) 3 min with real "zero" workload, obtained through an electrical system that moves the ergometer flywheel at 60 rpm; iii) the incremental phase; and iv) a 4-min recovery period. The power (work rate, WR) was continuously increased in a linear "ramp" pattern (10–25 $W{\cdot}min^{-1}$ in females and 15–30 $W{\cdot}min^{-1}$ in males). The increment rate was individually selected in such a way that the ramp duration (i.e., the duration of the incremental phase) was greater than 8 and lower than 14 min in all subjects (actual values being 11.5 ± 2.1 min). Participants were free to choose the pedaling frequency provided that this was not less than 50 rpm. The following data were obtained breath-by-breath and expressed as 15-s averages: pulmonary oxygen uptake ($\dot{V}O_2$, $mL{\cdot}min^{-1}$), carbon dioxide output ($\dot{V}CO_2$, $mL{\cdot}min^{-1}$); minute ventilation ($\dot{V}E$, $L{\cdot}min^{-1}$); respiratory rate (RR); and end-tidal partial pressures for O_2 and CO_2 ($PETO_2$ and $PETCO_2$, mm Hg). Cardiac electrical activity and HR (HR, bpm) were continuously recorded.

The VT were individually estimated by the researchers (i.e., the automatic detection of the VT by the software was not considered). The first VT (VT_1) was estimated by the gas exchange method inspecting the inflection point of $\dot{V}CO_2$ with respect to $\dot{V}O_2$ (modified V-slope) (3) and, secondarily, by the ventilatory method, when $\dot{V}E/\dot{V}O_2$ and $PETO_2$ increased while $\dot{V}E/\dot{V}CO_2$ and $PETCO_2$ remained stable, respectively. The respiratory compensation point, the second VT (VT_2), was defined where $\dot{V}E$ started to change out of proportion of $\dot{V}CO_2$ (i.e., systematic increase in $\dot{V}E/\dot{V}CO_2$ with a consequent decline on $PETCO_2$ (13)). These techniques have long been validated in either patients or apparently healthy subjects (3,22).

Ventilometry. The exercise ventilatory response ($\dot{V}E$, $L{\cdot}min^{-1}$) and RR were also obtained from a calibrated ventilometer. A 3-L syringe calibration was performed with the Pitot tube placed before the ventilometer (as in the experimental setting); dead space values of the tube were added to the ventilometer's dead space. In this device, a

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differential pressure transducer responds to changes in pressure on both sides of a fixed resistance; according to Bernoulli's principle, variations in pressure are proportional to the square of the turbulent flow induced by the resistance. To increase the signal-to-noise ratio, the interpolated values of two sequential data bins (each consisting of a 15-s mean) were used.

A dedicated software was used for data analysis (Ergo Pc13 version 2.4™, Micromed, Brazil). In this program, $\dot{V}E$ is plotted against exercise time; two user-controlled rulers are available for the estimation of the VT (Fig. 1, panel A). Identification of the VT is individually performed by the investigator. In addition, $\dot{V}E$ is divided by time ($L{\cdot}min^{-1}{\cdot}min^{-1}$) and expressed as a function of time (Fig. 1, panel B). The rationale for using this construct is as follows: assuming a linear relationship between $\dot{V}O_2$ and time in response to a ramp-incremental protocol (18), when time is used as a surrogate of $\dot{V}O_2$, the $\dot{V}E/\dot{V}O_2$ ($\dot{V}E$/time) should decrease hyperbolically as $\dot{V}O_2$ (time) increases with exercise progression. This is a necessary consequence of the linear $\dot{V}E$–$\dot{V}O_2$ relationship (at least until VT_1) with a positive y-intercept (26). Therefore, whenever $\dot{V}E$ increases out of proportion to exercise time ($\dot{V}O_2$) after its nadir, the $\dot{V}E$/time ratio would present with an inflection point (Fig. 1, panel B). Furthermore, RR has been found to accelerate after VT_2 in some subjects; therefore, RR is also expressed as a function of time (Fig. 1, panel C).

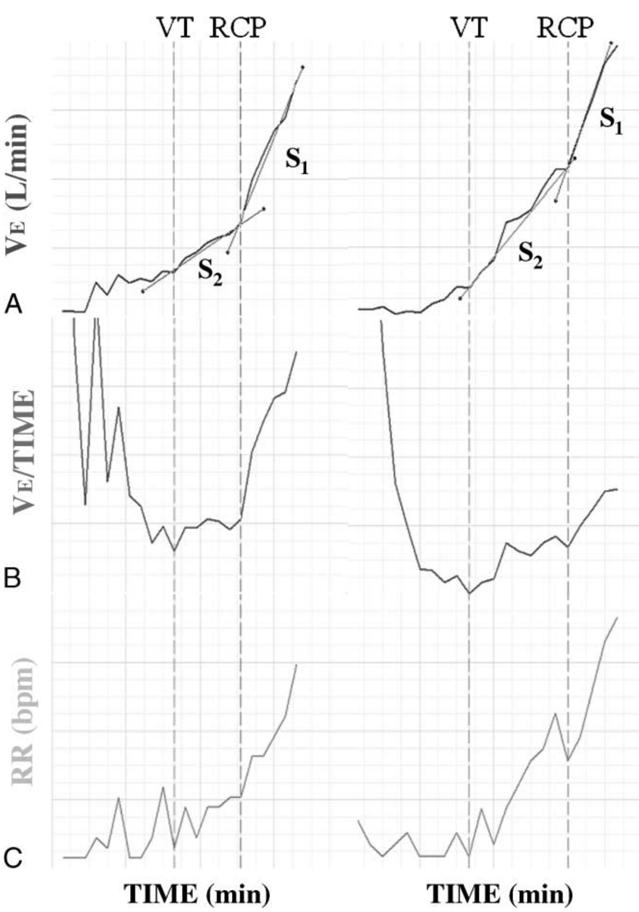

FIGURE 1—The ventilatory-only approach to estimate the first ventilatory threshold (VT_1) and the respiratory compensation point (RCP or the second ventilatory threshold, VT_2) during ramp-incremental exercise in a representative male (*left*) and a female (*right*). Minute ventilation ($\dot{V}E$, $L{\cdot}min^{-1}$), $\dot{V}E$/time ($L{\cdot}min^{-1}{\cdot}min^{-1}$), and RR are expressed as a function of time (*panels A, B, and C*, respectively). See the text for further explanation.

The following algorithm for evaluation was followed in each test (Fig. 1):

a. By manually operating the aforementioned user-controlled ruler available in the software ($\dot{V}E$ vs time graph), VT_2 was established by visually applying a "best fit" line from the end of exercise ventilation to the submaximal data (S_1 line). VT_2 was defined as the level where ventilation departed from linearity;
b. From this point, a second "best fit" line was drawn to the submaximal data registered earlier than VT_2 (S_2 line): VT_1 was defined as the level where ventilation also departed from linearity;
c. These provisional VT estimates were checked against the inflection points found on the $\dot{V}E$/time versus time graph, as described above;
d. An additional evidence of nonlinearity was examined in the RR–time plot; that is, by looking at any consistent increase in RR at these time points.

In this analysis, the VT estimation was performed by visually checking the points of interest on the different graphs. The $\dot{V}E$ versus time plot was assumed as the criterion graph; however, an additional evidence of the VT on one of the two remaining graphs was required to be present (Fig. 1). The following variables were also recorded for analysis: HR (bpm) at VT_1 and VT_2 (VT_{HR1} and VT_{HR2}, respectively) and $\dot{V}E$ ($L{\cdot}min^{-1}$) at VT_1 and VT_2 ($VT_{\dot{V}E1}$ and $VT_{\dot{V}E2}$, respectively).

Data Analysis

After certification of a symmetric distribution (Kolmogorov–Smirnoff), data are reported as mean values and standard deviations (SD). Differences between males and females were compared by using a Student's nonpaired *t*-test; in addition, responses to each technique in the same individual were contrasted by using a paired *t*-test. Correlation analysis (Pearson's product–moment) was applied to investigate the level of association between continuous variables. The probability of Type I error was established at 0.05 for the hypothesis tests.

The limits of agreement between CPET and ventilometric VT estimates for the whole group were investigated by plotting the individual differences against their respective means (Bland–Altman analysis); that is, a between-technique comparison was performed. Heteroscedasticity (i.e., a non-Gaussian distribution of the residuals, usually characterized by a between-method difference proportional to the mean measured value) was examined by plotting the absolute (i.e., ignoring any sign) differences against the individual means and calculating the Spearman's correlation coefficient (5). If the heteroscedasticity correlation was close to zero (i.e., no correlation between intermethod

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TABLE 1. Resting and exercise data in subjects separated by gender.

Variables	Males (N = 24)	Females (N = 18)
Demographic/antropometric		
Age (yr)	33 ± 8	29 ± 7
BMI ($kg \cdot m^{-2}$)	24.9 ± 2.6	22.1 ± 2.8*
Cardiopulmonary exercise testing		
Peak exercise		
WR (W)	210 ± 44	125 ± 28*
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	37. 9 ± 7.7	26.6 ± 4.7*
R	1.21 ± 0.06	1.20 ± 0.08
HR (bpm)	176 ± 12	175 ± 12
$\dot{V}E$ ($L \cdot min^{-1}$)	92.9 ± 19.6	61.1 ± 15.6*
Submaximal exercise		
VT_{HR1} (bpm)	131 ± 17	131 ± 18
VT_{HR1} (% peak HR)	74.1 ± 6.6	74.6 ± 6.6
VT_{HR2} (bpm)	160 ± 12	161 ± 14
VT_{HR2} (% peak HR)	91.1 ± 3.8	91.7 ± 3.8
$VT_{\dot{V}E1}$ ($L \cdot min^{-1}$)	42.9 ± 10.9	27.9 ± 6.2*
$VT_{\dot{V}E2}$ ($L \cdot min^{-1}$)	68.5 ±13.3	44.9 ± 8.5*
Ventilometry		
Peak exercise		
$\dot{V}E$ ($L \cdot min^{-1}$)	94.1 ± 18.3	62.9 ± 15.5
Submaximal exercise		
VT_{HR1} (bpm)	133 ± 17	128 ± 19
VT_{HR1} (% peak HR)	75.8 ± 7.1	73.2 ± 8.9
VT_{HR2} (bpm)	159 ± 13	158 ± 15
VT_{HR2} (% peak HR)	90.9 ± 4.2	90.3 ± 4.9
$VT_{\dot{V}E1}$ ($L \cdot min^{-1}$)	44. 2 ± 11.6	23.4 ± 9.3*†
$VT_{\dot{V}E2}$ ($L \cdot min^{-1}$)	65.6 ± 13.4	38.2 ± 11.7*†

Data are presented as mean ± SD.

BMI, body mass index; $\dot{V}O_2$, pulmonary oxygen uptake; R, respiratory exchange ratio; VT_{HR1}, heart rate at the first ventilatory threshold; VT_{HR2}, heart rate at the second ventilatory threshold; $VT_{\dot{V}E1}$, minute ventilation at the first ventilatory threshold; $VT_{\dot{V}E2}$, minute ventilation at the second ventilatory threshold.

* Males vs females (nonpaired *t*-test); † cardiopulmonary exercise test vs ventilometry in the same subject (paired *t*-test) (P < 0.05).

differences and the mean measured value), the mean bias and the 95% limits of agreement were calculated as mean ± 1.96 SD of the between-estimate differences. On the other hand, if heteroscedasticity was suspected, data were transformed by taking natural logarithms from both methods. The mean bias ± 1.96 SD were firstly calculated on the log scale; after taking antilogs, these values were expressed on ratio scale (CPET/ventilometry). Considering that adding and subtracting on the natural scale correspond to multiplying and dividing in the log scale, the mean bias was multiplied and divided by the error ratio to add and subtract 1.96 SD (5).

RESULTS

Effects of gender on the variables of interest. As expected, there were statistically significant differences between males and females in relation to peak exercise values as determined by the standard CPET (Table 1). Therefore, men showed higher absolute WR, $\dot{V}O_2$, and $\dot{V}E$ compared with women; in contrast, no significant gender effect was found for peak HR and VT_{HR1} or VT_{HR2} (% peak HR). Consequently, $VT_{\dot{V}E1}$ and $VT_{\dot{V}E2}$ were significantly lower in females than males (P < 0.01).

The VT were identified by the ventilometric approach in all subjects; Figure 1 depicts two representative subjects (a male on left and a female on right). There were no significant between-method differences in VT_{HR1} and VT_{HR2} either in males or females; in contrast, $VT_{\dot{V}E1}$ and $VT_{\dot{V}E2}$ were lower by ventilometry as compared with CPET in females, but not in males (Table 1, P < 0.05).

Between-method limits of agreement. The Bland–Altman analysis of the intermethod differences in VT_{HR} is depicted in Figure 2. After certification of data homoscedasticity (see Methods), the mean bias ± 95% confidence interval of the between-method differences were found to be lower for VT_{HR2} than VT_{HR1}: 2 ± 9 vs 0 ± 17 bpm. Of special note, VT_{HR2} and VT_{HR1} according to ventilometry differed more than 10 bpm from the standard procedure in 3 of 42 (9%) and 13 of 42 (31%) subjects, respectively. Using a stricter criterion (5-bpm difference), these values were 15 of 42 (36%) and 23 of 42 (59%) for VT_{HR2} and VT_{HR1}. The between-method differences in VT_{HR2} from VT_{HR1} were largely independent of peak $\dot{V}O_2$ (Fig. 3, P > 0.05). Similar results were

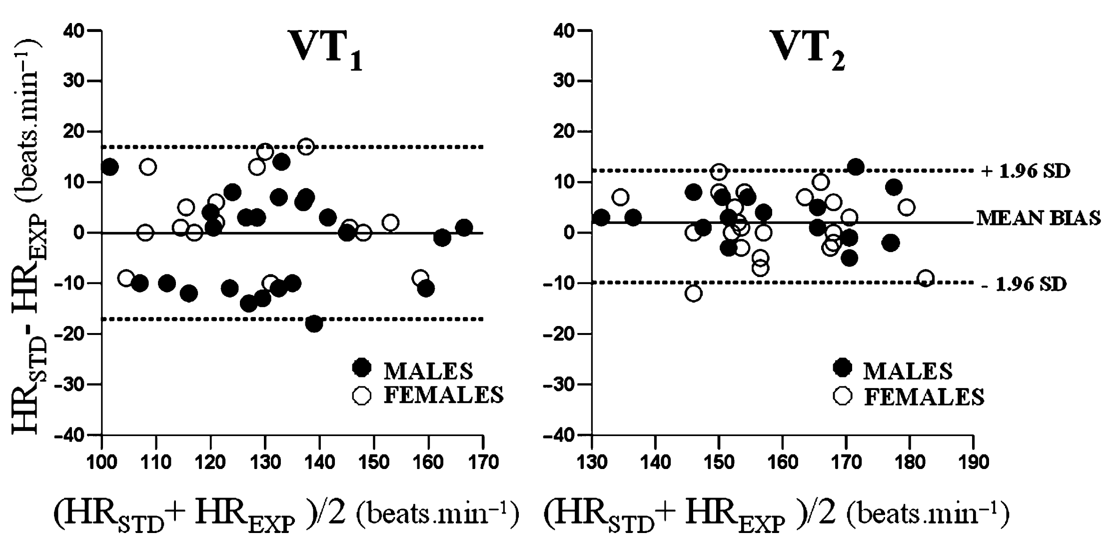

FIGURE 2—The Bland–Altman procedure for estimating the limits of agreement between standard (STD = cardiopulmonary exercise testing) and experimental procedures (EXP = ventilometry) to calculate the heart rate (HR, bpm) associated with the first and second ventilatory thresholds (VT_1 and VT_2, respectively). Note that the between-method limits of agreement were substantially narrower for VT_2 (± 9 bpm) than VT_1 (± 17 bpm), independent of gender.

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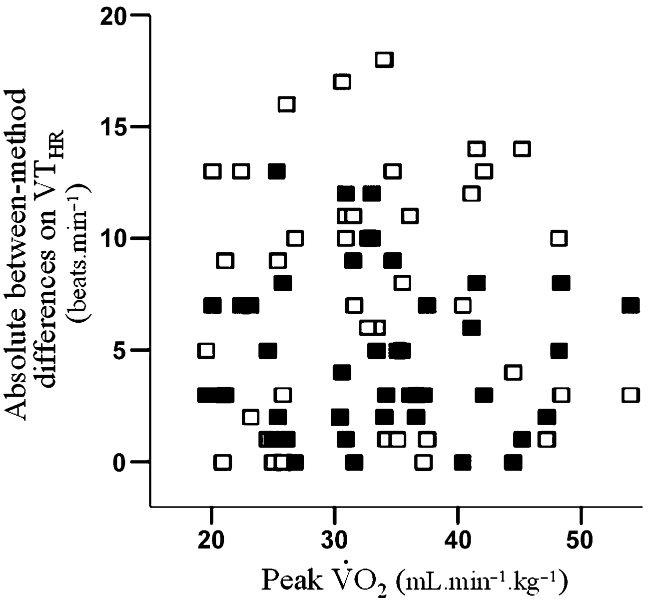

FIGURE 3—There were no correlations between the absolute intermethod differences in heart rate (HR, bpm) at the first and second ventilatory thresholds (VT: *open and closed squares*, respectively) and peak oxygen uptake (P > 0.05).

found in relation to $VT_{\dot{V}E2}$ and $VT_{\dot{V}E1}$. Interestingly, peak $\dot{V}E$ by ventilometry was almost equivalent to peak $\dot{V}E$ according to the criterion test (Fig. 4).

Usefulness of the secondary plots for estimation of the VT. On a *post hoc* analysis, we investigated whether the secondary indicators of the VT (i.e., those found for the $\dot{V}E$/time vs time and RR vs time plots) were judged useful for their determination, that is, if the different criteria helped the investigators to identify the VT with more confidence. Using an arbitrary three-point scale (0 = "not useful at all," 1 = "moderately useful," 2 = "very useful"), the $\dot{V}E$/time versus time plot was scored "1" or "2" in 36 of 42 (86%) and 34 of 42 (81%) subjects for $VT_{\dot{V}E2}$ and $VT_{\dot{V}E1}$, respectively. In contrast, the RR versus time construct was felt to be more useful for $VT_{\dot{V}E2}$, but not for $VT_{\dot{V}E1}$, confirmation (26 of 42 (62%) and 8 of 42 (19%), respectively).

DISCUSSION

This prospective study showed that a simplified, pulmonary ventilation-based algorithm could provide accurate estimates of the exercise ventilatory thresholds in nontrained adults. The limits of agreement were narrower for the second threshold (VT_2), which is of special practical importance, considering that this point is more relevant for exercise prescription than VT_1 in normal subjects (8,12,16). These data suggest that, by using such a user-friendly approach, the practitioner can individualize an exercise prescription program (at least for a population with similar characteristics of that evaluated in the present investigation).

The value of HR-based exercise intensity prescription. There are a number of different approaches to guide exercise prescription, ranging from predicted HR_{max}-based equations (e.g., $[0.7 \times (220 - \text{age})]$) to more sophisticated responses, such as $\dot{V}O_2$ (15). In practical terms, however, HR has been widely used for this purpose. Although general guidelines have been advocated as a valid procedure in population-based studies, several investigators have shown that an individualized approach is related to better outcomes (4,6,8,10,15,16).

In this context, the use of the VT for exercise training prescription presents with a sounder scientific rationale than an empirically estimated fraction of the maximal exercise capacity—as recently reviewed by Meyer and coworkers (16). It has been shown that the range of work rates below VT_1 is not associated with a sustainable increase in blood lactate levels and, therefore, exercise tolerability is greatly enhanced (26). However, training at these intensities is not commonly related to a substantial stress for the physiological systems that are responsible to increase oxygen delivery to the exercising muscles. In contrast, exercise tolerability decreases dramatically above VT_2, probably due to a combination of systemic (lactate, thermal, cardiovascular), and muscular local (contractile fatigue) and central factors—although it is currently far from clear whether there is a cause–effect relationship between lactate and fatigue (7,12). Therefore, the range of WR between VT_1 and VT_2 is prone to elicit a level of cardiovascular and metabolic stress that is sufficiently intense to stimulate the aerobic pathways but not excessively high to shorten exercise duration, which would reduce the total work performed on a training session.

Ventilometry for the VT estimation and its limitations. This study seems to be the first evaluation

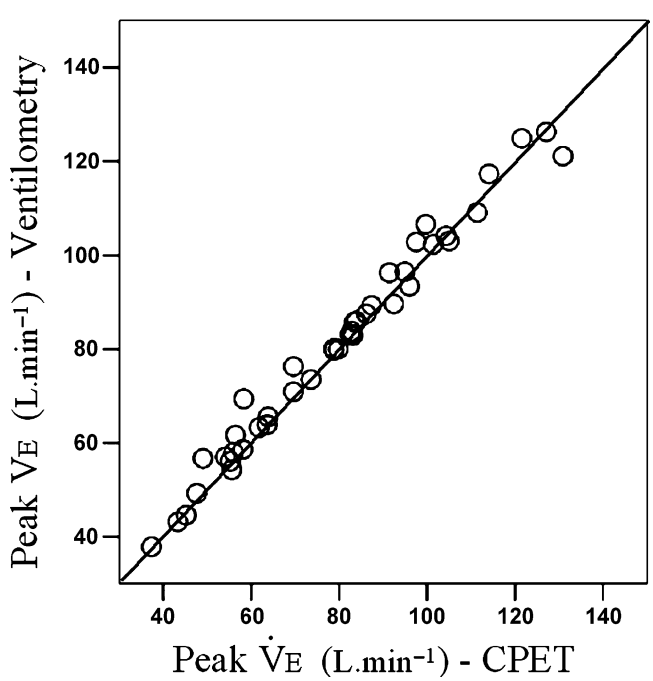

FIGURE 4—Pulmonary ventilation ($\dot{V}E$, L·min^{-1}) at peak exercise were seen to be remarkably similar when the two techniques were compared (ventilometry and cardiopulmonary exercise test, CPET); note the close proximity with the line of identity (r = 0.99, P < 0.001).

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of the validity of isolated ventilatory responses in estimating the VT during incremental exercise. Although our data are consistent with the notion that ventilometric data can be used for this purpose with an acceptable degree of accuracy (especially for VT_2), there are a number of aspects that should be carefully observed to obtain reliable estimates. Firstly, a ramp-incremental test (or, at least, a rapid-incremental test—a maximum of 2-min increments of equal size) *must* be used: only in these exercise paradigms, time can be used as a surrogate of $\dot{V}O_2$ (24). More specifically, the ventilatory response during traditional treadmill "cardiovascular" protocols (Bruce, Naughton, Ellestad) is known to be highly variable; this is prone to produce spurious VT when gas exchange data is not simultaneously recorded and, therefore, should be formally disencouraged. Due to the same issue of ventilation variability, it is recommended that whenever a treadmill is used, the subject should not be allowed to change from walking to running, since this increases ventilation out of proportion of the work actually performed. Therefore, treadmill ramp protocols should start with mild jogging and, afterwards, a progressive and continuous increase in speed and/or grade should be imposed; these preliminary recommendations, however, await further experimental confirmation. More importantly, however, this investigation validated a formal algorithm for VT estimation (see Methods); it is crucial that such a procedure be followed each time that the VT are estimated by ventilometry using the system under evaluation.

A note of caution should also be made in relation to hypothesis tests to evaluate intermethods agreement (Table 1). It is well known that they are quite insensitive to random variation; that is, they are less likely to detect significant differences if they are accompanied by large amounts of random error between estimates (1). On the other hand, an analytical goal analysis tries to estimate the implications of measurement error. This is better accomplished by the Bland and Altman procedure (Fig. 2), in which the limits of between-method (dis)agreement are provided and the practitioner should decide whether the observed discrepancies are, or are not, of practical relevance. In the present study, the authors defined a 10-bpm difference between VT values by ventilometry and CPET as "acceptable" in practical terms; these values fall inside the between-day, intrasubject HR variability during exercise training programs (typically 10–15 bpm) (11). However, this range is likely to be excessive for competitive athletes in whom a higher degree of precision on VT estimation is usually required.

Practical relevance of the method. The present investigation has demonstrated that a practical method could be used to determine the ventilatory thresholds and the related heart rate values during an incremental test. This approach seems to open a new perspective for exercise prescription in healthy individuals. Therefore, this may constitute a useful strategy for the development of an individualized aerobic exercise training program in the real world. The ventilometric approach, when used systematically in the same individual with the purpose of optimizing the aerobic training, may serve as a tool for periodized exercise prescription, especially for nonathletes. In fact, the procedures for VT estimation in the software under analysis is considerably simpler than those required using data from a CPET; in the authors' experience, most practitioners are able to correctly identify the VT after a few hours of training. Additionally, the cost of the entire system (hardware and software) compares favorably with that of a standard, stationary metabolic cart for CPET (\$3500–\$5000 vs \$30,000–\$40,000).

CONCLUSIONS

A relatively simple and inexpensive approach, based on the ventilatory response as a function of exercise duration, provided acceptable estimates of the exercise ventilatory thresholds—especially VT_2—during ramp-incremental cycle ergometry in males and females.

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J. Alberto Neder is an Established Investigator (level II) of the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil.

REFERENCES

1. Atkinson, G., and A. M. Nevill. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med.* 26:217–238, 1998.
2. Beaver, W. L., N. Lamarra, and K. Wasserman. Breath-by-breath measurement of true alveolar gas exchange. *J. Appl. Physiol.* 51:1662–1675, 1981.
3. Beaver, W. L., K. Wasserman, and B. J. Whipp. A new method for detecting the anaerobic threshold by gas exchange. *J. Appl. Physiol.* 60:2020–2027, 1986.
4. Billat, L. V. Use of blood lactate measurements for prediction of exercise performance and for control of training. Recommendations for long-distance running. *Sports Med.* 22:157–175, 1996.
5. Bland, J. M., and D. G. Altman. Measurement error proportional to the mean. *BMJ* 313:106, 1996.
6. Boulay, M. R., J. A. Simoneau, G. Lortie, and C. Bouchard. Monitoring high-intensity endurance exercise with heart rate and thresholds. *Med. Sci. Sports Exerc.* 29:125–132, 1997.
7. Brooks, G. A. Intra- and extra-cellular lactate shuttles. *Med. Sci. Sports Exerc.* 32:790–799, 2000.
8. Coplan, N. L., G. W. Gleim, and J. A. Nicholas. Using exercise respiratory measurements to compare methods of exercise prescription. *Am. J. Cardiol.* 58:832–836, 1986.
9. Dekerle, J., B. Baron, L. Dupont, J. Vanvelcenaher, and P. Pelayo. Maximal lactate steady state, respiratory compensation

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threshold and critical power. *Eur. J. Appl. Physiol.* 89:281–288, 2003.
10. Dickhuth, H. H., L. Yin, A. Niess, et al. Ventilatory, lactate-derived and catecholamine thresholds during incremental treadmill running: relationship and reproducibility. *Int. J. Sports Med.* 20:122–127, 1999.
11. Foster, C., D. J. Fitzgerald, and P. Spatz. Stability of the blood lactate-heart rate relationship in competitive athletes. *Med. Sci. Sports Exerc.* 31:578–582, 1999.
12. Gladden, L. B. Lactate metabolism: a new paradigm for the third millennium. *J. Physiol.* 558(Pt 1):5–30, 2004.
13. Goldberg, L., D. L. Elliot, and K. S. Kuehl. Assessment of exercise intensity formulas by use of ventilatory threshold. *Chest* 94:95–98, 1988.
14. Larsen, A. I., T. Aarsland, M. Kristiansen, A. Haugland, and K. Dickstein. Assessing the effect of exercise training in men with heart failure; comparison of maximal, submaximal and endurance exercise protocols. *Eur. Heart J.* 22: 684–692, 2001.
15. Londeree, B. R. Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Med. Sci. Sports Exerc.* 29:837–843, 1997.
16. Meyer, T., A. Lucia, C. P. Earnest, and W. Kindermann. A conceptual framework for performance diagnosis and training prescription from submaximal gas exchange parameters – theory and application. *Int. J. Sports Med.* 26(Suppl 1): S38–48, 2005.
17. Meyer, T., O. Faude, J. Scharhag, A. Urhausen, and W. Kindermann. Is lactic acidosis a cause of exercise-induced hyperventilation at the respiratory compensation point? *Br. J. Sports Med.* 38:622–625, 2004.
18. Myers, J. Applications of cardiopulmonary exercise testing in the management of cardiovascular and pulmonary disease. *Int. J. Sports Med.* 26(Suppl 1):S49–55, 2005.
19. Riley, M. S., and C. B. Cooper. Ventilatory and gas exchange responses during heavy constant work-rate exercise. *Med. Sci. Sports Exerc.* 34:98–104, 2002.
20. Scheuermann, B. W., J. M. Kowalchuk, D. H. Paterson, and D. A. Cunningham. Carbonic anhydrase inhibition delays plasma lactate appearance with no effect on ventilatory threshold. *J. Appl. Physiol.* 88:713–721, 2000.
21. Swain, D. P., and B. A. Franklin. $\dot{V}O_2$ reserve and the minimal intensity for improving cardiorespiratory fitness. *Med. Sci. Sports Exerc.* 34:152–157, 2002.
22. Wasserman, K. Determinants and detection of anaerobic threshold and consequences of exercise above it. *Circulation* 76(6 Pt 2):VI29–39, 1987.
23. Wasserman, K., W. L. Beaver, and B. J. Whipp. Gas exchange theory and the lactic acidosis (anaerobic) threshold. *Circulation* 81(1 Suppl):II14–130, 1990.
24. Whipp, B. J., J. A. Davis, F. Torres, and K. Wasserman. A test to determine parameters of aerobic function during exercise. *J. Appl. Physiol.* 50:217–221, 1981.
25. Whipp, B. J. Ventilatory control during exercise in humans. *Annu. Rev. Physiol.* 45:393–413, 1983.
26. Whipp, B. J. The bioenergetics and gas exchange basis of exercise testing. *Clin. Chest Med.* 15:173–192, 1994.

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