Identification of anaerobic threshold using heart rate response during dynamic exercise

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Abstract

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The objective of the present study was to characterize the heart rate (HR) patterns of healthy males using the autoregressive integrated moving average (ARIMA) model over a power range assumed to correspond to the anaerobic threshold (AT) during discontinuous dynamic exercise tests (DDET). Nine young (22.3 ± 1.57 years) and 9 middle-aged (MA) volunteers (43.2 ± 3.53 years) performed three DDET on a cycle ergometer. Protocol I: DDET in steps with progressive power increases of 10 W; protocol II: DDET using the same power values as protocol 1, but applied randomly; protocol III: continuous dynamic exercise protocol with ventilatory and metabolic measurements (10 W/min ramp power), for the measurement of ventilatory AT. HR was recorded and stored beat-to-beat during DDET, and analyzed using the ARIMA (protocols I and II). The DDET experiments showed that the median physical exercise workloads at which AT occurred were similar for protocols I and II, i.e., AT occurred between 75 W (116 bpm) and 85 W (116 bpm) for the young group and between 60 W (96 bpm) and 75 W (107 bpm) for group MA in protocols I and II, respectively; in two MA volunteers the ventilatory AT occurred at 90 W (108 bpm) and 95 W (111 bpm). This corresponded to the same power values of the positive trend in HR responses. The change in HR response using ARIMA models at submaximal dynamic exercise powers proved to be a promising approach for detecting AT in normal volunteers.

During the performance of dynamic exercise (DE) there is a point above a given power value when the production of lactic acid is greater than the capacity for its utilization by body tissues: this corresponds to the so-called anaerobic threshold (AT) (1-3). The accurate identification of AT is of great importance because this parameter allows the evaluation of aerobic performance at submaximal powers (4). Several techniques

have been developed to detect the AT (5,6). Recently, some studies have been performed to demonstrate the importance of the heart rate (HR) response for the measurement of AT (3,7). Among the advantages of these procedures, it should be emphasized that HR is a physiological variable that can be recorded non-invasively with a small methodological error using inexpensive equipment.

At the beginning of DE, during the initial 10-20 s, tachycardia is due to the withdrawal of vagal tonus acting on the sinus node. At low workloads, this is the only significant mechanism responsible for the increase in HR induced by DE. By using discontinuous DE protocols (step test), a full stabilization of the HR response can be observed after 2 min of DE. At medium and high powers, sympathetic stimulation of the sinus node is responsible for the appearance of a slow tachycardia from 1 to 4 min of DE. In this situation the HR response does not attain a steady-state condition (8-11). An important finding related to the autonomic control of HR during DE is the observation that the sympathetic contribution of exercise tachycardia appears above the AT (4). Thus, the loss of HR stabilization and changes in the variability of this parameter have been evaluated in our laboratory using standardized DE protocols as possible markers of AT in normal subjects (3).

The objective of the present study is to characterize the HR patterns of healthy males using the autoregressive integrated moving average (ARIMA) model over a power range

assumed to correspond to the AT during discontinuous DE tests (DDET).

The study was conducted on 18 male volunteers. Two different age groups were compared: 9 young (22.3 ± 1.57 years) and 9 middle-aged volunteers (43.2 ± 3.53 years). Their physical characteristics, HR and blood pressure at rest are shown on Table 1. All volunteers were in good health as determined by clinical and physical examination and by laboratory tests that included a standard electrocardiogram (ECG), maximum exercise test, total blood count, urinalysis, and clinical biochemical screening tests (glucose, uric acid, total cholesterol and fractions (LDL, HDL and VLDL), and triglycerides). The volunteers had an active life pattern, i.e., they performed physical exercises 3 h per week.

The volunteers were informed about the experimental protocols and their objectives and signed a formal consent form as required by the local Ethics Committee who approved the study (405/97).

The experiments were carried out in a climatically controlled room at 22ºC and 60% humidity, always at the same time of day in order to avoid different response due to circadian changes. The volunteers were studied during three dynamic exercise tests in the seated position on a calibrated cycle ergometer using discontinuous (protocols I and II) and continuous (protocol III) protocols on different days separated by 2-5-day intervals. A brake electromagnetic cycle ergometer equipped with a microprocessor (model Corival 400, Quinton, Seattle, WA, USA) facilitated the precise application of individualized power values. During the exercises (protocols) the volunteers pedaled at a rate of 60 rpm. The purpose of protocols II and I was to signal AT through the HR response and the purpose of protocol III was to measure ventilatory AT.

Protocol I. The initial power value was 25 W, followed by discontinuous steps with progressive power increments of 10 W of 6-

Table 1. Physical characteristics, heart rate and blood pressure of the volunteer subjects studied.

Variable	Young (N = 9)	Middle-aged (N = 9)
Age (years)	22.3 ± 1.57	43.2 ± 3.53*
Height (cm)	177 ± 6.93	172 ± 0.06
Weight (kg)	72 ± 12.57	76.8 ± 7.36
Body mass index (kg/m^2)	22.3 ± 3.5	25.4 ± 2.39
Systolic blood pressure (mmHg)	113 ± 5.29	115 ± 4.72
Diastolic blood pressure (mmHg)	76 ± 6.14	77 ± 10.55
Heart rate (bpm)	64 ± 5.69	63 ± 2.93

Data are reported as means ± SD. *P < 0.05 compared to young subjects (*t*-test).

min duration, until a tendency to inclination of HR data was observed.

Protocol II. The same power values as protocol I were used, but were randomly applied.

During protocols I and II, varying resting periods were allowed between the different powers, permitting HR to return to control levels. The volunteers were monitored at the CM5 lead at rest and during exercise. The ECG and HR were obtained from a channel heart monitor (ECAFIX TC500, ECAFIX Ind. e Com. Ltda., São Paulo, SP, Brazil) and processed using an analog-digital converter La. PC+ (National Instruments, Co., Austin, TX, USA), representing an interface between the heart monitor and a Pentium II microcomputer. Starting from the identification of "R" peaks of the ECG waves, the R-R intervals were calculated on a beat-to-beat basis from the ECG using signal-processing software (12). Recordings were obtained for 1 min prior to each exercise level throughout the 6-min dynamic exercise (protocols I and II), and for 1 min during the recovery period. Subsequently, the HR was adjusted using temporal series methodology (13) with ARIMA. Finally, the procedure included the search for a specific workload at which the series showed a tendency towards inclination.

Protocol III. Only two middle-aged volunteers performed protocol III involving the continuous DE test and oxygen uptake test. The volunteers performed an oxygen uptake test using a progressive incremental exercise protocol, which consisted of a 3-min warm-up period at 4 W followed by a continuous power increase set at a value of 10 W/min up to physical exhaustion. During the performance of protocol III the volunteers breathed through a low-resistance valve (Hans Rudolph 2900 device, Kansas City, MO, USA) with a small dead space; their metabolic and ventilatory variables and parameters were calculated using a specific metabolic analyzer (MMC Horizon System, Sensormedics, Yorba Linda, CA, USA) supplying average values at 15-s inter-

vals. The individual values of minute ventilation ($\dot{V}E$), CO_2 production ($\dot{V}CO_2$) and oxygen uptake ($\dot{V}O_2$) at each power were plotted as a function of time. In this protocol the ventilatory AT was measured when $\dot{V}E$ and $\dot{V}CO_2$ began to increase non-linearly as compared to $\dot{V}O_2$ (visual analysis) (1).

The results are reported as medians, quartiles (1st and 3rd quartiles) and minimum and maximum values using Tukey's box-plot. Due to the non-Gaussian distribution and/or non-homogeneity of variance of the data, nonparametric tests were selected for statistical analysis. The Wilcoxon and Mann-Whitney nonparametric tests were used for intra-group and inter-group comparisons, respectively, with the level of significance set at 5%.

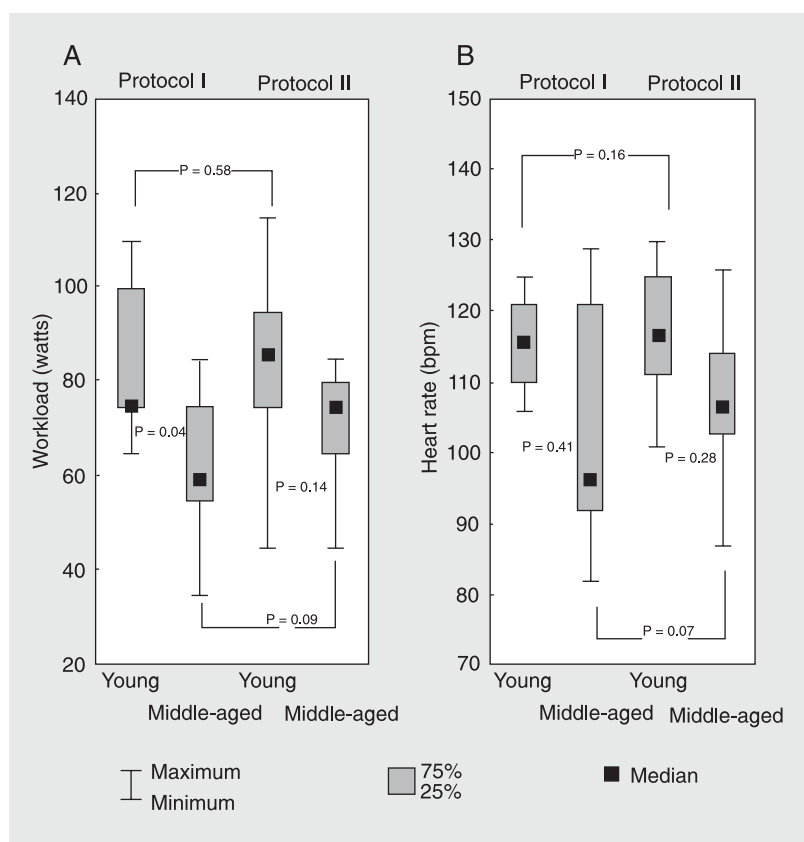Figure 1A shows that the workload values (W) at the AT level determined by the

Figure 1. *A*, Workload values, and *B*, heart rate at which the assumed anaerobic threshold (AT) of the young and middle-aged volunteer groups, respectively, occurred during a discontinuous dynamic exercise test (protocols I and II). $\alpha = 0.05$.

ARIMA model of adjustment to the HR data set during DDET (protocols I and II) were similar for both protocols (P > 0.05). However, when the groups studied were compared, significant differences were only observed in protocol I.

Figure 1B shows that there were no statistically significant differences in HR values at the AT level (P > 0.05) between groups and protocols (I and II).

In two middle-aged volunteers the ventilatory AT occurred at 90 W (HR = 108 bpm) and 95 W (HR = 111 bpm), corresponding to the same power values at which the positive trend in HR response was observed, i.e., AT.

The AT is an important parameter signaling a person's physical condition. It corresponds to a point above a determined power value when the production of lactic acid is greater than the capacity of its utilization by body tissues (1,14). AT shows a good correlation with $\dot{V}O_{2max}$ and has been proven to be very useful in quantifying oxygen transport and its modifications following physiological and pathological conditions (1,14). Several methods can be used to detect AT, including blood lactic acid sampling (invasive) (15) and changes in the response pattern of the ventilatory curves during continuous and incremental (non-invasive) dynamic physical exercise (1). Another method used to determine AT is the study of the HR response to DE. HR becomes non-linear at a workload equal to AT (3,16,17). Linnarsson (18) evaluated in detail the HR response to DE in healthy subjects. The HR response was subdivided into 3 phases; 1) from 10 to 15 s after the beginning of exercise, when a fast increase in HR due to the removal of vagal tonus of the heart was observed independently of the applied workload; 2) a slow increase in HR between 60 and 90 s of exercise, and 3) a very slow, almost linear, increase lasting throughout exercise, and depending on the intensity of the physical exercise, on the sympathetic stimulation of the heart, and on AT (16,17). However, we

decided to use mathematical and statistical analyses to determine AT using ARIMA (13) to signal the HR response. Box and Jenkins (13) proposed the use of time series of ARIMA models to analyze the standard response changes with the loss of their stability. Taking this into account, the set of HR data during the DDET can be seen as a time series composed of a *y* variable observation set taken from equally timed intervals. The methodology of Box and Jenkins (13), ARIMA, was used to signal the moment when HR showed a tendency (inclination) to increase. According to studies carried out under beta-adrenergic blockade (10), this increase is caused by stimulation of the sympathetic nervous system. Our results are similar to those reported by Marães et al. (3) in a study of DDET in a progressive power range with 6 min at each workload on 12 healthy middle-aged male volunteers using the same type of cycle ergometer and the same method of analysis, i.e., ARIMA. The HR response pattern increased at 60 W for middle-aged volunteers. These results agree with those reported by Petto et al. (17) who observed a change in HR pattern when using ARIMA, and also a higher decrease in HR variability. In a study on post-menopausal women using DDET, Ribeiro et al. (19) observed a loss of HR stability and a decrease in HR variability due to the prevalence of sympathetic activity on the sinus node. The inter-group differences in AT level are due to aging that markedly influences the cardiovascular system, promoting structural and functional changes (14). Takahashi et al. (20), studying cardiac patients without the use of betablockers during physical exercise and with a discontinuous protocol, verified that by the adjustment of the semiparametric mathematical model to the HR data, the AT was identified at the power of 37.5 W and at HR of 100 bpm. We point out that changes in AT values are induced by aging. The absolute median AT values, expressed as W, of our young volunteers were higher than those of

the middle-aged group, as also reported elsewhere (3,17).

Another important factor to be considered in the present study is that the ventilatory AT, obtained in two random cases, was very close to the ventilatory AT determined by ARIMA. Therefore, AT determination by ARIMA proved to be a promising methodology in view of its good performance compared to that of the standard method of ventilatory AT determination. However, a larger number of volunteers should be studied in order to determine the equivalence of AT determined by the methodologies mentioned with a higher degree of confidence.

The change in HR response using ARIMA models at submaximal DE powers appears to be a promising approach for determining AT in normal volunteers.

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