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Comparison between determination of second anaerobic threshold by respiratory compensating point and X-method in rowers

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim The aim of this study is to verify the X-method for determining the second anaerobic threshold in rowers.

Material and Methods Twelve male athletes from the national rowing team of Bulgaria were tested. Participants performed a one-time graded incremental exercise test to exhaustion on a rowing ergometer. The workload were conducted on rowing ergometer system Concept 2, and spirometry system Clark C5. We obtained ventilatory indices, intensity and heart rate bred-by-bred for each participant, for each test stage. The anaerobic threshold was determined by two methods: 1) by the localization of the respiratory compensation point visually, after polynomial regression analysis of the trends for the dynamics of the ventilatory variables related to time and 2) by the X-method using the change in the ratio between heart rate and pulmonary ventilation. We compared the heart rate corresponding to the anaerobic threshold determined by both methods.

Results We found similar values for heart rate at the respiratory compensation point and the anaerobic threshold determined by the X-method for each of the investigated. The Shapiro-Wilk test showed a normal distribution of the two samples with a significance level of $\alpha = 0.05$. Thus, the t-test for two paired samples showed a p-value of 0.202 at $\alpha = 0.05$. We found a correlation coefficient $r = 0.973$ between the heart rate at the anaerobic threshold (determined by X-method) and the heart rate at the anaerobic threshold (detected at the respiratory compensation point). The Blant-Altman analysis showed that 95% of the points in the scatter plot lie within the confidence interval.

Conclusions The two methods give similar results and can be applied alternatively in the investigation of rowers in the age group 18.3 ± 1.07 years. The X-method always gives a reliable intersection point, which in our studies is close to the second anaerobic threshold. Comparative studies are also needed in other contingents for the wider use of the X-method.

Keywords: ventilatory threshold, heart rate, anaerobic threshold, pulmonary ventilation, endurance, non-invasive

Introduction

After proposing the concept of anaerobic threshold (AnT) and its importance for planning the training process, scientists and coaches are trying to find a way to determine it that is easy to applicable, non-invasive, accurate enough for practice, reliable and inexpensive. The large number of proposed methods can be conditionally grouped according to certain criteria.

Most of the methods are related to determining the blood lactate concentration during and after exercise. They are performed by taking a blood sample, usually from the ear pendant, i.e. invasive. Although these methods are considered the "gold standard" in determining AnT, a number of methodological problems have been described in their use [1]. Furthermore, many authors dispute the direct link between anaerobic metabolism in muscle cells and blood lactate levels [2, 3]. The fact that these methods are invasive makes them less preferred by sports professionals.

Another part of the methods for determining AnT requires expensive spiroergometric equipment and laboratory conditions described in the second half of the last century [4, 5]. They determine AnT based on ventilatory parameters, such as volume of oxygen consumption (VO_2); volume of expired carbon dioxide (VCO_2); pulmonary ventilation (Ve); ventilatory equivalent of oxygen (Ve/VO_2); ventilatory equivalent of carbon dioxide (Ve/VCO_2); end-tidal partial pressures for oxygen ($P_{ET}O_{2)}$; end-tidal partial pressures for carbon dioxide ($P_{ET}CO_{2)}$; respiratory exchange ratio (RER) [6, 7]. The analysis of the ventilatory variables shows two inflection points, of which the first, called the first ventilatory threshold (VT1) shows the upper boundary between moderate and high intensity, while the second, called the second ventilatory threshold (VT2) shows the upper boundary between high and severe intensity. VT2 is thought to be associated with respiratory compensation point (RCP) in increasing metabolic acidosis [8]. On the other hand, the lactate threshold (LT) corresponds to VT1. Some authors define this lactate threshold as the first lactate threshold (LT1). The second lactate threshold (LT2)

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is associated with VT2 [9]. Other studies have linked VT2 to a RER of 1.00. Long known that "additional" CO_2 is released above this point as a product of the bicarbonate buffering system associated with lactate accumulation [10].

In principle, the anaerobic threshold is determined during an incremental exercise test to exhaustion by changes in ventilatory variables and / or blood lactate concentration. VT2 is determined non-invasively and seems to be an applicable training indicator and a key performance factor in endurance sports [11]. Usually AnT is compared with: the power of the work performed (W); the speed to cover a certain distance (V); the time against which the load is applied (t); and HR heart rate at the various stages of the test. The common between the different approaches is that they use incremental exercise test to exhaustion.

Maximum lactate steady state (MLSS) is another protocol and is considered the most accurate in determining AnT [12]. MLSS and critical power (CP) are two widely used indicators of higher oxidative metabolism that can be maintained under prolonged exercise and are often considered synonymous [13]. There is unarguable evidence that MLSS is specific to each sport. Furthermore, it has been accepted for at least 2 decades that although the speed at MLSS is an inarguable predictor of running endurance in a large group of runners, it also has a high risk of both overestimation and underestimation of performance [2]. Apart from the fact that the method is invasive, the procedure for its implementation requires the most time from the known methods for determination of AnT.

In the present study we analyze the upcoming changes in the observed variables according to the 3-phase model of Skinner and McLellan [14]. These authors, attempted to explain each stage of 3-phase double breakaway model and the physiological mechanisms underlying the events which occurred. These authors described the initial phase as being predominantly aerobic with a heavy reliance of type I muscle fibers and free fatty acids as the metabolic substrate. The aerobic threshold leads into the aerobic-anaerobic transition phase, which involves the recruitment of type IIa (FOG) fibers and the appearance of lactate in the blood. Lactic acid in turn decreases blood and intracellular pH and causes an increase in excess CO_2, ventilation (Ve) and RER, and a disproportionate increase in Ve/VO_2. The aerobic-anaerobic transition phase ends at the anaerobic threshold where lactate production equals its removal capacity. The anaerobic phase, the third phase follows. This phase involves the recruitment of type IIb (FG) fibers with a rapid rise in lactic acid production. Lactate production exceeds its removal with a rapid increase in blood lactate and Ve, and a decrease in the fractional concentration of expired O_2 [9].

Over the years, a number of methods have been developed to determine AnT avoiding invasive procedures and expensive spiroergometric equipment. Various strategies have been proposed, some based on responses to Ve or respiratory rate [8], while others are based on changes in HR or HR variability, all expressed as a function of time or load intensity [15]. One group of them uses changes in HR [16]. This method has caused great controversy over the years about its validity, repeatability and physiological validity. However, many coaches, especially in track and field, still use it today.

Recent studies suggest that determination the second anaerobic threshold (AT2) based on heart rate variability (HRV) during exercise may be a cheaper and non-invasive method [17, 18]. However, detailed validation studies are still lacking.

Iban Latasa [19] investigate the reliability of the surface electromyogram (EMG) for automatic detection of aerobic and anaerobic thresholds during a cycle ergometric test with increasing intensity (25 W / min) to exhaustion. They present an agreement between the first EMG threshold and VT1, on the one hand, and between the second EMG threshold and VT2, on the other, and define the method as valid and non-invasive [19]. There is still a lack of detailed research on different contingents in different sports.

Onorati et al. [15] used regression of Ve versus HR and RR (respiratory rate) versus HR. They obtain a bilinear response with a clear breakpoint of the curve. The breakpoint corresponds to the RCP determined by the standard technique with segmented regression of Ve versus VCO_2 and the ventilatory equivalents Ve/VO_2 and Ve/VCO_2 [20, 21].

Other exotic methods for determining AnT have been described, which have not been established in sports science, so I will not comment on them.

The determination of AnT by a method recently described by us [22] was compared with the AnT determined by two reference methods using blood lactate concentration. The method uses the intersection between difference (Diff) between the percentages of the %HR versus HR_{peak} and the %Ve versus Ve_{peak} on the one hand and the %Ve on the other to determine AnT. We called this method the X-method and so we will present it in the present study.

Hypothesis: After proving in a previous study [22] that there is a 95% of agreement between HR at AnT determined by the X-method, the modified D_{max} method and at fixed blood lactate concentration of 4 mmol/L, we assumed that a similar agreement there should be between X-method and VT2 determined by RCP.

The aim of this study was to verify the X-method for determination of AnT by comparing it with AnT determined by the ventilatory variables measured during the incremental maximum test in rowers.

Material and Methods

Participants.

Twelve male athletes from the national rowing team of Bulgaria were tested. Subjects admitted in the study were currently active in competition. Participants performed a one-time incremental maximum test to exhaustion on a rowing ergometer. This represents a control test for the effectiveness of the training process of the competitors from the national rowing team. The measurement procedures and potential risks were verbally explained to each subject prior to obtaining a written declaration of consent. Subject characteristics are presented in table 1.

Table 1. Subject characteristics.

Characteristics	Mean±Sd
Age (yrs)	18.3±1.07
Weight (kg)	186.7±6.54
Height (cm)	84.9±8.92
BMI	24.3±1.73

Procedure.

At the beginning of the examination, the anthropometric variables of the participants were measured and they were acquainted with the possible disadvantageous consequences of performing the test for them. Then they were familiarized with the conditions and equipment for the study. For determination of AnT, in this test we used the measurements for power (W), HR, Ve, VO_2, VCO_2, Ve/VO_2, Ve/VCO_2 and RER. Measurements were performed bred-by-bred and averaged every 30 s during the test. We used these measurements to determine the RCP. Each measurement was denoted by “t”, i.e. each unit “t” represents a period of 30 s. The workload were conducted on rowing ergometer system Concept 2, spirometry system Clark C5. The initial workload was 60 W. Each stage lasted 2 minutes. Each subsequent stage was 40 W higher than the previous. Thus, we obtained measurements for each participant for HR, Ve, W, VO_2, and VCO_2 of each stage. We used these measurements to determine the AnT by X-method.

Determination of AnT by RCP

To determine AnT by detecting of RCP, i.e. VT2, we used visual methods, after polynomial regression analysis of trends in the dynamics of ventilatory variables: Ve, VCO_2, VO_2, values of Ve/VCO_2, Ve/VO_2, and RER versus time [23, 24]. According to Beaver et al. [23] RCP cannot always be detected, which is also confirmed by the experience of Ekkekakis et al. [25]. Therefore, we used a complex of several approaches to identify RCP and searched for similarities in the variables between them. To illustrate the methodology for determining AnT, we present an analysis of the measurements for one of the participants. We used the following approach to determine the RCP in the several steps:

Step 1. We describe regression for VCO_2 on the abscissa and Ve on the ordinate with a 6-order polynomial. Visually determine where the linear part of the polynomial starts after half of the course of the described curve. At the point where the linear part of the curve begins, a change in the slope of the polynomial is detected (Figure 1). We find out what value for VCO_2 corresponds to this inflection point. We record the value for VCO_2. In case such an inflection point is not detected, go to step 2.

Step 2. We describe the regression for VCO_2 in the ordinate versus time ”t” on the abscissa, which corresponds to the consecutive number of the measurement. We describe a polynomial of 6-order and find the sequence number of the measurement denoted by “t” corresponding to the inflection point for Ve from step 1. This point usually coincides with the beginning of the increase in the slope of the curve (Figure 1) and we assign it as RCP.

Step 3. Regression for Ve versus “t” on the abscissa is described by a polynomial of 6-order and we look for the last linear segment in the second half of the test. At the beginning of this segment Ve begins a steeper rise (fig.1). According to the corresponding measurement number “t” we determine the achievement of RCP.

Step 4. We describe the regression for Ve/VCO_2 and Ve/VO_2 in the ordinate versus time on the abscissa expressed as “t”. We determine when the course of the Ve/VCO_2 curve decreases and achieve the lowest value, followed by an increase, and we compare it with the course of the Ve/VO_2 curve, which initially decreases, followed by an increase, which at one point becomes steeper (Figure 2) [23, 26]. For this corresponding number of “t” we determine the RCP.

Step 5. We describe a regression for RER versus “t” and determine at which measurement number its value remains permanently above 1.00 (Figure 2). At this point we determine the RCP [10].

Step 6. We compare the measurement numbers corresponding to the RCP obtained in steps 2, 3,4 and 5. In case of discrepancy in the time to reach the RCP, we analyze the adequacy of the determinations in the mentioned steps and select the appropriate “t”. We find HR in the corresponding measurement “t”. We average the measured HR with that of the previous and subsequent measurements. This HR corresponds to the AnT determined by RCP. We compare it with the HR achieved in AnT determined by the X-method.

Determination of AnT by X-method

For determination of AnT by the X-method, we used the peak heart rate (HR_{peak}) of each participant to calculate the percentage of HR achieved (%HR)

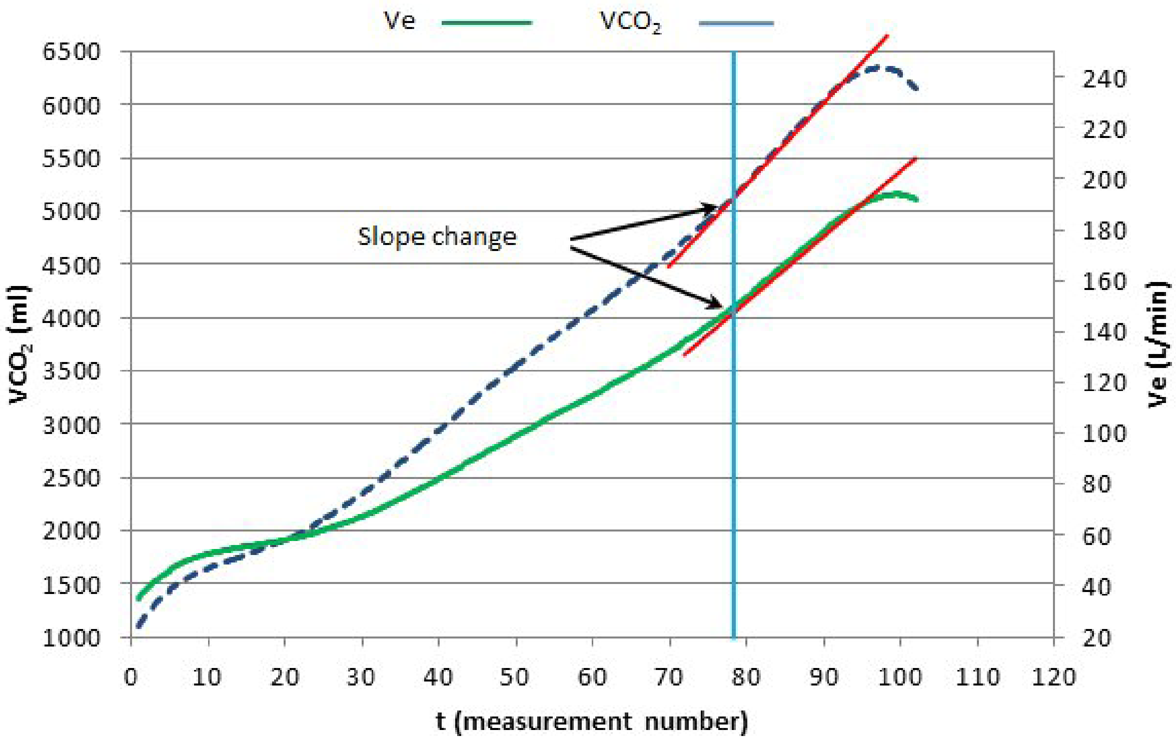

Figure 1. Represent the trends of the regression curves of 6-order polynomials for Ve and VCO2 versus t. The red, straight lines reflect the last linear segments of the two curves.

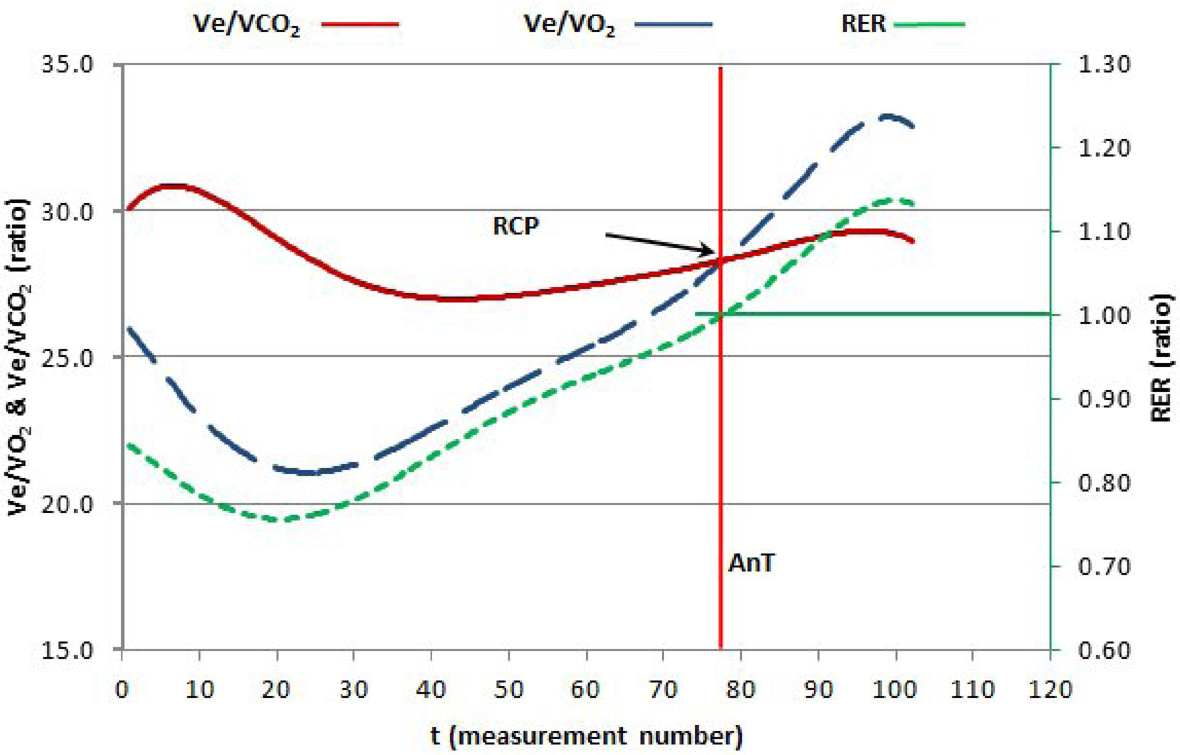

Figure 2. Represent the trends of the regression curves of 6-order polynomials for Ve/VO2, Ve/VCO2 and RER versus t. The red line indicates the RCP determined by the criteria described in steps 4 and 5, and t to which it corresponds. The green line indicates the RER corresponding to 1.00. AnT shows the measurement number corresponding to the anaerobic threshold

for each stage. Thus, we converted the absolute values for HR into percentages. We used the same procedure for pulmonary ventilation as the peak value (Ve_{peak}) was accepted as 100% of (% Ve). The approach we propose is graphical and the determination of AnT was done in a specific sequence. The difference (Diff) between the percentages of %HR and %Ve is compared with %Ve. The %Ve showed larger and more characteristic changes, and a steeper increase after a certain exercise intensity. As the exercise intensity increases, the difference in the relative proportions of the functions of the cardiovascular and respiratory systems decreases. Diff decreases while %Ve increases. This is expressed graphically by the intersection between the Diff and %Ve curves (Figure 3). This intersection point indicates AnT. The X-method uses averaged measurements for each exercise stage.

We then plot a regression between W and HR, which is described by a 3-order polynomial. We determine HR against the W detected by the X-method (Figure 4). Thus we find the HR achieved at AnT.

Statistical analysis

We first performed a variation analysis to determine the means, minimum, maximum, STDEV and coefficient of variation. The Shapiro-Wilk test showed a normal distribution of the two samples at a significance level of α = 0.05, which allowed us to use parametric methods for statistical analysis. To compare the samples of the two methods we used t-test for two paired samples at α = 0.05. To compare the two methods studied, we used Pearson's correlation coefficient. We plotted the scattering diagram of the HR obtained using both methods for determining AnT. We then used the Blant-Altman (B&A) graphical method to prove the similarity between the two compared methods at a 95% confidence interval. We used the Shapiro-Wilk test to prove a normal distribution of the differences between the two methods, which is a condition for the correct application of the B&A analysis.

For statistical data processing we used EXCEL 10 of Microsoft Office 10 and the XLSTAT application developed for the purpose.

Results

Table 2 presents the HR for AnT determined by X-method and for AnT determined by RCP for each of the participants. In the same table, the last two columns present "averages" and "differences" from (B&A) analysis, which we will discuss below.

On the table 2 they make an impression the quite close values of HR at RCP and AnT found by the X-method for each of the participants.

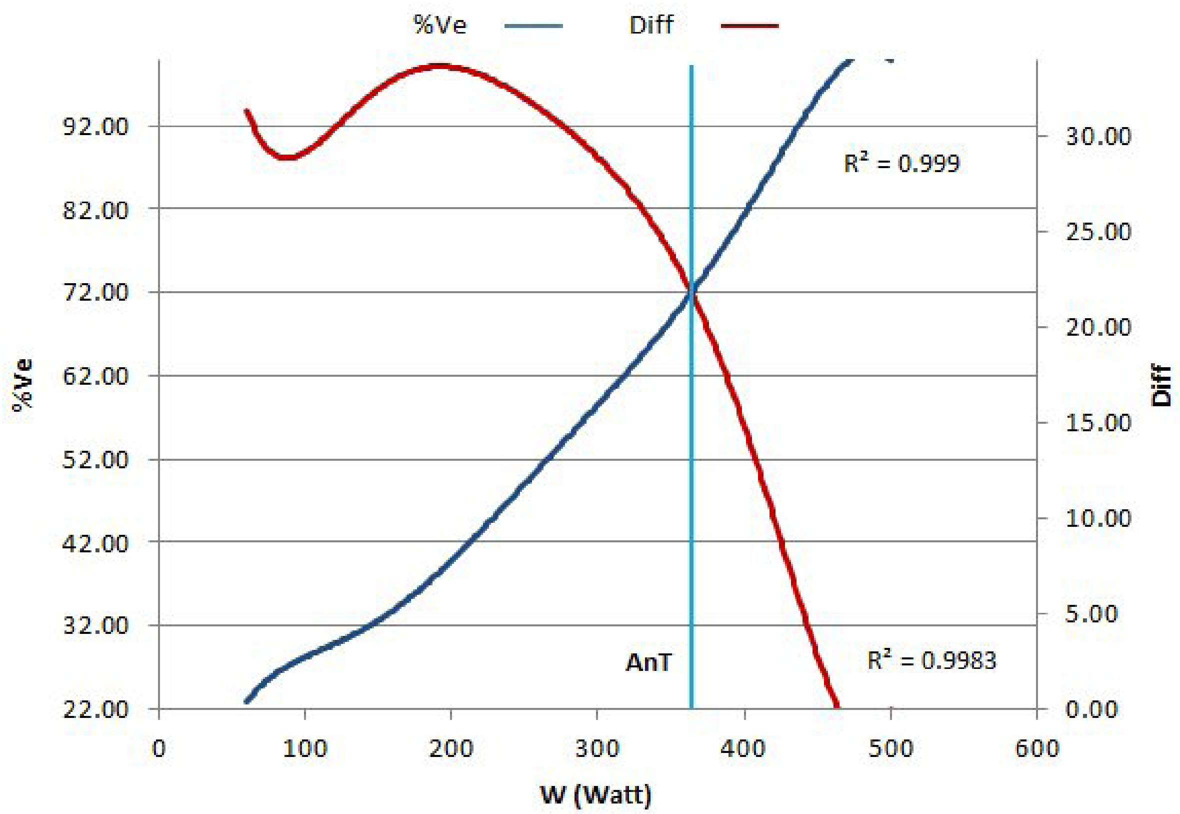

Figure 3. Represents the intersection of the curves for %Ve and Diff versus W, which corresponds to AnT. The blue line connects exercise intensity to the point of intersection.

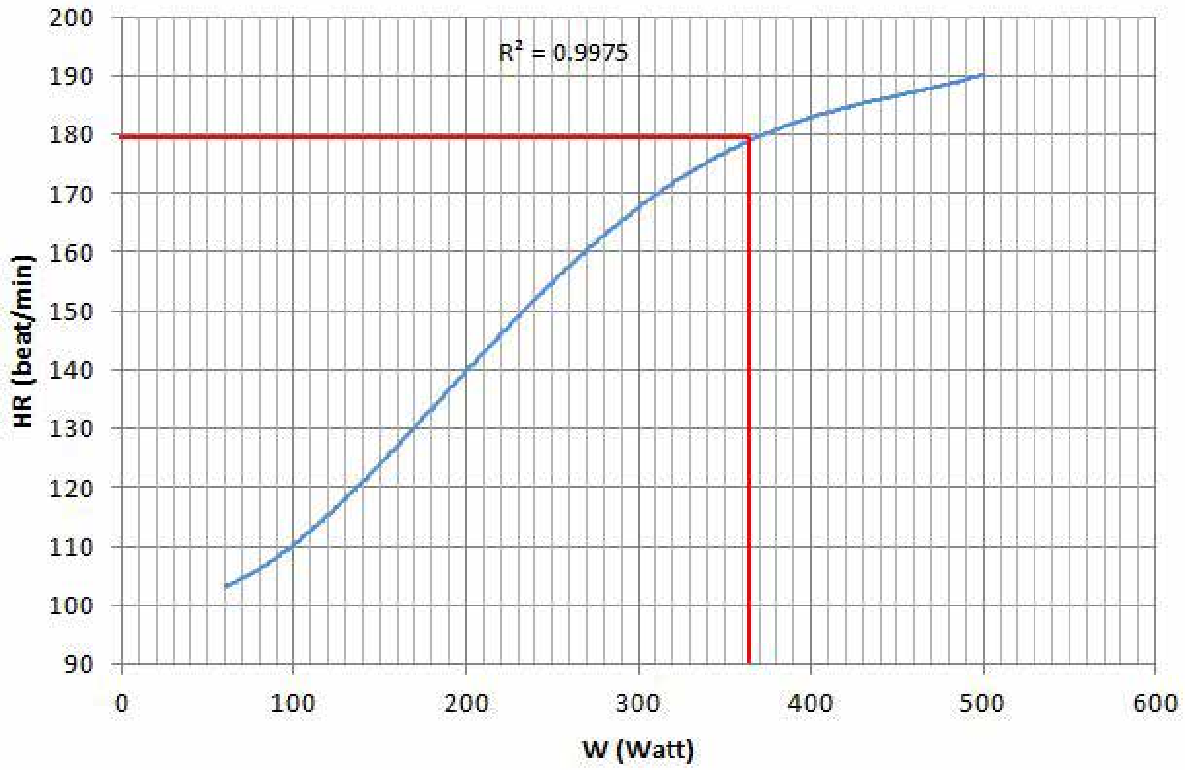

Figure 4. Reflects the ratio of HR to W. The intersection between the HR curve and the red lines determines the AnT in this case.

Table 2. Reflects the HR of each of the participants found for AnT determined by RCP and AnT determined by X-method. Presents averages and differences from B&A analysis.

Subject	HR at AT		Averages and differences from B&A analysis	
	HR at RCP	HR at X-method	Aver. (RCP + X)/2	Diff. (X - RCP)
A.N.	179	177	178.000	-2.000
N.J.	177	178	177.500	1.000
S.H.	177	175	176.000	-2.000
M.S.	184	185	184.500	1.000
N.P.	195	192	193.500	-3.000
R.K.	179	179	179.000	0.000
B.Y.	159	159	159.000	0.000
V.S.	178	175	176.500	-3.000
I.J.	184	183	183.500	-1.000
H.N.	181	184	182.500	3.000
C.M.	173	173	173.000	0.000
I.Y.	182	179	180.500	-3.000

The differences in the pairs of values between participants are bigger. In both approaches for determining AnT, the minimum and maximum values are similar, as can be seen from table 3, as the coefficient of variation (Var.) present a great homogeneity of the two samples. Dispersion (Std. Dev.) is similar for both samples, indicating that both approaches give similar results for HR.

Table 3. Presents descriptive statistics of variables for all participants.

Variable	Obs.	Min.	Max.	Mean	Std. dev.	Var.
HR at RCP	12	159	195	179	8.334	5
HR at X-method	12	159	192	178.25	8.047	5

The Shapiro-Wilk test showed a normal distribution of the two samples at a significance level of $\alpha = 0.05$. The value of $p = 0.119$ for HR at RCP and $p = 0.320$ for HR at X-method entitles us to use parametric statistical methods. Thus, the t-test for two paired samples showed a p-value of 0.202 at $\alpha = 0.05$, which means that there is no significant difference between the averages of the two compared methods.

To compare the results of the two methods, we first draw a scatter plot (Figure 5). The data is on both sides of the identity line (bisector), most of which is below the line. Therefore, the X-method slightly underestimates the HR achieved in AnT compared to the HR achieved in RCP.

Pearson's correlation coefficient presented a very large correlation $r = 0.973$ between HR at AnT determined by X-method and HR at AnT detected by RCP. The correlation coefficient **r** measures the strength of the relationship between two variables, but not the agreement between them. The Blant-Altman diagram describes the agreement between two quantitative measurements. It sets limits of agreement [27]. This method uses the differences between the two methods and the average between the two methods (Table 2, columns 4 and 5).

Table 4. Bland-Altman analysis

Bias	-0.75
Standard error	1.913
CI Bias (95%)	-1.965 ÷ 0.465
Confidence interval:	-4.499 ÷ 2.999

B&A recommends that 95% of the points in the scatter plot (Figure 6) lie within the confidence interval [28], which is -4,499 ÷ 2,999 in our study (Table 4), in order to assume that the two methods give similar results. An important condition for accepting this conclusion is that the distribution of the differences between the two methods is normal. Through the Shapiro-Wilk test we found that the differences between the two methods are normally distributed, which is a condition for the correct application of B&A analysis [27].

From the scatter plot shown in Figure 6 it is clear that the difference between the measurements of the two compared methods, drawn versus the average of the two measurements is in the confidence interval of 95%. Since the average of the two methods is 0.75 lower than 0, the X-method gives lower values compared to the determination of AnT by RCP.

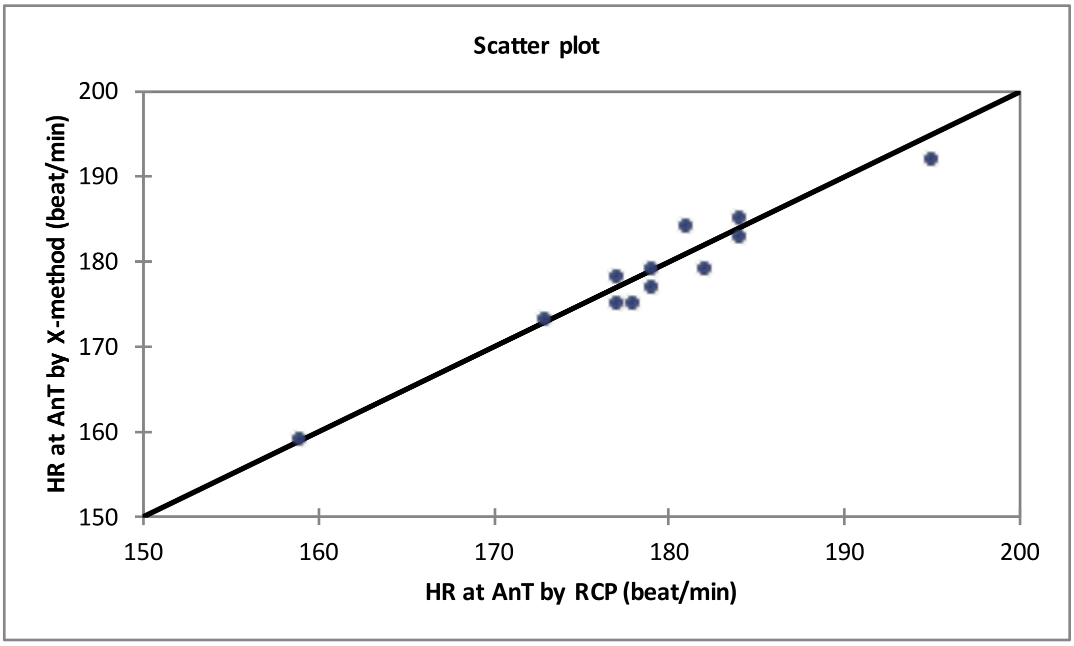

Figure 5. Scatter plot for HR measured at RCP and at AnT determined by the X-method.

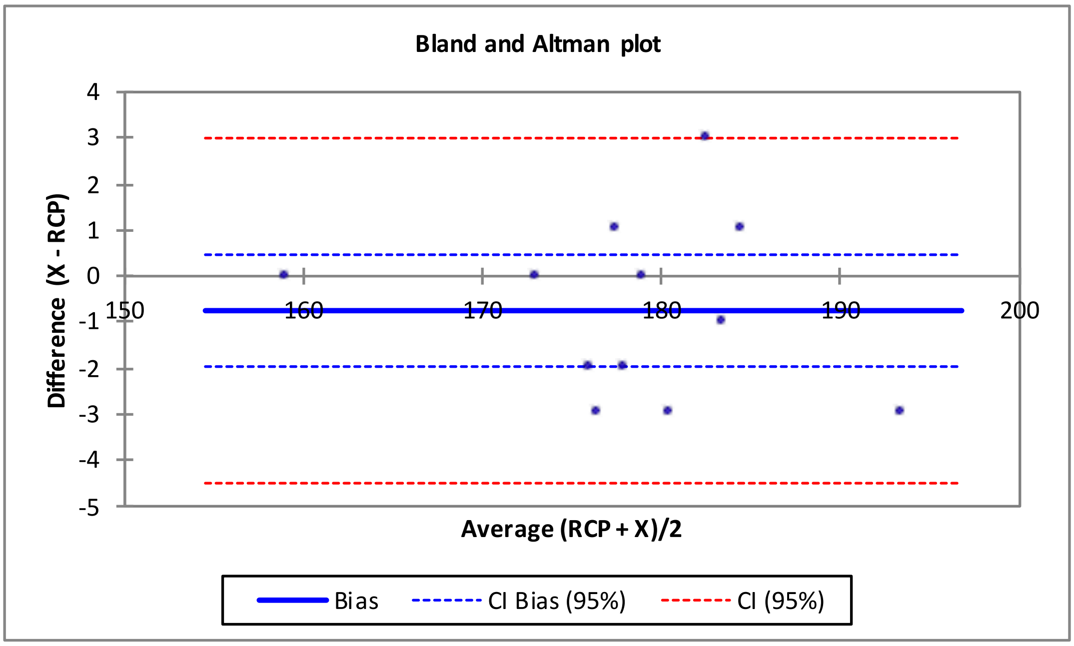

Figure 6. Diagram of Blunt-Altman analysis.

Discussion

As can be seen from the Diff curve, the difference between the function of the cardiovascular and respiratory systems decreases with increasing intensity of exercise, while %Ve increases. As the intensity of the exercise increases, the relationship between the function of the cardiovascular and respiratory systems changes. The dynamics of the heart rate is well known, at exercise with increasing to the maximum intensity, which increases linearly and close to the maximum power for the individual, this linearity is disturbed [29]. On the other hand, when the workload increases to the maximum intensity, Ve increases linearly to about 50 ÷ 75% of the maximum working capacity (W_{max}). After this point, Ve continues to rise steeper to about 85 ÷ 95% of W_{max}, where the linearity breaks again, and Ve begins to rise even steeper. The VT2 is located at this W [30]. In our study, the mean intensity at which AnT was detected, expressed as %VO2max, was 89.73% for RCP and 88.19% for X-method. The percentage of VO_{2max} in which AnT is detected, according to other authors, is similar to that found by us. Jones et al. indicate that AT2 is usually at 75-90% of VO_{2max} [13]. Laurent Bosquet [31] report that calculated thresholds using different “scientific” techniques using the same data set vary between 79 and 92% of VO_{2max}. Santos & Giannella-Neto detected RCP in 88% of VO2max [32]. Pühringer et al. detect VT2 at 83 ± 10% of VO_{2peak} [24].

The correlation coefficient between the methods we compared is r = 0.973. Ekkekakis et al. investigated the correlation between methods for determining RCP. The correlation coefficients are from 0.88 to 0.96 for computerized methods and from 0.85 to 0.97 for visual methods [25]. The indices Ve/VCO_2 and Ve used to determine RCP have a correlation coefficient r = 0.88 for automatic and r = 0.94 for visual methods [32].

From this similarity in the results it follows that in our study there are no significant errors in the methodology for determining RCP and that the X-method gives comparable results with other methods for determining AnT. The results of our study are at the upper boundary of this range, probably because the participants are athletes at national and international level. In addition to the similar $\%VO_{2max}$ in favor of the proposed method is the lower STDV of 8.047 compared to 8.334 for RCP. From a practical point of view, we can summarize that the intersection between Diff and %Ve is easy to detect and is located at about 88.4% of $\%VO_{2max}$ for the group of rowers we studied.

Ventilatory threshold measurements demonstrate significant differences between trained and untrained subjects. These differences are the result of variation in muscle mass activation, movement efficiency, or both. Another characteristic influencing the thresholds is the sex of the subjects. Differences were found between men and women for VO_{2max} and ventilatory threshold, expressed as a percentage of VO_{2max}. The type of ergometer (manual, foot or treadmill) has a significant effect on the ventilatory threshold. Activation of specific muscle groups also leads to significant differences in the ventilatory threshold [33]. Therefore, research on different sports will give different results in the determination of AnT. From this point of view, research of different contingents is needed to describe the regularities in the application of our proposed method.

Conclusions

The presented results and the performed statistical analysis show that the two methods give similar results at a correlation coefficient r = 0.973 and can be applied alternatively. In addition, the t-test for two paired samples showed a p-value of 0202 at α = 0.05, which means that there is no significant difference between the averages of the two compared methods in the study of rowers in the age group 18.3 ± 1.07 years. The determination of AnT by the X-method is more reliable, as the intersection point between the Diff and %Ve curves is easily detected graphically and its determination can be facilitated by mathematical formulas. Such automation of the method needs further development.

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Conflict of interest

The authors declare no conflict of interest.

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