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Original Research

A New Mathematical Method for the Estimation of Aerobic Threshold in Sports Physiology

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ABSTRACT

Aim: The aim of this study was to determine the aerobic threshold by means of the maximum distance method (Dmax) based on heart rate performance curve (HRPC) in active young men.

Methodology: For this purpose, in a laboratory trial, 35 active young men (Age 22.03 ± 2.20 years, Height 176.26 ± 6.65 cm, Weight 68.94 ± 9.56 kg and body fat 17.8 ± 3.41%) were selected on a targeted basis as subjects and executed the Conconi standard protocol. The aerobic threshold of the subjects was determined by means of criterion method (respiratory gas analysis) and maximum distance model based on HRPC. Bland–Altman plots, Intraclass Correlation Coefficient and Paired Sample T-test were used for data analysis.

Results: The aerobic threshold of all of the subjects was obtained by the means of the HRPC using the method of Dmax. However, supplementary results revealed that moderate agreement exist between two methods (±1.96; CI = 95%, -35.9 to +32.8 b/min). Similarly, significant but moderate Intraclass Correlations observed (ICC= 0.312), while there was no significant differences exists between two methods (p= 0.599).

Conclusion: The application of the Dmax method based on HRPC model in predicting of the aerobic threshold gives us relatively good results. Therefore, the HRPC model can be useful method for predicting the aerobic threshold.

Key Words: Aerobic threshold, Maximum distance method (Dmax), HRPC.

Introduction

Aerobic threshold is the minimum intensity and duration of exercise, which is effective in improving aerobic capacity [1]. Studies have shown that achieving exercise goals for improving cardio-respiratory capacity requires activity at the intensity equivalent to the aerobic threshold. In fact, activity at the aerobic threshold is the most appropriate intensity for achieving health goals, improving physical fitness, cardiovascular capacity and even cardiovascular rehabilitation [2, 3]. Significant effects of exercise activity with the intensity equivalent to the aerobic threshold on cardiac rehabilitation in patients and improvement of cardio-respiratory capacity in healthy subjects in athletic and non-athlete have been observed in previous studies, and this indicates the importance of aerobic thresholds [4-6].

The occurrence of the first threshold (aerobic threshold or Lactate threshold point 1 (LTP1)) during incremental exercise intensity is when, with increasing workload, plasma lactate levels increase from about 2 mmol/l, which coincides with the first ventilation threshold (VT1);Thus, in VT1, an increase in the oxygen ventilation equation (VE/VO_2), occurs with the rising defect of the linear mode of ventilation, without increasing the carbon dioxide equation (VE/VCO_2) [2, 7-11]. In the distribution classification of intensity, intensity is equivalent to the aerobic threshold; the intensity is low which can easily be used by people with different conditions, including the elderly and patients. In fact, activity at the aerobic threshold is the starting point for the effectiveness of exercise activities on various aspects of improving the level of health and Cardiorespiratory fitness. The findings show that although High intensity interval training (HIIT) have time efficiency, they cannot be a suitable substitute for low intensity and moderate periods in the inactive people [5] and on the other hand, activity on the aerobic threshold can improve performance in high intensity endurance activities [4]. Therefore, determining the aerobic threshold can be very helpful in designing training programs with different purposes and plays an important role. There are various methods for estimating the aerobic threshold in literature. The most accurate method for determining the aerobic threshold is an invasive method that involves taking blood samples frequently and determining the amount of blood lactate during a cardiopulmonary exercise testing that it is complicated and expensive [12].

Therefore, it is very important to replace the methods that are simpler in nature, so that aerobic threshold measurements are easily possible. Review the scientific evidences indicate that the use of noninvasive methods has been considered for estimating the first threshold, and in most of these methods, the analysis of respiratory gases has been established [2, 13, 14]. One variation in respiratory volumes and ratios coinciding with the first threshold is VCO_2 vs. VO_2, which is currently the most commonly used method for determining the aerobic threshold. This method is known as the V-slope due to the V-shaped curve slope Changes. Also, the use of Respiratory gas exchange ratio (RER) versus workload is another method used to determine the aerobic threshold [2, 14]. Beaver et al (13) used the model Log10 volume of oxygen consumption versus Log10 power output to estimate LTP_1. Skinner et al [9], also showed that the first threshold could be determined by changing the minute ventilation during the incremental exercise. The curve of minute VE shows a curvilinear slope pattern with two break points. The first coincides with the 'aerobic threshold. In another study, Beaver et al. Proposed using VE/VO_2 versus work load curve changes and pressure end tidal O_2 ($P_{ET}O_2$) versus work load to determine the first threshold [2, 14]. Given that the variables of these methods are the volumes and the ratio of respiratory volumes, the estimation of aerobic threshold using these methods involves the collection and analysis of instantaneous respiratory gases that through advanced laboratory equipment is possible.

The use of heart rate has been proven to be a non-invasive, simple and precise method for assessing the intensity distribution of exercise [2, 4, 7]. The heart rate-work load curve provides information on the aerobic-anaerobic balance during exercise which can be used as an indicator for assessing the intensity of the activity. During an incremental exercise training, heart rate changes proportional to work load are considered as the heart rate performance curve (HRPC) [7]. Conconi et al first proposed the use of the heart rate performance curve for estimating the Anaerobic Threshold [15]. The researchers showed that there is a point in HRPC that the heart rate does not increase by increasing the work load and the heart rate performance curve deviates from the straight line and takes on the plateau, That called heart rate deflection point (HRDP) [7, 15]. Conconi et al. method, in future studies by other researchers was considered and amended use of the maximum distance model (Dmax) by Cheng et al [16] and in its completion, the parallel straight line slope (PSLS) model was proposed by Siahkouhian (17), which made it possible to accurately estimate the HRDP. Although literature suggests that using heart rate changes to estimate the second threshold is a precise method and has a high agreement with the criterion method (direct measurement of blood lactate), but the use of the heart rate curve has not been considered in the first threshold estimate so far. In the Initial investigations and laboratory observations, HRPC represents a significant change in the process of heart rate distribution during the gradual increase in the intensity of exercise in the aerobic threshold from linear mode. This evidence led us to test for the heart rate changes accurately through mathematical methods for estimating the first threshold. Therefore, considering the existing literature and the lack of information in this regard as well as the simple in nature, low cost and precise method, the main objective of this study was to determine the aerobic threshold using the HRPC-based maximum model during the incremental exercise test.

Material and Methods

Experimental design and subjects

Thirty five active young men volunteers (mean ± SD of Age 22.23 ± 2.02 yrs, Height 176.26 ± 6.65 cm, and Weight 68.49 ± 9.5 kg), attended the sport physiology laboratory on three separate phases after giving written informed consent according to the Ethical Committee regulations of the University of Mohaghegh Ardabili. During the first phase participants undertook body composition and physiological tests. A minimum of 72 h after the initial session, during the second phase, the participants completed a fitness-dependent HRDP maximal treadmill test protocol to volitional exhaustion (GXT) with continuous respiratory gas measurements (Ganshorn Medizin Electronic GMBH, Germany) [18]. During the final experimental test, the aerobic threshold determined by means of the Dmax method based on HRPC. The physical and physiological characteristics of the subjects are summarized in Table 1.

Methods of body composition and physiological variables measurements

The body fat percent was measured using the Harpenden Caliper and the three-point equation [19]. Height and weight as well as the body mass index were calculated via standard methods [20]. The Vo2max of the participants was calculated by the continuous respiratory gas measurements (Ganshorn Medizin Electronic GMBH, Germany) during GXT on the treadmill (Sport ART, Model 6150E)[18].

Aerobic threshold determination method

To determine the Aerobic threshold, firstly, HRDP was predicted based on the Mod-Craig et al. method [21] by the means of Narita et al. equation [22]. Then, HR data points between test protocol beginning to HRDP was recorded continuously in 2 second time intervals by a cardio frequency meter (Polar Vantage Sport Tester XL) and each subject's data was recorded during the exercise test. The third order curvilinear regression curve was calculated the HR values vs. the Time. To compute the Dmax between the straight lines formed by the two end points of HR in each curve, the PSLS mathematical model was used (Figure 1)[5, 16-17].

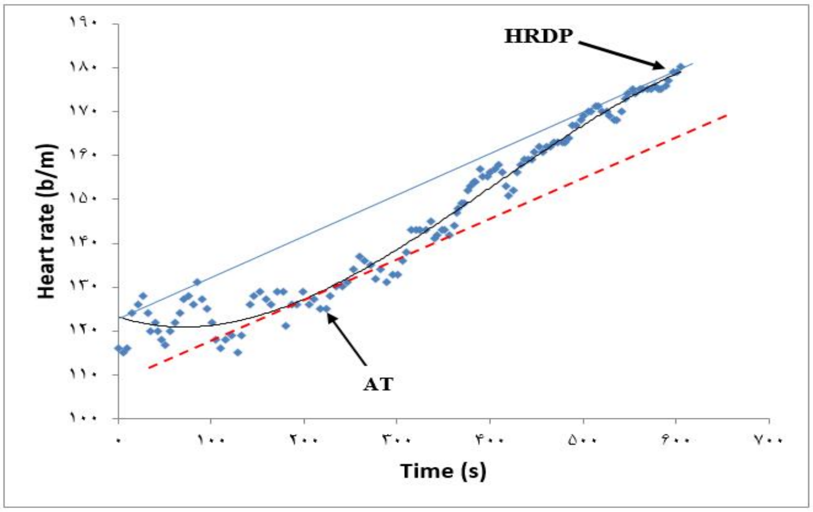

Figure 1. A sample of aerobic threshold estimation based on the Dmax model in one of the subjects

Statistical method

Shapiro-Wilk tests were used to analysis the distribution of normality. The Bland-Altman graphical model [23] as well as the IntraClass Correlation Coefficient (ICC) methods [24] were used to analysis the data. Statistical analyzes were performed at the P≤0.05 level using SPSS 23, MedCalc and Excel 2013 software.

Results

The demographic and some physiological indices of the subjects are presented in Table 1. The results of the Shapiro-Wilk tests showed the normal distributions of the data.

Table1. Physical and physiological characteristics of the subjects (Mean ± SD, n = 35)

Parameters	Values
Age (yrs.)	21 ± 1.32
Height (cm)	176.26 ± 6.65
Weight (kg)	68.94 ± 9.56
Body fat (%)	17.80 ± 3.41
Body mass index (kg/m2)	24.31 ± 3.78
Vo_2max (ml/kg/min)	52.07 ± 2.54
Resting Heart Rate (b/min)	61.00 ± 5.86

Based on the HRPC, we observed the aerobic threshold in all of the subjects. A sample of the estimation of the aerobic threshold based on the Dmax method is shown in the Figure 1.

Bland and Altman plots revealed a moderate agreement between predicted AT by the HRPC and criterion method (±1.96; 95% CI = -35.9 to 32.8 b/min; Figure 2). Although the mean difference between the two methods is 1.6 b/min, according to the type of data distribution and their high distance from the mean difference, the agreement of the estimated aerobic threshold is reduced (ICC= 0.312).

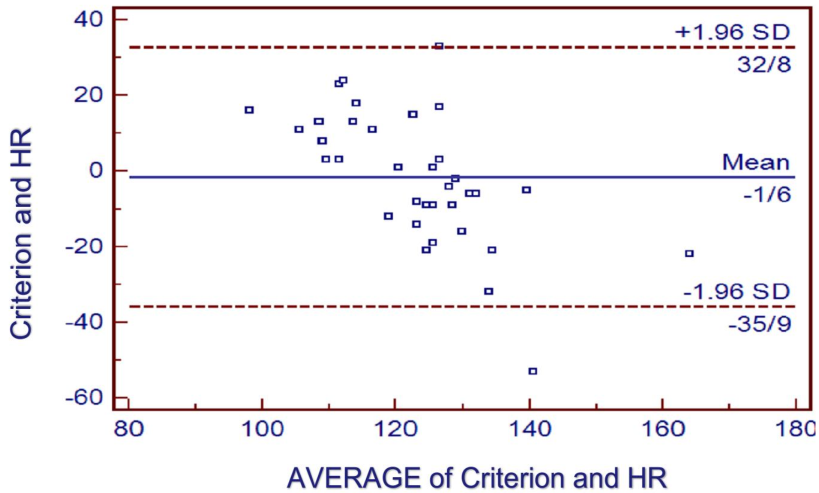

Figure 2. The agreement between predicted AT by the HRPC and criterion method

The results showed that there was no significant difference between the criterion (respiratory gas analysis method) and HRPC methods (122.46 ± 9.52 b/min versus 124.03 ± 18/89 b/min; P = 0/599; Figure. 3).

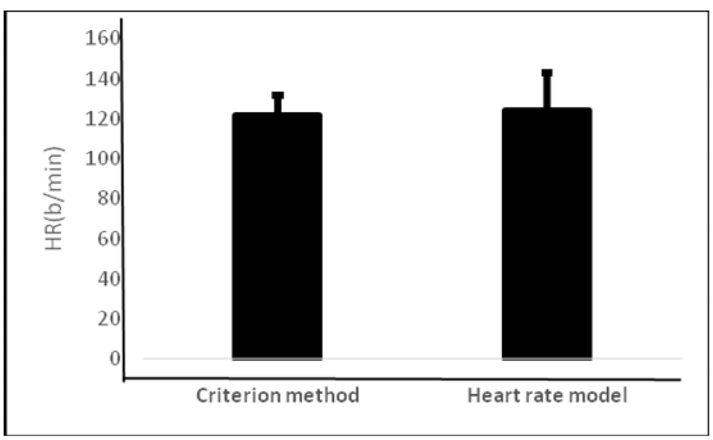

Figure 3. Mean and standard deviation of aerobic threshold (AT) estimated by the criterion and Dmax model.

Discussion and Conclusion

Upward inflection of HRPC was noticed in all subjects. Comparison of the Dmax methods with the criterion method (respiratory gas analysis) showed that aerobic threshold determined by the max and lactate methods were not significantly different (122.46 ± 9.52 vs. 124.03 ± 18/89 b/min; P = 0/599), while Bland-Altman plots revealed a moderate agreement between Dmax and lactate methods (±1.96; 95% CI = -35.9 to 32.8 b/min).

Non-invasive methods for estimating aerobic thresholds was widely used by ventilation or gas exchange parameters. Beaver et al. showed that log–log transformation of VO2 versus power output [13] is a demonstrative way for the detection of this 'first lactate threshold', which may approximate BL levels around 2 mmol/l. A plot of this function exhibits a phase of very slow increase followed by a phase of rapid increase, defining a transition in the underlying relationship between VO2 and power output. These phases were found to be linear on the log-log plot; therefore, linear regression analysis was used to determine the transition between them (lactate threshold). Whether this method is a good alternative to the criterion method has not yet been investigated.

Similarly, respiratory exchange ratio (RER) (VCO_2/VO_2) vs. work load to estimate aerobic threshold is used. It has been shown that the first threshold may also be defined at the point where the RER versus WL curve having been flat or rising slowly, changes to a more positive slope [15].The numerical value of RER on the aerobic threshold always remains below 1. But the anaerobic threshold is determined as the point at which the RER is more than 1 and after that does not return to the low levels [25-26].

The first threshold is also determined by a sudden increase in ventilation [9]. The variation of the VE/VO_2 curves versus WL and the particle Pressure end tidal O_2 ($P_{ET}O_2$) curves versus WL are also indicated the aerobic threshold, $P_{ET}O_2$ decreases during the initial WL increments because of changes in the physiological dead space and tidal volume ratio. At the first threshold, when ventilation increases out of proportion to VO_2, $P_{ET}O_2$ reaches a minimum and increases thereafter. In other words, the VE/VO_2 slope breaks with linearity and increases, whereas the VE/VCO_2 slope first decreases and subsequently remains constant. Correspondingly, $P_{ET}O_2$ is noted to increase, whereas $P_{ET}CO_2$ does not change [2, 10, 11, 14]. VCO_2 versus VO_2 (V-slope) method is one of the most frequently used method for the determining the first threshold. During the early WL increments in cardiopulmonary exercise testing, VCO_2 rises as a linear function of VO_2, but as exercise intensity increases, a subsequent increase in this slope occurs. This increase will be exactly on the first threshold. In this method, the VCO_2-VCO_2 curve is practically divided into two regions, consisting of a two-line regression at the intersection of the threshold which does not increase the curve slope after the intersection point proportional to the linear slop of the curve before the intersection [2, 14]. To estimate the aerobic threshold using these non-invasive methods, necessitate continuous respiratory gas measurements, which is expensive and time consuming.

In the Dmax model, measurement and recording of the HR during progressive protocol is very convenient and simple approach. HRDP during GXT may be explained by the means of catecholamine Influences It is reasonable to hypothesis that catecholamines may be a constituent in the mechanism(s) of HR deflection, since they contribute to the tachycardic response during exercise. However, time courses of plasma adrenaline and Noradrenaline levels compared with both regular and inverse HRDP. It can be concluded that it was unlikely that parasympathetic regulation was a cogent explanation for the HRPC. The results of our study may be supported by recent evidence demonstrating that exercise intensities corresponding to 50 to 60% of maximal VO_2 are devoid of vagal influences on HR. It seems that Cardio acceleration beyond first AT is mediated completely by the sympathetic drive [2, 7].

Therefore, it can be concluded that the Dmax model is an applied model for estimating the aerobic threshold. Furthermore, it can also be applied a model for health and fitness training programs.

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