CHRONOTROPIC RESPONSE TO MAXIMAL ANAEROBIC RUNNING TEST - MART

EXERCISE AND SPORTS MEDICINE CLINIC

ORIGINAL ARTICLE

Flávio Areal Lemos[1,2]
Tony Meireles Santos[1,2,3]

1. Stricto Sensu Post-Graduation Program in Exercise and Sports Science of the Gama Filho University (UGF) – Rio de Janeiro, RJ, Brazil.
2. Research Group Performance – UGF.
3. Department of Physical Education, Federal University of Pernambuco (UFPE) - Recife, PE, Brazil.

Mailing address:
Tony Meireles dos Santos.
Laboratório *Performance*
Universidade Federal de Pernambuco (UFPE) - Campus Recife
Departamento de Educação Física
Avenida Jornalista Anibal Fernandes, s/n
CEP: 50670-901
E-mail: tony.meireles@ufpe.br, tonyms@prohealth.com.br

ABSTRACT

Introduction: Heart rate (HR) in maximal anaerobic running test (MART) expresses the cardiac autonomic behavior in exercise. It has not been investigated whether such responses are associated with chronotropic aerobic and anaerobic performance. Objective: To describe the cardiac chronotropic response during the MART in seconds of stimulation (HR_{ON}) and recovery (HR_{OFF}), and establish the association between chronotropic variables with aerobic and anaerobic performance. Methods: Thirteen male volunteers were asymptomatic and physically active, with 25.1 ± 4.9 years, 76.8 ± 12.5 kg, 178.4 cm and 50.6 ± 9.0 ± 4.1 $mL \times kg^{-1} \times min^{-1}$. On the first visit after the interview and anthropometric measurements, we performed a cardiopulmonary exercise testing (CPET) with direct monitoring of expired gases. The second visit was carried to familiarize the MART and the third, the test was performed until exhaustion MART. Results: Heart rate recovery (58 ± 20 bpm) compared to the peak HR achieved in the first and last stage of MART (39 ± 14 bpm) had a higher slope, resulting in greater range of variation over the test, characterizing differences ($P = 0.0017$). The HR_{ON} presented between the time the initial, middle and end of the MART significant differences (start *versus* final, $p = 0.007$). To HR_{OFF} significant differences were found starting with the middle ($p = 0.035$) and the starting to the final ($p = 0.005$) test. The chronotropic correlations between variables, including decrease in HR, and TCPE performance were not statistically significant ($P < 0.05$), as nor as the performance variables. Conclusion: The MART model seems to be a physiological overload suitable for investigation of cardiac autonomic modulation. There was action of the parasympathetic system even in supramaximal loads by the end of the test.

Keywords: heart rate, vagal reflex, cardiac vagal modulation, sprint interval exercise, autonomic nervous system.

INTRODUCTION

Increasing clinical interest in protocols of intermittent effort has been observed lately[1-3]. In that test modality, there is higher possibility to investigate the alterations in the cardiac autonomic modulation, especially the immediate responses of heart rate (HR) at the beginning of exercise (HR_{ON}) and at the beginning of recovery (HR_{OFF})[4,5].

Intermittent activities of high intensity and low duration on inclination produce increase of the recruiting of the knee extensor muscles [6] and of the accumulation of metabolites. Such alterations contribute in the delay of the HR recovery after effort (HR_{REC}), indirectly representing the response in the cardiac autonomic modulation[3,7,8]. In one of these studies, Nakamura *et al.*[7] used two intermittent protocols with handball players and found significant differences in the indices of HR variability. Moreover, Ostojic *et al.*[9] observed more remarkable decrease of HR_{REC} in 10 seconds and 20 seconds after maximum exercise in athletes of intermittent modalities compared with endurance athletes.

The maximal anaerobic running test (MART), proposed by Rusko *et al.*[10], presents a 1:5 ratio of stimulus (20 s) *versus* recovery (100 s) with supramaximal progressive characteristic. In the last years, this protocol has been used in the determination of maximal anaerobic power and running neuromuscular competence[11-13]. Although its original configuration does not contemplate the HR response, its outlining seems to be suitable for clinically testing the chronotropic responses[10,12,14].

Traditionally, the chronotropic alterations determined by the decrease in HR in recovery during the first minute after maximal effort have been associated with mortality[15]. However, this measure does not consider the five initial seconds of this phase, which better represent the cardiac vagal reentering[3,5,16]. It is observed in the literature that individuals with high aerobic condition compared with less conditioned ones, present faster parasympathetic activation and lower sympathetic activity[8,17-19]. However, the behavior of the parasympathetic nervous system during repeated stimuli of high intensity and low duration has not been completely elucidated yet[20,21]. Thus, the present study had the aim to verify the cardiac chronotropic response during a supramaximal intermittent test (MART) through the HR_{ON} and HR_{OFF} behavior. Additionally, we tried to correlate the chronotropic variables with the aerobic and anaerobic performance variables.

METHODS

Thirteen men with no symptoms aged 25.1 ± 4.9 years, 76.8 ± 12.5 kg, 178.4 ± 9.0 cm, 50.6 ± 4.1 $mL.kg^{1}.min^{1}$ and 24.0 ± 2.7 $kg.m^{-2}$, volunteered to the study. All of them have regularly trained (≥ 90 min. $week^{-1}$) continuous or intermittent aerobic exercises for at least three months before data collection and did not make regular use of any drug or ergogenic substance. The volunteers formally agreed on the participation in the study signing a free and clarified consent form. The procedures were previously approved by the ethics and research committee of the Gama Filho University (Rio de Janeiro, RJ, Protocol 004.2011).

Experimental outline

Data collection occurred in three visits. On the first one, after anamnesis and anthropometric measures, a scale maximal exertion cardiopulmonary test with direct monitoring of expired gas was performed. On the second visit, MART familiarization took place. On the third visit, the MART was carried out until maximal voluntary exhaustion. The HR responses were monitored during the stimulus--recovery cycles. The performance variables derived from the aerobic and anaerobic tests aassociated with the chronotropic patterns observed during the MART were investigated.

Anthropometry

In order to characterize the sample, the individuals were submitted to a battery of anthropometric measures[22,23]. Body mass (Sport Mea 07400, Plenna Especialidades Ltda., São Paulo, Brazil), height and skinfolds (Slim Guide, Rosscraft, Surrey, Canada) were determined.

Maximal cardiopulmonary exercise test

Maximal aerobic power (VO_{2Max}) and its corresponding velocity (V_{VO2Max}) were determined through a test on treadmill, with 2-minute stages, steady inclination in 1% and increments of 1.0 $km.h^{-1}$ (0.28 $m.s^{-1}$) from the 5.0 $km.h^{-1}$ velocity (1.39 $m.s^{-1}$)[24]. Such increments were equal, in the running phase, to load of 3.5 $mL.kg^{-1}.min^{-1}$ [25]. The test was interrupted when the volunteer gave up, despite the verbal stimuli provided in order to encourage him to reach the highest intensity as possible. In the last 10 minutes which preceded the maximal cardiopulmonary exercise test (CPET), rest heart rate was measured (HR_{REP}) and at the end of the test HR was measured for a period of 1 minute, representing the HR decrease after the CPET (HR_{REC}_CPET). During the test, the volunteers had their HR monitored at every five minutes (*Vantage, Polar Electro Oy, Kempele, Finland)* and at the end of each stage for subjective perceived exertion (SPE). Direct measures with sampling of 20 seconds of the fractions of VO_2, VCO_2 and VE from an automatized gas analyzer system (TEEM 100, *MedGraphics Corp., St. Pau*l, USA) previously calibrated for the known gas concentrations were performed. Ventilation was quantified by a medium flow pneumotachometer (with 20 to 110 $L.min^{-1}$ amplitude) and recorded at barometric pressure was recorded at each test (675 ± 1 mmHg), temperature (24 ± 2ºC) and air relative humidity (73 ± 11%). The VO_{2Max} was established as the mean of the three higher measures of O_2 at the end of the maximal progressive test.

Maximal anaerobic running test (MART)

Progressive stimuli of 20 s and passive recovery of 100 s were performed, starting from 10.2 $km.h^{-1}$ with increments of 0.97 $km.h^{-1}$ at each stage with steady inclination of 12% until maximal voluntary exhaustion, adapted to the protocol by Rusko and Nummela *et al.* 1993[10]. Warm-up with 3-minute duration was performed at 5.0 $km.h^{-1}$ and with no inclination. The aim in this phase was HR stabilization, minimizing the anticipation effects of the nervous system over the HR, which was monitored as previously described for the CPET[26]. The velocity corresponding to the last stage of the test was considered as MART maximal velocity (v_{MART})[10].

Analysis of the cardiac autonomic behavior

During the MART stages, the HR response was analyzed under the time domain at each five seconds (figure 1). Thus, it was possible to observe the MART HR kinetics represented by HR acceleration moments in the 20 seconds of stimuli followed by recovery represented by HR deceleration in the 100 seconds of recovery.

Thus, the analysis of the cardiac chronotropism during each beginning of the MART stage was recorded through four HR measures, possibly represented by the cardiac vagal removal immediately to the beginning of the exercise[5]. In order to represent the HR extreme responses, the variable 'highest heart rate during 20 seconds of each MART stage' (HR_{PEAK}) and the variable 'lowest heart rate in the period of 60 seconds during each MART stage' (HR_{REC}) were recorded. These responses were separately assessed through linear equations of the straight line and used to observe the autonomic nervous system behavior, represented by the progressive reduction of the parasympathetic activity by the overlap of the sympathetic nervous system. The parasympathetic activity behavior was investigated by the HR reduction at 60 seconds of recovery. In addition to that, the amplitude of HR alteration relativized by the reserve method between the MART second and last stages was investigated.

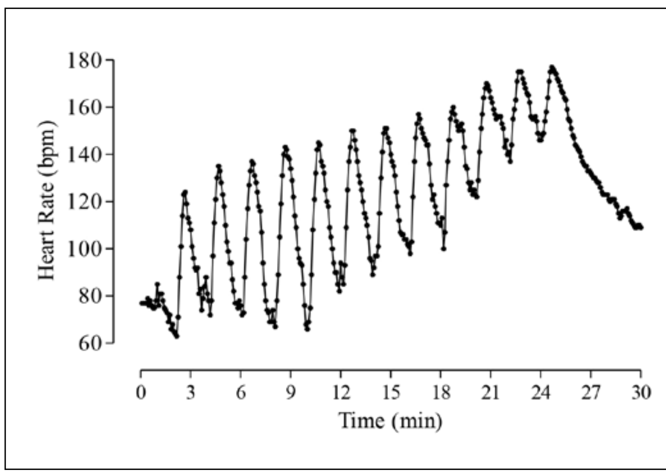

Figure 1. HR response of one of the individuals investigated randomly chosen who performed the MART to represent the complete protocol until maximal exertion.

D_{MART} determination

In order to characterize the behavior of the HR decrease during the MART (D_{MART}), a common point between the tests was set. In all protocols there was HR decrease in the first MART stage ($D_{HR'}$) and in the last MART complete stage ($D_{HR''}$). Through these two variables, the ratio between the two decrease moments ($D_{HR''}$ and $D_{HR'}$) was set, making the MART recovery behavior relative.

Cardiac vagal removal and reentrance

In order to represent with the same distance the behavior of the cardiac vagal removal and reentrance, the first 20 seconds of stimulus and 20 seconds of recovery were highlighted. Subsequently, the ratio between the difference between HR_{PEAK} and initial HR during the MART stimulus (HR_{ON}) with the difference between HR_{PEAK} and recovery initial HR (HR_{OFF}) was calculated. Such measurement was performed in three MART stages (initial, middle and final). Through these measures six measures, the behavior of cardiac vagal removal by the HR_{ON} and cardiac vagal reentrance by the HR_{OFF} was analyzed (figure 2).

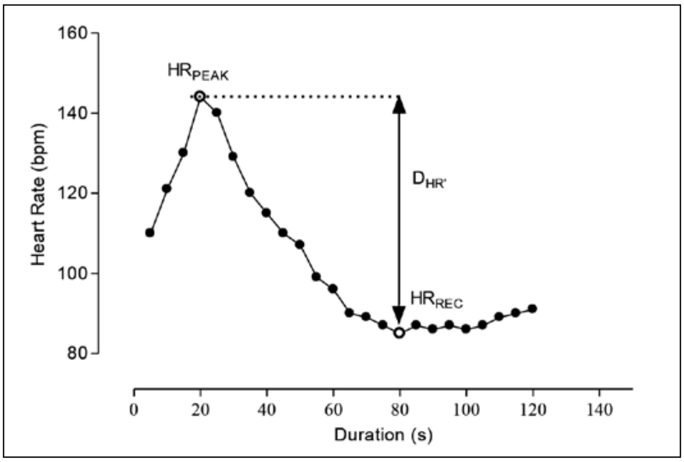

Figure 2. HR decrease during one of the MART stages. HR_{PEAK} – HR reached in the MART stage; HR_{REC} – recovery HR in the MART stage.

Statistical analysis

The chronotropic and aerobic and anaerobic performance responses were expressed by the mean ± standard deviation, confidence interval of 95% ($CI_{95\%}$) and standard error of the mean (SE_{mean}). The variables HR_{ON}, HR_{OFF} and $\Sigma HR_{ON/OFF}$ were compared with on-way ANOVA with repeated measures and Bonferroni *post hoc* test, at the beginning, middle and end of the MART. Paired Student's *t* test was used for the variables HR_{ON} and HR_{OFF} in the extremes of MART (initial and final stages). Finally, the associations between the performance variables (V_{MART} and VO_{2MAX}) with the chronotropic variables ($D_{HR'}$, $D_{HR''}$, D_{MART} and D_{CPET}) were established. All statistical analyses were performed in the SPSS v.17 software (SPSS Inc., Chicago, IL, USA) and significance level of $P \leq 0.05$ was adopted for all analyses).

RESULTS

The hemodynamic and performance responses are presented in table 1, demonstrating characteristics of cardiorespiratory fitness (VO_{2MAX} and VO_{2MAX}) and anaerobic fitness (v_{MART}) within the expectation for the investigated individuals.

The HR_{PEAK} and HR_{REC} kinetics presented linear and progressive response during the MART (figure 3). The HR_{REC} kinetics compared with the HR_{PEAK} one, presented higher inclination, resulting in higher variation amplitude during the test. While the HR_{PEAK} ranged mean of 39 ± 14 bpm between the first and last MART stages, the HR_{REC} ranged 58 ± 20 bpm characterizing significant differences ($P = 0.0017$).

The cardiac vagal response in the MART stimulus (HR_{ON}) and recovery (HR_{OFF}) presented significant differences (figure 4). When the HR_{ON} is compared in the MART initial, middle and final moments, differences between the initial and final stages ($P = 0.007$) were observed. Concerning the HR_{OFF} differences between the beginning and the middle ($P = 0.035$) and between the beginning and end of the test ($P = 0.005$) were observed. These findings evidenced progressive reduction of parasympathetic activity from the middle of the MART. The HR_{ON} and HR_{OFF} analyzed as a whole ($\Sigma HR_{ON}/HR_{OFF}$) resulted in linear and decreasing responses of the parasympathetic activity all along the test (figure 4). Statistically different responses were observed between the end and beginning of the test ($P = 0.001674$). The chronotropic variables ($D_{HR'}$, $D_{HR''}$, D_{MART}), when correlated with the performance variables (VO_{2MAX}, V_{MART}), did not present statistical significance ($P > 0.05$) (Table 2).

Table 1. Performance physiological characterization of the investigated group (n = 13).

Variable	Mean ± SD	$CI_{95\%}$	SE_{Mean}
HR_{REP} (bpm)	64 ± 8	60 - 68	2,1
$HR_{MÁX}$ (bpm)	189 ± 11	183 - 195	3,0
v_{VO2MaX} (km.h^{-1})	13,5 ± 1,2	12,9 - 14,2	0,3
VO_{2MAX} (mL.kg^{-1}.min^{-1})	50,6 ± 4,1	48,4 - 52,9	1,2
v_{MART} (km.h^{-1})	18,6 ± 1,3	17,9 - 19,3	0,4

n – number of subjects; HR_{REP} – recovery heart rate; HR_{MAX} – maximal heart rate; v_{VO2MAX} – maximal velocity reached in the maximal exercise cardiopulmonary test; VO_{2MAX} – maximal oxygen consumption; vMART – maximal velocity reached in the MART stage at 12% of inclination; SD – standard deviation; CI – confidence interval 95%; SE_{Mean} – standard error of the mean.

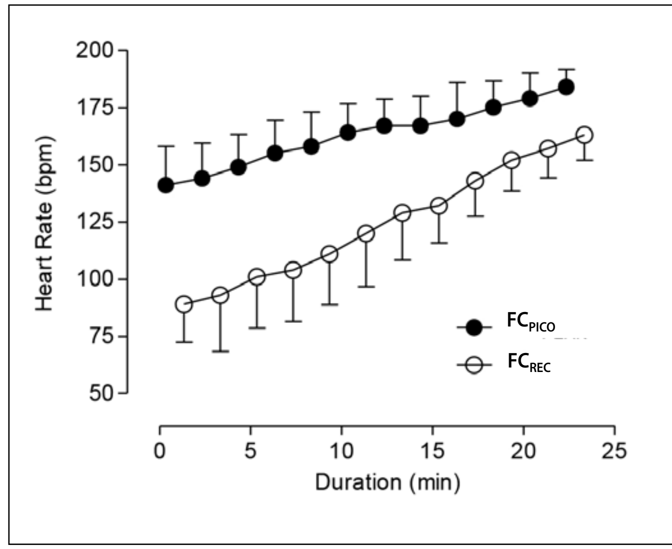

Figure 3. HR response in the MART stages. HR_{PEAK} – HR reached in each MART stage; HR_{REC} – recovery HR in each MART stage.

Table 2. Association (r) and significance level (P) of the ratios between the chronotropic variables and MART performance (n = 13).

Chronotropic variables	VO_{2MAX} r; P	V_{MART} r; P
$D_{HR'}$	-0.322; 0.283	0.336; 0.262
$D_{HR''}$	-0.303; 0.315	-0.148; 0.630
D_{MART}	-0.325; 0.278	-0.325; 0.278
DHRCPET	-0.107; 0.728	0.148; 0.629

n – number of individuals; $D_{HR'}$ – HR decrease in the second MART period; $D_{HR''}$ – HR decrease in the last MART period; D_{MART} – ratio between $D_{HR'}$ and $D_{HR''}$ decrease during the entire MART; VO_{2MAX} – consumption.

DISCUSSION

The present study was pioneer in demonstrating that in progressive, supramaximal and interval stimuli, the activation of the parasympathetic nervous system presents reduction inversely proportional to the increase of the activity intensity, with greater emphasis on the second half of the MART when HR_{ON} and HR_{OFF}

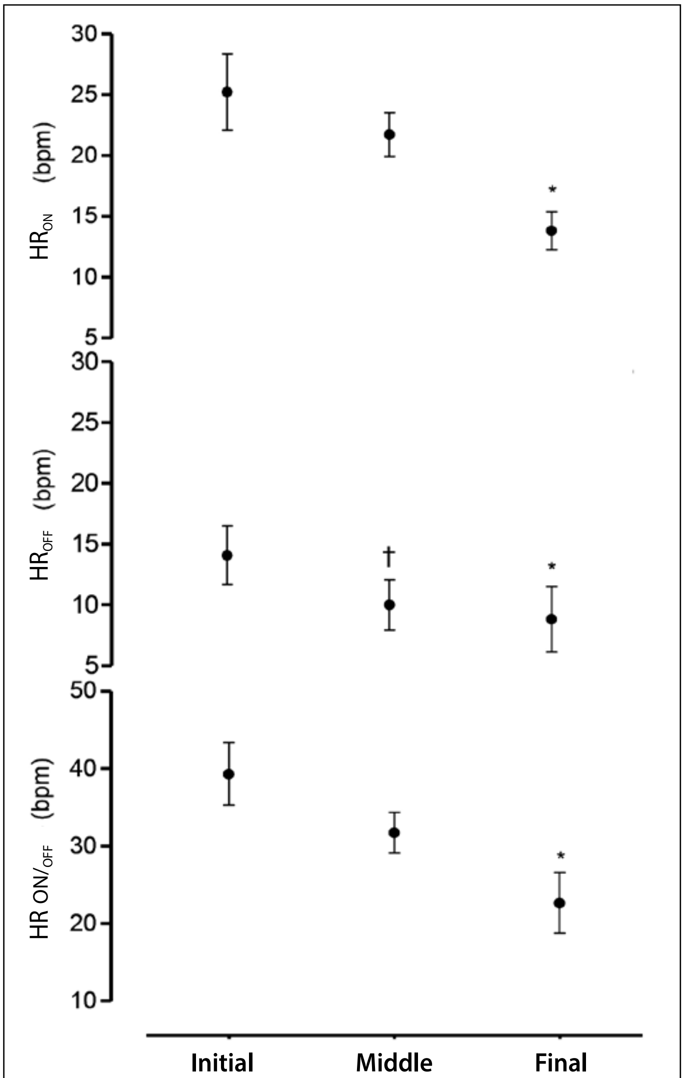

Figure 4. Behavior of the cardiac vagal removal and entrance at the beginning, in the middle and end of the MART. HR_{ON} – HR response in the 20 s of MART stimulus; HR_{OFF} – HR response in the initial 20 s of MART recovery; $\Sigma HR_{ON/OFF}$ – Sum of HR responses during the MART stimulus and recovery. * – Significant difference ($P < 0.05$) between the initial and final stages of MART. † – Significant difference ($P < 0.05$) between the initial and middle stage.

were separately analyzed. Another original aspect of the present study was the use of MART for autonomic modulation evaluation. Its brief stimuli duration (20 s) and long recovery period (100 s), even with high accumulation of metabolites[13], made it impossible to reach the maximal HR all through the test. Possibly, aspects related to the time necessary for noradrenaline removal may explain this phenomenon.

The parasympathetic removal occurs approximately in the five initial seconds of exercise by the pre-ganglionary medullary activity, while the sympathetic nervous system has its mean latency at 2.5 minutes of exercise, when the noradrenaline and adrenaline concentration reaches its maximum value[4]. Thus, during short stimuli of 20 seconds the activity of the parasympathetic nervous system presents higher predominance, even at the end of the test. Although the HR does not exclusively represent the manifestations of the parasympathetic nervous system[16], its monitoring reported in the literature immediately after a CPET corroborates its use as a marker of activation of the parasympathetic nervous system. This finding is supported by Arai *et al.*[18], Imai *et al.*[27] and Pierpont and Voth[28] demonstrating that the vagal reactivation at the end of the CPET occurs before the sympathetic removal. However, Savin *et al.*[17] support the sympathetic activity prior to the parasympathetic one. Altogether, this evidence support that the HR response during the stimulus and recovery model used in the present study mainly represents the activity of the parasympathetic nervous system, even at supramaximal intensities.

The cardiac vagal removal velocity in the 20 seconds of stimulus observed in the present study was higher than the one in the vagal reentrance in the 20 seconds of recovery, well characterized by the HR_{OFF} until the second half of the MART. Probably, the cardiac autonomic imbalance occurred due to the increased intensity at every stage may explain this superiority, despite being in lower conditions when compared with a CPET.

The results of the present study indicated that the chronotropism analysis in the MART as an instrument for performance diagnosis needs to be better explored, making the usefulness of anaerobic running test broader. Studies with cardio depressor pharmacological blocking should be carried out in an attempt to physiologically meet the autonomic nervous system response in the MART. Traditionally, the chronotropism analysis is commonly performed in the CPET in clinical dimension and for performance[17, 29]. Additionally, low and insignificant correlation was observed between the performance and chronotropic variables investigated, as reported by Vesterinen *et al.*[30]

The present study limited to record the HR measures at every five seconds. We recommend that future studies perform analysis at every millisecond, avoiding hence that the screening used by different cardiofrequency meter models influence on the measurement. Moreover, the use of pharmaceutical agents, both adrenergic and cholinergic, could demonstrate the autonomic nervous system response more clearly during the MART.

CONCLUSION

The MART demonstrated its applicability in the investigation of the HR responses with emphasis on the parasympathetic system activity. Its intermittent and supramaximal model allowed, besides the traditional identification of anaerobic and neuromuscular performance, a suitable scenario for the investigation of the autonomic modulation when facing the adaptations provided by training, detraining and adverse clinical conditions. The low association between the chronotropic variables in the MART and aerobic and anaerobic performance suggests independent cause mechanisms between these variables. Therefore, further investigation on this issue should be conducted.

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All authors have declared there is not any potential conflict of interests concerning this article.

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