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ABSTRACT

This study compared cardio-respiratory and perceived exertion responses for four cranking rates (50, 60, 70 and 80 rpm) during a continuous maximal arm ergometry protocol in order to determine the most efficient cranking rate for maximal testing. Fifteen male volunteers from 18-30 years of age performed a continuous arm ergometry stress test in the sitting position using a Modified Schwinn Ergometric Model EX2-0 ergometer modified for arm work. After completion of the tests, subjects were asked to compare overall rates as to which were easiest and most difficult. Analysis of the resulting data indicated that the majority of subjects ranked slower cranking rate within a given comparison as the most difficult rate; the fastest cranking rate was rated as being the easiest overall. Since higher metabolic data was obtained at 80 rpm, it was concluded that in testing, the higher cranking rates should be used. Details of the instruments used in the study are discussed and test results are displayed on tables. (JD)

CARDIO-RESPIRATORY AND PERCEIVED EXERTION RESPONSES TO DIFFERENT CRANKING RATES DURING MAXIMAL ARM ERGOMETRY

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ABSTRACT

CARDIO-RESPIRATORY AND PERCEIVED EXERTION RESPONSES TO DIFFERENT CRANKING RATES DURING MAXIMAL ARM ERGOMETRY

The purpose of this study was to compare cardio-respiratory and perceived exertion (RPE) responses to four cranking rates (50, 60, 70, & 80 rpm) during maximal arm ergometry in order to determine the most efficient cranking rate for maximal testing. Fifteen healthy male subjects (aged 18-30) performed continuous maximal arm ergometry (Modified Schwinn Ergometric Exerciser Model EX2-0) exercise tests at the four cranking rates. The initial exercise load was 300 kgm/min and was sequentially increased every 2 min by 150 kgm/min until the subject could no longer maintain the metronome-paced cranking rate. HR was recorded from the ECG, and VO2, VE, and respiratory frequency were obtained using a Beckman MMC. Borg's 15-point graded category scale was used to obtain RPE. All variables were measured each min and for five min of recovery. Treatment order was randomized and performed on separate days. VE and VO2 max were significantly higher ($p < .05$) at 80 rpm than for all other cranking rates. HR max was significantly ($p < .05$) higher at 80 rpm than at 50 or 60, while there was no significant ($p > .05$) difference between HR max at 70 and 80 rpm. There was no significant difference ($p > .05$) between cranking rates for RPE, total endurance time, O2 pulse, or VE/VO2. Since no difference existed in RPE between cranking rates and higher metabolic data was obtained at 80 rpm, the authors concluded that in testing asymptomatic individuals the higher cranking rates should be utilized.

Key words: Arm ergometry, oxygen uptake, cranking rates

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INTRODUCTION

Current trends in the development of exercise equipment continue to effectively eliminate the sedentary lifestyle resulting from many kinds of illness and injury. Evidence suggests that endurance training can significantly enhance cardiovascular function and possibly reduce the risk of cardiovascular disease in the normal mobile population. Additionally, studies (1,2) have shown that arm training programs can signficiantly increase the cardio-respiratory function of persons with various types of lower extremity disabilities. Initial maximal arm ergometry stress test evaluations would enhance the safety and efficiency of these arm training programs; however, little work has been conducted to indicate the most appropriate maximal arm testing protocols.

Previous work from our laboratory (3) has shown that the sitting position was the most appropriate position for maximal arm testing and submaximal arm training (4) when compared to upright and supine postures. Additional work (5) has shown 70 rpm to be the most appropriate submaximal arm cranking rate for paraplegics. Therefore further investigation was believed warranted to determine the ideal arm cranking rate(s) to be used during maximal stress tests. Therefore, the purpose of this study was to compare cardio-respiratory and perceived exertion (RPE) responses to four cranking rates (50, 60, 70 & 80 rpm) during a continuous maximal arm ergometry protocol in order to determine the most efficient cranking rate for maximal testing.

METHODS

Fifteen healthy male volunteers ranging in age from 17-30 years of age with a mean of 22.6 years served as subjects. Signed informed consent was obtained. Subjects performed a continuous arm ergometry stress test in the sitting position using a Schwinn Ergo-metric model Ex 2-0 cyle ergometer modified for arm work. The ergometer was firmly positioned on a table such that the axis of the rotary mechanism of the ergometer was horizontal with the glenohumeral joint of the subject. The ergometer was adjusted to allow full extension of the arms during rotation. The legs were crossed and bound to the chair.

The testing order for the different cranking rates was randomly assigned and performed on separate days. The initial exercise load was 300 kgm/min and the workload was increased every two minutes by 150 kgm/min until the subject could no longer maintain the metronome paced cranking rate. Subjects also received visual cranking rate feedback from the RPM dial on the modified ergometer.

Heart rate was recorded from the ECG during the last 10 seconds of each minute on a Burdick single channel recorder. Pulmonary ventilation (VE), oxygen uptake (VO2), and respiratory exchange ratio (RER) were obtained each minute during exercise and for five minutes of recovery on a Beckman metabolic measurement cart (MMC). Standard calibration procedures were used for the ergometer and MMC (6,7). A Sholander verified calibration gas of

16% O_2 and 4% CO_2 was used to calibrate the O_2 and CO_2 analyzers, respectively. The Borg (8) fifteen-point graded category scale was used to obtain ratings of perceived exertion. Since subjects could not speak due to the non-rebreathing valve they were trained to nod their head when the investigator pointed to the appropriate number on the Borg scale comparable to their perceived effort.

A questionnaire was devised for the subjects to express their cranking rate preference. Subjects completed the questionnaire immediately following the recovery phase of the 2nd, 3rd and 4th tests. The comparisons were: more difficult, less difficult, and no difference. After completion of the tests subjects were asked to compare overall rates as to which was easiest and most difficult.

Data were analyzed using a one-way analysis of variance (ANOVA) with repeated measures. A Duncan's New Multiple Range test was used for post hoc analysis. All values were tested for significance at the $\alpha=.05$ level.

RESULTS

The ANOVA for total endurance time (TET), respiratory exchange ratio (RER), rating of perceived exertion (RPE), oxygen pulse (O_2 pulse), and ventilatory equivalent (VE/VO_2) revealed no significant ($p > .05$) difference between cranking rates (See Table 1).

Although not significantly different ($p=.07$) VE/VO_2 and O_2 pulse show a relatively linear increasing pattern as cranking rates increased.

The ANOVA for maximal heart rate provided a significant ($p < .05$) F-ratio of 3.65. The Duncan's post hoc analysis indicated that maximal HR was significantly greater at 80 rpm than at 50 or 60 rpm(s), while no significant differences existed between all other comparisons for maximal heart rate (See Table 2).

The ANOVA for maximum pulmonary ventilation provided a significant ($p < .05$) F-ratio of 7.18. The post hoc analysis indicated that maximal VE was significantly ($p < .05$) greater at 80 rpm than at 50, 60, or 70 rpm. This test also indicated that maximal VE was significantly greater at 70 than at 50 rpm while there were no significant differences for VE max between 70 and 60 rpm or between 60 and 50 rpm(s).

The ANOVA for maximal oxygen consumption (VO2 max) provided a significant ($p < .05$) F-ratio of 5.60. The data analyses indicated that maximal VO2 was significantly higher ($p = .05$) at 80 rpm than at 50, 60, or 70 rpm(s). No significant differences existed between all other comparisons for VO2 max.

Data displayed in Table 3 indicate results of the rate comparison questionnaire where subjects compared their just completed cranking rate to their previous rate. The comparisons were more difficult, less difficult, and no difference. The questionnaire results indicated that the majority of subjects ranked the slower cranking rate within a given comparison as the most difficult rate. On the overall comparison the slowest cranking rate (of 50 rpm) was rated as the most difficult by 67% of the subjects. The fastest cranking rate (80 rpm) was rated as being the easiest overall by 73% of the subjects.

DISCUSSION

The results of the current investigation indicated that maximal HR was significantly higher ($p < .05$) when cranking at 80 rpm as compared to 50 or 60 rpm(s). These findings are indirectly in agreement with the results of Grimby, Hedbert, and Nording (9) who reported that at all submaximal work levels heart rate was higher when arm work was carried out at 75 rpm as compared to 50 rpm. The results of the current study conflicted with the findings of Alcala (10) who compared arm cranking rates for 50 and 80 rpms and reported that submaximal HR was significnatly higher at 80 rpm than at 50 rpm but his study failed to indicate significant differences in maximal HR for the two cranking rates. However, Alcala used a mechanically braked ergometer and did not equilabrate the power outputs at the different cranking rates.

Previous work by Edwards, et al. (11) and Henirich, et al. (12) studying maximal HR and VO2 responses to bike ergometry at varying cycling rates has shown that pedalling at low speeds ($\leq$ 30 rpm) and high seeds ($\geq$ 90 rpm) is associated with higher HR and VO2 values than the intermediate pedalling speeds at a given power output. Their observations on bike work indicated a parabolic function between these physiological responses and rpm.

Maximal oxygen uptake in the current study was significantly higher ($p < .05$) at 80 rpm than at 50, 60, or 70 rpm. These findings are indirectly in agreement with the work of Grimby et al. (9) who reported that at all submaximal work levels VO2 was higher when arm work was carried out at 75 vs. 90 rpm. The results of the current study are in agreement with the previously mentioned bike study by Edwards and others (11) who concluded that pedalling at high speeds (> 90 rpm) was associated with higher VO2 than intermediate pedalling speeds (50 - 80 rpm) at a given workload. Banister and Jackson (13) found that during bike work, alterations in the speed of pedalling at equivalent power outputs (360 - 2100 kgm/min) did not substantially change the VO2 for pedalling speeds between 50 and 80 rpm. The VO2 at higher pedalling speeds (100 and 120 rpm) was found to be greater when compared to lower speeds at similar power outputs. These authors' results seem to conflict with the results of the current study; however, observation of our subjects during arm cranking at 80 rpm indicates that this is possibly the highest rate of cranking that can be consistently maintained with the arms for a prolonged period. Consequently attempts to compare metabolic data obtained in arm and bike studies at specific cranking or pedalling rates may be impossible. Since an arm cranking rate of 80 rpm may be comparable to bike pedalling rates of greater than 100 rpm in terms of task difficulty.

In the current study maximal pulmonary ventilation (VE max) was significantly ($p < .05$) higher at 80 rpm as compared to 50, 60, or 70 rpm(s). These findings are directly in agreement with the findings of Lollgen, et al. (14) who reported significantly higher ($p < .05$) VE max values at 100 rpm vs 40 and 60 rpm and significantly higher VE at 80 vs. 40 rpm during bike work at equal power outputs.

The results of the current investigation indicated that there were no significant differences ($p < .05$) in rating of perceived exertion (RPE) between the different cranking speeds, although the higher cranking rates elicited significantly higher values for HR and VO2. Studies by Lollgen, Ulmer and Nieding (15), Pandolf and Noble (16), and Stanford and Noble (17) have reported that in bike work at various pedalling rates, the same power output is perceived differently, being minimal at rates of 60 to 80 rpm. In addition subjects in these experiments expressed a preference for higher pedalling rates. Results of the Rate Comparison Questionnaire in the current study indicated that 73% of the subjects felt the 80 rpm was the easiest overall, while 67% felt that the 50 rpm cranking rate was most difficult overall.

The fact that RPE was generally the same at the higher cranking rates as the lower may have application to submaximal arm training, since subjects may have a tendency to adhere to training programs better if allowed to crank at a faster rate. However, this assumption must be experimentally tested since submaximal HR and metabolic responses may not follow a similar pattern.

The cardio pulmonary changes (HR, VE, VO2) associated with the faster limb movements at the higher cranking rates are probably contributable to increased proprioceptive output from the working joints and muscles. Future studies designed to differentiate between central and peripheral contributions to the rating of perceived exertion could yield important information regarding the perception of effort during arm work.

The purpose of a stress test designed to assess maximal aerobic capacity is to obtain peak values for VO2 and HR for a given subject using a given mode of exercise. Data from the current investigation suggest that during arm ergometry stress testing, higher maximal metabolic and HR values will be obtained using a cranking rate of 80 rpm as compared to the other rates tested. Additionally, a majority of the subjects expressed a preference for the faster cranking rates.

TABLE 1

Within Treatment, F-Ratios and Probability of Greater F for all Variables from one way ANOVA

Variables	Units	F-Ratio*	P > F**
Ventilation	L/min	7.177	P < .05
Maximal Oxygen Consumption	L/min	5.588	P < .05
Maximal HR	bpm	3.652	P < .05
Total Endurance Time	sec	.018	.99
Respiratory Exchange Ratio		.993	.43
Rating of Perceived Exertion		1.177	.33
Ventilatory Equivalent	L/L	2.482	.07
Oxygen Pulse	ml/beat	2.433	.07

* F-Test is the ratio of M.S. within treatment to M.S. error with 3/42 df.

** P>F is the probability that a random variable from an F distribution with 3/42 df will exceed the calculated value F, therefore, if this value is less than α =.05, one rejects the null hypothesis.

TABLE 2

Treatment Means and Largest Duncan's LSR Values

Variables	Units	TREATMENTS 1 50rpm	2 60rpm	3 70rpm	4 80rpm	Largest Duncan's LSR **
Ventilation	L/min	74.34 [b]	78.87 [ab]	83.28 [a]	91.5[illegible]	8.47
Maximal Oxygen Consumption	L/min	1.94 [a]	2.02 [a]	2.03 [a]	2.18	.12
Maximal HR	bpm	171.27 [b]	171.93 [b]	174.47 [ab]	179.07 [a]	5.74
Total Endurance Time	sec	409.00 [a]	414.53 [a]	411.00 [a]	410.33 [a]	--
Respiratory Exchange Ratio		1.21 [a]	1.21 [a]	1.23 [a]	1.22 [a]	--
Rating of Perceived Exertion		18.27 [a]	18.80 [a]	18.27 [a]	18.47 [a]	--
Ventilatory Equivalent	L/L	38.52 [a]	39.19 [a]	41.22 [a]	41.87 [a]	--
Oxygen Pulse	ml/beat	11.35 [a]	11.80 [a]	11.74 [a]	12.14 [a]	--

* Treatment means with the same superscript are not significantly different from each other

** When differences between treatment means exceed the largest Duncan's LSR Value with (3/42 df) these means are considered significantly different.

TABLE 3

Comparison of Cranking Rates from Questionnaire

Comparison rpm	No Difference	Most Difficult Frequency rpm			
		50	60	70	80
50 - 60	2	10	3		
50 - 70	1	8		6	
50 - 80		11			4
60 - 70	1		8	6	
60 - 80			11		4
70 - 80	2			8	5
Easiest Overall	2		2		11
Most Difficult Overall		10	2	1	2

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