

The influence of a fast ramp rate on peak cardiopulmonary parameters during arm crank ergometry

Renata R. T. Castro^{1,2,3}, Sabrina Pedrosa¹, Fernanda Chabalgoity¹, Eduardo B. Sousa¹ and Antonio C. L. Nobrega³

¹Exercise Physiology Laboratory, National Institute of Traumatology and Orthopedics, Rio de Janeiro, ²Post-graduate Program in Clinical and Experimental

Pathophysiology, Rio de Janeiro's State University, Rio de Janeiro, and ³Department of Physiology and Pharmacology, Federal Fluminense University, Niterói, Brazil

Summary

Correspondence

Renata R. T. de Castro, Exercise Physiology Laboratory, National Institute of Traumatology and Orthopedics, Rua Washington Luis, 61, 9th floor, Centro- Rio de Janeiro, RJ 20230-024, Brazil
E-mail: castrorrt@gmail.com

Accepted for Publication

Received 4 December 2009;
accepted 29 June 2010

Key words

arm ergometry test; exercise test; exercise tolerance;
maximal oxygen consumption

The influence of a very fast ramp rate on cardiopulmonary variables at ventilatory threshold and peak exercise during a maximal arm crank exercise test has not been extensively studied. Considering that short arm crank tests could be sufficient to achieve maximal oxygen consumption (VO_2), it would be of practical interest to explore this possibility. Thus, this study aimed to analyse the influence of a fast ramp rate (20 W min^{-1}) on the cardiopulmonary responses of healthy individuals during a maximal arm crank ergometry test. Seventeen healthy individuals performed maximal cardiopulmonary exercise tests (Ultima Cardio2; Medical Graphics Corporation, St Louis, USA) in arm ergometer (Angio, LODE, Groningen, The Netherlands) following two protocols in random order: fast protocol (increment: 2 W/6 s) and slow protocol (increment: 1 W/6 s). The fast protocol was repeated 60–90 days after the 1st test to evaluate protocol reproducibility. Both protocols elicited the same peak VO_2 (fast: 23.51 ± 6.00 versus slow: $23.28 \pm 7.77 \text{ ml kg}^{-1} \text{ min}^{-1}$; $P = 0.12$) but peak power load in the fast ramp protocol was higher than the one in the slow ramp protocol (119 ± 43 versus $102 \pm 39 \text{ W}$, $P < 0.001$). There was no other difference in ventilatory threshold and peak exercise variables when 1st and 2nd fast protocols were compared. Fast protocol seems to be useful when healthy young individuals perform arm cardiopulmonary exercise test. The usefulness of this protocol in other populations remains to be evaluated.

Introduction

Interest in the physiological responses to upper-body exercise has grown in recent years. Thus, arm ergometers are not as difficult to be found in exercise laboratories nowadays as they were in the last decade. Assessing upper-arm exercise, physiological responses can be very useful in different situations, ranging from patients with lower extremities disabilities (Ilias et al., 2009) to high-performance athletes of kayaking, swimming and canoeing (Obert et al., 1992; Forbes & Chilibeck, 2007).

Several important parameters must be defined when applying arm ergometry to evaluate athletes or patients. Some studies have focused on the influence of crank rates in attaining peak oxygen consumption during incremental arm ergometry and concluded that crank rates around 70 cycles per minute are optimal (Smith et al., 2001, 2007). Other studies focused on the profile of work increment. The comparison between continuous and step protocols elicited comparable values of peak oxygen

consumption, ventilation and heart rate responses (Sawka et al., 1983; Washburn & Seals, 1983; Walker et al., 1986; Smith et al., 2004). Currently, the continuous increment ramp protocol is widely used not only in treadmill and bicycle exercise tests (Buchfuhrer et al., 1983) but also in arm ergometry (Forbes & Chilibeck, 2007; Ilias et al., 2009).

When small muscle groups are exercised as in arm ergometry, most individuals are not physically conditioned to sustain prolonged exercise, thus local fatigue can lead to exercise interruption before maximal oxygen consumption is achieved (Phillips et al., 1998; Levine, 2008). Considering that the ramp protocol is usually programmed to achieve maximal effort around ten minutes for leg exercise (Myers & Bellin, 2000), and the suggested crank rate is 70 rpm for arm exercise, around 700 crank rotations are planned to occur during a typical maximal exercise test with the same duration of leg exercise. This protocol might be too long, potentially leading to precocious exercise interruption before peak oxygen consumption is achieved (Jameson & Ring, 2000).

Smith et al., (2006) compared two different ramp rates during arm crank ergometry. They concluded that peak VO_2 and peak heart rate are not influenced by ramp rate in tests where time to fatigue is between 8 and 16 minutes. Nevertheless, they found that peak VCO_2 , work rate and respiratory exchange ratio are variables that suffer influence from the ramp rate. Considering that even shorter arm crank tests could be sufficient to achieve peak VO_2 , it would be of practical interest to explore this possibility. To our knowledge, the influence of a faster ramp rate in cardiopulmonary variables at ventilatory threshold and peak exercise has never been studied.

Thus, the main objective of this study was to analyse the influence of a fast ramp rate (20 W min^{-1}) on the cardiopulmonary responses of health individuals during a maximal arm crank ergometry test. As a second objective, reproducibility of the proposed fast ramp rate protocol was assessed.

Methods

Volunteers

Seventeen individuals were selected for the study among our hospital staff and students of our University. All of them were considered healthy based on clinical evaluation and a maximal exercise test in a cycle ergometer. The exclusion criteria were use of any medication, except oral contraceptives, and chronic diseases. None of the volunteers were acquainted to arm crank exercise.

All volunteers gave written informed consent to participate in the study after full explanation of the procedures and their potential risks. The investigation conformed to the principles outlined in the Declaration of Helsinki and have been approved by the Institutional Research Ethics Committee on Human Research.

Study protocol

The study included four visits of each volunteer to the Laboratory. On the first visit, volunteers underwent a maximal exercise on a cycle ergometer (Excalibur Sport, Lode, Groningen, The Netherlands), according to an individualized ramp protocol, with initial work load of 50 W and 15 s increments set to achievement of maximal effort in 8–12 min, considering individual physical activity habits, gender, body mass index and age. This first test was used for the subjects to get familiarized with the laboratory and to the cardiopulmonary exercise test facial mask (Ultima Cardio₂; Medical Graphics Corporation, St Louis, USA), as well as to determine each individual's exercise tolerance.

In the second and third visits, each individual performed a maximal cardiopulmonary exercise test on an electronically braked arm ergometer (Angio, Lode, Groningen, The Netherlands) following linear ramp protocols with different increments every six-seconds: fast ramp: $2 \text{ W (} 20 \text{ W min}^{-1}\text{)}$; slow ramp: $1 \text{ W (} 10 \text{ W min}^{-1}\text{)}$. Each individual was carefully

positioned on the ergometer so that the rotational axis of the glenohumeral joint was at the same level as the axis of the ergometer's crank arm. All tests started with a warm-up period of one minute duration with a 30 W workload. Individuals were instructed to maintain a 70 rpm crank rate during both tests. The crank rate was used as the principal criterion to determine fatigue; thus, a failure to maintain a crank rate above 60 cycles per minute resulted in termination of the test.

The first three visits were separated by at least 2 days. All tests were performed in the afternoon. The potential effect of test sequence was controlled by using a counterbalanced design, where volunteers were randomly, but evenly (50%–50%) assigned to fast ramp–slow ramp or slow ramp–fast ramp protocols, in the second and third days of the study.

After the analysis of the first three tests, all individuals were invited to return to the laboratory and perform another fast ramp protocol. This test happened 2–3 months after the first trial and was performed to evaluate the reproducibility of the proposed protocol. Two of the 17 volunteers could not be contacted and did not participate in this reproducibility phase of the study. All 15 individuals kept their usual physical activity during this period.

Cardiopulmonary exercise test

Cardiopulmonary exercise tests were performed with gas exchange and ventilatory variables being analysed breath-by-breath using a calibrated computer-based exercise system (Ultima Cardio₂ System). The O_2 and CO_2 analyzers were calibrated before each test using a reference gas (12% O_2 ; 5% CO_2 ; nitrogen balance). The pneumotachograph used was also calibrated, with a 3-L syringe using different flow profiles.

Oxygen consumption (VO_2), carbon dioxide production (CO_2) and minute ventilation (V_E) were registered breath-by-breath. Derived variables were calculated online (Breeze Software 6.4.1, Medical Graphics, St. Paul, MN, USA). Ventilatory threshold was identified by two experienced evaluators by the combination of the following methods: (Ilias et al., 2009) at the point of upward inflection of the ventilation vs. time curve (Fig. 1a); (Forbes & Chilibeck, 2007) at the beginning of a consistent increase in the ventilatory equivalent for O_2 (minute ventilation/oxygen consumption) without a concomitant increase in the ventilatory equivalent for carbon dioxide (minute ventilation/carbon dioxide production) (Fig. 1b); and (Obert et al., 1992) at the beginning of an increase in expired oxygen fraction (Fig. 1c). Ventilatory threshold was considered as the point identified by at least two of these three criteria. There was no case in which each of the criteria identified different thresholds. Peak variables were defined as the maximum individual value of each variable during the final 30 s of exercise.

During each cardiopulmonary exercise test, 12-lead electrocardiogram was continuously recorded (Cardioperfect, Welch Allin, USA) and heart rate registered.

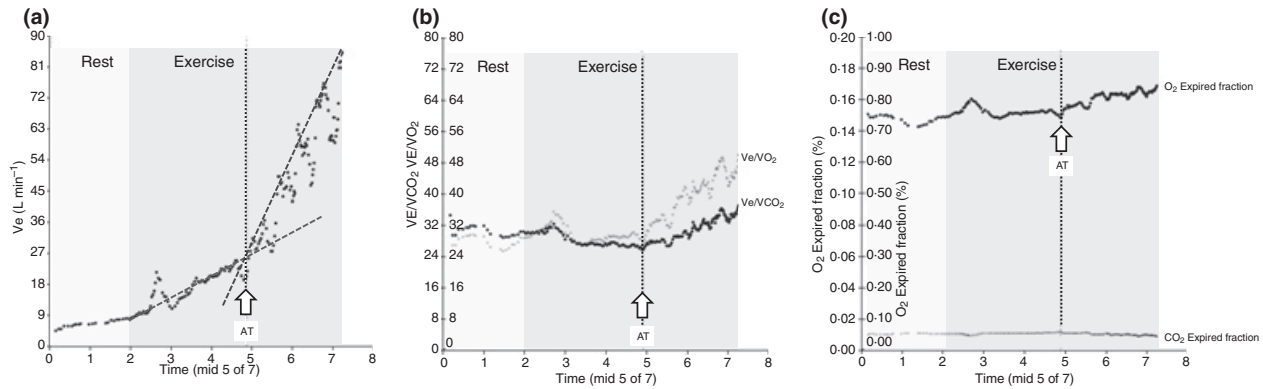


Figure 1 Example of methods used to detect ventilatory threshold. Arrows shows ventilatory threshold (AT) when each of the following methods were used: a) point of upward inflection of the ventilation vs. time curve; b) beginning of a consistent increase in the ventilatory equivalent for O₂ (Ve/VO₂) without a concomitant increase in the ventilatory equivalent for carbon dioxide (Ve/VCO₂); c) the beginning of an increase in expired oxygen fraction.

Statistical analysis

Statistical analysis was performed using the software Statistica 7.0 (Statsoft Inc, Tulsa, OK, USA). Descriptive data are presented as mean $\pm$ SD of the mean. Based on a pilot study, a sample size of 11 patients was estimated to detect a 10% difference in the exercise economy, with an alpha error of 0.05 and power of

0.90. Variables from the cardiopulmonary exercise tests showed normal distribution when analysed by the Shapiro Wilk's-W test. Variables obtained during fast and slow ramp tests were compared by the paired t-test. Reproducibility of fast ramp protocol was assessed by intraclass correlation and Bland-Altman plot. Significance was set at $P < 0.05$.

Results

Seventeen volunteers were enrolled in the study. Their demographic data is presented in Table 1.

As expected, when fast ramp protocol was performed, maximal effort was achieved in shorter time ($05'23'' \pm 2'09''$) when compared to the slow ramp protocol ($7'59'' \pm 3'53''$; $P < 0.01$). Ventilatory and heart rate data in ventilatory threshold and peak exercise are presented in Table 2. Except for the peak power load, which was higher in fast ramp protocol, there were no differences between the studied protocols. As expected, peak VO₂ during arm crank ergometry

Table 1 Demographic data of volunteers included in the study (n = 17).

Male: female	8:9
Age (years)	27 ± 4
Body mass index (kg m ⁻²)	23.4 ± 2.8
Peak VO ₂	32.1 ± 8.4

Data presented as mean $\pm$ SE.

Peak VO₂, Peak oxygen consumption achieved in cardiopulmonary exercise test performed on a cycle ergometer.

Table 2 Ventilatory threshold and peak exercise data during arm ergometry following fast and slow ramp protocols.

	Fast ramp protocol	Slow ramp protocol	P-value
Ventilatory threshold			
VO ₂ (ml kg ⁻¹ min ⁻¹)	11.78 ± 2.50	13.22 ± 5.61	0.28
VCO ₂ (ml min ⁻¹)	799.00 ± 285.37	958.53 ± 490.58	0.12
Ve (l min ⁻¹)	22.88 ± 6.41	27.36 ± 12.85	0.13
Breath rate (br min ⁻¹)	25 ± 5	26 ± 5	0.25
Heart rate (beats min ⁻¹)	126 ± 12	132 ± 15	0.12
Power (W)	53 ± 20	58 ± 26	0.12
Peak exercise			
VO ₂ (ml kg ⁻¹ min ⁻¹)	23.51 ± 6.00	23.28 ± 7.77	0.84
VCO ₂ (ml min ⁻¹)	$2205.12 \pm .52$	2076.88 ± 768.63	0.21
Ve (l min ⁻¹)	77.48 ± 30.87	73.52 ± 28.49	0.34
Breath rate (br min ⁻¹)	51 ± 12	51 ± 11	0.98
Heart rate (beats min ⁻¹)	166 ± 15	169 ± 20	0.82
Power (W)	119 ± 43	102 ± 39	<0.001
Respiratory quotient	1.35 ± 0.13	1.31 ± 0.21	0.26

Table 3 Ventilatory threshold and peak exercise data during arm ergometry following fast ramp protocols on two different days separated by 60 to 90 days.

	1st fast protocol	2nd fast protocol	r^2 (P)
Ventilatory threshold			
VO ₂ (ml kg ⁻¹ min ⁻¹)	11.78 ± 2.50	12.71 ± 2.71	0.65 (0.009)
VCO ₂ (ml min ⁻¹)	799.00 ± 285.37	874.33 ± 332.55 ^a	0.86 (<0.001)
Ve (l min ⁻¹)	22.88 ± 6.41	24.98 ± 8.08	0.83 (<0.001)
Breath rate (br min ⁻¹)	25 ± 5	26 ± 6	0.59 (0.020)
Heart rate (beats min ⁻¹)	126 ± 12	129 ± 18	0.12 (>0.05)
Power (W)	53 ± 20	58 ± 23 ^a	0.84 (<0.001)
Peak exercise			
VO ₂ (ml kg ⁻¹ min ⁻¹)	23.51 ± 6.00	23.73 ± 6.21	0.67 (0.008)
VCO ₂ (ml min ⁻¹)	2205.12 ± 744.52	2125.07 ± 871.12	0.91 (<0.001)
Ve (l min ⁻¹)	77.48 ± 30.87	72.82 ± 29.07	0.91 (<0.001)
Breath rate (br min ⁻¹)	51 ± 12	51 ± 13	0.64 (0.013)
Heart rate (beats min ⁻¹)	166 ± 15	167 ± 19	0.61 (0.018)
Power (W)	119 ± 43	112 ± 41	0.98 (<0.001)

^at-test: P < 0.05 versus 1st protocol.

was smaller than in the bicycle tests (peak VO₂ in arm ergometry/peak VO₂ in bicycle: 75 ± 3%).

Fifteen volunteers repeated the fast protocol for reproducibility evaluation. Although VCO₂ and power during the ventilatory threshold were higher in the 2nd test, there were no differences between variables measured at peak effort when both fast ramp rate tests were compared (Table 3). Table 3 also shows the good reproducibility of most variables when the two tests that followed fast protocol were compared. Figure 2 shows Bland–Altman plots of peak variables so that test–retest reliability of fast ramp protocol can be accessed.

Discussion

The continuous increment ramp protocol is widely used in clinical and experimental settings, with a variety of ergometers

being used. The American Thoracic Society/American College of Chest Physicians cardiopulmonary exercise guidelines (Ross, 2003) recommend 8–12 min as the desired duration of ramp exercise protocol. This recommendation is based on data generated from exercise tests performed in treadmill and bicycle (Buchfuhrer et al., 1983). However, exercise involving smaller muscle mass, such as during arm ergometry, may lead to precocious fatigue before peak VO₂ is reached. In addition, considering practical issues, it would be desirable to employ shorter tests as long as it would be sufficient to provoke enough physiological strain so that the subject would achieve maximal VO₂. Actually, Burnley et al., (2006) showed that a 3-min all-out exercise test performed on a cycle ergometer is sufficient to achieve peak VO₂. Nevertheless, all-out tests are not progressive and, thus, important information regarding ventilatory threshold cannot be obtained, diminishing their utility in clinical

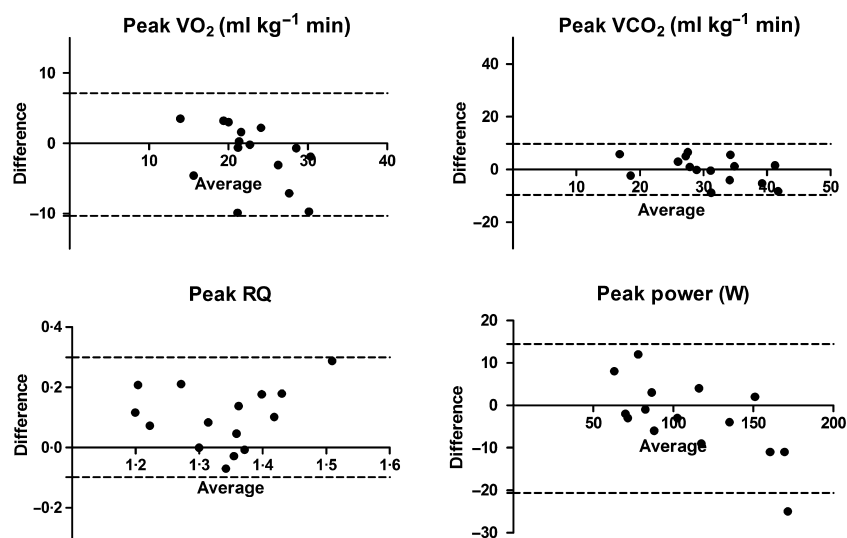


Figure 2 Bland–Altman plot of test–retest differences against test–retest means and 95% confidence interval limits for peak variables during arm ergometry following fast ramp protocol in healthy individuals. VO₂: oxygen consumption; VCO₂: Carbonic gas production; RQ: respiratory quotient (VCO₂/VO₂).

setting. Although other authors have studied fast arm ergometry protocols (Smith et al., 2006), to our knowledge, the present study proposes and validates an incremental protocol where duration has not been previously tested.

In the present study, the same peak VO_2 was achieved in two different ramp rates during arm ergometry where exercise time was not the same. Fast protocol elicited the achievement of peak VO_2 with an average of 5'23" test duration. This is shorter than the 8–12 min duration that is usually recommended for exercise incremental test in healthy subjects (????, 2003). Except for peak power, there was no difference between peak exercise variables in both protocols, and all variables showed a high degree of reproducibility when fast protocol was repeated. Thus, this study expands the previous findings regarding ramp rates during arm ergometry tests. Smith et al., (2006) found that differences in ramp rate within the range of 6–12 W/min influence the peak values of work rate, VCO_2 and respiratory quotient (RQ) but do not influence peak values of VO_2 or heart rate during arm crank ergometry. The present study has shown that ramp rate within the range of 10–20 W min^{-1} do not influence VO_2 , VCO_2 , RQ, ventilation, breath rate and heart rate during ventilatory threshold and peak exercise.

As previously shown in bicycle tests (Benzo et al., 2007), we found that different ramp increments in arm ergometry can produce differences in peak power, although not differing in peak VO_2 values. This is important information because maximal workload is sometimes used as predictor of mortality, as in patients with chronic pulmonary obstructive disease (Martinez et al., 2006). The present results reinforce the concept that the same protocol should be followed when longitudinal comparisons are performed. If the same protocol cannot be used, peak VO_2 seems to be a more reliable exercise tolerance parameter than peak power load.

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A recent study evaluated the reproducibility of peak VO_2 in healthy females during incremental arm ergometry test (Leicht et al., 2009) and found that, although respiratory variables exhibited substantial intra-individual variability, peak VO_2 showed high reproducibility in tests separated by 7- to 11-day interval. This study (Leicht et al., 2009) only tested female active volunteers, who were used to arm ergometry testing. The present study has shown good reproducibility of peak and ventilatory threshold variables even in individuals who had never exercised on arm ergometer previously and with a 60- to 90-day interval between tests.

The current results are limited to healthy individuals not engaged in sports activity whose movements are predominantly performed with the arms. Considering that arm ergometry is used in individuals with lower-leg disabilities and athletes who practise upper-body sports, it is desirable that the fast protocol is tested in other specific populations.

Conclusions

Exercise exhaustion was achieved in five minutes when fast protocol was used. This protocol elicited the achievement of the same peak oxygen consumption with higher peak power when compared to the slow protocol. Fast protocol has shown high reproducibility of cardiopulmonary variables when repeated 60–90 days. Thus, fast protocol seems to be useful when cardiopulmonary exercise test in arm ergometer is performed by healthy young individuals. The usefulness of this protocol in other populations remains to be evaluated.

Conflict of interest

The authors declare no conflict of interest regarding this study.

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