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ORIGINAL ARTICLE

DETERMINATION OF THE VENTILATORY ANAEROBIC THRESHOLD BY THE RESPONSE OF THE HEART RATE OF INDIVIDUALS WITH RISK FACTOR FOR CARDIOVASCULAR DISEASES: COMPARISON WITH A VISUAL METHOD

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Introduction: Cardiovascular diseases (CVD) are the leading cause of death worldwide. The sedentary lifestyle stands out as one of the main risk factors related to CVD. A thorough evaluation must be carried out to prescribe properly, respecting the biological individuality. Cardiopulmonary exercise test (CPET) is a useful tool in determining functional capacity. The ventilatory anaerobic threshold (VAT) is shown as an important parameter for exercise prescription. The gold standard method for obtaining VAT is a visual analysis of the curves obtained from the ventilatory variables of the CPET. However, analysis of heart rate (HR) response appears as a promising strategy as a useful, simple and low-cost tool for determining VAT. **Objective:** To evaluate the validity of the VAT determination through the HR response during the CPET. **Methods:** Men and women were recruited, aged over 18 years and who presented risk factors for CVD. All volunteers underwent a clinical evaluation and the CPET through an incremental power protocol (10W/min) until physical exhaustion. The VAT was determined by the graphical visual method and by the heteroscedastic statistical model, where the variables time, power, HR and oxygen consumption (VO2) were analyzed. **Results:** No significant differences were found in VO2 (mL/ kg/min), VO2 (L/min) and power (W) values, comparing the determined methods. In addition, for all variables, strong correlations were found. **Conclusion:** The determination of VAT by the HR response proved to be an adequate model.

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INTRODUCTON

Cardiovascular diseases (CVD) are the leading cause of death worldwide. In 2008, according to the World Health Organization (WHO), more than 17 million people died from CVD and over 3 million of these deaths occurred in individuals under the age of 60[1]. In Brazil, CVD represents about 30% of deaths[2]. However, many of these events are preventable. This can occur through public health measures or individual health care interventions capable of controlling risk factors for CVD and, consequently, reducing the development of diseases.

Epidemiological studies have shown that regular physical exercise is closely associated with a significant reduction in cardiovascular morbidity and mortality3. However, some care must be taken about the variables that make up physical training, such as intensity, duration, and frequency. Especially in patients with CVD[4,5], since they may have reduced functional capacity and electrocardiographic abnormalities, which makes them more susceptible to cardiovascular complications during physical exercise[6,7].

The cardiopulmonary exercise test (TECP), considered as the gold standard in the cardiorespiratory functional evaluation, is shown to be a useful tool in the interpretation of parameters that are capable of judiciously determining the functional capacity of healthy or sick individuals[8]. Among the various parameters analyzed, the ventilatory anaerobic threshold (VAT) has been shown to be an important index of aerobic performance, with particular importance for exercise prescription[9]. This is because it is able to reflect the anaerobic threshold (AT) that occurs in the peripheral muscles and marks the maximum oxidative capacity to an imposed demand. The gold standard method for obtaining the VAT is a visual analysis of the curves obtained from the ventilatory variables of CPET[10]. However, the analysis of heart rate (HR) response has been described as a valid and low-cost strategy to determine AT in progressive physical exercise.[11, 12]

Although several methods for determining VAT by HR have been described, a few have been investigated about the validity of the application of the methods in individuals with risk factors for CVD and their conception based on the modeling of least squares in segmented mathematical equations. The possibility of using a simpler and more economically viable method can contribute to adequate and safe assessments and prescriptions of physical exercise and more accessible to healthy individuals or those with risk factors for CVD.

Given the above, the present study was prepared with the purpose of verifying the validity of the heteroscedastic statistical model for determining AT from the behavior of HR.

MATERIAL AND METHODS

Study design

This is an observational, experimental and cross-sectional study.

Sample

Men and women were recruited, who met the following inclusion criteria: individuals over 18 years old and who presented a risk factor for the development of CVD. The following risk factors were considered for the inclusion of individuals in the research: SAH, overweight, obesity, dyslipidemia and physical inactivity.

Individuals with clinical and/or functional evidence of chronic obstructive pulmonary disease, exercise-induced asthma, history of coronary heart disease, angina or significant arrhythmias who had musculoskeletal changes that prevented the performance of CPET were excluded, as well as diabetic individuals.

This work was approved by the Comitê de Ética da Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, RJ, Brazil (nº 926770). All volunteers signed the Free and Informed Consent Form and the privacy of the research subjects and data confidentiality were fully guaranteed during all stages of the study.

Clinical evaluation

First, the volunteers underwent a detailed assessment (anamnesis and physical examination), in which personal, anthropometric data, vital signs and nutritional status (body mass index [BMI]) were collected. The variables considered for inclusion in the study were also analyzed: SAH (systolic blood pressure>140mmHg and diastolic blood pressure>90mmHg[13]), overweight/obesity (BMI≥25 kg/m^2)[14], dyslipidemia (LDL>130 mg/dL and HDL<40 mg/dL).[15]

Maximum or symptom-limited cardiopulmonary exercise test

In a second step, the individuals were submitted to an incremental CPET following the protocol of Wasserman[10] followed by the visual analysis of the VO2 and VCO2 correlation curves, VE/VO2 and VE/CO2 ratios, and the FEO2 and FECO2 variables that were plotted breath to breath in Excel software. In the sequence, three independent observers performed the determination of the VAT in the occurrence of the following situations: [10]

- VE/VO2: the lowest value of this relationship, making sure that, from there, there is a systematic increase;
- FEO2: the lowest point of this variable, from which a systematic rise begins.

The selected stretch of analysis was based on the responses of the cardiorespiratory variables, that is, from the moment when they begin to respond to the increase in power until the moment of interruption of exercise. The analysis of each observer was performed independently, on the 15-inch monitor display (SyncMaster 550V, Samsung) interfaced to the Aerograph system. From the mean value of the time obtained, the corresponding power (W), VO2 (mL/min), VO2 (mL/kg/min) and HR (bpm) values were checked in the spreadsheet of the variables generated by the ergospirometry system, interpolated second by second.

The qualitative control of the experiment was carried out by several criteria: constant rotation speed (60 rpm) until physical exhaustion; occurrence of artifacts that could impair the quality of the test and the determination of the AT; the presence or not of steady-state in the heating phase; whether the onset of HR responses and ventilatory variables coincided with the increase in power; and whether the ventilatory variables showed linear behavior at the beginning of the ramp. This method was used as the gold standard in comparison with the other methods of determining the AT.

Heteroscedastic statistical model

The heteroscedastic statistical model was developed using a mathematical algorithm in the software Sigmaplot for Windows® version 10.0, which determines the point of change of the HR data series. This model was applied to the data collected beat by beat of HR, in which, from the VAT identification, the values of time (seconds), power (W), HR (bpm) and VO_2 (mLO_2/kg/min and L / min) were established.

The simple linear heteroscedastic regression model, considering a sequence of observations (yi, xi), is given as follows:

$$y_i = \begin{cases} \alpha_1 + \beta_1 x_i + \varepsilon_{i1}, & \text{se} \quad i = 1, \ldots, k, \\ \alpha_2 + \beta_2 x_i + \varepsilon_{i2}, & \text{se} \quad i = k+1, \ldots, n. \end{cases}$$

Where yi is the dependent variable, xi is an independent "fixed" variable (in this case, time) and εi1 and εi2 are random errors of the relationship, which are independent and generally distributed with mean zero and variance σi2. A1, β1, α2, and β2 coefficients are unknown and need to be estimated.

Figure I illustrates the application of the heteroscedastic statistical model to HR data, beat by beat, as a function of time. The vertical line determines the point of change of HR and the time representing at the bottom of the graph, the time of occurrence of VAT was considered by this method.

The sections selected for the application of this model were the same as those used in the visual method, that is, from the moment of protocol insertion until the peak of the exercise. The time, power, HR and VO_2 data on the VAT determined by these methods, for each of the variables, were then tabulated.

Statistical analysis

The statistical program Sigmaplot version 11.0 for Windows® was used to process the data. Initially, the Kolmogorov-Smirnov normality tests and Levene's homogeneity of variances were applied to the data. For the parametric variables, time (seconds), power (W), HR (bpm) and VO_2 (mlO_2/kg/min and L / min), the paired t-student test was used. On the other hand, on the non-parametric variables, the Wilcoxon test was applied. Pearson's correlation test was also applied where: 0-0.19 - very weak correlation; 0.20-0.39 - weak correlation; 0.40-0.69 - moderate correlation; 0.70-0.89 - strong correlation; 0.90-1 very strong correlation. Finally, it is worth noting that, with 26 patients included, the power was 0.91 with an alpha of 5% for the HR variable. Data were presented as mean and standard deviation or median and interquartile and the level of significance was set at $p < 0.05$.

Table I. Anthropometric and clinical characteristics, risk factors for CVD and ventilatory variables of CPET.

Variables	Volunteers (n=26)
Gender (M / F) (n)	18/8
Age (years)	57 ± 11
Body mass (kg)	86 ± 24
Height (cm)	167 ± 10
BMI (kg/m^2)	31 ± 7
Risk factors	
Sedentary lifestyle (%)	100%
Family history of CVD (%)	53,8%
Systemic Arterial Hypertension (%)	27,2%
Dyslipidemia (%)	18,1%
History of previous smoking (%)	13,6%
Smoking (%)	4,5%
Medications	
Diuretics (%)	18,1%
Ara II (%)	13,6%
ACE inhibitor (%)	13,6%
Beta-blockers (%)	4,5%
Calcium channel inhibitor (%)	9%
CPET	
Ventilatory anaerobic threshold	
VO_2 VAT (L /min)	1,18 ± 0,57
VO_2 VAT (mL /kg/min)	10,40 ± 4,34
Peak exercise	
VO_2 peak (L/min)	1,89 ± 0,68
VO_2 peak (mL/kg/min)	21,58 ± 5,45
Predicted VO2 (L / min)	1,87 ± 0,13
VO2 (% predicted)	101,06 ± 5,23
VE (L/min)	39,13 ± 21,67
Peak load (W)	125 ± 46
BORG Dyspnea	4 (4-7)
BORG LL	5.5 (4-8.5)

Data in mean and SD. BMI: body mass index; CVD: cardiovascular disease; CPET: cardiopulmonary exercise test; VO_2: oxygen consumption; VAT: ventilatory anaerobic threshold; VE: ventilation; ACE: angiotensin-converting enzyme. LL: lower limbs.

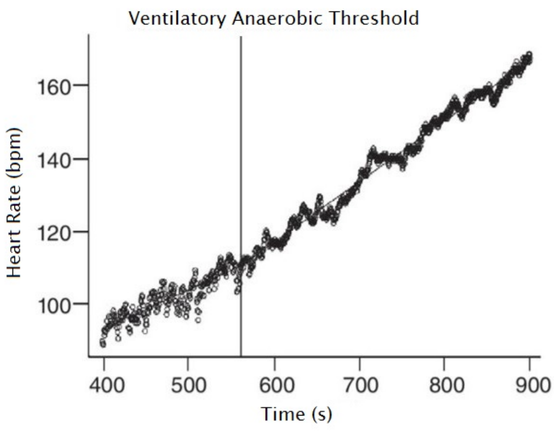

Figure I. Illustration of the heteroscedastic statistical model to HR data. The circles represent the behavior of HR, beat by beat, during CPET, as a function of time. The vertical line determines the point of change of HR and the time representing at the bottom of the graph, the time of occurrence of VAT was considered by this method. (Source: own author).

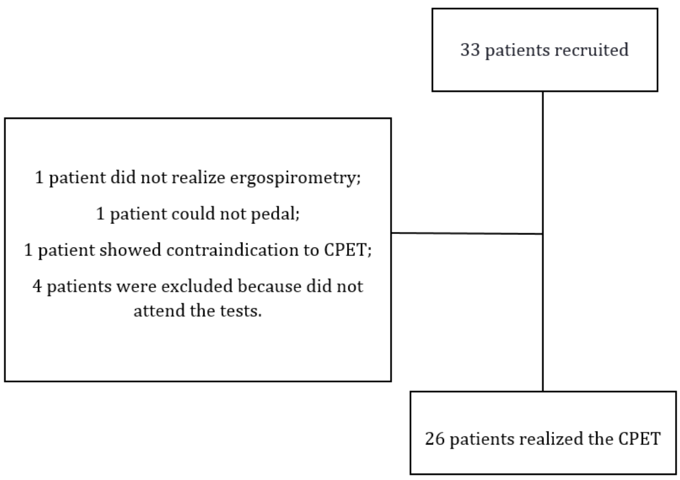

Figure II. Flowchart of recruitment and selection of study participants.

RESULTS

All individuals who met the previously established eligibility criteria were recruited to participate in the study. Over the course of five months, 33 patients were recruited for the project. However,[7] patients were excluded, remaining only 26 patients, duly analyzed, as can be seen in detail in the flowchart (Figure II). Anthropometric and clinical characteristics, risk factors for CVD and ventilatory variables of CPET were presented in Table I.

After evaluating the volunteers and analyzing the variables, we found that there was a statistical difference in the values of time (s), and HR (bpm) in the VAT identified by the heteroscedastic statistical model compared to the graphic visual method ($p <0.05$). Unlike the time and HR values, the VO_2 (mL/kg/min), VO_2 (L/min) and power values, where no significant differences were found.

Figure IV presents the results of the correlation analyzes between time (s), power (W), HR (bpm) and VO_2 (mL/kg/min) at the VAT level, determined by the graphic visual method and mathematical-statistical model. Regarding Pearson's correlation, strong associations were found ($p <0.05$). The Bland-Altman analysis revealed 99% agreement between the methods for the variables time (s), power (W), HR (bpm) and VO_2 (mL/kg/min).

DISCUSSION

The main findings of this study suggest that the heteroscedastic statistical model proved to be adequate in determining the VAT in a population of individuals with a risk factor for the development of CVD, as it did not show statistical difference and good agreement between the methods in the values of relative VO2, HR, time and power when compared to the visual graphic method.

Based on the responses of ventilatory and metabolic variables to incremental physical exercise, AT can be determined by the relationship between the behavior of the VAT and the VCO2, concerning the linear increase in VO2. VCO2 and VE increase linearly in relation to oxygen consumption to a certain point where additional increments of power determine an exponential increase in both VE and VCO2 concerning the linear increase in VO2. This situation is due to the excessive production of carbon dioxide from both oxidative metabolism and the dissociation of carbonic acid formed by the buffering of lactic acid, reflecting cellular metabolism[17, 18]. The point of change of these ventilatory variables characterizes the moment of the VAT, that is, the moment when the level of physical exercise above which the production of energy by the aerobic mechanism is supplemented by anaerobic mechanisms[10].

Another variable of great importance that is under the control of the sympathetic and parasympathetic nervous system is HR. The HR response obtained during different exercise protocols can provide important physiological information and becomes a reason for the great interest in identifying and relating the change in the response pattern of this variable in determining the VAT. Besides, the focus on HR behavior can be justified based on other considerations, such as, for example, HR is the cardiovascular variable that can be measured with the least methodological error (less than 1%)[19] and also because of its measurement is usually obtained with non-invasive methods and low-cost equipment. Conconi et al.[20], represent the pioneer study in investigating the change in cellular metabolism signaled by the HR response. These researchers resorted to this cardiorespiratory assessment indicator, as they consider HR to be a simple and easy to capture variable.

The authors report that the method is based on a linear relationship between HR and the intensity of physical effort up to a certain moment in the exercise, above which the linear relationship suffers a deflection, which according to these authors, would be the moment of occurrence of VAT. Although this pioneering study was questioned because of the difficulties found in the reproducibility of this model in some volunteers, it aroused interest in the field of research, and currently, it is possible to find in the literature several studies improving the methods of determining the VAT through the behavior of HR during physical exercise[12,21,22,23,24,25].

In order to improve knowledge about statistical models applied to HR behavior during physical exercise in determining VAT, Hoffman et al[26]. and Bunc et al.[22], applied a mathematical model of linear adjustment to the HR data collected during the incremental dynamic physical exercise test, which detected the point where the HR response lost linearity about the increase in power. The authors state that this breakpoint is strongly correlated with the VAT determined by the blood lactate concentration. Hoffman et al.[26] studying the HR response of sixteen women, refer that the correlation coefficients of the variables power (r = 0.923), VO2 (r = 0.974) and HR (r = 0.857) in the VAT determined by the two studied methodologies, were significant. Bunc et al.[22] report that the correlation of VO2 (r = 0.870) and HR (r = 0.857) in the VAT determined by the two studied methodologies were also significant. It is worth mentioning that, in these previous studies, the reference method in comparison with the statistical model for identifying the VAT was the analysis of lactacidemia. Although in the study developed by our group, the reference method was the visual graphic analysis of the behavior of ventilatory and metabolic variables, the results are in line with those observed by these two previous studies, with regard to the use of mathematical algorithms for the identification of the VAT, when compared with traditional methodologies.

Pozzi et al.[23] carried out a study with nine active elderly people, intending to determine the VAT using the graphic visual ventilatory method, using the statistical models Heteroscedastic and Hinkley, applied to the HR, RMS data sets of the myoelectric signal (Root Mean Square) and VCO2 and compare the VAT obtained by the three methods, during a continuous dynamic ramp test. After applying the statistical models and identifying the behavior breakpoints, the values of power, VO2 and HR were recorded at this time, compared and correlated to those obtained by the graphic visual method. The authors found no significant differences, about the graphic visual method, between the values of power, VO2 and HR, at the time of VAT identified by the different models. In addition, significant correlations were found between the HR values identified by the statistical models between the VO2 values when identified by the HR and power only when identified by the Hinkley model applied to the RMS data of the myoelectric signal. As in the present study, in the studied group, the statistical models proved to be sensitive in the non-invasive determination of VAT, both of which were better adjusted to HR data, followed by VCO2 and RMS.

In a study by Marães et al.[18], nine young people (22.3 ± 1.57 years) and nine middle-aged volunteers (43.2 ± 3.53 years), were submitted to three different protocols (continuous and discontinuous) of dynamic exercise tests on alternate days. The objective of the study was to characterize the HR patterns of healthy men using an autoregressive integrated moving average model (ARIMA) at a power level supposed to correspond to the VAT. The authors showed that the median working powers at which VAT occurred were similar for protocols I and II, that is, VAT occurred between 75W (116 bpm) and 85W (116 bpm) for the group of young individuals and between 60W (96 bpm) and 75W (107 bpm) for the group of middle aged individuals in protocols I and II, respectively. In two middle-aged volunteers, the VAT occurred at 90W (108 bpm) and 95W (111 bpm). Thus, the change in HR response using ARIMA models in power levels during submaximal dynamic exercise proved to be a promising approach to detect VAT in normal volunteers.

Unlike the study by Marães et al.[18], due to its particularities, the present study opted to use only an incremental ramp-type protocol for this study, to determine the VAT of individuals with a CVD risk factor. The incremental ramp CPET protocol uses load increments applied individually, that is, according to the functional capacity previously reported by the volunteer, thus allowing a more accurate measurement of the functional capacity and better visualization of the kinetics of the variables cardiorespiratory measures to determine the VAT.

In the study by Reis et al.[12], the authors had as primary objective to identify the VAT obtained from the V-slope method, as well as the visual inspection of the oxyhemoglobin (O2Hb) and deoxyhemoglobin (HHb) curves and to compare findings with the method heteroscedastic (HS) applied to the production of VCO2, FC, and HHb. As a secondary objective, the authors assessed the degree of agreement between the VAT determination methods. For this, fourteen healthy men underwent CPET in a cycle ergometer until physical exhaustion. The authors observed temporal equivalence and similar values of power (W), absolute and relative VO2 and HR at the VAT level by the detection methods performed. Besides, through the Bland-Altman analysis, the HR variable confirmed a good agreement between the methods. Thus, as in the present study, all detection methods were sensitive in determining the VAT, including the heteroscedastic statistical model applied to HR, and the methods also showed a good correlation in the identification of VAT.

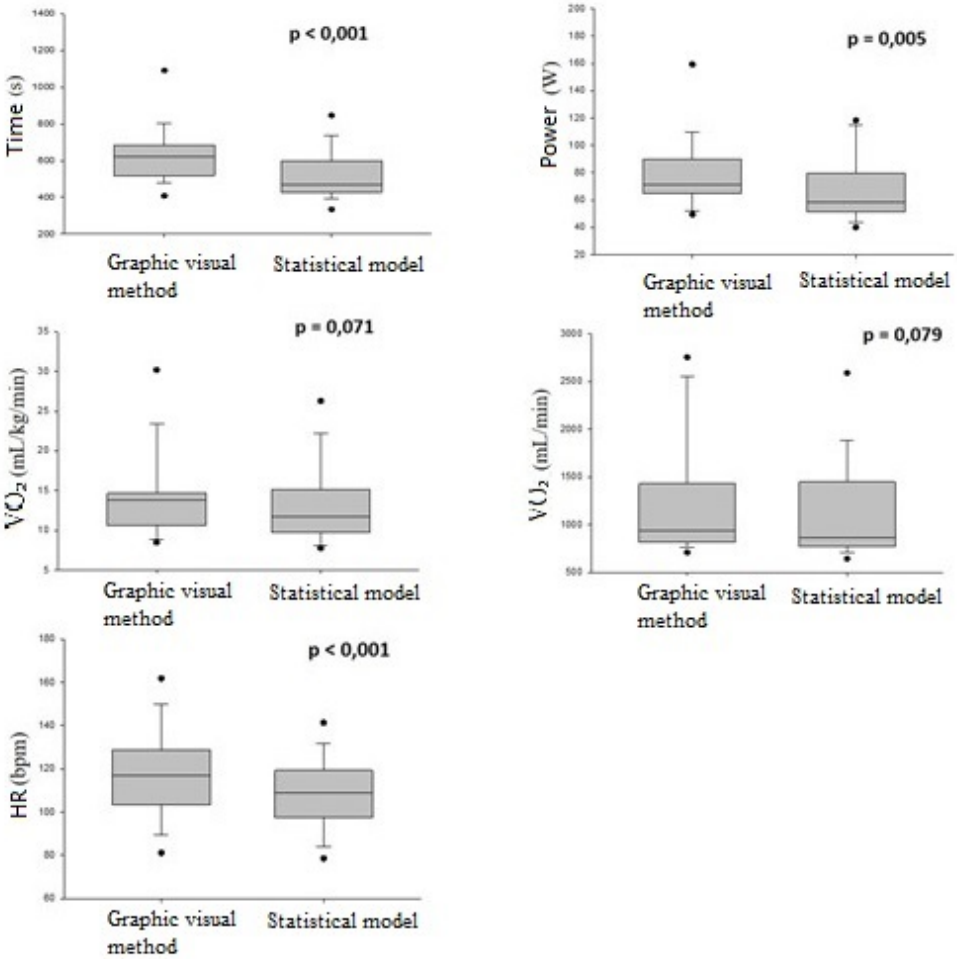

Figure III: Statistical analysis of the variables time (s), power (W), VO_2 (mL/kg/min), VO_2 (L/min) and HR (bpm) using the graphic visual method and heteroscedastic statistical model.

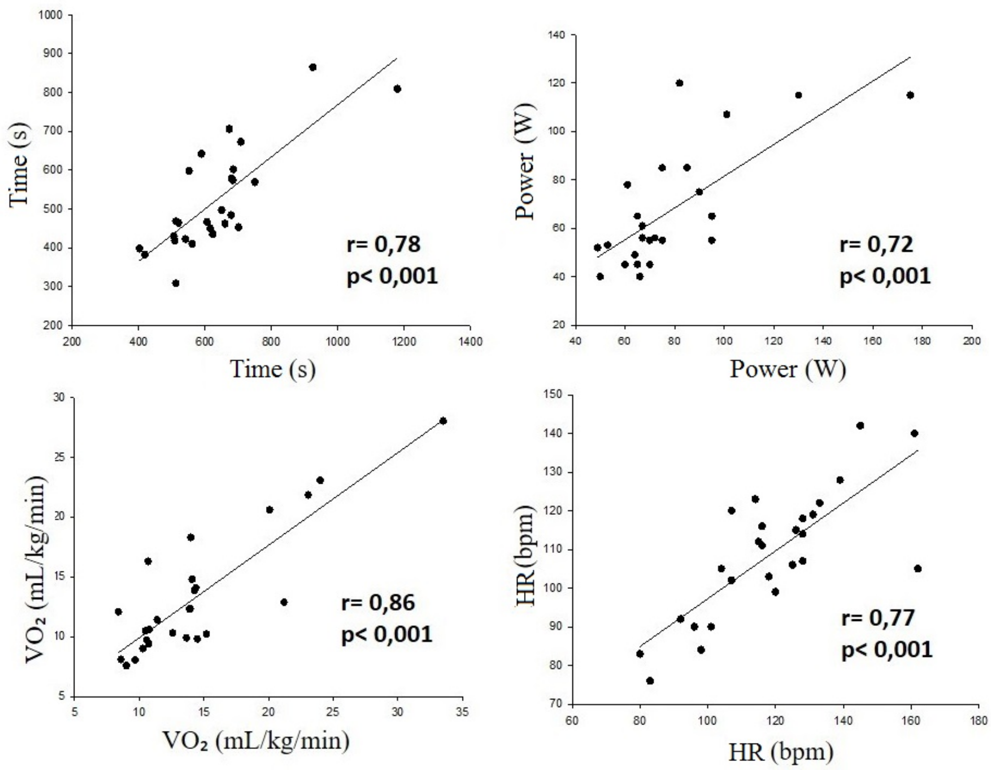

Figure IV: Pearson's correlation of the variables (A) time (s); (B) power (W); (C) oxygen consumption - VO_2 (mL / kg / min); and, (D) heart rate - HR (bpm) using the graphical visual method and heteroscedastic statistical model.

The limitation of our study was: 1) Some individuals did not want to perform ergospirometry; 2) Other individuals were unable to perform the exercise on the cycle ergometer; 3) The use of beta-blockers was another aspect that may have influenced the findings of our study (however, it is worth noting that the dose of the beta-blocker administered affects HR and aerobic capacity, considering that the supply of O2 is exactly impaired by the depressed HR response); 4) We admit that there was a selection of men and women, and that they have different functional capacity, however, we emphasize that our study aimed to improve the use of the heteroscedastic statistical model.

Thus, in the present study developed by our group, the HR response during physical exercise analyzed using the heteroscedastic statistical model, obtained values of the variables at the level of the VAT similar to the visual graphic method, suggesting that the HR can be an adequate variable in VAT identification.

CONCLUSION

We conclude that the relative and absolute VO_2, in addition to the power, showed temporal similarity in the determination of the VAT by the HR response and visual graphic method, with a strong correlation between the variables time, VO_2, HR and power in the determination methods. Finally, the determination of the VAT through the HR response seems to be an adequate model.

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