Influence of the Ergometric Protocol in the Onset of Different Criteria for Maximal Effort

CLÍNICA MÉDICA DO EXERCÍCIO E DO ESPORTE

Original Article

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ABSTRACT

Introduction and Objectives: The aim of this study was to investigate the influence of different exercise protocols in the onset of maximal effort parameters. Methods: Nine healthy individuals (23 ± 4 year old; 177 ± 10 cm; and 77.1 ± 16 kg) participated in three progressive exercise tests (PR1 – 15 W•min-1, PR2 – 50 W•3 min-1, and PR3 – 50 W•5 min-1) in a cycle ergometer. Oxygen consumption was measured in open circuit and was calculated at 20 s intervals. The maximal effort parameters considered here were: plateau in oxygen consumption ≤ 150 mL•min-1; maximal heart rate ≥ 95% predicted by age; blood lactate concentration (8.0 mM; and RER ≥ 1.1. Results: The $VO2_{max}$ was not different among exercise tests (2.68 ± 1.0; 2.58 ± 1.0 and 2.99 ± 1.3 L•min-1 for PR1; PR2 and PR3, $p = 0.72$). The highest plateau occurrence was in PR1 (5 individuals). The heart rate criterion was observed in 3 individuals in PR3, while the lactate criterion was fulfilled in 6 subjects in the same PR3 protocol. Regarding the RER parameter, only 6 subjects in PR1 achieved values ≥ 1.1. Conclusion: It was concluded that the maximal effort parameters evaluated in this study are influenced by the exercise test, even when there are no differences in the $VO2_{max}$.

Keywords: plateaus in oxygen consumption, $VO2_{max}$, effort test.

INTRODUCTION

Maximal oxygen consumption (VO_{2max}) is considered one of the main determinant factors in physical aptitude for its association with athletic performance[1,2] and with exercise diagnosis and prescription for cardiac and pneumonia patients[3,4]. The main criterion of VO_{2max} determination is the onset of a plateau in oxygen consumption close to exhaustion[5,6]. This criterion was previously established by Taylor et al.[7], having as grounding discontinuous protocols, with long stages and loads applied with hours and even days of interval. Although there is no consensus among the exercise scientific community on the choice of the optimum criterion of maximum effort[5], the reference proposed by Taylor et al.[7] is the most widely used.

The plateau criterion has been little efficient[8-10] in ramp protocols or with small increment in short duration; thus, the term "oxygen consumption peak" has been applied whenever the plateau is not observed. However, many investigations have shown that there is not distinction between the VO_{2max} value observed in discontinuous or with increments tests [10,11]. Low incidence of VO_2 plateau led to the application of other markers of maximum effort. The respiratory exchanges ratio (RER), maximum heart rate (HR_{max}) and blood lactate concentrations ([Lac]) have also been considered in the determination of the maximum effort, although the indices used as reference may present variations between studies[5,6].

It is known that variation in load increase or duration of stage in ergometric tests may lead to different responses of metabolic and respiratory parameters, such as: mechanical efficiency[12], maximum power reached and VO_{2max}[13,14]. Considering that it is not clear whether the onset of the complementary criteria of maximum effort is affected by the different combinations of load increase and duration of ergometric test, the aim of the present retrospective investigation was to determine the effect of the protocol in cycle ergometer in the onset of different criteria of maximum effort.

METHODS

Subjects

The present investigation was composed of nine volunteers (among them seven men) aged 23 ± 4 years, 177 ± 10cm of stature, and 77.1 ± 16.0kg of body mass, apparently healthy, non-smokers and non-athletes, experienced in a cycle ergometer, engaged or not in aerobic training programs.

Abstinence from extenuating physical exercises for the 24h prior to the exam (> 5 METs) and alcohol ingestion were recommended. Additionally, maintenance of mixed diet in the 48h before the test and abstinence from food and caffeine in the three hours before the effort was recommended. Each subject was informed about the risks associated with the adopted procedures. A clarified consent form was read and signed. All procedures here adopted were aproved by the Local Ethics Committee for Experiments with Humans (Rio de Janeiro, CEP/HSE 000.021/99). This study was conducted according to the Declaration of Helsinki.

Experimental Procedure

The subjects were submitted to three different scaled, continuous and maximum effort protocols in a mechanical cycle ergometer (Monark , São Paulo, SP, Brazil), performed in a 7-14 days interval, at the same period of the day. Tests order was randomly established. Seat height was adjusted to each subject so that knee would keep an angle close to total extension (aprox. 175º). After six-minute rest, seated on the cycle ergometer seat, the subjects pedaled without load during four minutes and the scaled phase was initiated subsequently. Intensity was specific for each protocol: Protocol 1 (PR1) – 15W·min^{-1}; Protocol 2 (PR2) – 50W·3min^{-1}; and Protocol 3 (PR3) – 50W·5min^{-1}. The subjects maintained cadence during the exam (1.0Hz). The rhythm was controlled by na audiovisual metronome (Witter Junior Plast 826, Isny/ Allgäu, Germany).

Analysis of the physiological and metabolic parameters

The minute ventilation (V_E) and oxygen and carbon dioxide expired fractions were continuously measured by indirect calorimetry of open circuit (TEEM 100® Total Metabolic Analysis System, Aerosport, Ann Arbor, Mich., USA)[15-18]. The subjects used a nose clip and a medium flow pneumotachometer (Hans Rudolph®, Kansas City, MO, USA). Oxygen consumption per minute (VO_2) and excretion of carbon dixide per minute (VCO_2) were presented at every 20 seconds. Heart rate (HR) was continuously monitored during the test by telemetry (Vantage NV®, Polar Electro Oy, Kempele, Finland) and the concept of perceived exertion (CPE), in Borg's scale from 6 to 20, was collected at the end of each stage.

25µL ob blood were collected by earlobe puncture at hyperemia, according to procedures described by Shephard[19]. Collections were performed during rest, at the two minutes before the exam and at every two minutes of effort in PR1 and at the final minute of each stage in PR2 and PR3. The samples were immediately assessed by electroenzymatic method (YSI 1500 Sport L-Lactate Analyser®, Yellow Springs, USA). Total blood lactate was determined by the addition of the Triton X-100 hemolytic agent (YSI #1515 Agent Cell Lysing, USA) at 0.25% to the buffering solution. Blood collections were performed by an experienced evaluator between 20 and 25 seconds.

Controls and calibration

The metabolic analyzer, the lactate analyzer and the cycle ergometer were calibrated before each test. The ergospirometer was calibrated in closed circuit through a certified gas mixture containing 17.01% of oxygen, 5.00% of carbon dioxide and balanced with nitrogen (AGA®, Rio de Janeiro, RJ, Brazil). The flow was calibrated with the use of a three-liter air syringe (Hans Rudolph®, Kansas City, MO, USA). At the end of each test, measurement of the oxygen and carbonic dioxide percentage fractions in the gase misture applied for calibration was performed. Maximum variation allowed was 16.16 to 17.86% for FO_2 and 4.75 to 5.25% for FCO_2. The lactate analyzer had calibration confirmed before the test, through a standard solution of 5mmol·L^{-1} (YSI #2327 Lactate Standard YSI®, USA) of lactate. A new calibration was performed before each test and at each hour of use. Equipment linearity was confirmed until 15mmol·L^{-1} of lactate. Equipment accuracy was checked before the beginning of the experiment through a calibration curve with patterns of 1.0; 2.5; 5.0; 7.5; 12.0; 15.0; 18.0; 24.0; and 30.0mmol·L^{-1}, prepared through the dilution of the patterns provided by the manufacturer (YSI #2327: 5mmol·L^{-1}; YSI #2328: 15mmol·L^{-1}, YSI #1530: 30mmol·L^{-1} Lactate Standard YSI®, USA). The association between the values measured and expected in the calibration curve was r = 0.999, y = 0.9436x + 0.33011 and EPE = 0.20mmol.L^{-1}. The cycle ergometer was calibrated through 3kg load.

Maximum effort criteria

The plateau of oxygen consumption was used as main criterion of maximum effort. For the plateau determination, the difference in the VO_2 measurement between the last two stages of the ergometric test was applied. Such difference was defined as ΔVO_{2final}. Considering the original criterion of the plateau of oxygen consumption established in the work by Taylor et al.[7], the onset of this phenomenon was determined when ΔVO_{2final} was ≤ 150mL·min^{-1}. Other maximum effort criteria were also considered[6]: RER ≥ 1.1; HR_{max} ≥ 95% of the maximum expected by age (220 – age); and [Lac] at the end of the test ≥ 8.0 mM.

Statistical analysis

Statistical treatment was performed through Statistica® (Statsoft®, version 7.0, USA) and Microsoft Excel® for Windows XP® programs (Microsoft, USA). Descriptive statistics with mean ± standard deviation was applied (SD). The experimental outlining of the present study was counterbalanced. Variance analysis (ANOVA) with one factor (protocol) for repeated samples and Tukey-HSD post-hoc test were used for comparison of the different protocols used. Significance level established for this study was of p ≤ 0.05.

RESULTS

The physiological responses obtained in each protocol are found in table 1. Duration of the progressive effort test ($T_{exhaustion}$) in PR3 was significantly higher than in PR1 and PR2 (p = 0.0002). The maximum power reached (P_{max}) did not present differences between protocols (p = 0.28), although PR2 has suggested lower values in this parameter. Moreover, no difference was observed in the VO_{2max} (p = 0.72), RER (1.1 ± 0.1 in all tests, p = 0.72), and HR_{max} (p = 0.59), despite a tendency of higher values in PR3 in this last index. Final concentration of blood lactate ([Lac]) was significantly higher in PR3, when compared to the other protocols ($p = 0.04$). The ΔVO_{2final} presented great variation between individuals and between protocols (figure 1), reaching minimum and maximum values of: 5-485mL·min^{-1} in PR1, 68-1798mL·min^{-1} in PR2, and 230-1375mL·min^{-1} in PR3. Significant differences were observed for ΔVO_{2final}, being it lower in PR1, when compared to PR2 and PR3 ($p = 0.01$).

Table 1. Physiological and metabolic responses in the three investigated protocols.

	PR1		PR2		PR3	
$T_{exhuation}$ (min)	11 ± 1	(9-14)	10 ± 3	(6-15)	24 ± 3**	(17-30)
P_{max} (Watts)	183 ± 57	(135-325)	153 ± 29	(125-225)	182 ± 43	(120-250)
$VO2_{max}$ (L⊕min-1)	2.68 ± 1.0	(1.48-4.53)	2.58 ± 1.0	(1.47-4.81)	2.99 ± 1.3	(1.63-5.60)
HR_{max} (bpm)	168 ± 15	(141-195)	165 ± 12	(153-186)	180 ± 13	(159-200)
[Lac]	6.4 ± 1.6	(4.0-8.2)	5.3 ± 2.6	(1.8-9.3)	8.1 ± 2.3*	(5.1-11.3)

Mean ± standard deviation (minimum and maximum values); Texhaustion, exhaustion time; Pmax, maximum power reached; VO2max, oxygen maximum consumption; HRmax, maximum heart rate; [Lac], blood lactate concentration at the end of the test; *significant difference for $p \leq 0.05$; ** significant difference for $p \leq 0.01$..

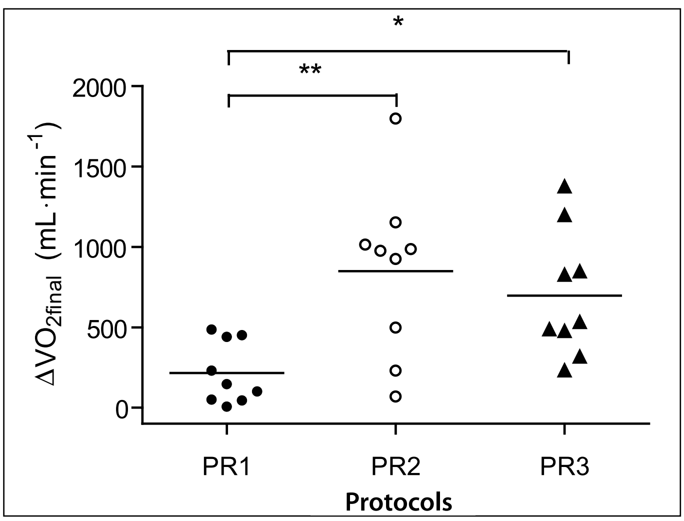

Figure 1. ΔVO_{2final} of each individual, in PR1, PR2 and PR3. Horizontal bars indicate mean. *Significant difference for $p \leq 0.05$. **Significant difference for $p \leq 0.01$.

The onset of the maximum effort criteria used in this study was sensitive to the ergometric protocol (table 2). There was higher occurrence of plateau in the oxygen consumption in PR1, being it low in PR2 and not being observed in PR3; however, the subjects who reached the plateau in PR1 and PR2 were not the same. The heart rate criterion (HR) was met in few subjects in PR1 and PR3, not being met in PR2. The [Lac] reached higher or equal to 8.0mM values in a high number of subjects in PR3, with low occurrence of this criterion in PR1 and PR2. RER was the criterion of highest occurrence among the observed ones. When the maximum effort criteria were combined, little coherence was observed. Out of the five subjects who presented plateau in PR1, only four reached RER values within the pre-set cohort, with no occurrence of HR and [Lac] criteria. In PR2, in the only subject who presented plateau, no other criterion adopted was observed. In PR3, although we have not observed plateau in any subject, this was the protocol with the highest occurrence of the HR and [Lac] criteria, with occurrence for RER as well (table 2).

Table 2. Onset frequency of the different criteria of maximum effort in the assessed protocols.

	PR1	PR2	PR3
Plateau (≤ 150 mL.min-1)	05/set	01/set	0/9
HRmax (≥ 95%)1	01/set	0/9	03/set
[Lac] (≥ 8.0 mM	02/set	01/set	06/set
RER (≥ 1.1)	06/set	07/set	04/set

1 HRmax = 220 – age; Number of occurrences/total of observations; the abbreviations follow table 1 format.

DISCUSSION

The present investigation considered that the plateau in the O_2 consumption may not be a suitable criterion for determination of of VO_{2max} when compared with different ergometric protocols, and the use of different maximum effort criteria, separately or combined analyzed, may not be guarantee of higher accuracy in the determination of this important metabolic index. Thus, we aimed to determine the effect of protocol in cycle ergometer in the occurrence of different maximum effort criteria.

The sample of this study was composed of subjects with the following characteristics: non-athletes, healthy, with high or low experience in cycle ergometer, engaged or not in aerobic training programs. Hereditary characteristics and involvement in exercise programs may influence in the VO_{2max} values. Regardless of considering the individuals' experience with a cycle ergometer, this equipment may overload the lower limbs, causing hence early fatigue[4]. Fatigue of lower limbs may result in low VO_{2max}[20]. The influence of different protocols in the measurement of the VO_{2max} has been examined and it was observed that variations in the stage duration or load increase in progressive tests do not significantly affect the VO_{2max}[12,21] measurement; however, other investigations have shown clashing results[14,22]. In the present study, we assessed protocols with difference in stage duration as well as load increase and no significant difference has been observed in VO_{2max}. Previous investigations observed VO_{2max} lower indices in protocols with higher total duration[13,14].

Accuracy in the measurement of the gas and ventilatory exchanges is crucial to enable data reproduction. The measurements quality control should be assured through calibration, operation and assessment procedures conducted by experienced technicians[23]. Tests in which these care measures are taken present low variation in the repeated measurements in close moments[15-17,23,24]. The intra-individual daily variation, due to error and physiological fluctuations of VO_2, V_E and HR are [24] respectively 3.8%, 8.0% and 3.0%. Granja Filho et al.[17] observed intra-individual variation index of 5.5% for the VO_{2max}. Nogueira and Pompeu[25] and Magrani and Pompeu[26] observed satisfactory indices for the measurements assessed in equipment similar to the one adopted here. Despite the higher inaccuracy of obtained measurements, comparing to the more sophisticated equipments (3.8% versus 5.5%), the ergospirometer adopted here was validated by other groups[15,16] and is widely used in Brazilian laboratories due to its lower cost.

There are countless criteria used for VO_{2max} assessment; however, no consensus is presented concerning which method is the most suitable[5]. Nevertheless, this controversy does not make the use of criteria established for the present study invalid, since the intention was to demonstrate the influence of the ergometric protocol in the onset of these indices. Originally established in ergometric tests of constant load [7], the plateau criterion has been criticized about its adaptability for characterization of the VO_{2max} in progressive tests[5,6]. Many studies comparing tests of constant load and progressive tests were not able to observe significant differences in the VO_{2max} value between tests, although the plateau of oxygen consumption has been observed only in some of the tested subjects[8-10].

The use of other criteria of maximum effort determination, separated or combined, has also been previously assessed. Duncan et al.[9] observed the incidence of plateau in 50% of the subjects tested in two ergometric protocols, although the [Lac] and RER criteria had been reached by a higher number of individuals (90-100%). Similar results were obtained by Doherty et al.[11], in which RER and HR were satisfied by more than 60% of the subjects, although the plateau had only been reached by less than 40% of these subjects. When the onset of different criteria of maximum effort between elite athletes and sedentary individuals was compared, using analyses similar to the ones in the present study (RER > 1.1; HR_{max} > 95% of maximum expected by age; [Lac] > 8 mM), but a distinct definition of plateau ($\Delta VO_2 < 1.5$ mL kg-1(min-1)), Lucia et al.[27] observed that the RER was met in 100% of the volunteers. However, significant differences between athletes and sedentary individuals were found for the onset of HR criterion (82% for athletes and 68% for sedentary subjects), for [Lac] (84% and 73%, for athletes and sedentary subjects, respectively), and for the plateau (47% for athletes and only 24% for sedentary subjects). Lacour et al.[28] attribute the onset of plateau in high levels of blood lactate reached by their subjects. [Lac] was assessed at the end of the test and during recovery and results lower in the group which presented plateau were observed (~6 mM) compared to the ones who obtained higher indices (~8 mM). Difference in the VO_{2max} between groups was not observed. The outcomes of the present investigation are in agreement with the ones by Lacour et al.[28]. Using statistical techniques for the plateau determination and different criteria for RER and HR, Poole et al.[29] concluded that the use of these criteria is not in fact determinant for VO_{2max} validation.

Considering that the plateau of oxygen consumption onset as well as of other criteria used for VO_{2max} determination is influenced by the choice of the ergometric protocol and that differences in this onset do not indicate distinct VO_{2max} values between protocols, it can be concluded that the general use of plateau or other criteria of maximum effort for comparison of different ergometric tests does not seem to be adequate.

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