Peak heart rate responses in maximum laboratory and field tests

Alexandre Lima dos Santos[1], Sidney Cavalcante Silva[2,3],
Paulo de Tarso Veras Farinatti[1] and Walace David Monteiro[1,2,4]

ABSTRACT

Background and objective: The peak heart rate (HR_{peak}) assessed in maximum laboratory tests has been used to determine the aerobic exercise intensity in field situations. However, HR_{peak} values may differ in field and laboratory situations, which can influence the relative intensity of the prescribed workloads. The objective of this study was to measure the HR_{peak} responses in laboratory and field maximum tests, analyzing their influence in the exercise prescription. **Methods:** Twenty-five physically active men aged 21-51 yrs (28.9 ± 8 yrs) executed a 2,400 m field test in a running track and an individualized maximum treadmill ramp protocol. All tests were performed within two weeks, in a counterbalanced order. Before each test, the temperature and air humidity were checked, and the subjects were told no to engage in any physical activity 48 hours before. Differences between HR_{peak} and environmental conditions (temperature and humidity) in field and laboratory situations were respectively tested by paired and simple Student's *t* tests ($p < 0.05$). **Results:** HR_{peak} values were significant higher in the field test than in the laboratory protocol, reaching 10 beats per minute in some cases. These differences may be partially accounted for a significant higher temperature and air humidity in the field conditions. **Conclusion:** In conclusion, maximum field tests seem to elicit higher HR_{peak} values than laboratory protocols, suggesting that the former procedures are more likely precise to determine the relative intensity of aerobic effort in physical training.

Key words: Aerobic training. Effort intensity. Running. Measurement and evaluation.

INTRODUCTION

One of the most important aspects in the aerobic exercise prescription is the adequate control of the effort intensity. There are some variables that may be used in this purpose. Among them, the maximal oxygen intake ($\dot{V}O_{2max}$), the metabolic equivalent, the exertion subjective perception, the ventilatory and lactate threshold and the heart rate (HR)[1-6] may be mentioned. Among these indicatives, perhaps the HR is the most practical, although its responses may be influenced by several aspects besides effort itself. Among them, the room temperature[7], anxiety[8], use of medications[9], wind resistance[10], air relative humidity[11] and the mechanical efficiency to perform some activity[12].

One of the physiological bases that guide the HR application as indicative of effort intensity is the relation relatively linear of its relative values (HR_{max} percentiles) with the oxygen intake relative values ($\dot{V}O_{2max}$ percentiles)[1,13-15]. This relation allows estimating the behavior of a variable in function of other. In other words, when an individual exercises in a given percentile of his $\dot{V}O_{2max}$, he exhibits a corresponding percentile of his HR_{max}. The American College of Sports Medicine[1] recommends that the effort intensity for improvements on the cardiorespiratory fitness should lie between 55% and 90% of the HR_{max} (50% to 85% of the $\dot{V}O_{2max}$).

Besides its relation with $\dot{V}O_{2max}$, another aspect that promotes the HR use is the fact that it composes an indicative easily measurable in efforts of varied nature. In this context, it is worth observing that a strategy usually adopted in exercise prescriptions is to estimate the HR_{max} with the use of predictive equations. This procedure, however, may present unacceptable error margins in the activity intensity determination[5,16,17]. Thus, one uses to adopt data obtained in laboratory tests in order to determine the actual HR_{max} of the individual.

Another aspect that may influence the responses of the HR_{max} to effort is the amount of muscular mass involved. In this case, perhaps the most suitable way to express the HR responses in situations where one intends to determine it is to use the term 'HR peak' or simply HR_{peak}. The HR_{peak} would express the maximum value of the HR response for a specific elective activity. For example, one frequently verifies differentiated HR_{peak} responses in maximum efforts performed in arm ergometers, cycle ergometers, treadmills and paddle-ergometers[18-21]. For nomenclature purposes, in the present study we will call the highest HR responses in maximum tests as HR_{peak}.

It seems to exist an agreement in literature in which the highest HR values are obtained in maximum tests conducted in laboratory[22]. However, many aspects may influence the attainment of the actual HR_{peak}. Although some of these aspects may be controlled in laboratory conditions, this control becomes quite difficult when the training is applied in field. Some of the variables upon which one loses control, on the other hand, have potential to influence the HR responses during exercise. One deduces that differences between field and laboratory situations may affect the behavior of the HR_{peak}. This may result in an under or overestimation of the actual intensity of effort performed. Thus, the objective of the present study is to verify the responses of HR_{peak} obtained in field and laboratory maximum tests and to analyze their influence on the aerobic exercise prescription.

MATERIAL AND METHODS

Sample

Twenty-five men physically active aged between 20 and 51 years (average = 28.9 ± 8.5 years) participated in this study. The volunteers performed previous aerobic training at least three times a week for at least 30 minutes a day. All were used to perform their

1. Physical Activity and Health Promotion Laboratory, Rio de Janeiro State University (LABSAU-UERJ).
2. Exercise Physiology Laboratory – Air Force Physical Activity Sciences Institute (ICAF – Air Force).
3. Petropolis Catholic University (UCP).
4. Department of Physical Education – Gama Filho University (UGF).

Received in 6/12/04. 2nd version received in 11/3/05. Approved in 20/4/05.

Correspondence to: Walace David Monteiro, Laboratório de Atividade Física e Promoção da Saúde – Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier, 524, 8º andar, sala 8.133 F. E-mail: wdm@uerj.br

training in treadmill and running track. None of the individuals presented health problems that could impair the performance of the tests. Previously, all individuals signed the post-informed consent term and the study was approved by the Institutional Ethics Committee.

Protocol

Initially, all individuals responded to the PAR-Q questionnaire. Later, they underwent an anamnesis specially elaborated to identify aspects regarding the practice of physical activities including the adaptation to treadmill work.

In the first visit to laboratory, the volunteers were submitted to an anthropometrical evaluation in which measurements of stature (anthropometer *GPM Instruments*, Geneva) and body mass (*Filizola* scales, Brazil) were performed. Later, the body density and fat percentage were estimated through Jackson and Pollock[23] and Siri[24] equations, respectively (caliper, *Lange* Cambridge Scientific Instruments, USA).

The laboratory tests were conducted in treadmill (*Quinton*, model Q65, USA). The room average temperature was of 22°C, ranging from 20 to 23°C. The air relative humidity was of 62.55%, ranging from 59 to 65%. For the HR_{peak} determination, an individualized maximum treadmill ramp protocol was used with velocity increments. The tests duration ranged from 8 to 12 minutes. As maximum test criterion, the appraised should present at least three of the following characteristics: maximum voluntary exhaustion, attainment of a plateau for oxygen intake between two consecutive loads, $R \geq 1.15$ and absence of HR increase despite the increase on the workload. During the tests performance, the $\dot{V}O_{2max}$ was directly measured (*Medical Graphics* gas analyzer, model CPX, USA). During the application of the protocols, the individuals were encouraged to perform maximum effort. Holding the side or frontal bars of the treadmill was not allowed to participants. The test was only interrupted by means of maximum voluntary exhaustion.

The field test was conducted in official running track and was composed of running 2,400 m in the shortest time as possible. All performed previous warm-up exercises composed of light running and stretching exercises for lower limbs. During the test, the volunteers were verbally encouraged to cover the distance established in the shortest time as possible. The HR was measured during the test through monitor label *Polar* (model Accurex Plus, Finland). The room average temperature during the performance of the test was of 32°C, ranging from 26 to 38°C. The air relative humidity was of 76%, ranging from 72 to 84%.

The field and laboratory tests were performed with maximum interval of two weeks between each other. The volunteers were told not to perform physical exercises 24 hours before each test.

Statistical treatment

In order to check possible differences between HR_{peak} responses in field and laboratory situations, the paired Student's *t* test was applied and to check differences in temperature and air relative humidity between the situations studied, the simple Student's *t* test was applied. For both procedures, the significance level adopted was of $p < 0.05$.

RESULTS

Data with regard to age and anthropometrical characteristics of the sample studied are shown in table 1. The descriptive statistic values for environmental conditions of field and laboratory situations are illustrated in table 2. Finally, the HR_{peak} values verified in field and laboratory are illustrated in table 3. As we can see, the HR_{peak} values exhibited in field conditions presented statistically significant difference in relation to values obtained in laboratory conditions.

TABLE 1
Ages and anthropometrical characteristics of volunteers

Descriptive statistics	Age (years)	Body mass (kg)	Stature (cm)
Average	28.9	76.0	177.0
Standard deviation	8.5	12.5	7.3
Minimum	20.0	53.4	165.0
Maximum	51.0	106.8	199.0

TABLE 2
Environmental conditions presented in field and laboratory tests

Descriptive statistics	Temperature in field tests (°C)	Air relative humidity in field tests (%)	Temperature in laboratory tests (°C)	Air relative humidity in laboratory tests (°C)
Average	32*	76*	22	63
Standard deviation	3	7	1	6
Minimum	26	72	20	59
Maximum	38	84	23	65

* Significant difference in relation to value obtained in laboratory ($p < 0.05$).

TABLE 3
HR_{peak} values verified in field and laboratory tests

Descriptive statistics	HR_{peak} field (bpm)	HR_{peak} laboratory (bpm)
Average	195.8*	191.8
Standard deviation	12.2	12.1
Minimum	168.0	166.0
Maximum	218.0	214.0

* Significant difference in relation to value obtained in laboratory ($p < 0.05$).

DISCUSSION

The adequate quantification of the effort intensity is vital for the aerobic exercise prescription, regardless the population involved[1,25,26]. In this context, the HR responses to effort have been widely employed[27]. The hypothesis that the field and laboratory HR_{peak} values could be different, thus influencing significantly the effort intensity determination, was tested. Based on the principle that an evaluation must be specific to the training prescription conditions, variations on the field and laboratory responses may affect the prescription efficiency.

One of the limitations of the present study lies on the fact that there is no guaranty that the effort was maximum in field tests, as it was in laboratory tests. The maximum test criteria for laboratory tests are well defined and accepted. In the case of field tests, perhaps the most used is the exhaustion for a given distance, as the case of the present experiment. Notwithstanding, the HR responses observed in field were higher than those obtained in laboratory, leading us to believe that the effort in field was actually maximal.

In the present study, significant differences between field and laboratory HR_{peak} responses were verified. Among the 25 individuals investigated, 20 of them presented higher HR_{peak} in field tests. Although the average HR_{peak} have been differentiated in approximately 5 bpm in both conditions studied, individual variations of up to 10 bpm were observed on behalf of field tests. Only five individuals presented lower HR_{peak} in field, of which all exhibited values below 4 bpm in relation to values observed in laboratory.

The most likely explanation for this response seems to be related to the influence of the environmental conditions in the HR_{peak} responses in the situations studied. Indeed, significant differences were observed for temperature and air relative humidity on behalf of field tests. A hot environment, as observed in field tests, may require the cardiovascular system to work more in comparison to controlled environment in laboratory tests. As emphasized by Coris *et al.*[11] and Montain and Coyle[28], exercises performed in hotter environments cause a deviation on the blood flow from the muscle to the periphery in the attempt of controlling the body temperature by transporting heat to the external environment. Due to this adjustment, a smaller amount of blood remains available for muscles in activity, thus decreasing the O_2 uptake. As result, the HR increases in order to supply the organism's necessities.

In addition, the air relative humidity may affect the HR_{peak} responses more significantly in field tests. This parameter influences directly on the sweat evaporation possibility, once it depends on the water vapor pressure gradient between skin and environment[29]. Therefore, in efforts performed in excessively low air relative humidity, the volemy and the blood solvent-solute relation tend to modify due to the loss of liquid to the environment, hence generating a higher HR response in order to maintain the cardiac debt. In case of high air relative humidity, the sweat tends to find difficulty to evaporate, impairing the body temperature regulation process[30]. As result, the field HR tends to elevate drastically in relation to controlled environments such as laboratories.

The modifications on the hydration degree may also cause differences on the field and laboratory HR_{peak} responses. Although it is known that the duration of a maximum field test is not sufficiently long to induce an accentuated dehydration, small variations in the hydration state may help to exacerbate the HR_{peak} responses. In field tests under hot and humid conditions, the chances for this situation to occur are not to be neglected.

Another aspect that may cause higher cardiovascular stress in field tests in relation to laboratory ones is the wind resistance. This effect may be higher when the individual's dislocation direction is the opposite to the wind dislocation, leading to a higher effort to overcome the resistance[10]. An important observation on the influence of the wind resistance on the HR responses is obtained in runners in groups. As emphasized by Kyle[32] and Pugh[33], running performed in groups may have the performance significantly facilitated due to exercise being conducted in the vacuum, and a reduction on the HR and O_2 intake may also be observed in comparison to running performed individually.

The results of this study show that the field and laboratory HR_{peak} may be significantly different. In our sample, from the 25 individuals observed, 20 of them obtained higher HR_{peak} values in field tests. The average difference between field and laboratory values for these individuals was of 6 bpm, with results ranging from 2 to 10 bpm on behalf of field tests. Obviously, this brings implications on the effort intensity determination with strong variations of loads suitable to the aerobic training. For example, using the range from 75 to 90% of the HR_{peak} as training range for an individual who presents a difference of 6 bpm, the training range would lie between 146 and 185 bpm based on the reference value obtained in laboratory. For the same individual, the same training range lies between 151 and 180 bpm based on a HR_{peak} of 201 bpm obtained in field test. In case we take the difference of 10 bpm between both situations studied as reference, the training range prescribed in function of a HR_{peak} of 180 bpm obtained in laboratory would be from 135 to 162 bpm. On the other hand, for a value of 190 bpm obtained in field test, the training range lies between 142 and 171 bpm. In this case, taking the described training range as reference, one observes a difference of 7 bpm in the lower limit and of 9 bpm in the upper limit of the HR ranges used in training tests. From this point on, one observes that the impacts on the work relative intensity and expected effects are evident.

Another source of error in the determination of the correct training intensity regards the adoption of equations to estimate the HR_{peak} based on age. With this purpose, several equations have been presented in literature[16]. The problem of using these equations befalls on the high estimation standard error obtained in all equations, thus influencing the error possibilities in the exercise prescription[5,17,34]. Robergs and Landwehr[16] report that the estimation error for prescription purposes based on HR may be higher than that associated to $\dot{V}O_{2max}$ estimation. The authors yet emphasize that, for exercise prescription purposes, acceptable errors in the HR_{max} determination should lie below 8 bpm and, if the objective is the $\dot{V}O_{2max}$ prediction, below 3 bpm. As result, laboratory tests are usually indicated as the most accurate in order to obtain an actual HR_{peak}[22]. Data from this study contradict that statement.

At least for training prescription purposes, the results here presented indicate that tests involving the activity the individual is used to perform seems to be better when compared to laboratory tests in the determination of training target-ranges. Thus, the overvaluation of laboratory tests as the best way to obtain the aerobic exercise prescription intensity should be questioned, especially when the training is performed at field conditions.

In short, field tests present higher HR_{peak} values when compared to laboratory tests, and in some cases these tests provide more precise data for the quantification of the exercise intensity. In practical terms, this means that field tests, specific for actual activity and training conditions, may represent a more reliable option in the determination of the effort relative intensity. For the performance of further studies, one recommends the investigation of other motor gestures in order to evaluate the influence of field and laboratory tests in the HR_{peak} responses as well as their impact on the aerobic training intensity prescription.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES

1. ACSM. Guidelines for exercise testing and exercise prescription. 6th ed. Williams & Wilkins, 2000.
2. Borg G, Ljunggren G, Ceci R. The increase of perceived exertion, aches and pain in the legs, heart rate and blood lactate during exercise on a bicycle ergometer. Eur J Appl Physiol Occup Physiol 1985;54:343-9.
3. Nicholson RM, Sleivert GG. Indices of lactate threshold and their relationship with 10-km running velocity. Med Sci Sports Med 2001;33:339-42.
4. Noble BJ, Borg GA, Jacobs I, Ceci R, Kaiser P. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. Med Sci Sports Exerc 1983;15:523-8.
5. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 2001;37:153-6.
6. Bosquet L, Leger L, Legros P. Methods to determine aerobic endurance. Sports Med 2002;32:675-700.
7. Pandolf KB, Cafarelli E, Noble BJ, Metz KF. Hyperthermia: effect on exercise prescription. Arch Phys Med Rehabil 1975;56:524-6.
8. Bouchart C. Physical activity, fitness and health. Champain: Human Kinetics, 1994.
9. Wonisch M, Hofmann P, Fruhwald FM, Kraxner W, Hodl R, Pokan R, et al. Influence of beta-blocker use on percentage of target heart rate exercise prescription. Eur J Cardiovasc Prev Rehabil 2003;10:296-301.
10. Shepard RJ, Astrand PO. Endurance in sport. 2nd ed. Oxford: Blackwell Science, 2000.
11. Coris EE, Ramirez AM, Durme DJV. Heat illness in athletes: the dangerous combination of heat, humidity and exercise. Sports Med 2004;34:9-16.
12. Stromme SB, Ingjer F, Meen HD. Assessment of maximal aerobic power in specially trained athletes. J Appl Physiol 1977;42:833-7.
13. Londeree BR, Ames AS. Tread analysis of %$\dot{V}O_{2max}$-HR regression. Med Sci Sports Exerc 1976;8:122-5.
14. Gilman MB. The use of heart rate to monitor the intensity of endurance training. Sports Med 1996;2:73-9.
15. Zavorsky GS. Evidence and possible mechanisms of altered maximum heart rate with endurance training and tapering. Sports Med 2000;29:13-26.

16. Robergs RA, Landwehr R. The surprising history of the "HRmax = 220-age" equation. JEPonline 2002;5:1-10.
17. Ricard RM, Leger L, Massicote D. Validity of the "220-age formula" to predict maximal heart rate. Med Sci Sports Exerc 1990, 22, Suppl S96 (Abstract 575).
18. Londeree BR, Moeschberger ML. Effect of age and other factors on maximal heart rate. Res Q Exerc Sport 1982;53:297-304.
19. Tanaka H, Fukumoto S, Osaka Y, Ogawa S, Yamaguchi H, Miyamoto H. Distinctive effect of three different modes of exercise on oxygen uptake, heart rate and blood lactate and pyruvate. Int J Sports Med 1991;12:433-8.
20. Tanaka H. Effects of cross-training: transfer of training effects on $\dot{V}O_{2máx}$ between cycling, running and swimming. Sports Med 1994;18:330-9.
21. Kravitz L, Robergs RA, Heyward VH, Wagner DR, Powers K. Exercise mode and gender comparisons of energy expenditure at self-selected intensities. Med Sci Sports Med 1997;29:1028-35.
22. Froelicher VF, Myers JN. Exercise and the heart. 4th ed. Philadelphia: W.B. Saunders Company, 2000.
23. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 1978;40:497-504.
24. Siri WE. Body composition from fluid space and density. In: Brozek J, Henschel A, editors. Techniques for measuring body composition. Washington DC: National Academy of Science 1961;223-4.
25. Blair SN, Kohl HW, Barlow CE, Paffenbarger RS, Gibbons LW, Macera CA. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. JAMA 1995;273:1093-8.
26. Pollock ML, Gaesser GA, Butcher JD, Després JP, Dishman RK, Franklin BA, et al. ACSM position stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 1998;30:975-91.
27. Achten J, Jeukendrup AE. Heart rate monitoring: application and limitations. Sports Med 2003;33:517-38.
28. Montain SJ, Coyle EF. The influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. J Appl Physiol 1992;73:1340-50.
29. Powers SK, Howley ET. Fisiologia do exercício. 3ª ed. São Paulo: Manole, 2000.
30. González-Alonso J, Mora-Rodríguez R, Coyle EF. Stroke volume during exercise: interaction of environment and hydration. Am J Physiol Heart Circ Physiol 2000; 278:H321-30.
31. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exerc Sport Sci Rev 1999;27:167-218.
32. Kyle CR. Reduction of wind resistance and power output of racing cyclists and runners traveling in groups. Ergonomics 1979;22:387-97.
33. Pugh LGCE. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. J Physiol 1971; 213:255-76.
34. Inbar O, Oren A, Scheinowitz M, Rotstein A, Dlin R, Casaburi R. Normal cardiopulmonary responses during incremental exercise in 20- to 70-yr-old men. Med Sci Sports Exerc 1994;26:538-46.