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Metabolic Responses to Exercise

DETECTING THE ONSET OF ADDED CARDIOVASCULAR STRAIN DURING COMBINED ARM AND LEG EXERCISE

JERRY J. MAYO[1], LEN KRAVITZ[2], JATAPORN WONGSATHIKUN[3]

[1]Department of Kinesiology, Hendrix College, Conway, AR 72032; [2]Center for Exercise and Applied Human Physiology, University of New Mexico, Albuquerque, NM; [3]Department of Exercise Science and Leisure Management, The University of Mississippi

ABSTRACT

JERRY J. MAYO, LEN KRAVITZ, AND JATAPORN WONGSATHIKUN. **Detecting The Onset Of Added Cardiovascular Strain During Combined Arm And Leg Exercise**. JEP**online**. 2001;4(3):53-60. The purpose of this study was to determine the preferred distribution of arms to legs during combined arm-leg exercise. Fourteen subjects (7 males, 7 females) completed seven experimental testing sessions: one maximal oxygen consumption (VO_2max) test on a cycle ergometer and six submaximal exercise trials at 60% of leg cycling maximal power output (MPO), with total power output (PO) being distributed between the upper and lower body. All combined work incorporated synchronous arm cranking and leg cycling at 50 rev/min using two cycle ergometers. The 7 randomized exercise trials involved combined arm and leg exercise where the arm involvement contributed 0, 8, 17, 25, 33 and 42% of total power output. Heart rate (HR) and oxygen consumption (VO_2) were significantly ($p<0.05$) greater during the 33% and 42% arm trials compared to the 0% arms (leg-only cycling). Trials using 17% and 25% arms elicited significantly lower ($p<0.05$) blood lactate (BLa) compared to 0% arms. No significant differences were found in respiratory exchange ratio, ratings of perceived exertion or O_2 uptake kinetics across conditions. Results of this study suggest that at 60% MPO the preferred ratio of arm to total PO ranged from 17-25% arms. When compared to 0% arms, the 17% and 25% arms trials produced a similar HR response, and slightly higher (non-significant) VO_2, and a significantly lower BLa.

Key Words: Arm cranking, Leg cycling, Heart rate, Oxygen uptake, Arm-leg exercise

INTRODUCTION

It is established that physiological differences exist between upper and lower body submaximal and maximal aerobic exercise. At equal power outputs (PO), arm exercise elicits an increased strain on the cardiovascular system compared to the legs as evidenced by measurements of heart rate (HR), blood pressure (BP), and oxygen consumption (VO_2) (1-3). Several possible explanations for the greater cardiovascular stress include smaller muscle mass involvement (4), decreased venous return to the heart (5), greater neural stimulation (6) and an increased static component imposed during upper body exercise (7).

Toner and associates (5,8) performed combined upper and lower body submaximal exercise experiments to better understand the circulatory responses of arm-leg exercise. Toner et al. (8) held VO_2 constant at three submaximal intensities and measured HR and stroke volume (SV) changes resulting from increasing percentages of arm to total PO. At higher submaximal VO_2 values, SV significantly decreased while HR increased when the arms contributed between 25-50% of the total PO. However, to maintain VO_2 across trials absolute workloads were reduced with increasing arm involvement, thus limiting the practicality of these findings.

The purpose of this study was to extend the work of Toner et. al (5,8) by determining the precise arm-leg ratio that elicits an increased cardiovascular and metabolic strain during combined arm-leg exercise. To answer this question we assessed different arm-leg ratios while maintaining a constant relative percent (60%) of maximal power output (MPO). Of interest was the optimal arm-leg distribution that meets cardiovascular guidelines and could be maintained over a typical 30-min workout. This is particularly relevant as many of the new aerobic exercise machines currently on the market employ simultaneous upper and lower body work. It was hypothesized that graded changes in the amount of arm work would elicit heightened physiological responses, however, the point where this occurs is uncertain.

METHODS

Subjects

Fourteen healthy college-aged volunteers (7 male, 7 female) were recruited from university classes and community fitness clubs. Subjects were informed of the research protocol and signed a statement of informed consent in adherence with the university guidelines for research involving human subjects. Subjects were non-smokers and free of any cardiovascular, pulmonary, or musculoskeletal disorders.

Exercise Familiarization

Prior to testing, each subject reported to the lab a minimum of two times to be familiarized with simultaneous arm cranking and leg cycling exercise. During familiarization, subjects performed leg-only cycling and combined arm-leg cycling that corresponded to the varied workloads of the testing protocol. Each familiarization session lasted approximately 15 min. For all total body exercise, synchronous arm and leg movement at 50 rev/min was employed. To aid synchronous arm-leg cycling, a metronome and verbal coaching were provided from the same research scientist throughout practice and during all exercise testing sessions. Subjects requiring additional sessions to improve technique were required to return to the laboratory until they demonstrated satisfactory skills, as identified by the primary investigator.

Exercise Testing

Each subject was required to report to the laboratory on seven separate occasions. To reduce intra-subject trial variability, subjects reported to the laboratory at the same time each day on consecutive days for experimental testing and were instructed not to make changes in their diet or physical activity pattern. Subjects abstained from food and caffeine consumption for 2 hours before testing. The initial testing session consisted of descriptive data collection and a cycle ergometer test to determine MPO and VO_2max. Descriptive data included exercise habits, height, weight, and 3-site skinfold thickness to estimate body density (9,10) and determine percent body fat (11). All testing was performed utilizing either one or two Monarch cycle ergometers (Monarch Model 818E, Varberg, Sweden). The ergometers were calibrated prior to each test with standard weights of known value.

For leg-only cycling, a seat height was adjusted to allow near complete extension (5-10 degree bend) of the knee when foot placement was at its lowest point in the revolution. One cycle ergometer was mounted on a specially built platform to allow arm cranking. This platform was adjustable so that the crankshaft of the ergometer was at shoulder height for each subject as suggested by others (5). The pedals were replaced with hand grips (6 cm in diameter).

Prior to exercise testing, subjects rested quietly in a seated position for 5-min. A pre-trial HR was obtained at min 5 by telemetry (Polar® Favor, Port Washington, New York). This was followed by a measurement of pre-exercise blood lactate (BLa) concentration. Expired gases were collected continuously and analyzed for the determination of VO_2, V_E and RER by open circuit spirometry using a SensorMedics Vmax Series 29 metabolic cart (SensorMedics Corporation, Yorba Linda, California). CO_2 and O_2 analyzers were calibrated prior to each test against known gas concentrations and the flowmeter was calibrated against a 3.0 L syringe. HR was continuously measured during each maximal and submaximal test. HR was recorded every stage on maximal tests and at 30 sec intervals during submaximal trials. For the submaximal trials, cardiorespiratory data from the last 2-min of the 7-min trial were averaged and used for the analyses. RPE were attained at the end of each submaximal test using the Borg Scale (12).

Maximal Testing

Each subject performed a continuous maximal aerobic capacity test to volitional fatigue to assess leg cycling VO_2 max. For maximal leg testing, a 2-min warm-up at 25 Watts (W) and 50 rev/min preceded maximal testing. At the conclusion of the warm-up the workload was immediately increased to 50 W at a pedal frequency of 50 rev/min. Testing consisted of 60 s stages with the cycling resistance being increased by 25 W until the subject reached exhaustion or could no longer maintain the required pedal frequency of 50 rev/min for 15 sec. The workload at which exhaustion occurred was identified as MPO. VO_2max was defined as the highest VO_2 achieved over a continuous 30 sec time period after reaching the following criteria: (a) HR with 10 b/min of age-predicted HRmax, (b) RER $\geq$ 1.1, and/or (c) plateau of VO_2 or a decease in relation to increasing workload (13).

Submaximal Testing

Subjects were randomly assigned to complete six submaximal exercise trials at 60% MPO. A leg-only trial (0% arms) and five different combinations of arm-leg exercise at 60% MPO were performed. Exercise combinations included 8, 17, 25, 33 and 42% arms, with the percent expression representing the proportion of total PO completed on the arm crank ergometer. All combined work incorporated synchronous cranking and cycling at 50 rev/min, with appropriate force (kg) adjustments made based on the MPO of each subject. All submaximal exercise tests were 7 min in duration.

Blood Lactate Determination

A Yellow Springs Instrument 1500 Sport Lactate Analyzer (Yellow Springs Instrument Co., Inc., Ohio) was used to determine BLa. Prior to and between all exercise testing, validity and linearity of the lactate analyzer was assessed using standards of known concentration. Between testing sessions, the analyzer was calibrated to 5 mM after every third blood sample.

Capillary blood was sampled prior to each exercise session to establish baseline values and immediately following maximal and submaximal tests from a manual finger stick using a lancet device. The blood specimen was first drawn using a 25 uL "Syringepet" and injected into the lactate analyzer. The analyzer immediately assayed the blood specimen and values were recorded. To insure reliability of the BLa measurement, 23% of the trial samples were performed in duplicate. The reliability of the BLa testing was r=0.99.

Statistical Analyses

To describe the kinetic behavior of submaximal VO_2 data, each trial was analyzed using non-linear regression. Either a first or second order exponential fit was applied to the raw data using Prism (GraphPad Software, Inc., San Diego, California). The appropriate equation for fitting was determined by the model which produced the least sums of squares error. Time constants (rate of change in VO_2), where τ=0.69K, were determined for each submaximal test and subsequently used for data analysis.

MANOVA (SPSS, 1995) with repeated measures was used to determine significant differences between the cardiovascular variables among test conditions. If MANOVA (SPSS, 1995) indicated a significant Wilks' Λ, ANOVA with repeated measures was performed on each dependent variable. A repeated measures ANOVA was used to determine significant differences in VO_2 kinetics and BLa. When main effects were significant a Tukey post hoc analysis was computed to assess where differences occurred. Alpha was set at $p \leq 0.05$. With 7 subjects per group, the observed power coefficients for VO_2, V_E, HR, and BLa were 0.78, 0.97, 0.99, and 0.99, respectively, and the effect sizes for all dependent variables exceeded 1.23.

RESULTS

The descriptive data of the subjects are presented in Table 1. Table 2 represents the mean distribution of the different arm-leg exercise trials.

Table 1. Descriptive data.

Variable	*Group Means±SD (N = 14)*
Age (yr)	22 ± 2
Height (cm)	168.6 ± 9.2
Weight (kg)	67.9 ± 12.8
BMI (kg/m²)	24 ± 2.4
Body fat (%)	14.7 ± 5
Resting HR (b/min)	66 ± 9
Leg VO_2 max (L/min)	2.80 ± 0.74
Leg VO_2 max (ml/kg/min)	40.94 ± 4.60
Leg HRmax (b/min)	183 ± 8
Leg max BLa (mM)	10.33 ± 2.30
MPO (Watts)	233 ± 46
60% MPO (Watts)	134 ± 28

Table 2. Distribution of mean power output completed by arms and legs at 60% MPO.

	% arms					
	0	8	17	25	33	42
AC (Watts)	0	11	20	34	44	56
LC (Watts)	134	123	114	100	90	78

AC = arm crank ; LC = leg cycling

The overall MANOVA indicated a significant Wilks' Λ (p = 0.0001). Repeated measures ANOVAs completed on the dependent variables indicated a significant trials effect for HR {F=7.9, p =0.0001}, VO_2 {F=2.8, p=0.02} and V_E {F=6.2, p=0.0001} (see Figures 1, 2, and 3). HR data denoted that subjects exercised at intensities ranging from 81-87% of leg-cycling HRmax across the six submaximal arm-leg combinations. The percent HRmax for each trial was as follows: 0% arms=81%, 8% arms=83.5%, 15% arms=81.6%, 25% arms=82.9%, 33% arms=84.8% and 42% arms=87.1%. The highest HR values occurred when more total work was performed by the arms. Results showed that the 42% arm trial elicited a significantly (p<0.05) greater mean HR compared to all other exercise trials. Also, 0% arms elicited HRs that were significantly lower than the 8% and 33% arm trials.

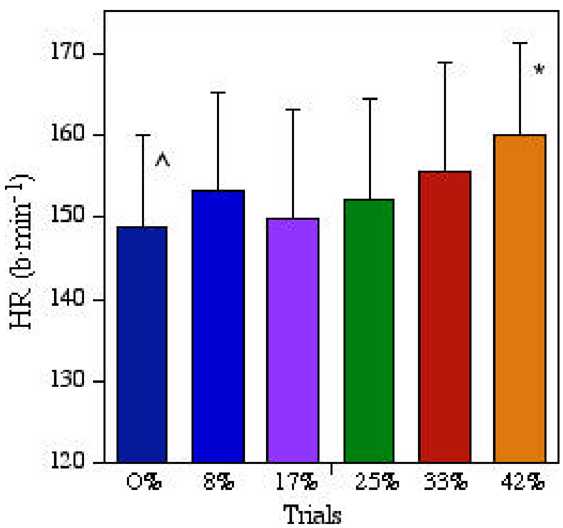

Figure 1. HR trial effect. *42% significantly greater than other trials, ^0% significantly less then 8% and 33%

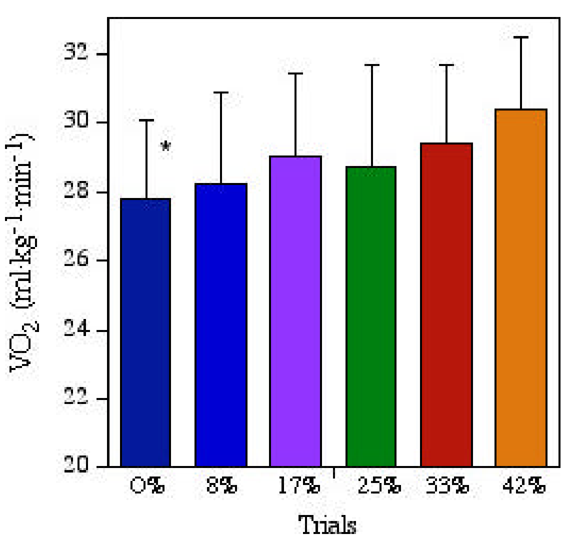

Figure 2. VO_2 trial effect. *0% significantly less then 33% and 42%.

Mean VO_2 (mL/kg/min) responses during the submaximal arm-leg exercise trials ranged from 68-74% of leg-cycling VO_2 max. Relative VO_2 expressed as %VO_2max of leg cycling across all trials were as follows: 0% arms=68%, 8% arms=69%, 17% arms=71%, 25% arms=70.3%, 33% arms=72% and 42% arms=74%. VO_2 values attained during the 0% arm trial were significantly (p<0.05) less than during the 33% and 42% arm trials.

The highest V_E value was recorded when the arms contributed more of the total work. The 42% arm trial was significantly (p<0.05) greater than 0%, 8%, 17%, and 25% arms. Although trends were noted, no significant differences were observed between trials for RER, RPE or O_2 uptake kinetics.

Results from ANOVA for BLa revealed a significant trials (F=2.4, p=0.048) effect. Figure 4 illustrates BLa of the combined arm-leg exercise trials. The 0% arm trial resulted in a similar BLa response to trials 8%, 33%, and 42% arms, however, it was significantly higher than the 17% (p=0.03) and 25% arm (p=0.009) combinations.

DISCUSSION

The purpose of this study was to determine the arm-leg ratio that increased physiological strain during combined arm-leg exercise. This was accomplished by varying the arm-leg distribution at 60% of MPO. The data from this study demonstrated that the amount of work allocated to the arms affect physiological and metabolic responses during submaximal arm-leg exercise. Overall, VO_2, HR and V_E responses were higher when the arms contributed the greatest amount of total work. BLa was significantly lower when arms contributed 17% and 25% of total PO.

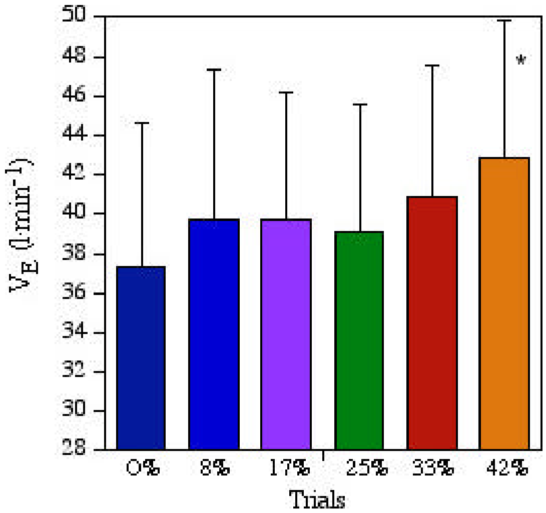

Figure 3. V_E trial effect. *42% significantly greater than 0%, 8%, 17% and 25%

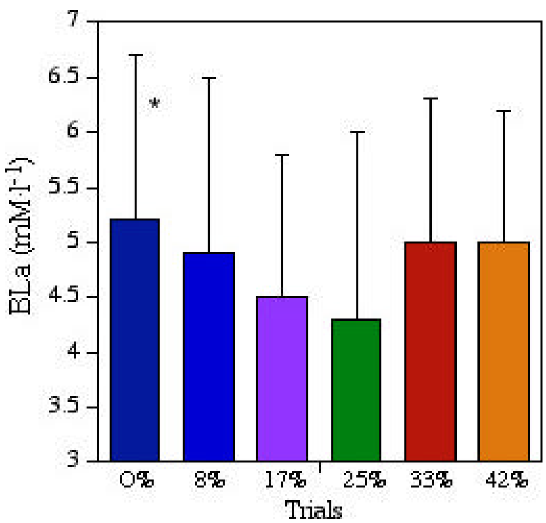

Figure 4. Bla trial effect. *0% significantly greater than 17% and 25%

The greater physiological response to increased arm work can be attributed to the hemodynamic differences between arm and leg exercise (7). Research has demonstrated that for a given submaximal PO, arm exercise produces increased systolic and diastolic BP (4,14), HR (1,5,15), TPR (5, 7), decreased SV (13,14), and either a similar or decreased cardiac output (Q) (13,14). In the present study, the mean HR for the subjects increased 11 b/min across the six exercise trials. Based on this information, it is suggested that the significant HR response at higher arm loads (33% and 42% arms) occurred due to dilation of a smaller vascular muscle bed (cross-sectional area) leading to increased total peripheral resistance (TPR), a greater afterload on the heart, and decreased venous return resulting in lower SVs. Also, increased sympathetic drive may have contributed to the significant HR response in the 33% and 42% arm trials compared to leg-only cycling (5,16). Although these cardiovascular variables were not directly measured in this study, they have been reported by Toner et al. (8), who observed decreases in SV and increases in rate pressure product (RPP) when the arms contributed between 25-50% of the total PO.

The HR response of leg-only exercise was significantly less than the 8% trial. This 4 b/min increase represents a 3% increase which although significant statistically, may have little practical significance. Subjects in this study self-reported the 8% arm trial to be the most challenging with respect to maintenance of a synchronous cadence due to the disproportionately small amount of arm work. This may explain the higher HR during the 8% arm trial. Results suggest that exercising (at 60% of MPO) with arms contributing ≤25% of the total PO produces HRs that are similar to leg-only exercise. Additionally, results indicate that the lowest HR responses during the combined arm-leg trials occurred when the arms contributed 17 and 25% of the total PO. As self-reported by the subjects, these trials were the most comfortable because the resistance was more equally distributed between the upper and lower body.

Analysis of the submaximal VO_2 data demonstrate that subjects consumed significantly more oxygen when arms contributed the greatest amount of total work (see Figure 2). Like HR, arm work significantly influenced VO_2 responses at loads ≥ 33% of the total PO. Results revealed a significant ($p=0.04$) trial effect for absolute VO_2 . Further inspection of the data indicate that subjects were performing a greater amount of absolute work during the combined exercise trials compared to Toner et al. (5). Average VO_2 ranged from 1.9 L/min to 2.04 L/min across the six combined trials. Toner et al. observed VO_2 responses between 1.70 L/min and 1.96 L/min (0-60% arms). The small but significant increases in VO_2 across trials are in agreement with Hoffman et al. (17) who found the average difference between leg-only cycling and combined work to be 0.04 L/min in POs ranging from 50 to 175 Watts.

When evaluating the increased VO_2 response of combined arm-leg exercise, it has been suggested that in addition to the physiological affects of hand gripping during incremental arm work there is also an interplay of two additional factors: 1) size of the active muscle mass (17,18) and 2) mechanical efficiency (5,19). It has been shown that cardiovascular responses to exercise are largely determined by the amount of active muscle mass and absolute oxygen uptake (17,18). Evidence suggests that the amount of muscle mass employed to complete the combined arm-leg task produces an increased VO_2 requirement compared to cycling utilizing solely the legs (1, 17). Additionally, the metabolic efficiency as determined by work indices were lower during arm cranking compared with leg cycling at the same relative intensities (19). Because of the decline in mechanical efficiency with increasing amounts of arm work during combined exercise there is also a concomitant increase in VO_2. This decrement in efficiency is attributed to increased energy expenditure necessary for postural and body stabilization (5). Toner et al. (5) suggested that another unmeasurable exercise component is excessive body movement which may occur at higher upper body POs.

A significant difference in V_E existed at varied arm-leg combinations. The circulatory demand at 42% arms produced significantly greater V_E responses compared to 0%, 8%, 17% and 25% arms. These values are comparable to others who have measured respiratory responses during combined work (1,5,8). Toner et al. (5) reported significant differences in V_E at 109 Watts when arms contributed 60% or more of the total work. This difference in arm contribution is directly related to the higher PO used in the present study.

The BLa data reported in this study are similar to previous published values during cycle ergometry (14,15,16) and combined arm-leg exercise (17,20). The results of BLa data show significantly less accumulation of lactate in the 17% and 25% arm trials compared to leg-only cycling (see Figure 4). This is in agreement with Zeni et al. (20) who found that at a given RPE, BLa for cross-country skiing, which employs the upper and lower body, was lower than cycle ergometry, Airdyne cycling (involving elbow flexion and extension) and stairstepping. Research by Hoffman et al. (17) observed BLa to be lower during arm-leg ergometry compared with leg-cycling at similar POs, however, the results did not reach statistical significance ($p=0.08$). These investigators also reported a higher VO_2 response during combined arm-leg ergometry compared to leg cycling at the same BLa. Hoffman et al. (17) suggested that the use of larger muscle masses promotes a greater cardiorespiratory training effect if BLa is used to establish exercise intensity.

When taken together these results lend support for the notion that a preferred arm-leg ratio exists during combined arm-leg exercise. To avoid the circulatory strain associated with strict upper body work, it is suggested that during combined work the arms should contribute no more than 25% of the total PO. This may have safety implications for those individuals in rehabilitation settings as well as general exercisers wanting to work at a comfortable intensity using a combined arm-leg exercise mode such as a cross-country skier, Airdyne cycle ergometer, or an elliptical trainer. Although the physiological responses were greater during higher arm work compared to leg-only cycling, the practical application of these results should be viewed with caution due to the short exercise duration used for testing. With combined arm-leg exercise becoming more popular, continued research should further clarify the effects of exercise duration and its implication for weight control as well as metabolic and hormonal responses to this form of exercise.

CONCLUSIONS

The results of this study indicate that varying the distribution of arm and leg work during total body exercise affects cardiovascular and metabolic responses. The HR and V_E responses were significantly higher than all other trials when arms performed the greatest amount of total work. Although the physiological responses were greater during higher arm work compared to leg only cycling, the practical application of these results should be viewed with caution due to the short exercise duration used for testing. However, the submaximal trials of 17% and 25% arm to total PO appear to be safer for individuals to perform due to the insignificant change in cardiovascular strain. Compared to leg only cycling, these trials produced similar HR responses, a slightly greater (non-significant) VO_2, trends of lower RPE, while eliciting a significantly lower BLa.

Address for Correspondence: Jerry Mayo, Ph.D., Department of Kinesiology, Hendrix College, 1600 Washington Ave., Conway, AR 72032; Phone: (501) 450-1316 ; email: mayo@hendrix.edu

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