Brazilian Journal of Medical and Biological Research (2005) 38: 731-735
ISSN 0100-879X Short Communication

Identification of anaerobic threshold using heart rate response during dynamic exercise

V.R.F.S. Marães[1,2],
E. Silva[1,3], A.M. Catai[1],
L.D. Novais[1],
M.A.S. Moura[4],
L. Oliveira[5] and L. Gallo Jr.[6]

[1]Núcleo de Pesquisa em Exercício Físico, Departamento de Fisioterapia,
Universidade Federal de São Carlos, São Carlos, SP, Brasil
[2]Curso de Fisioterapia, Centro Universitário de Anápolis, UniEvangélica,
Anápolis, GO, Brasil
[3]Laboratório de Fisioterapia Cardiovascular e de Provas Funcionais,
Faculdade de Ciências da Saúde, Universidade Metodista, Piracicaba, SP, Brasil
[4]Departamento de Estatística, [5]Departamento de Física,
Universidade Federal de São Carlos, São Carlos, SP, Brasil
[6]Divisão de Cardiologia, Departamento de Clínica Médica,
Hospital das Clínicas, Faculdade de Medicina de Ribeirão Preto,
Universidade de São Paulo, Ribeirão Preto, SP, Brasil

Correspondence
L. Gallo Jr.
Divisão de Cardiologia
Departamento de Clínica Médica
FMRP, USP
Av. Bandeirantes, 3900
14049-900 Ribeirão Preto, SP
Brasil
Fax: +55-16-633-1144
E-mail: vrmaraes@yahoo.com.br

Presented at the XIX Annual Meeting of the Federação de Sociedades de Biologia Experimental, Águas de Lindóia, SP, Brazil, August 25-29, 2004.

Research supported by FAPESP, CNPq and CAPES.

Received April 15, 2004
Accepted March 9, 2005

Abstract

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.

Key words
- Heart rate
- Anaerobic threshold
- Dynamic physical exercise
- Autonomic nervous system
- Healthy male 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).

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).

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-

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 intervals. 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

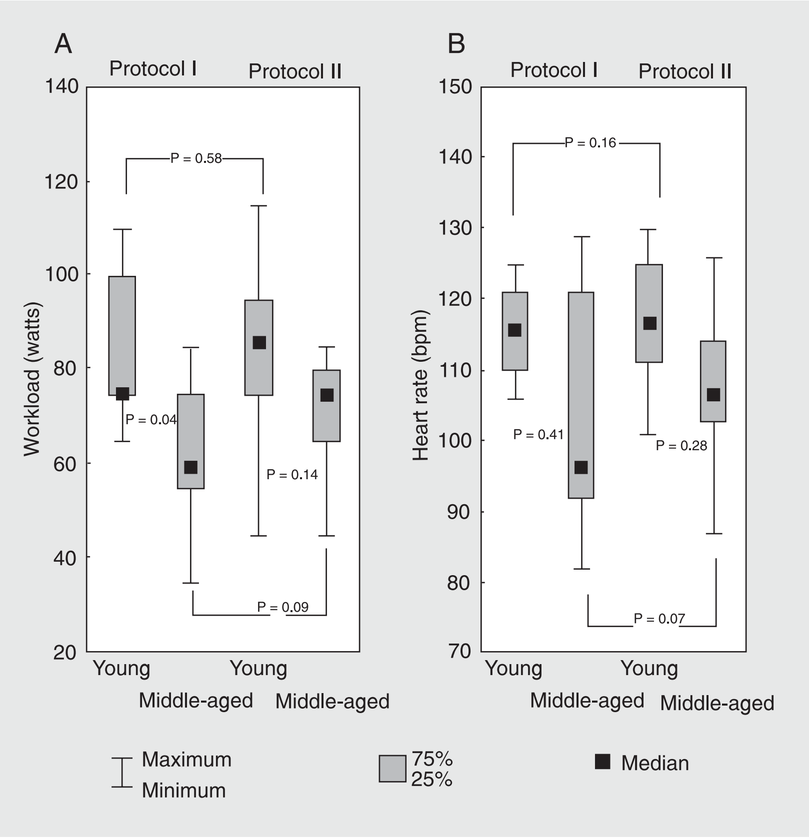

Figure 1. *A*, Workload values, and *B*, heart rate at which the assumed anaerobic threshold (AT) of the young and middle-aged volunteer groups, respectively, occurred during a discontinuous dynamic exercise test (protocols I and II). $\alpha = 0.05$.

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.

References

1. Wasserman K, Hansen JE, Sue D, Whipp BJ & Casaburi R (1999). *Principles of Exercise Testing and Interpretation*. 3rd edn. Lea & Febiger, Philadelphia, PA, USA.
2. Ekkekakis P, Hall EE & Petruzzello S (2004). Practical markers of the transition from aerobic to anaerobic metabolism during exercise: rationale and a case for affect-based exercise prescription. *Preventive Medicine*, 38: 149-159.
3. Marães VRFS, Teixeira LCA, Gallo Jr L, Catai AM, Oliveira L, Milan LA, Rojas FR & Silva E (2003). Determinação e validação do limiar de anaerobiose a partir de métodos de análise da freqüência cardíaca e de sua variabilidade. *Revista da Sociedade de Cardiologia do Estado de São Paulo*, 13 (Suppl 4): 1-16.
4. Gallo Jr L, Maciel BC, Marin Neto JA, Martins LEB, Lima Filho EC, Golfetti R, Chacon MPT & Forti VAM (1995). Control of heart rate during exercise in health and disease. *Brazilian Journal of Medical and Biological Research*, 28: 11-12.
5. Myers J & Ashley E (1997). A perspective on exercise, lactate and the anaerobic threshold. *Chest*, 111: 787-795.
6. Jammes Y, Caquelard F & Badier M (1998). Correlation between surface electromyogram, oxygen uptake and blood lactate concentration during dynamic leg exercises. *Respiration Physiology*, 11: 167-174.
7. Conconi F, Grazzi G, Casoni I et al. (1996). The Conconi test: methodology after 12 years of application. *International Journal of Sports Medicine*, 17: 509-519.
8. Maciel BC, Gallo Jr L, Marin-Neto JA, Lima Filho EC & Martins LEB (1986). Autonomic nervous control of the heart rate during dynamic exercise in normal man. *Clinical Science*, 71: 457-460.
9. Silva E (1988). Modelos matemáticos da resposta da freqüência cardíaca ao exercício físico dinâmico em indivíduos normais. Master's thesis, Universidade Estadual de Campinas, Campinas, SP, Brazil.
10. Gallo Jr L, Morelo Filho J, Maciel BC, Marin Neto JA, Martins LEB & Lima Filho EC (1987). Functional evaluation of sympathetic and parasympathetic system in Chagas' disease using dynamic exercise. *Cardiovascular Research*, 21: 922-927.
11. Catai AM (1992). Adaptações cárdio-respiratórias em atletas: estudo em diferentes fases do treinamento físico. Master's thesis, Faculdade de Educação Física, Unicamp, Campinas, SP, Brazil.
12. Silva E, Catai AM, Trevelin LC, Guimarães JO, Silva Jr LP, Silva LMP, Oliveira L, Milan LA, Martins LEB & Gallo Jr L (1995). Design of a computerized system to evaluate the cardiac function during dynamic exercise. *Annals of the World Congress on Medical, Physical and Biomedical Engineering*, 1: 409 (Abstract).
13. Box GEP & Jenkins GM (1970). *Time Series Analysis*. Holden-Day, San Francisco, CA, USA.
14. Chacon-Mikahil MPT, Forti VAM, Catai AM et al. (1998). Cardiorespiratory adaptations induced by aerobic training in middle-aged men: the importance of a decrease in sympathetic stimulation for the contribution of dynamic exercise tachycardia. *Brazilian Journal of Medical and Biological Research*, 31: 705-712.
15. Brooks GA (1991). Current concepts in lactate exchange. *Medicine and Science in Sports and Exercise*, 23: 895-906.
16. Alonso DdeO, Forjaz CL, Rezende LO, Braga AM, Barretto AC, Negrão CE & Rondon MU (1998). Heart rate response and its variability during different phases of maximal graded exercise. *Arquivos Brasileiros de Cardiologia*, 71: 787-792.
17. Petto J, Ribeiro TF, Gomes VR et al. (1999). Determinação do limiar de anaerobiose (LA) pela variabilidade da freqüência cardíaca (VFC), utilizando-se o modelo autorregressivo integrado médias móveis. *Revista da Sociedade de Cardiologia do Estado de São Paulo*, 9: 33 (Abstract).
18. Linnarsson D (1974). Dynamics of pulmonary gas exchange and the heart rate changes at start and end of exercise. *Acta Physiologica Scandinavica*, 415 (Suppl): 1-68.
19. Ribeiro TF, Gomes VR, Moura MAS et al. (1998). Estudo do limiar de anaerobiose em mulheres sedentárias durante esforço físico dinâmico. *Anais da XIII Reunião da Federação de Sociedades de Biologia Experimental*, August 26-29, 258 (Abstract).
20. Takahashi ACM, Novais LD, Iwai Sakabe D, Salvino FMS, Oliveira L, Milan AL, Silva E & Catai AM (2004). Análise da freqüência cardíaca e sua variabilidade no limiar de anaerobiose de homens de meia idade saudáveis e coronariopatas. *Anais da XIX Reunião da Federação de Sociedades de Biologia Experimental*, August 25-29, 04.095 (Abstract).