

A Novel Approach for Lactate Threshold Assessment Based on Rating of Perceived Exertion

Nicolas Fabre, Laurent Mourot, Livio Zerbini, Barbara Pellegrini,
Lorenzo Bortolan, and Federico Schena

This study tested the hypothesis that the D_{MAX} (for maximal distance) method could be applied to ratings of perceived exertion (RPE), to propose a novel method for individual detection of the lactate threshold (LT) using RPE alone during an incremental test to exhaustion. Twenty-one participants performed an incremental test on a cycle ergometer. At the end of each stage, lactate concentration was measured and the participants estimated RPE using the Borg CR100 scale. The intensity corresponding to the fixed lactate values of 2 or 4 $\text{mmol} \cdot \text{L}^{-1}$ (2mM and 4mM), the ventilatory threshold (VT), the respiratory-compensation point (RCP), and the instant of equality of pulmonary gas exchange ($\text{RER}_{=1.00}$) were determined. Lactate ($D_{MAX La}$) and RPE ($D_{MAX RPE}$) thresholds were determined using the D_{MAX} method. Oxygen uptake (VO_2), heart rate, and power output measured at $D_{MAX RPE}$ and at $D_{MAX La}$ were not statistically different. Bland-Altman plots showed small bias and good agreements when $D_{MAX RPE}$ was compared with the $D_{MAX La}$ and $\text{RER}_{=1.00}$ methods (bias = -0.05% and -2% of $\text{VO}_{2\text{max}}$, respectively). Conversely, VO_2 from the $D_{MAX RPE}$ method was lower than VO_2 at 4 mM and at RCP and was higher than VO_2 at 2 mM and at VT. VO_2 at $D_{MAX RPE}$ was strongly correlated with VO_2 at $D_{MAX La}$ ($r = .97$), at $\text{RER}_{=1.00}$ ($r = .97$), at 2 mM ($r = .85$), at 4 mM ($r = .93$), at VT ($r = .95$), and at RCP ($r = .95$). The combination of the D_{MAX} method with the RPE responses permitted precise and individualized estimates of LT using the D_{MAX} method.

Keywords: anaerobic threshold, perceived exertion, incremental test

The determination of lactate threshold (LT) is of critical interest to appropriately set training intensity for rehabilitation¹ or for athletes interested in enhancing endurance.² As an easy and inexpensive tool that can be used in daily routine, some authors have proposed using the ratings of perceived exertion (RPE) 6–20 Scale³ or the Category Ratio 10 (CR-10) Scale⁴ to obtain LT. This is because the combination of heart rate and blood lactate is a good predictor of perceived exertion and feelings of aches and pain in the legs^{5,6} and because central signals involving ventilation and relative oxygen uptake act as amplifiers that potentiate the perception of exertion during dynamic exercises.⁷

A fixed value of 12 to 13 on the Borg RPE 6 to 20 Scale³ or 5.85 on the Borg CR-10 Scale⁴ could be used to approach LT (estimated using the ventilatory method). Despite promising interest, the major limitation of these studies is the use of a fixed RPE without considering the possible individual variations according to gender,⁸ age,⁹

emotional state,¹⁰ dietary carbohydrate,¹¹ or use of ergogenic supplements such as caffeine,¹² reducing the interest of such a method. The same problem appears when the intensity corresponding to LT is determined using fixed lactate-concentration values of 2 or 4 $\text{mmol} \cdot \text{L}^{-1}$, again without taking into account the individual variation in lactate concentrations, depending on external factors such as test protocol or diet.¹³ To circumvent this problem, the D_{MAX} (for maximal distance) method was proposed.¹⁴ D_{MAX} is an objective and reliable method for threshold determination that can be applied to various ventilatory and metabolic variables. This method involves calculating the point that yields the maximal perpendicular distance to a straight line formed between the 2 end data points of the lactate versus time or workload curve. The reliability of this method or its modified version has been confirmed in cyclists,¹⁵ in runners,¹⁶ and in cross-country skiers.¹⁷

The primary aim of this study was to test the hypothesis that the D_{MAX} method could be applied to RPE ($D_{MAX RPE}$), to find a novel and inexpensive method for individual detection of the LT using RPE alone. To do this, we compared the results of the $D_{MAX RPE}$ (the novel method) with the results of the D_{MAX} method applied to the lactate concentrations ($D_{MAX La}$, the criterion method). Second, we compared these results with other standard indicators used for training-intensity management (fixed lactate-concentration values, ventilatory thresholds, and the instant of equality of pulmonary gas exchange).

Fabre is with the Swedish Winter Sports Research Center, Mid Sweden University, Östersund, Sweden. Mourot is with the Exercise Performance Health Innovation Platform and Clinical Investigation Center, Franche-Comté University, Besançon, France. Zerbini, Pellegrini, Bortolan, and Schena are with the Research Center for Mountain, Sport, and Health, Rovereto, Italy.

Methods

Subjects

Twenty-one physically active and fit participants (13 men and 8 women) were involved in this study. They mostly practiced endurance activities such as running, cross-country skiing, cycling, or hiking. Their mean \pm SD age was 20.9 ± 5.9 years, height was 172.9 ± 8.3 cm, body mass was 68.2 ± 7.2 kg, VO_{2max} was 3466 ± 651 mL \cdot min $^{-1}$, and maximal aerobic power was 282.9 ± 52.7 W. They were asked to refrain from ingesting caffeine or alcohol for at least 12 hours before testing, to eat a light meal 3 hours before testing, and to refrain from performing exhaustive training for at least 48 hours before testing. The study protocol complied with the Declaration of Helsinki for Human Experimentation and was approved by the ethics committee for human research at the University of Verona. Possible risks and benefits were explained, and written informed consent was obtained from each subject before participation.

Experimental Protocol

The participants performed an incremental cycling test to volitional exhaustion on an electromagnetically braked cycle ergometer (Lode Excalibur, Groningen, Netherlands). Participants were asked to maintain a constant pedal rate of 80 rpm. The initial power output was set at 70 W for 5 minutes, followed by 30-W increases every 3 minutes until exhaustion. The attainment of VO_{2max} was confirmed by achieving at least 3 of the following criteria: VO_2 reaching a plateau with increasing work rate, respiratory-exchange ratio above 1.1, heart rate corresponding to 95% age-predicted maximal values, and exhaustion with impossibility to continue despite verbal encouragement.

Physiological Measures

Ventilation. Values of minute ventilation (V_E), end-tidal partial pressure of oxygen, end-tidal partial pressure of carbon dioxide, carbon dioxide output (VCO_2), respiratory-exchange ratio (RER), and oxygen uptake (VO_2) were continuously measured by a breath-by-breath gas-exchange measurement system (Quark b^2 , Cosmed, Rome, Italy). Gas analyzers were calibrated before each test with ambient air (O_2 20.93% and CO_2 0.03%) and a gas mixture of known composition (O_2 16.04% and CO_2 5.00%). An O_2 analyzer with a polarographic electrode and a CO_2 analyzer with an infrared electrode sampled expired and inspired gases at the mouth. The face mask had a low dead space (70 mL) and was equipped with a low-resistance, bidirectional digital turbine (28-mm diameter). This turbine was calibrated before each test with a 3-L syringe (Cosmed, Rome, Italy). Face masks allowed participants to breathe simultaneously through mouth and nose. Heart rate was continuously measured via Polar heart-rate monitor (Polar Electro Oy, Kempele, Finland) and acquired by the Cosmed system.

Lactate. Earlobe capillary blood (20 μ L) was sampled in the last 20 seconds of each 3-minute work stage during the incremental test. Blood lactate concentration was determined using a Biosen C-Line Sport Analyzer (EKF Diagnostics, Magdeburg, Germany). Before blood analysis, the analyzer was calibrated with standard 12-mmol \cdot L $^{-1}$ solution.

RPE. Since it has been observed that during an incremental test to exhaustion, both blood lactate concentration and data from the category-ratio scales follow a power function⁶ (in contrast with the RPE 6–20 scale, which was constructed to give data that grow linearly with intensity), the overall RPE was estimated using the Borg CR-100 scale.¹⁸ This scale is the follower of the Borg CR-10 scale. The CR-100 scale is more finely graded and covers subjective variations from minimum to maximal with intermediate verbal descriptors (*minimum, extremely weak, very weak, weak, moderate, strong, very strong, extremely strong, and maximal*; Figure 1).

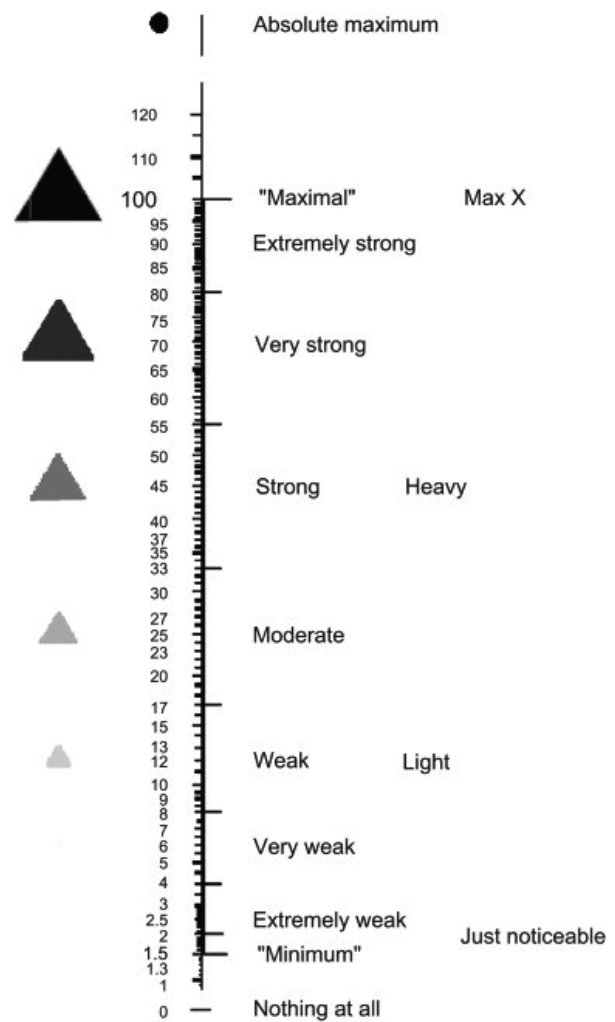


Figure 1 — The Borg CR100 scale®. Reprinted with permission of Borg Perception (www.borgperception.se).¹⁸

⁶ Instructions on the use of the scale were read to the participants before the beginning of the test. The CR-100 scale was shown to the participants during the last 20 seconds of each stage, and they were asked to give a rating of their perceived overall exertion.

Data Analysis

LT. LT ($D_{MAX La}$) was determined using a customized software program (LabView 7.1, National Instruments, Austin, TX) using the D_{MAX} method.¹⁷ This threshold was identified as the point on the third-order polynomial curve that yielded the maximal perpendicular distance to the straight line formed by the lactate point measured at the end of the first step and the lactate point measured immediately at the end of the test (Figure 2). The fixed lactate-concentration values of 2 and 4 mmol · L⁻¹ were also determined.

RPE Threshold. We applied the same principle used for LT determination (ie, D_{MAX} method) to the perceived exertion responses obtained at the end of each step of the incremental test. The RPE threshold ($D_{MAX RPE}$) was identified as the point on the third-order polynomial curve that yielded the maximal perpendicular distance to the straight line formed by the 2 end RPE responses (Figure 2).

Ventilatory Thresholds. Three independent reviewers determined in a blinded way the individual ventilatory threshold (VT) and respiratory-compensation point (RCP) by visual analysis of the breakpoints of ventilatory equivalent of carbon dioxide (V_E/VCO_2), ventilatory equivalent of oxygen (V_E/VO_2), and V_E changes over time. The first increase of V_E with a rapid increase in V_E/VO_2 and with no concomitant increase in V_E/VCO_2 corresponds to VT, and the second increase in V_E with a concomitant rapid increase in V_E/VO_2 and V_E/VCO_2 corresponds to RCP.¹⁹

The Instant of Equality of Pulmonary-Gas Exchange.

The power output associated with the instant of equality of pulmonary gas exchange ($RER_{=1.00}$) has been shown to correspond to the power output associated with the maximal lactate steady-state intensity,²⁰ a concept widely used in the assessment of aerobic endurance.²¹ The VO_2 corresponding to $RER_{=1.00}$ was determined graphically.

Statistical Analysis

Values presented are means \pm SD. A paired *t* test was used to compare $D_{MAX La}$ and $D_{MAX RPE}$. We considered a maximal bias between the 2 methods of less than

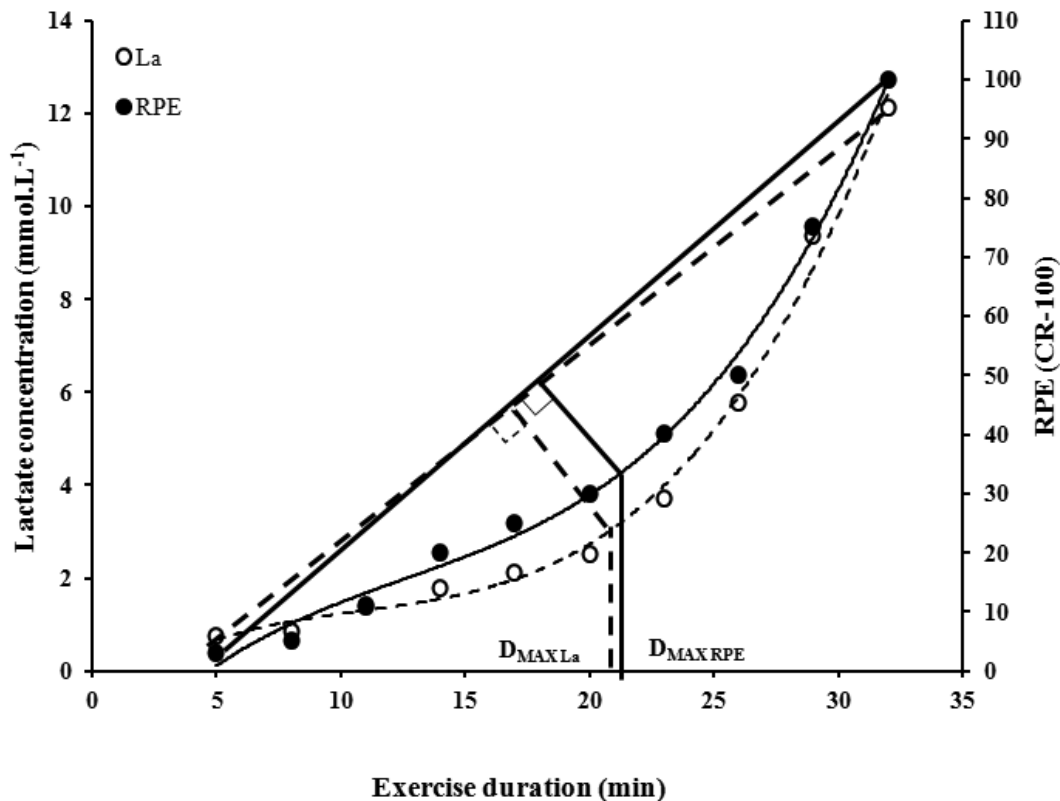


Figure 2 — Schematic figure of the $D_{MAX La}$ and $D_{MAX RPE}$ methods. Data from 1 participant representative of the group. $D_{MAX La}$ indicates individualized lactate (La) threshold measurement identified as the point on the third-order polynomial curve that yielded the maximal perpendicular distance to the straight line formed by the lactate point measured at the end of the first step and the lactate point measured immediately at the end of the test (dashed line); $D_{MAX RPE}$, an adapted $D_{MAX La}$ method using rating of perceived exertion (RPE) instead of lactate concentration (solid line).

5%. With $P < .05$ and a power of 90%, the number of participants needed to test our hypothesis was 18. The Pearson product-moment zero-order correlation coefficient demonstrated any significant relationship between $D_{\text{MAX RPE}}$ and $D_{\text{MAX La}}$, VT, RCP, and $\text{RER}_{=1.00}$. Finally, Bland-Altman plots²² were used to compare the agreement between the measurement of VO_2 at $D_{\text{MAX RPE}}$ and VO_2 at $D_{\text{MAX La}}$, VT, RCP, and $\text{RER}_{=1.00}$. The difference between the values measured from 2 methods on the y-axis was plotted against their averages on the x-axis. Limits of agreement (LOA) involved the mean difference between 2 methods ± 1.96 SD. Statistical significance was accepted at $P < .05$. Data were analyzed with the Statistical Package for the Social Sciences (SPSS v 15.0, SPSS Inc, Chicago, IL).

Results

The mean RPE value corresponding to $D_{\text{MAX RPE}}$ on the CR-100 scale was 35.3 ± 11.8 (range 15.8–59.8). The mean La value corresponding to $D_{\text{MAX La}}$ was 2.8 ± 1.2 $\text{mmol} \cdot \text{L}^{-1}$ (range 1.4–5.6 $\text{mmol} \cdot \text{L}^{-1}$).

The paired t test showed that values of VO_2 , heart rate, and power output obtained at $D_{\text{MAX RPE}}$ and at $D_{\text{MAX La}}$ were not significantly different ($P > .05$, Table 1).

The Bland-Altman plots confirmed this result and showed very small bias and LOA (-1.8 $\text{mL} \cdot \text{min}^{-1}$ or -0.05% of $\text{VO}_{2\text{max}}$; LOA = -241 to 237 $\text{mL} \cdot \text{min}^{-1}$) between the VO_2 measured at $D_{\text{MAX RPE}}$ and $D_{\text{MAX La}}$ (Figure 3, plot A). In the same way, the Bland-Altman plots (Figure 4, plot E) for the comparison between the VO_2 measured at $D_{\text{MAX RPE}}$ and $\text{RER}_{=1.00}$ methods showed a small bias and LOA (-68.9 $\text{mL} \cdot \text{min}^{-1}$ or -2.0% of $\text{VO}_{2\text{max}}$; LOA = -310 to 172 $\text{mL} \cdot \text{min}^{-1}$).

Conversely, there was a systematic bias for VO_2 whereby the VO_2 at $D_{\text{MAX RPE}}$ was consistently higher than VO_2 at 2 mM (206.9 $\text{mL} \cdot \text{min}^{-1}$ or $+6.0\%$ of $\text{VO}_{2\text{max}}$; LOA = -485.1 to 899.0 $\text{mL} \cdot \text{min}^{-1}$; Figure 4, plot A) and at VT (258.3 $\text{mL} \cdot \text{min}^{-1}$ or $+7.4\%$ of $\text{VO}_{2\text{max}}$; LOA = -129 to 646 $\text{mL} \cdot \text{min}^{-1}$; Figure 4, plot C) and lower than VO_2 measured at 4 mM (-204.1 $\text{mL} \cdot \text{min}^{-1}$ or -5.9% of $\text{VO}_{2\text{max}}$; LOA = -676.7 to 268.4 $\text{mL} \cdot \text{min}^{-1}$; Figure

4, plot B) and at RCP (-237.8 $\text{mL} \cdot \text{min}^{-1}$ or -6.8% of $\text{VO}_{2\text{max}}$; LOA = -573 to 97 $\text{mL} \cdot \text{min}^{-1}$; Figure 4, plot D).

VO_2 at $D_{\text{MAX RPE}}$ was strongly correlated with VO_2 at $D_{\text{MAX La}}$ ($r = .97$, $P < .001$; Figure 3, plot B), VO_2 at 2 mM ($r = .85$, $P < .01$; Figure 4, plot A), VO_2 at 4 mM ($r = .93$, $P < .001$; Figure 4, plot B), VO_2 at $\text{RER}_{=1.00}$ ($r = .97$, $P < .001$), VO_2 at VT ($r = .95$, $P < .001$), and VO_2 at RCP ($r = .95$, $P < .001$).

Discussion

The results of the current study clearly showed that the D_{MAX} method applied to RPE could be used as a surrogate of the LT estimated by the D_{MAX} lactate. Indeed, no differences were observed between $D_{\text{MAX La}}$ and $D_{\text{MAX RPE}}$ methods for VO_2 , heart rate, and power output, with a very strong correlation ($r = .97$) and a very small bias between the VO_2 values (ie, lower than 0.1% of $\text{VO}_{2\text{max}}$). In most studies that compared methods for anaerobic threshold evaluation,²³ the bias was higher than in the current study. We provide further confirmation for the validity of this procedure.

$D_{\text{MAX La}}$ is a well-documented and validated method for detecting LT in various modes of locomotion^{16,17} and has been shown to be strongly related to 1-hour cycling performance in trained female cyclists.¹⁵ Moreover, the results of a recent study indicate that, among a variety of LT markers (ie, Rest+1, fixed 2 and 4 $\text{mmol} \cdot \text{L}^{-1}$, visual lactate turn point), only the D_{MAX} was observed to have good reproducibility, which could be used to identify small but meaningful changes in training status.²⁴ The major interest of this method is the individuality of the measurement taking into account the individual variation in lactate concentrations, unlike the methods using fixed lactate-concentration values (ie, 2 or 4 $\text{mmol} \cdot \text{L}^{-1}$). This latter point is confirmed in the current study by the wide range (ie, 2.8 ± 1.2 $\text{mmol} \cdot \text{L}^{-1}$, range 1.4–5.6 $\text{mmol} \cdot \text{L}^{-1}$) of La value at $D_{\text{MAX La}}$. In the same way, a wide range (ie, mean 35.3 ± 11.8 , range 15.8–59.8) was observed for RPE at the $D_{\text{MAX RPE}}$ point, lending more weight to the choice of this new individual $D_{\text{MAX RPE}}$ method in comparison with the use of a fixed RPE value for precise estimation

Table 1 Relevant Physiological and Mechanical Data Observed (N = 21), Mean \pm SD

Method	VO_2 ($\text{mL} \cdot \text{min}^{-1}$)	% $\text{VO}_{2\text{max}}$	HR (beats/min)	Power output (W)	% maximal power output
$D_{\text{MAX RPE}}$	2717.6 ± 470.9	78.8 ± 5.8	169.7 ± 13.8	207.1 ± 32.8	74.0 ± 7.8
$D_{\text{MAX La}}$	2719.4 ± 504.1	78.7 ± 6.1	169.7 ± 13.8	212.8 ± 36.6	75.8 ± 6.9
2 mM	2510.7 ± 648.7	72.5 ± 13.1	161.8 ± 21.2	190.0 ± 48.4	67.3 ± 12.4
4 mM	2921.8 ± 608.3	84.5 ± 9.5	176.0 ± 17.1	227.1 ± 51.9	80.4 ± 11.5
$\text{RER}_{=1.00}$	2786.6 ± 510.2	80.7 ± 6.9	170.5 ± 13.4	211.4 ± 34.4	75.4 ± 7.3
Ventilatory threshold	2459.3 ± 573.1	70.6 ± 7.1	162.2 ± 16.2	185.7 ± 45.8	65.1 ± 6.6
RCP	2955.4 ± 537.0	85.5 ± 5.07	176.9 ± 11.2	230.0 ± 44.8	81.5 ± 6.6

Abbreviations: VO_2 indicates oxygen uptake; HR, heart rate; $D_{\text{MAX RPE}}$, the rating of perceived exertion threshold; $D_{\text{MAX La}}$, lactate threshold; 2 mM, fixed lactate-concentration value of 2 $\text{mmol} \cdot \text{L}^{-1}$; 4 mM, fixed lactate-concentration value of 4 $\text{mmol} \cdot \text{L}^{-1}$; $\text{RER}_{=1.00}$, the instant of equality of pulmonary gas exchange; RCP, respiratory-compensation point.

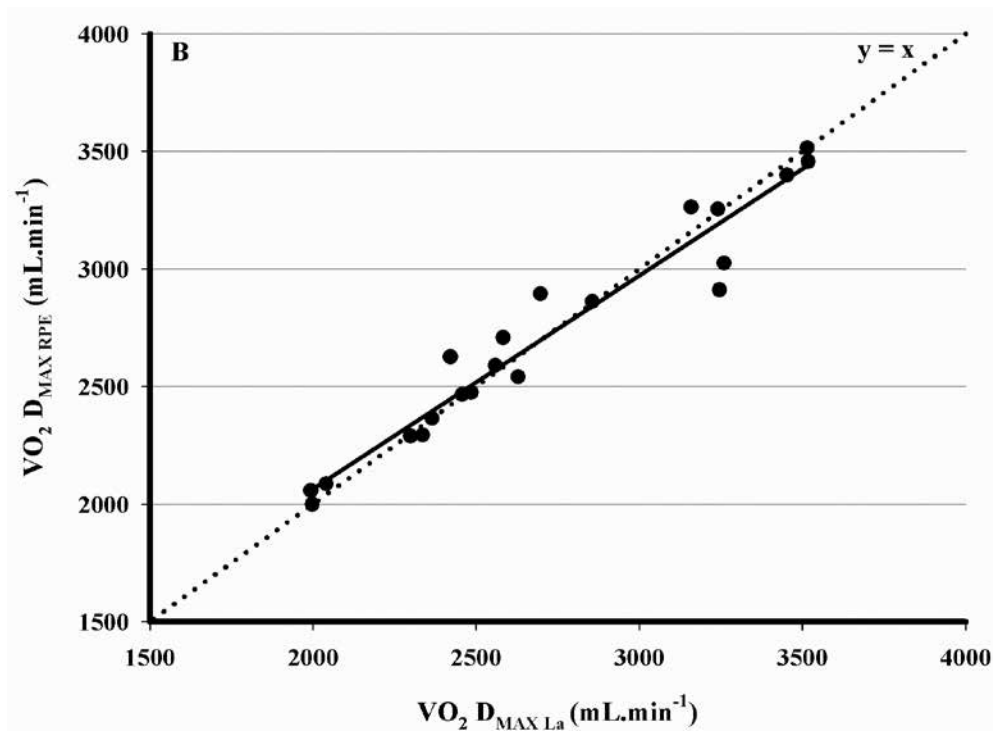
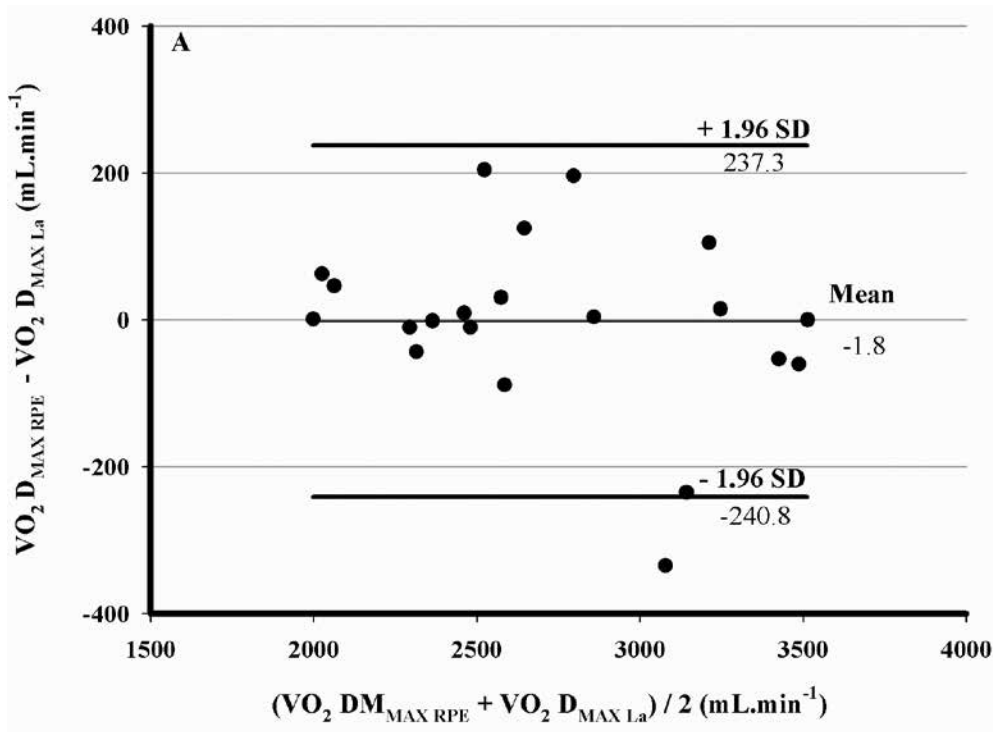


Figure 3 — Comparison of the $D_{MAX RPE}$ and at $D_{MAX La}$ methods. $D_{MAX RPE}$ indicates an adapted $D_{MAX La}$ method using rating of perceived exertion (RPE) instead of lactate concentration; $D_{MAX La}$, individualized lactate (La) threshold measurement identified as the point on the third-order polynomial curve that yielded the maximal perpendicular distance to the straight line formed by the lactate point measured at the end of the first step and the lactate point measured immediately at the end of the test. (A) Bland-Altman plot²² with the thin line showing mean difference (systematic bias) between the methods and the 2 extreme lines showing the limits of agreement (1.96 SD around the mean difference). (B) Correlations between oxygen uptake (VO_2) at $D_{MAX RPE}$ and at $D_{MAX La}$ with the line of identity (dotted line) and the regression line (solid line).

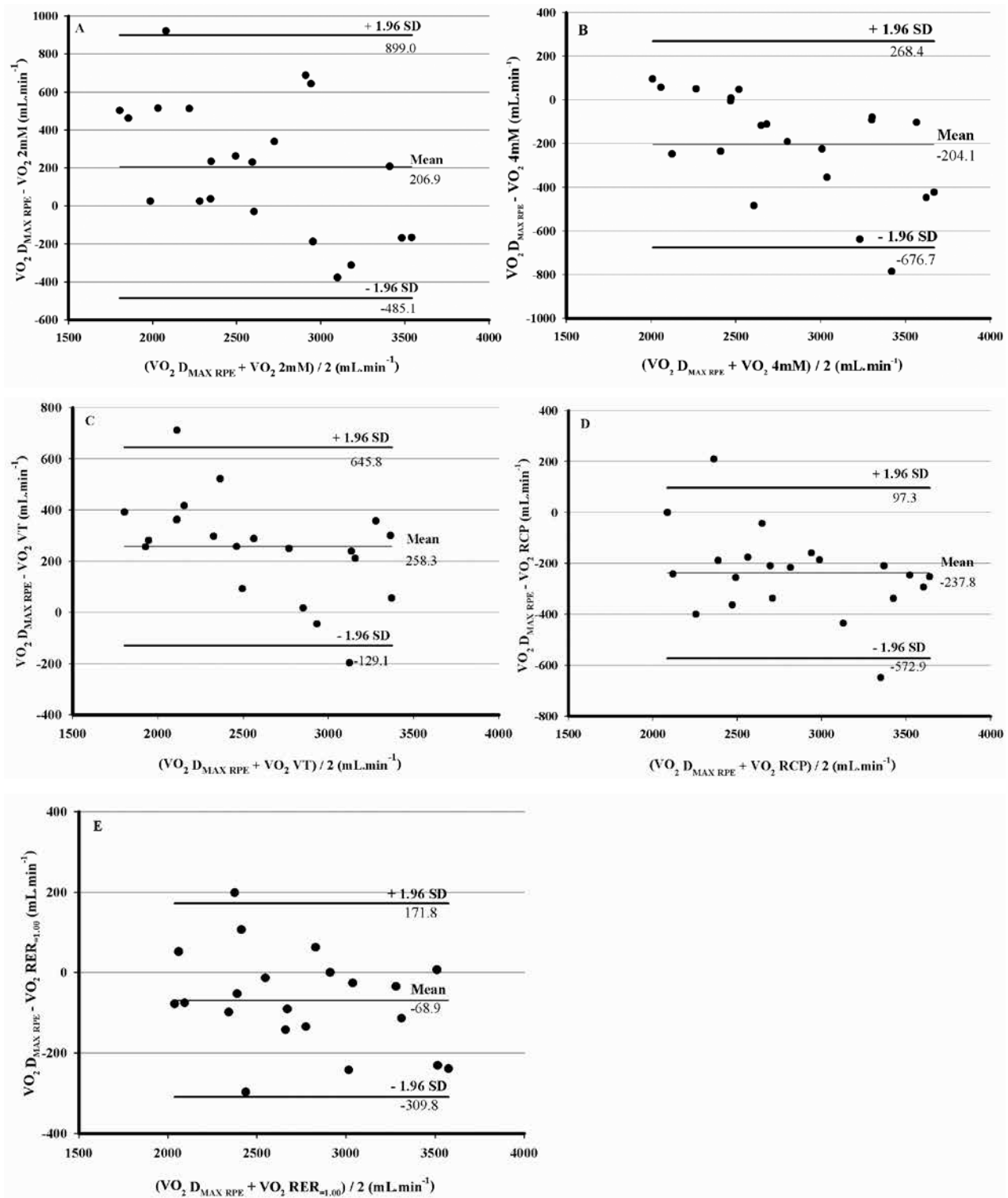


Figure 4 — Bland-Altman plots²² with the thin line showing mean difference (systematic bias) between $D_{\text{MAX RPE}}$ and standard indicators used for training intensity management: fixed lactate-concentration values of $2 \text{ mmol} \cdot \text{L}^{-1}$ (2 mM, plot A) and $4 \text{ mmol} \cdot \text{L}^{-1}$ (4 mM, plot B), the ventilatory threshold (VT, plot C), the respiratory-compensation point (RCP, plot D), and the instant of equality of pulmonary gas exchange ($\text{RER}_{=1.00}$, plot E). $D_{\text{MAX RPE}}$ indicates an adapted $D_{\text{MAX La}}$ method using rating of perceived exertion (RPE) instead of lactate concentration; $D_{\text{MAX La}}$, individualized lactate (La) threshold measurement identified as the point on the third-order polynomial curve that yielded the maximal perpendicular distance to the straight line formed by the lactate point measured at the end of the first step and the lactate point measured immediately at the end of the test. The 2 extreme lines represent the limits of agreement (1.96 SD around the mean difference).

of the LT. Even if a number of studies have already concluded that a strong relationship exists between RPE and LT,^{25,26} to the best of our knowledge, this is the first study that found individual and precise estimation of LT based on computation of the RPE scores obtained at each workload of an incremental test to exhaustion. Until now, this estimate was proposed using a fixed RPE value of 12 to 13 on the Borg RPE 6-to-20 Scale³ or a mean value of 5.85 on the Borg CR-10 Scale,⁴ falling back into the same bias as using fixed lactate-concentration values to monitor athlete training.

It is important to point out that these results were made possible by the use of the CR-100 scale. CR scales have the advantage of being psychophysical ratio scales, giving more correct growth function (positively accelerating with power output) in contrast with the RPE 6-to-20 scale.⁶ Moreover, the CR-100 scale is more finely graded than the CR-10 and permits the use of more numbers than those primarily associated with verbal anchors.⁶ We believe that this point is important to ensure maximal effectiveness of the $D_{MAX\ RPE}$ method. We could also suggest that the already high level of precision of the new $D_{MAX\ RPE}$ method could be improved with better knowledge of and experience in the use of RPE scales.²⁷ In fact, in 2 of the participants of the study (those less experienced in this kind of evaluation), the tendency to use primarily the numbers at the exact locations of the verbal anchors was still strongly marked. So, although instructions on how to administer the scale were fully read and explained to each participant at the beginning of the test, it is highly important to emphasize the use of the whole scale (ie, not only the numbers associated with verbal anchors). Our encouraging results should also be confirmed with participants with different levels of expertise in the use of subjective scales and to test if specific training in the use of such a scale could change the precision of LT determination with the CR-100 scale. In the same way, it has been reported that LT determination depends on both the protocol used with the same locomotion (ie, work-rate increase and duration of the steps during the incremental exercise²⁸) and the locomotion itself (ie, running vs cycling or cross-country skiing). It should be tested whether the precision of the LT determination with the CR-100 scale depends on the methodology used during the incremental test. Further studies should be useful to validate the $D_{MAX\ RPE}$ by testing the response to training and to test the repeatability of this method since RPE responses may be more susceptible to bias with increased exposure to a test.

Comparing the novel $D_{MAX\ RPE}$ method with other standard indicators used for training-intensity management (lactate fixed values, VT, and $RER_{=1.00}$), it appears that the intensity corresponding to $D_{MAX\ RPE}$ was strongly correlated with the intensity at 2 mM, 4 mM, VT, and RCP. However, it was located roughly midway between VT/2 mM and RCP/4 mM with bias higher than 6% VO_{2max} . Conversely, very small bias between $D_{MAX\ RPE}$ and $RER_{=1.00}$ was observed (ie, lower than 2% VO_{2max}). The correspondence of VO_2 at $D_{MAX\ RPE}$ and $RER_{=1.00}$ is interesting. Indeed, the workload associated with an RER value equal

to 1.00 has been shown to correspond to the workload associated with the maximal lactate steady-state workload (MLSS).²⁰ In addition, it has been recently shown that LT workload determined with the $D_{MAX\ La}$ method and workload at MLSS were not different in cyclists.²⁹ Moreover, Dekerle et al³⁰ reported that the power output developed at MLSS corresponded to an intermediate power set between VT and RCP, which is in agreement with the results of the current study. So, it might be possible that $D_{MAX\ RPE}$ is a good predictor of the MLSS, a concept widely used in the assessment of aerobic endurance,²¹ but, since we did not directly measure this intensity, this question has to be addressed in future research.

Practical Applications and Conclusions

The current study clearly shows that the application of the D_{MAX} method to RPE permitted precise and individualized estimates of the LT estimated by the D_{MAX} method. This encouraging result should be confirmed with different populations, incremental protocols, and training and dietary statuses, but we believe this finding is of great interest. Indeed, there is no need for expensive tools or invasive methods to detect this useful index of endurance performance in an accurate and individual way, both in the laboratory and on the field.

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