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INFLUENCE OF VARIED, CONTROLLED DISTANCES FROM THE CRANK AXIS ON PEAK PHYSIOLOGICAL RESPONSES DURING ARM CRANK ERGOMETRY

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ABSTRACT

INFLUENCE OF VARIED, CONTROLLED DISTANCES FROM THE CRANK AXIS ON PEAK PHYSIOLOGICAL RESPONSES DURING ARM CRANK ERGOMETRY. **Thomas L. Miller, Carl G. Mattacola, Mayra C. Santiago**. **JEP**online 2004;7(3):61-67. The purpose of the study was to determine the influence of varied, controlled distances from the crank axis during arm crank ergometry (ACE) on peak physiological responses and physical work capacity (PWC). Physiological responses to ACE were evaluated using three controlled distances from the crank axis based on 0°, 15°, and 30° from full extension in the elbow while at the furthest point in the crank rotation. Eleven adult, able-bodied women (age = 24.5 ± 4.7 yrs) performed graded maximal ACE tests at each of three distances from the crank axis. Data were analyzed for differences in peak physiological responses and PWC between the three positions. VO_2peak at 30° (1.33 L/min) was lower ($F(2,20) = 7.171$, $p < 0.01$) than at 0° (1.42 L/min) or at 15° (1.41 L/min). No differences existed between the three distances for any other dependent variable. We conclude that distance from the crank axis during ACE influences VO_2peak values, and thus should be controlled for when using ACE to predict aerobic fitness.

Key Words: Oxygen Consumption, Exercise Testing, Body Position.

INTRODUCTION

Assessment of exercise tolerance and aerobic fitness levels using exercise-testing protocols provides important health risk information. The most widely accepted modes of exercise testing are treadmill and cycle ergometry. These exercise modes use many of the largest muscle groups in the body and typically elicit the greatest physiological values (e.g., VO_2max) (1, 2). However, such testing modes are usually not appropriate for all individuals or situations (e.g., individuals with lower extremity impairments; assessment of upper body muscular capacity, function, or exercise tolerance). VO_2peak values recorded from upper body maximal exercise tests have been validated as predictors of aerobic fitness (3) and as a diagnostic tool for CVD (2,4). Arm crank ergometry (ACE) is a commonly used upper body testing modality that provides a practical and convenient means of assessing cardio-respiratory fitness in clinical and laboratory settings (1,5-8).

Reproducible exercise testing measures are needed to relate aerobic fitness to health risk (9), as well as to design and modify training programs for exercise performance (10). Standardizing protocols for any type of exercise test is critical in order to control for consistency in exercise stimuli. Changes in body position during exercise can cause alterations in muscle mass recruitment and/or working joint angles, which subsequently can change muscle loading. For example, findings in a study by Nordeen-Snyder (11) demonstrated that alterations in seat height changed mechanical efficiency during leg cycling.

A small number of studies have focused on variations to ACE protocols and the resulting physiological responses (12-16). However, the question of how distance from the crank axis affects peak physiological values during ACE has not been addressed. Furthermore, the distance from the crank axis as described in numerous study protocols has been inconsistent (17-19). Varying the distance from the crank axis and/or not controlling for it during the test may alter energy requirements and/or the amount of muscle mass recruited. Subsequently, the physical stress per unit of muscle mass may also vary and alter peak physiological responses to the work effort. We hypothesized that three distinct, controlled distances from the crank axis during ACE will elicit variations in VO_2peak values and/or PWC.

METHODS

Eleven able-bodied, adult women gave informed consent to participate in the protocol that was approved by Temple University's Institutional Review Committee for the Protection of Human Subjects. Participants had above average physical activity levels as determined by a physical activity questionnaire, and participants were of moderate upper body strength as assessed by a grip strength test. Preliminary data from a comparable sample population (N = 25) indicated that bilateral grip strength was a moderate predictor of VO_2peak during ACE (right & left grip, r = 0.58 & 0.63, respectively, $p < 0.05$).

All tests were performed on a Saratoga Cycle ergometer (Saratoga Access and Fitness, Fort Collins, CO) shown in Figure 1. The ergometer was modified with a tension mechanism from a Monark 818 leg cycle ergometer (Monark Exercise AB, Varberg, Sweden) in order to calibrate work rate in watts (W). All equipment specified below was manufactured by Saratoga Access and Fitness Corp. The three-way handgrips were used in the horizontal position. The ergometer was mounted onto an adjustable height ergometer table. A headrest, adjusted for height and reach, was used to provide control for distance from the crank axis. Revolutions of the crank axis were measured by a tachometer with digital display.

Figure 1. Saratoga Cycle ergometer modified with a Monark 818 tension mechanism. The faceplate was recalibrated for this device.

Oxygen consumption and associated variables were assessed by means of an open circuit, indirect calorimetry system using a Quinton Q-Plex I metabolic cart (Quinton Instrument Co., Bothell, WA). Prior to each testing session gas analyzers were calibrated with gases of known oxygen and carbon dioxide concentrations and the pneumotach was calibrated for integrated volume measurement with a 3 L syringe. Heart rate (HR) was measured by electrocardiography using a Quinton Q-4000 ECG (Quinton Instrument Co., Bothell, WA) with a pre-cordial CM-5 lead setup.

Three controlled distances from the crank axis were established based on full extension (0° from), 15° from, and 30° from full extension of the elbow at the furthest point in the crank rotation. Crank axis height was set to the level of participants' acromion processes of the scapulae. The headrest height was set to the level of participants' forehead. Participants were braced in the chair by a waist strap. When setting the distance from the crank axis, shoulders were in a relaxed, neutral position. With hands on the crank grips, the headrest and seat distance were set to attain the appropriate controlled distance from the ergometer. The front legs of the chair rested on metal plates attached to the ergometer table and the chair position was maintained with markings on the metal plates.

A familiarity session was conducted to acquaint participants with the exercise mode and instrumentation and to obtain preliminary measurements. Each participant was tested for right and left hand grip strength with a Baseline hydraulic handgrip dynamometer (Fabrication Enterprises, Inc., Irvington, NY). Settings for the three experimental positions were established, recorded, and standardized for future testing sessions. Participants were instructed to limit their physical exertion (i.e., exercise) for 24 hours prior to each testing session. Participants were requested to refrain from food and caffeinated beverages for at least 4 hours prior to testing. The first testing session was held no sooner than 24 hours after the familiarity session. Subsequent testing sessions were separated by at least 4 days.

Initially, each participant performed a 2-min warm-up at 10 W followed by a 2-min rest period. The test protocol began with a work rate of 25 W for 2 min, which was then increased to 50 W for 1 min, then 60 W for 1 min, followed by 5 W increases every min thereafter until volitional exhaustion or the participant could no longer sustain a crank rate of 60 rev/min. Expired air was collected continuously throughout the duration of each test and, at every 20-sec interval; averages for flow rate and fractions of expired oxygen and carbon dioxide were measured. Heart rates were recorded for the final 10 sec of every work stage and at the termination point of each test.

In an attempt to confirm attainment of a maximal effort, each of the three experimental positions was reproduced two times for a total of six experimental sessions. Data from the test that produced the highest VO_2peak value for each of the three experimental positions (n = 33) were used for subsequent statistical analyses of peak physiological parameters and PWC. In an effort to reduce possible learning effect influences on data results, a counter-balance model was used to assign the order of the experimental positions (20).

Data were analyzed using a SPSS statistical software package (version 10.0). Descriptive statistics (means and standard deviations) were obtained for all variables. One-way repeated measures ANOVAs across the three experimental conditions were run for each of the peak physiological parameters and PWC. For all analyses, statistical significance was set at $p < 0.05$. Any significant main effect for experimental condition was followed up by multiple comparisons using the Bonferoni adjustment technique.

RESULTS

The demographic and grip strength data for study participants are given in Table 1. Table 2 summarizes the means and standard deviations for peak measures and PWC.

A significant main effect for experimental condition (F(2,20) = 7.171, $p < 0.01$) revealed that VO_2peak at the distance based

Table 1. Demographic and grip strength data for participants (n=11)

Variable	Mean ± SD	Range
Age (yr)	24.5 ± 4.7	21 to 36
Weight (kg)	61.1 ± 6.9	54 to 74
Height (cm)	159.9 ± 7.4	145 to 168
Grip strength (kg)	68.2 ± 12.2	54 to 95

Grip strength = sum of right and left hand values.

on 30° from full elbow extension (1.33 L/min) was approximately 6% lower than the VO_2peak at the distances based on 0° (1.42 L/min) and 15° (1.41 L/min) from full elbow extension. No differences were detected between the three experimental conditions in any other peak variable (PWC, VCO_2, HR, VE, RER, V_E/VO_2, V_E/VCO_2). Figure 2 illustrates the consistency in sub-maximal VO_2 values at 25W and 50W workloads.

Table 2. Summary of peak measures and physical work capacity

Test Variables	0° (n=11)	15° (n=11)	30° (n=11)	All Tests (n=33)
PWC (W)	70.4 ± 9.1	70.9 ± 8.0	69.6 ± 7.2	70.3 ± 7.9
VO_2 (L/min)	1.42 ± 0.28	1.41 ± 0.27	1.33 ± 0.24*	1.39 ± 0.26
VCO_2 (L/min)	1.78 ± 0.34	1.81 ± 0.28	1.69 ± 0.25	1.76 ± 0.29
HR (beats/min)	168 ± 17	169 ± 16	170 ± 15	169 ± 16
V_E (L/min)	52.52 ± 12.84	53.86 ± 13.79	50.44 ± 9.62	52.27 ± 11.91
RER	1.27 ± 0.14	1.30 ± 0.11	1.28 ± 0.09	1.28 ± 0.11
V_E/VO_2	36.94 ± 6.36	38.00 ± 5.84	37.98 ± 2.51	37.64 ± 5.05
V_E/VCO_2	29.31 ± 2.83	29.61 ± 4.74	29.78 ± 2.25	29.57 ± 3.34

* denotes a significant difference from other positions ($p < 0.01$). Data are mean ± SD.

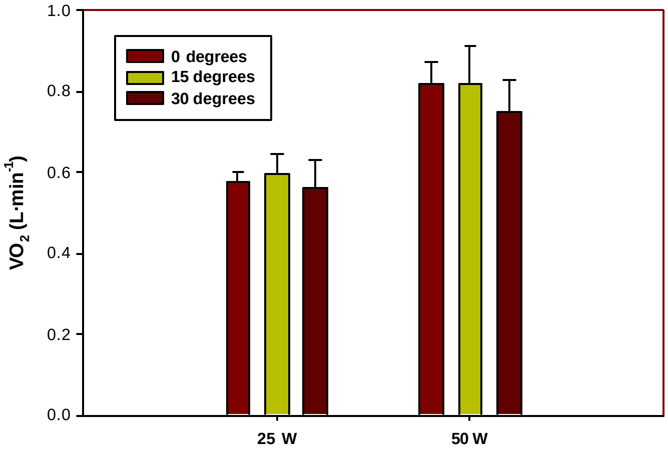

Figure 2. Submaximal VO_2 data at 25 W and 50 W workloads. The graph demonstrates the consistency in oxygen uptake at the end of each submaximal stage during the peak test despite the short duration of these stages. Data are mean ± SD.

DISCUSSION

The current study found that, except for VO_2peak, varied controlled distances from the crank axis during ACE had no effect on peak physiological responses. The lack of differences in other peak physiological responses may allow for suspicion that this VO_2peak finding may be spurious. However, this suspicion can be countered by the level of significance attained in light of a small sample size ($N = 11$, $p < 0.01$).

The finding that differences in VO_2peak occur at the shortest distance from the crank axis without a significant difference in PWC may seem contradictory. This possibility warrants a discussion of possible mechanisms that may explain such a discrepancy. Among possible mechanisms that account for a change in VO_2 of a specific exercise are: 1) a change in mechanical efficiency, 2) a change in the actual amount of physical work being performed, and/or 3) a change in the amount of muscle mass recruited to support the primary movers.

The literature describes the efficiency of performing a given amount of exercise with varied terminology (i.e., metabolic efficiency; mechanical efficiency; gross efficiency) (21). In all cases, the definitions of these terms are based on the ratio of the amount of external work accomplished to the amount of internal work (i.e., energy cost as in VO_2 or Kcals) required. In this discussion the term "mechanical efficiency" is used to represent this variable.

Due to the short duration of the two submaximal stages (i.e., 2 min for the 25 W and 1 min for the 50 W stages), VO_2 values determined during the final 20 sec of the stages could not be used as representative steady-state values for the workloads. Nonetheless, the values at this point in the VO_2 kinetics for each of the three controlled distances at both the 25 and 50 W stages were not different (Figure 2). This observation may cautiously allow for the suggestion that mechanical efficiency was unaffected by varying controlled distances from the crank axis. If true, this would mean that changes in controlled distance from the crank axis during ACE do not alter the range of motion in the active joints in such a way that overall muscle energetics differ in producing the same torque against the crank handle (22). Since data from this study does not allow for definitive conclusions with respect to mechanical efficiency, future research is warranted that addresses the potential role of controlled distances from the crank axis on submaximal ACE.

The finding in this study that VO_2peak values elicited by the furthest two distances from the crank axis were greater cannot be explained by a change in the actual amount of physical work being performed. This notion can be ruled out due to the finding that PWC did not differ between any of the three positions ($p = 0.58$). However, the VO_2peak findings of this study may be the result of additional muscle mass contributing to the oxygen demand during the use of the greater two distances from the crank axis. Taken in conjunction with the lack of difference in PWC, this additional active musculature must have played a stabilizing role only.

Muscle mass is one of the primary factors that influence VO_2 values during exercise (23). Maximal exercise testing modes that utilize upper versus lower body muscles typically produce lower physiological values at the point of test termination (21), thus scientific consensus is to refer to these reduced physiological values as "peak" (e.g., VO_2peak) rather than "maximal" values (e.g., VO_2max) (1,24,25). Typically, upper body VO_2peak values tend to be approximately two-thirds of VO_2max values recorded from leg work in able bodied individuals (26). Physical work capacity (PWC) and its associated peak physiological variables are limited by the lesser amount of muscle mass being utilized with upper versus lower limb exercise (23). As such, during ACE the cardiovascular system can potentially support the work of additional musculature that may be called to play in a supportive, stabilizing role.

Other researchers have indicated that stabilization musculature can influence oxygen requirement during arm crank exercise (27). Beyond the similarities in PWC, other findings support the conclusion that stabilizing musculature accounted for the increased VO_2peak at the furthest two distances from the crank axis. Indicators of non-oxidative contributions at peak effort (i.e., VCO_2 and RER) were similar across the three distances. This suggests that non-oxidative energy production from the musculature actively contributing to the crank movement was also not different since at PWC this musculature would be working near, at, or beyond its oxidative potential.

The total energy required to support any given external work output is a combination of oxidative and non-oxidative energy production. If the greater VO_2peak accomplished at the further two distances represented the actual oxidative energy requirement of the attained PWC, then greater indicators of non-oxidative metabolism would be expected at the shorter distance from the crank axis. Since there was no such indication of a greater non-oxidative energy production for this shorter distance, it can be surmised that this lesser VO_2peak amount was ample to accomplish the work of all three positions. Justifiably, any additional oxygen utilization beyond the VO_2peak of the shorter distance was likely due to energy demands from muscle mass not working near, at, or beyond its oxidative potential. Thus, it can be inferred that the additional VO_2 demands at the furthest distances were that of stabilizing muscles working at submaximal levels.

The implication of these findings has relevance when performing maximal upper body exercise testing in able-bodied individuals in clinical and non-clinical settings. In such populations, the two furthest distances from the crank axis can incorporate greater muscle mass and induce greater VO_2peak values, without increasing PWC. However, validation of these findings is required in individuals with lower limb impairments, as the data suggest a potential important consideration in this population during maximal upper body testing.

CONCLUSION

The purpose of this study was to determine if variations in controlled distance from the crank axis influence peak physiological responses and PWC during maximal ACE. Data suggests that supporting musculature influences VO_2peak as a function of distance from the crank axis but PWC is unaltered. We therefore conclude that distance from the crank axis during ACE influences predictive values of aerobic capacity and should therefore be controlled to make ACE testing more consistent and reliable in assessing aerobic fitness.

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REFERENCES

1. Glaser RM, Davis GM. Wheelchair-dependent individuals. In: Franklin BA, Gordon S, Timmis GC, editors. *Exercise in modern medicine.* Baltimore: Williams & Wilkins; 1989. p. 237-267.
2. Langbein WE, Maki KC, Edwards LC, Hwang MH, Sibley P, Fehr L. Initial clinical evaluation of a wheelchair ergometer for diagnostic exercise testing: a technical note. ***J Rehabil Res Dev*** 1994;31(4):317-25.
3. Longmuir P, Shephard RJ. A simple upper body analogue of the Canadian home fitness test for the assessment of mobility impaired adults. ***Can J Rehabil*** 1993;7:133-141.
4. Balady GJ, Weiner DA, McCabe CH, Ryan TJ. Value of arm exercise testing in detecting coronary artery disease. ***Am J Cardiol*** 1985;55(1):37-9.
5. Davis GM, Kofsky PR, Kelsey JC, Shephard RJ. Cardiorespiratory fitness and muscular strength of wheelchair users. ***Can Med Assoc J*** 1981;125(12):1317-23.
6. Klefbeck B, Mattsson E, Weinberg J. The effect of trunk support on performance during arm ergometry in patients with cervical cord injuries. ***Paraplegia*** 1996;34(3):167-72.
7. Pitetti KH, Snell PG, Stray-Gundersen J. Maximal response of wheelchair-confined subjects to four types of arm exercise. ***Arch Phys Med Rehabil*** 1987;68(1):10-3.
8. Sedlock DA, Knowlton RG, Fitzgerald PI. Circulatory and metabolic responses of women to arm crank and wheelchair ergometry. ***Arch Phys Med Rehabil*** 1990;71(2):97-100.
9. Wilson PW, Paffenbarger RS, Jr., Morris JN, Havlik RJ. Assessment methods for physical activity and physical fitness in population studies: report of a NHLBI workshop. ***Am Heart J*** 1986;111(6):1177-92.
10. Grazzi G, Alfieri N, Borsetto C, Casoni I, Manfredini F, Mazzoni G, et al. The power output/heart rate relationship in cycling: test standardization and repeatability. ***Med Sci Sports Exerc*** 1999;31(10):1478-83.
11. Nordeen-Snyder KS. The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics. ***Med Sci Sports*** 1977;9(2):113-7.
12. Sawka MN, Foley ME, Pimental NA, Toner MM, Pandolf KB. Determination of maximal aerobic power during upper-body exercise. ***J Appl Physiol*** 1983;54(1):113-7.
13. Fujii N, Nagasaki H. Efficiency and proficiency of bimanual cranking: differences between two cranking patterns. ***Percept Mot Skills*** 1995;80(1):275-83.

14. Langbein WE, Maki KC. Predicting oxygen uptake during counterclockwise arm crank ergometry in men with lower limb disabilities. ***Arch Phys Med Rehabil*** 1995;76(7):642-6.
15. Dotson CO, Israel RG, Burke R, Leppo ML. Cardio-respiratory and perceived exertion responses to different cranking rates during maximal arm ergometry. ***Med Sci Sports Exerc*** 1982;14:158.
16. Cummins TD, Gladden LB. Responses to submaximal and maximal arm cycling above, at, and below heart level. ***Med Sci Sports Exerc*** 1983;15(4):295-8.
17. Hooker SP, Greenwood JD, Hatae DT, Husson RP, Matthiesen TL, Waters AR. Oxygen uptake and heart rate relationship in persons with spinal cord injury. ***Med Sci Sports Exerc*** 1993;25(10):1115-9.
18. Temes AG. A comparison of the physiologic responses between two upper body ergometers. ***Clin Kinesiol*** 1996;50:10-16.
19. Kang J, Chaloupka EC, Mastrangelo MA, Angelucci J. Physiological responses to upper body exercise on an arm and a modified leg ergometer. ***Med Sci Sports Exerc*** 1999;31(10):1453-9.
20. Campbell DT, Stanley JC. *Experimental and quasi-experimental designs for research.* Boston: Houghton Mifflin; 1963.
21. Sawka MN. Physiology of upper body exercise. ***Exerc Sport Sci Rev*** 1986;14:175-211.
22. Lieber RL, Boakes JL. Muscle force and moment arm contributions to torque production in frog hindlimb. ***Am J Physiol*** 1988;254(6 Pt 1):C769-72.
23. Edwards BG, Marsolais EB. Metabolic responses to arm ergometry and functional neuromuscular stimulation. ***J Rehabil Res Dev*** 1990;27(2):107-13; discussion 113-4.
24. Howley ET, Bassett DR, Jr., Welch HG. Criteria for maximal oxygen uptake: review and commentary. ***Med Sci Sports Exerc*** 1995;27(9):1292-301.
25. Rowell LB. Human cardiovascular adjustments to exercise and thermal stress. ***Physiol Rev*** 1974;54(1):75-159.
26. Astrand PO, Saltin B. Maximal oxygen uptake and heart rate in various types of muscular activity. ***J Appl Physiol*** 1961;16:977-81.
27. Bar-Or O, Zwiren LD. Maximal oxygen consumption test during arm exercise--reliability and validity. ***J Appl Physiol*** 1975;38(3):424-6.