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COMPARISON OF METHODS FOR DETERMINATE THE HEART RATE VARIABILITY THRESHOLD IN INCREMENTAL TREADMILL TEST PROTOCOL

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Abstract.*The aim of this research is to compare methods to determine the aerobic threshold from the heart rate variability, with an incremental test protocol. These methods were applied in 8 runners and compared to others metodologies. Four methods were applied to determine the aerobic and anaerobic threshold: (1) the difference between two consecutive intervals of SD1 is less than 1 ms; (2) SD1 value falls below 3 ms; (3) the both methods applied together; (4) the proposal is to analysis the change in the behavior of the mean standard deviation of R-R intervals curves. In each case, different formats have been shown for the same data (SD1 and MSD), whereas the part of the techniques, a new approach has been proposed for determining the anaerobic threshold of subjects. The HRVT is a promising technique, which is increasingly efficient displays for determine other thresholds. More tests are needed for a definitive conclusion of its efficiency.*

Keywords: *heart rate variability, aerobic threshold, autonomous nervous system, incremental treadmill test protocol, heart rate.*

1. INTRODUCTION

The study of heart rate variability (HRV) is currently related to various applications like study of the autonomic nervous system, physiological and psychological phenomena, cardiovascular risk factors and exercise. The electrocardiogram is composed of P, Q, R, S and T waves which is the polarization and depolarization of the atria and ventricles. The heart rate variability is obtained from the RR interval sequence. With an external stimulus such as exercise, it is observed that the parasympathetic response is earlier and faster than precoce, but later it turns out that, according to the continuity of the activity and load increase, the sympathetic response predominates. The vagal modulation of heart rate usually goes away in 50-60 % of maximum O2 consumption. This is the point where the lactate accumulation can also be seen, causing an increase in ventilation and CO2 excretion (Karapetian *et al.*, 2008; Cambri *et al.*, 2008; Tulppo *et al.*, 1998).

To choose the form of analysis of heart rate variability to be used in a particular physiological condition, it should be considered the type of record that was accomplished. These may be short (5 to 30 minutes) or long term (24 hours) and conducted at rest or during a stimulus, such as respiratory manipulation or exercise. For linear analysis 256 R-R intervals are needed, while for the non-linear analysis is recommended a greater number, around 1000 R-R intervals (Cambri *et al.*, 2008; Marães, 2010; Bilchick and Berger, 2006).

The analysis in the time domain is the simplest and fast (Camm *et al.*, 1996), based on statistical calculations performed in the R-R interval series with regard to the variability of their heart rate. Among the analyzes available for temporal studies, there are some based on the intervals between beats as: average, standard deviation, median, extremes, lower and upper quartiles and difference between the maximum R-R interval and the minimum R-R interval. There are also analyzes based on comparisons of the time intervals between adjacent cycles, such as RMSSD, RMSM and pNN50 (Cambri *et al.*, 2008; Marães, 2010; Camm *et al.*, 1996).

The Poincarè plot is a nonlinear method widely used for the study of HRV. It can be analyzed visually or through mathematical approaches, observing the shape formed in 24 R-R intervals and quantitative analysis by curve fitting: SD1 is the instant record heart rate beat to beat; the SD2 represents the long-term record; while SD1/SD2 shows the ratio between short and long variations of R-R intervals (Tulppo *et al.*, 1998; Marães, 2010; Camm *et al.*, 1996).

1.1 Heart rate variability in exercises

Physical exercise is a behavior that causes significant changes in the functioning of the cardiovascular system and its mechanisms of autonomic adjustments. Thus, the study of HRV during exercise may allow an additional and non-invasive analysis of the neural control of the heart rate. Throughout the progressive test, HRV gradually decreases to about 50 % of the maximum load and, from that point, tends to stabilize. This should occur, possibly due to the intense relationship between reduced HRV and withdrawal of vagal influence on the sinoatrial node (Cambri *et al.*, 2008; Marães, 2010).

Alonso *et al.* (1998) and Lima and Kiss (2012) used different test protocols and several methods of identification showing this behavior of HRV during exercise. Although HRV declining since the early stages, it only reaches significant levels at 60 % of VO2 peak, stabilizing right after.

A major application of HRV in physical exercise is the possible determination of aerobic and anaerobic threshold. Traditionally, the anaerobic threshold is determined by detecting the increase in blood lactic acid concentration above a certain power exertion (lactate threshold), or by analyzing the concentrations of O2 and CO2 in the expired breath (respiratory thresholds). But with the study of the autonomic system during exercise, it was found that this could be a non-invasive and inexpensive technique to identify the anaerobic threshold. Bunc *et al.* (1995) and Marães (2010) showed that there is a non-linear increase in heart rate in relation to the applied power during exercise. Conconi *et al.* (1982) was a pioneer in determining heart rate nonlinearity, with physical incremental exercise protocol in more than four subjects.

1.2 Heart rate variability threshold

As well as the anaerobic threshold is being widely studied from the HRV, several other metabolic thresholds can be studied and identified by the threshold of heart rate variability (HRVT), such as lactate, ventilation and heart rate (HR) (Tulppo *et al.*, 1998; Alonso *et al.*, 1998; Lima and Kiss, 2012) . The HRVT can be considered an indicator of aerobic capacity, i.e. can be used as a physiological parameter in the exercise prescription (Cambri *et al.*, 2008).

Lima and Kiss (2012) studied the HRVT of several subjects in progressive test bikes and through the Poincarè plot, found significant results (Pearson correlation with r = 0, 76) in the comparison between HRVT and the lactate threshold when the SD1 is less than 3 ms, in the curve of HRV as a function of exercise intensity. Tulppo *et al.* (1998) found as the first stage of HRVT decreasing in the HRV as a function of the intensity curve, and the difference between two consecutive stages SD1 may not be greater than 1 ms. Some linear regression methods can also be used as criteria for determining HRVT, however, it is necessary adaptation of the methods for the study (Cambri *et al.*, 2008).

The great advantage in the measurement of HRV during exercise is the fact that it is determined by the balance between vagal and sympathetic activity of autonomic nervous system (ANS). Their analysis allows to quantify the ANS modulation in firing frequency of the sinoatrial node (Camm *et al.*, 1996). Thus, during exercise, as well as measurement of HR to evaluate the training, HRVT it can be used as a parameter for exercise prescription in healthy people or those with heart disease (Cambri *et al.*, 2008).

2. METODOLOGY

The sample consists of 8 young adults, male, healthy, physical exercise practitioners (Silva, 2012). For testing we used a ® Polar heart rate monitor that allows the recording of HRV and an ergo-spirometer (Truemax 2400 Metabolic Measurement System, Consentius Technologies) for respiratory threshold. For data analysis has been used its own software developed for analysis in C ++.

The incremental test protocol is based on the average speed at which the individual claims to run, and it starts the test with 70 % of express speed. From this, every 4 minutes the speed is increased by 1 km/h until exhaustion, with a 5 minute rest period before testing begins and a time for recovery right after exercise. The experimental procedure was approved by the ethics committee of the Faculty of Medicine, University of São Paulo (CAPPesq).

Some methods known in the literature can be used for the data analysis. Four methods are applied to determine the aerobic and anaerobic threshold: (1) difference between two consecutive intervals of SD1 is less than 1 ms; (2) SD1 value falls below 3 ms; (3) the both methods applied together; (4) change the behavior of the curve of the mean standard deviation of RR interval. The method (1) was proposed by Tulppo *et al.* (1998) and, following the same idea, Lima and Kiss (2012) proposed the (2) method. The third is both criterias applied together (Brunetto *et al.*, 2005) and the fourth is proposed by the authors as a new method to determine aerobic or anaerobic threshold.

Regardless the method, all samples were analyzed for 30 seconds preceding the speed change. This was used because a minimum number of values is required to perform the analysis and in that period the runner will be close to a steady state. To each sample, the percentage of volume of O2 (% VO2) that occurred the threshold was acquired and these values were compared with aerobic and anaerobic threshold stated in the medical report, approved by the doctors in the data collection team.

Although % VO2 is the most widely used, the purpose of this research work makes possible the use of other variables to better adapt the data. Therefore, besides the usual data, were used as the runner speed (km/h), volume of O2 (VO2) (ml/kg/min), logarithm of SD1 (log(ms)), SD2 log(ms) and logarithm of mean standard deviation (MSD) (log(ms)).

3. RESULTS

The anthropometric and functional characteristics of the subjects are presented in Tab. 1. Training time and speed are estimations made by the runners and only be applied for reference.

Table 1. Anthropometric and functional characteristics of the subjects

Age (years)	31.6± 9.8
Training time (times/week)	4.9± 1.0
Speed (min/km)	4.6± 0.4
$VO2_{max}$ (ml/kg/min)	52.1± 5.7

Figure 1 shows the behavior of SD1 throughout the exercise, applying different measurement data for the construction of graphics and show what the best kind of display for this application. In all graphics, was possible to note a tendency of their curves for all subjects. This analysis is important because in the literature are found different kinds of analyzes, such as presented, but in no case has been presents an analysis of what is the best to be displayed.

The Fig. 2 (a;b) shows the MSD behavior throughout the exercise and was applied to the method (4) analysis. It can be seen that both proceeding are almost the same, regardless of the amount of the variables. Figure 2 (c) shows the SD1 difference between the current value and the previous one. Differences greater than 1 ms shold be disregarded from the threshold analysis.

In Tab. 2 are presented the comparison between the methods (1), (2), (3), (4) and the aerobic / anaerobic threshold. All values were calculated individually and independently, used for comparison and identification of possible correlations between anaerobic and aerobic thresholds with the method graphic behavior.

Table 2. Comparison between the methods applied

	$\%VO2_{max}$
(1) HRVT (Tulppo et. al.)	76.0± 9.2
(2) HRVT (Lima e Kiss)	72.5± 6.5
(3) HRVT (both methods (1) and (2))	74.2± 7.9
(4) HRVT (MSD criteria)	87.4± 4.5
Aerobic Threshold	71.9± 5.8
Anaerobic Threshold	89.4± 4.0

4. DISCUSSION

This study presents several forms of analysis and comparison with the literature methods (Tulppo *et al.*, 1998; Lima and Kiss, 2012; Brunetto *et al.*, 2005). These methods are applied in most recent studies of HRV and especially when the focus is HRVT functional capacity test. To this end, it is common to determine only the aerobic and anaerobic threshold of the patient when he enters the maximum effort condition during exercise, but there may be a strong relationship between the threshold values and HRV.

At first sight, it was proposed different ways to assess the SD1's behavior throughout the exercise. Among them, the most common is the SD1 or its logarithm by % VO2max, which on average had almost a decreasing linear distribution. Despite being the most widely used proposal, often the data is interpolated for specific % VO2max values (such as 30-90 %), actually they are not the values that the subjects were. It is possible that this interpolation does not allow the best visualization of the behavior of the curves in the graphs. Instead, the plot of the actual values enables to check the behavior of individual subjects and their influence on the total sample.

Another point to be discussed is whether the % VO2max really is the best choice, because the active VO2 or the speed

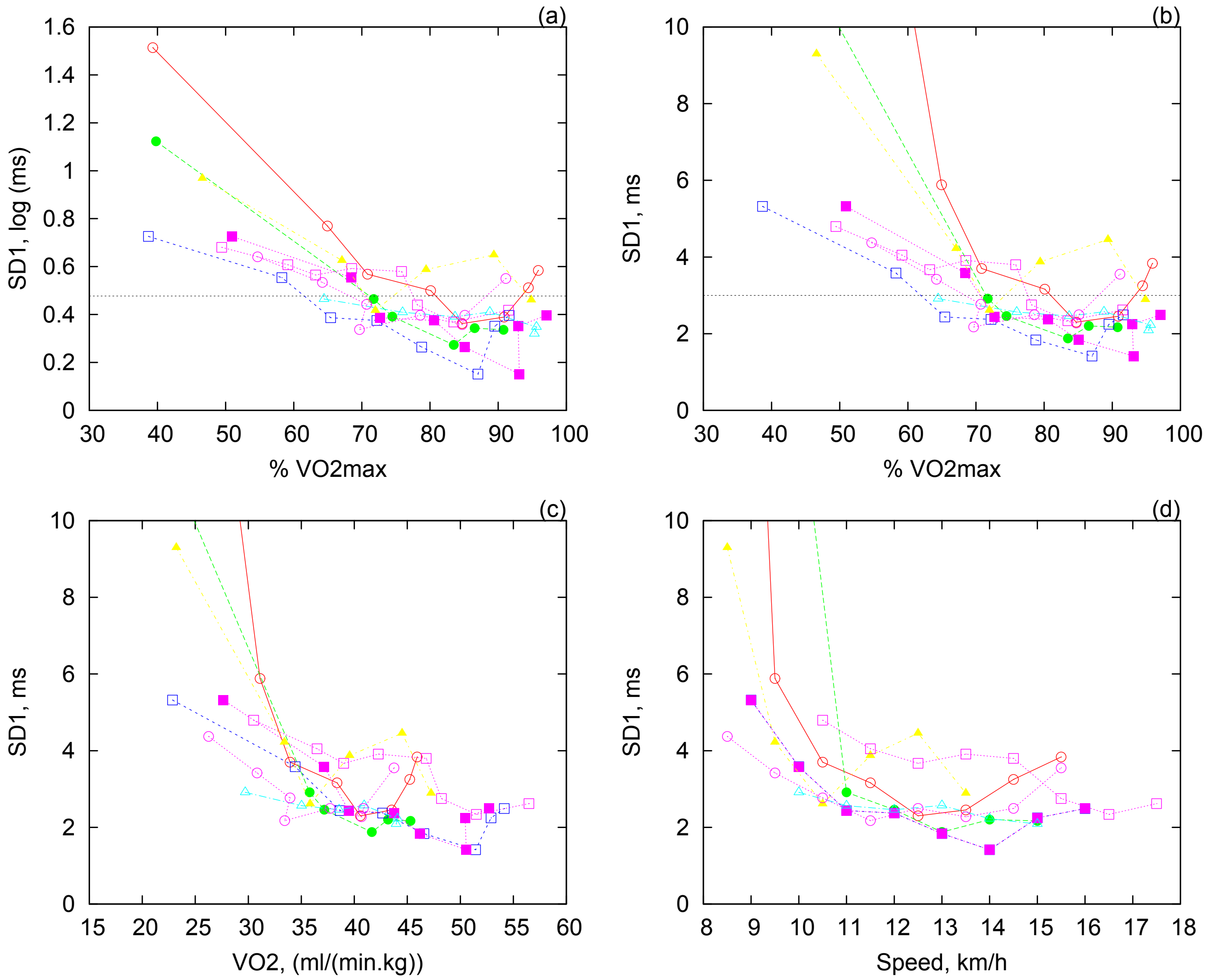

Figure 1. SD1 behavior throughout the exercise, represented by the % VO2 (a;b), VO2 (c) and speed (d) for the 8 runners. The line indicates 3 ms, applied to the (2) method.

(in the test case on a treadmill) may be a good representation for the case. In the VO2, there is a large concentration points 35-45 (ml/kg/min), which suggests that for a good part of the test subjects remain at this value until a small amount to increase or exercise cease. So it does not seem to be the best choice for analysis, as it is very difficult to clear visualization of values. However, for the analysis of speed proved to be an easy distribution of interpretation and very clear where it's occurring every case. This is a very viable option, as well as item (a) of Fig. 1.

The next analysis is to be done of methods of analysis of HRV presented in literature. The method proposed by the authors suggests that HRV threshold can be checked when a variation occurs in the curve tendency in Fig. 2 (a, b). This variation indicates that after a while the sample standard deviation is greatly increased compared to its previous value, which suggests the occurrence of a threshold (aerobic or anaerobic).

For the methods (1), (2) and (3), the aim is to show a relationship between the aerobic threshold and methods. To this end a comparison is necessary, being shown in Tab. 2. In it can be seen that to the top three methods there is a close correlation of aerobic threshold. These values, despite having a considerable standard deviation is lower than those found by Brunetto *et al.* (2005). If you can perform an association between this method and the aerobic threshold, functional capacity tests may be more simple, to the point that only a heart rate will be required for this analysis.

In the fourth method, a very good correlation can be verified. The values presented in Tab. 2 show that the values are very close to the anaerobic threshold of the subject, which in clinical analysis may indicate the best technique to be applied for each person. However, more tests are needed so that it can be said that the determination of the threshold can be made only through the HRV, without the need of data from the spirometer or even the blood lactate.

5. CONCLUSION

In this paper several forms of assessments of HRV and HRVT were studied. Methodologies already used in the literature were compared regarding the format are displayed and the techniques used to determine the threshold of heart

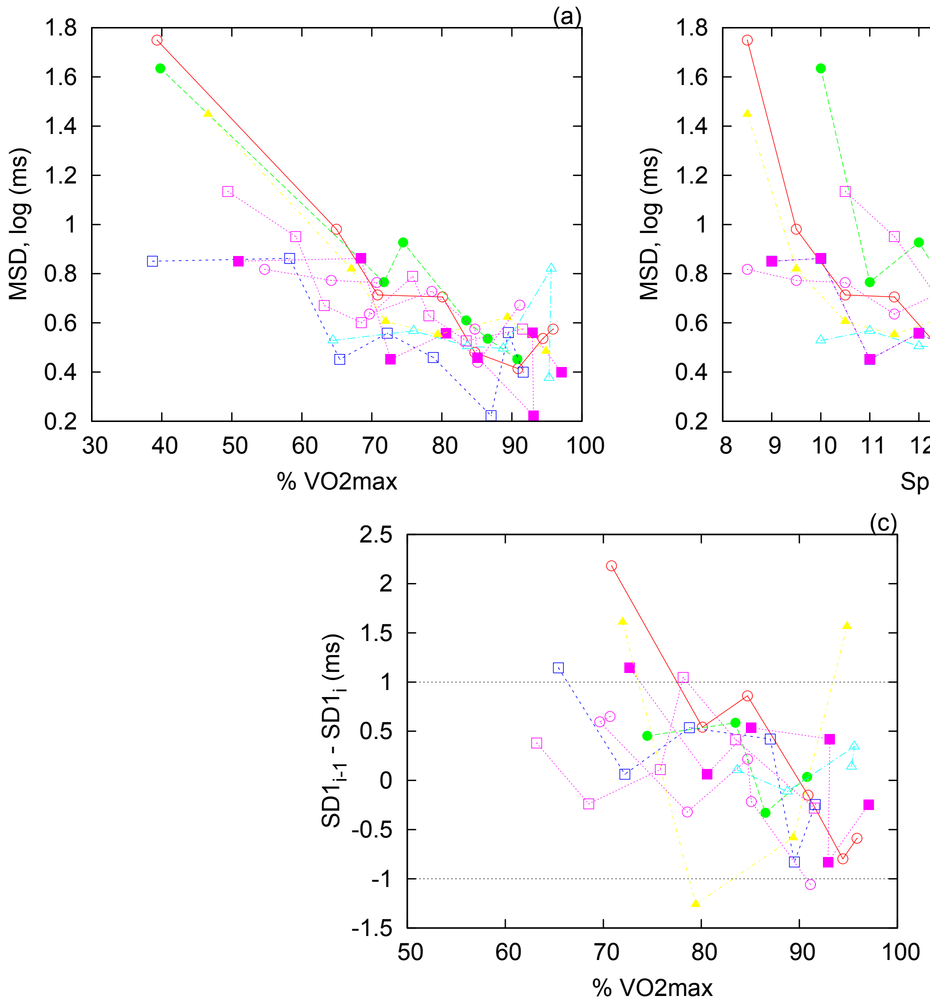

Figure 2. MSD behavior throughout the exercise, to the % VO2 (a) and speed (b) to the method (4). Plot (c) shows the application of the method (1).

rate variability. In each case, different formats have been shown for the same data (SD1 and MSD), whereas the part of the techniques, a new approach has been proposed for determining the anaerobic threshold of subjects. Although these methods are not really proved as effective in the literature for assessment of thresholds, gradually it approachs the aerobic threshold values (method (2) mainly) and the anaerobic threshold (method (4)). Tests with a larger group, it should be possible to characterize most notable correlations and its needed for a definitive conclusion of its efficiency. The HRVT is a promising technique, which is increasingly efficient displays to determine other thresholds.

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