To the Graduate Council;

I am submitting herewith a thesis written by Michael F. Shipe entitled "The effects of muscle mass on metabolic responses and perceived exertion during prolonged exercise." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Human Performance and Sport Studies.

David R. Bassett, Jr., Major Professor

We have read this thesis and recommend its acceptance

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Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

THE EFFECTS OF MUSCLE MASS ON METABOLIC RESPONSES AND PERCEIVED EXERTION DURING PROLONGED EXERCISE

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

Michael Faine Shipe

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ABSTRACT

This study compared the effects of arm and leg (A+L) and leg (L) exercise on metabolic responses and ratings of perceived exertion, using an air-braked cycle ergometer (Schwinn Air-Dyne). Twelve healthy subjects performed a maximal graded exercise tests with L and A+L. Subsequently, they performed a 30 minute exercise bout at 70% of VO_{2max} using L and A+L. Oxygen uptake (VO_2), ventilation (V_E), respiratory exchange ratio (R), heart rate (HR) and ratings of perceived exertion (RPE) were measured throughout all tests. Venous blood samples were taken 3-5 minutes after incremental test completion and at 10 minute intervals during the endurance test. Using planned contrasts, it was determined that RPE and R values for A+L exercise were significantly lower ($p < 0.05$) compared to L exercise at 147, 171, 196, and 221 Watts during the incremental test. In addition, VO_2 was higher for A+L versus L exercise at 74, 122, 147, 171, and 196 Watts ($p < 0.05$). RPE, blood LA, and R values were significantly higher ($p < 0.05$) for L compared to A+L exercise throughout the endurance test. These results demonstrate that during prolonged work at moderately high intensities, RPE, R, and blood LA are lower for combined A+L versus L work. Further, the decrease in RPE appears to be due to a reduction in peripheral factors (blood LA and muscle strain) during A+L exercise.

Key words: ratings of perceived exertion, oxygen uptake, VO_{2max}, blood lactate accumulation, respiratory exchange ratio, heart rate, and power output.

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CHAPTER 1

INTRODUCTION

In order to develop and maintain cardiorespiratory fitness, the American College of Sports Medicine recommends modes of activity that utilize large muscle groups and are continuous, rhythmical, and aerobic in nature (2). Using large muscle groups (i.e., legs versus arms) allows a given rate of energy expenditure to be maintained with less effort (9). Some types of exercise equipment (i.e., Schwinn Air-Dyne) permit aerobic exercise to be performed while simultaneously using arms and legs (A+L). There has been little research regarding whether increasing muscle mass in this manner alters an individual's perceived effort, compared to using legs (L) alone during endurance exercise sessions. Also, the metabolic responses for A+L versus L exercise at moderately high intensities during prolonged exercise have not been thoroughly examined.

When exercising with arms (A) alone, a typical individual is able to attain 65 to 75% of L VO_{2max} (maximal oxygen consumption) (7, 16, 43, 51, 54, 60). Arm exercise is accompanied by a higher heart rate (HR), oxygen uptake (VO_2), ventilation (V_E), tidal volume, respiratory rate, blood lactate (LA) level, and O_2 pulse compared to L exercise at a given power output during moderate and heavy intensities (9, 17, 40, 43, 56, 60). These responses also persist in endurance exercise situations (60 minutes) (44). Given these results it is not surprising to find that when Borg et al. (9) compared perception of effort for A versus L exercise at a given power output, ratings of perceived exertion (RPE) were significantly higher for A versus L.

When A input is added to L exercise there is minimal (7, 25, 46, 53, 59) or no increase in VO_{2max} (5, 21, 29, 38, 56) compared to L work alone, due to limitations of the central circulatory system. Few studies have evaluated the effects of A+L versus L exercise on

RPE at fixed, submaximal work rates. Eston and Brodie (24) evaluated RPE for A+L versus L exercise at low power outputs (49, 74, and 98 Watts) and found no difference in RPE between the two exercise modes. However, Duey et al. (21) reported that RPE were lower for A+L versus L exercise during an incremental test at moderate power outputs of 147, 196, and 245 Watts. This finding suggests that A+L exercise might be perceived as less difficult compared to L work during prolonged exercise at moderate intensities.

Gutin et al. (27) compared RPE and cardiopulmonary responses to A+L and L exercise as subjects were exercising at 110-115% of their ventilatory breakpoint for 60 minutes. Ten men performed A+L work with either 10 or 25% A input, and solely L exercise. The overall cardiopulmonary and RPE responses for the three tests were not significantly different. As would be expected, RPE gradually increased with time for both modes. Interestingly, RPE were lower for A+L from 5 to 40 minutes compared to L but from 50 to 60 minutes RPE for A+L work were higher, yet no statistical significance was found (27).

Various central and peripheral physiologic factors have been proposed to contribute to RPE. Central factors include: HR, VO_2, and V_E. Local factors are lactate concentration, proprioceptive responses from the working limbs, and general leg muscle sensations (23, 35). Many RPE studies focus on a primary sensory input for the perceptual system that determines an individual's exertion level but fail to acknowledge the mediating influence of such relevant modifying variables as exercise modality, intensity, and duration (35). This study will examine the extent to which central and local factors contribute to RPE during a prolonged exercise bout.

The purposes of this study were to: (1) replicate previous reports that significant differences exist in RPE between A+L and L exercise at moderate power outputs during an incremental test; (2) ascertain whether there are significant differences in RPE for A+L versus L exercise over a long-term (30 minutes) exercise bout at a fixed,

submaximal workload, and (3) examine physiologic variables (i.e., lactate accumulation, HR, VO_2, and V_E) to determine if these RPE "cues" differ between exercise modes.

List of Terms

Cardiac output (Q) is the amount of blood pumped by the heart per unit of time; equal to product of heart rate and stroke volume.

Heart rate (HR) is the number of heart beats per minute.

Lactate threshold (LT) is the point during a graded exercise test when the blood lactate concentration increases abruptly.

Maximal oxygen consumption (VO_{2max}) is the greatest amount of oxygen that can be processed by the body during maximal work.

Oxygen consumption (VO_2) is the amount of oxygen consumed in liters per minute.

Rating of perceived exertion (RPE) is a scale, developed by Gunnar Borg, that is used to quantify the subjective feeling of physical effort. The original scale was 6-20 and has undergone revision to a 0-10 scale.

Respiratory exchange ratio (R) is the volume of carbon dioxide produced divided by the volume of oxygen consumed

Stroke volume (SV) is the amount of blood pumped by a ventricle in a single heart beat.

Ventilation (V_E) is the volume of air inspired during one minute.

Ventilatory equivalent (VEQ) is the ratio of minute ventilation to oxygen consumption; calculated as V_E/VO_2.

Hypotheses

1. There will be significant differences in RPE at moderate power outputs between A+L and L exercise during the incremental test protocols. In contrast, HR, VO_2, VO_{2max}, V_E, R, and blood lactate accumulation (LA) responses will not differ for the two modes.

2. There will be significant differences in RPE, blood LA, and R responses for A+L work compared to L work during the 30 minute endurance tests.

3. There will be no difference in HR, VO_2, and V_E for A+L work versus L work during the 30 minute endurance tests.

Significance

The results of this study may have practical applications for settings in which Schwinn Air-Dynes are employed. It is hypothesized that A+L exercise will elicit lower RPE than exercise with L only, at the same rate of energy expenditure. If true, this could lead to longer exercise bouts performed with less fatigue, which would have implications for exercise adherence and compliance. Further, the present work may help to determine the relative importance of central versus peripheral input to RPE.

CHAPTER 2

REVIEW OF LITERATURE

Several investigators have reported no significant difference in VO_{2max} for A+L versus L exercise (5, 21, 29, 38, 56). However, some researchers have demonstrated that VO_{2max} is greater for A+L exercise compared to L exercise (7, 25, 46, 53, 59). This review of literature will cover the classic studies examining circulatory and ventilatory results of A+L work versus L work and the possible reasons why some of these studies have produced conflicting results. Also, the more recent studies examining the physiologic responses to A+L and L work will be addressed. In addition, the literature evaluating the physiological variables that have been found to be most highly correlated with contributing to RPE during exercise will be discussed.

Historical Perspective

In 1932, Edward Christensen hypothesized that the maximal rate of oxygen consumed during physical activity was predicated upon the load placed on the muscles as well as the muscle mass at work. Christensen supported this theory by reporting that during cross-country skiing one man was able to attain a higher VO_{2max} compared to running on a treadmill using their legs only (59). Taylor et al. (59) supported Christensen's findings by demonstrating that in one man adding arm cranking while running on a treadmill resulted in an oxygen uptake 0.2 $L \cdot min^{-1}$ greater than running alone. These results reinforce the theory that an important element of VO_{2max} is the amount of muscle mass engaged in performing the physical activity. It is important to emphasize that only one subject was used in each of the aforementioned studies.

In 1961, Åstrand et al. (5) examined the effects of muscle mass on VO_{2max}. Seven male subjects performed maximal work using A, L, and A+L. In order to perform the A+L work, the investigators used two ergometers so that the subject in a sitting position could exercise by pedaling on one and arm cranking on the other ergometer. The average arm and leg contributions to total work rate were 600 and 2,100 kpm $\cdot$ min^{-1}, respectively (23% A and 77% L input) (5). All subjects did not complete every exercise treatment. The comparison of the six subjects who performed cycling in a sitting position versus combined A+L work demonstrated almost identical VO_{2max} values (4.23 versus 4.24 L $\cdot$ min^{-1}, respectively). The VO_{2max} results of the five subjects who completed the L, A+L, and skiing tests were 4.47, 4.48, and 4.55 L $\cdot$ min^{-1}, respectively (no significance tested). Thus, the researchers concluded that VO_{2max} is independent of muscle mass employed once it surpasses a certain mass. Instead, they hypothesized that 'the capacity of the heart' limits VO_{2max} (5).

In 1967, Stenberg et al. (56) studied ten subjects as they performed maximal work with A, L, and combined A+L input, sitting and supine. In the sitting position, VO_{2max} values for the six participants who completed all tests for L and A+L work were very similar (3.87 and 3.95 L $\cdot$ min^{-1}, respectively). Maximal V_E, Q, BP, total peripheral resistance, and stroke volume (SV) values were similar for L and A+L work except at the highest workload in the supine position, in which SV was significantly higher for A+L work. These results agreed with Åstrand et al. (5); work with the A+L does not result in higher VO_{2max} than L work in a sitting position (56).

These results contrast with those of previous researchers who indicated that maximal work with A+L during skiing or simultaneous A+L exercise elicited a higher VO_{2max} than utilizing legs only (59). Thus, there was controversy as to whether or not VO_{2max} is influenced by the addition of A work performed simultaneously with L work.

VO_{2max} Responses to A Exercise

When exercising with A alone, a typical individual is able to attain 65 to 75% of L VO_{2max} (7, 16, 43, 51, 54, 60). Further, maximal HR, Q, and V_E responses are generally lower during A work. These responses are not unexpected considering the relatively small amount of muscle mass utilized during A cranking. At the same submaximal work intensities, A exercise elicits higher VO_2, HR, V_E, blood LA, and blood pressure responses than L exercise (9, 17, 40, 43, 56). These disparities are more apparent with increasing power output and are sustained in long-term endurance situations (60 minutes) (44).

The differences in physiological responses to A and L work, at the same power output, have been attributed to several factors including; greater sympathetic output to the heart during A work compared to L work (34), dilation of a smaller vascular bed (26), lack of ample blood perfusion which limits the intrinsic power of arm muscles (36), lower mechanical efficiency (ME) during A work due to static muscle contraction (musculature contraction required to stabilize the torso) that fails to contribute to the work accomplished (56), delayed VO_2 kinetics (43), and increased glycolysis leading to lactate accumulation (43).

Researchers have shown that in highly arm-trained subjects (elite kayakers and canoeists) HR, VO_2, and blood pressure values are similar during submaximal A work as in L work at a given submaximal workload (26, 58). Thus, differences in the metabolic responses to A and L work are dependent on the specificity of training. Consider that some of the physiological (V_E, HR, mean arterial pressure, arterial bicarbonate, pH) and RPE differences between A and L work are decreased or completely eliminated when the work rate is adjusted for the relative exercise intensity (ergometer-specific % VO_{2peak}) in average-trained subjects (41, 58). Further, Pimental et al. (44) reported that average-

trained subjects who performed 60 minutes of exercise at the same relative percent (60%) of arm VO_{2peak} or leg VO_{2peak} demonstrated a lower HR for A versus L work. Therefore, many of the differences in the metabolic responses between A and L work can be attributed to differences in VO_{2max} for these two muscle groups, since they are no longer evident when comparisons are made at the same relative percent of ergometer-specific VO_{2peak}.

Evidence that Simultaneous A+L Input Elevates VO_{2max} versus L Exercise

In the 1930s and 50s, two researchers reported that an individual was able to increase his VO_{2max} (approximately 0.2 L $\cdot$ min^{-1}) by adding A work to L work (59). More recent studies have also reported that the amount of muscle mass active during exercise may limit an individual's VO_{2max} (7, 25, 46, 53). However, the lack of continuity in the experimental designs employed in these studies makes comparisons between them difficult to interpret. Specifically, the inconsistencies in methodology in these studies include: lack of a uniform device for A+L work performance (25, 53), no standardization in the percentage of A or L input (7, 25), and varying A position during L exercise (25, 53).

Gleser et al. (25) studied ten male subjects who performed L and A+L work in a sitting position. Each subject worked at two submaximal loads (100 and 175 W) and one supramaximal load to determine L VO_{2max}. Arm work during A+L exercise was chosen to be either 50 or 67 W, dependent on the subject's size. A Quinton cycle ergometer was placed at shoulder level for A+L work. When the L exercise was performed, the subject's arms were allowed to hang freely at the subject's side. The average A and L input for combined A+L work was 58 and 223 W, or a 21% and 79% contribution,

respectively. A significant increase of 10% in VO_{2max}, 3.09 to 3.39 L · min^{-1} resulted when A work was added to already maximal L work (25). These results confirmed Gleser et al.'s theory that previous studies reporting no increase in VO_{2max} during combined A+L work (5, 56) had placed a supramaximal load on the A and submaximal load on the L. Therefore, A+L VO_{2max} values were lower than if both A and L loads were maximal during simultaneous A+L work.

In order to assess the influence of a subject's relative arm fitness when adding A to L work, Secher et al. (53) studied 16 subjects (11 A and 2 L trained plus 3 non-athletes). Subjects performed A, L, and A+L maximal exercise tests. These tests were carried out with the subject pedaling a Krogh ergometer while sitting, accompanied by two von Döbeln ergometers on either side at waist level for A work. The position of the A was not specified during L work. In addition, subjects performed another maximal L work during "conventional bicycling" (53). The VO_{2max} results during A+L exercise were 106% of L VO_{2max} and A VO_{2max} was 85% of L VO_2. The investigators stated that these results suggests an elevated VO_{2max} during A+L work proportional to the relative capacity of the arms. Interestingly, there was no significant difference ($p < 0.10$) in VO_{2max} between conventional bicycling and A+L work. Although the positioning of the arms was not specified during A+L work, the authors noted "the arms are used to some degree during maximal bicycling". Further, since differences in VO_{2max} were most pronounced in A trained subjects; the authors stated that local factors in the exercising muscles must limit VO_{2max} (53).

Reybrouck et al. (46) examined the metabolic variables that might limit VO_{2max} of subjects with different aerobic capacities. Three men performed A, L, and combined A+L ergometry in a seated position. Two subjects had a VO_{2max} of less than 45 ml · kg^{-1} · min^{-1} and the other subject greater than 50 ml · kg^{-1} · min^{-1}. A multitude of tests were conducted (a total of 71 submaximal and 33 maximal) with the three subjects to control

the considerable inter- individual variability differences in VO_{2max}. A+L work was performed by having subjects sit on one ergometer while cranking another ergometer that was set above and in front of the first one. Arm positioning during L work was not specified. During A+L ergometry, the total work rate was set and then divided between arms and legs. The division was made such that the percentage of the maximum work rates achieved during A and L ergometry performed separately was the same for each. At any submaximal work rate above zero there were no significant differences in VO_2, V_E, and VEQ between A+L and L work. Q and HR were higher during combined A+L than L work and the anaerobic threshold was reached at a lower work rate in L compared to A+L work. VO_{2max} results for A+L versus L work were 4.05 and 3.74 L $\cdot$ min^{-1}, respectively. The researchers hypothesized that a critical determinant of whether a subject attains a higher VO_{2max} with A+L versus L work is the degree to which the subject is conditioned for L work. They tested this theory by having two additional subjects, both with a VO_{2max} of 53 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} during L work, perform maximal work with A+L. No significant differences were observed for VO_{2max} or Q_{max} between A+L and L work. Therefore, the researchers concluded that highly conditioned subjects may reach their maximal total body capacity for O_2 delivery when using L only, while less trained subjects may show an increase in VO_{2max} when the active muscle mass is increased (46).

Bergh et al. (7) studied the effect of varying the percent contribution of A on VO_{2max} during A+L exercise. Ten males performed maximal A, L, and A+L work. A positioning during L work was not specified. A+L exercise was performed with A output contributing 10, 20, 30, and 40% at the same total work rate. A+L work was performed on a cycle ergometer with two independent braking systems (one for arms and another for legs). VO_{2max} values were not significantly different ($p < 0.05$) in the A+L tests (4.32, 4.34, and 4.27 L $\cdot$ min^{-1}), except when the work rate for the arms was 40% (4.01 L $\cdot$

min^{-1}) in which VO_2 values were between 5% and 8% lower ($p < 0.01$). VO_{2max} for L work was 4.12 L · min. It is important to note that the VO_{2max} during A+L work was compared to maximal running values and not maximal cycling with the legs. All subjects did not attain their peak VO_2 values in A+L exercise at the same ratio of A to L work intensity. Eight subjects achieved their VO_{2peak} at 10% or 20%, one at 30%, and one at 40%. The researches noted that the A conditioning of the subjects affects maximal A+L VO_2 values. This observation is supported by the fact that A+L VO_{2max} values were positively correlated, especially at high work intensities, with maximal A VO_2 values (12); this result agrees with the results of Secher et al. (53). A summary of the results of these six experiments are listed in Table 1.

Table 1. Previous results of VO_{2max} responses to L and A+L exercise

Reference	L work ($L \cdot min^{-1}$)	A+L work ($L \cdot min^{-1}$)	Arm positioning during L work
Åstrand et al. (5) (n=5)	4.23 ± .30	4.24 ± .31*	- Hands gripping bars
Stenberg et al. (56) (n=7)	3.98 ± .18	4.01 ± .16*	- Hands gripping bars
Gleser et al. (25) (n=10)	3.09 ± .10	3.39 ± .10†	- Arms hung freely at side
Secher et al. (53) (n=15)	4.31 ± .27	4.58 ± .28†	- Arm positioning not specified but 4 subjects performing conventional cycling displayed no significant difference compared to A+L
Reybrouck et al. (46) (n=3)	3.74 ± .85	4.05 ± .61†	- Arm positioning not specified
Bergh et al. (7) (n=10)	4.20 ± .21	4.34 ± .18**	- Arm positioning not specified

Values are means ± standard error

* no significant difference versus L exercise ($p < 0.05$)

† significant difference between L and A+L VO_2 max ($p < 0.05$)

** no significanct difference between L or A+L VO_{2max} versus running VO_{2max} ($p < 0.05$)

Equivalent VO_{2max} Values for A+L and L Work Using Air-braked Ergometry

Using an air-braked ergometer (Schwinn Air-Dyne), Hagan et al. (29) examined the cardiorespiratory responses to incremental maximal tests involving A, L, and combined A+L work in 15 men and 15 women. A work was performed with subjects standing upright behind the ergometer seat and throughout L work subjects gripped the underside of the seat with their hands. During submaximal work, the VO_2, HR, and V_E responses between A+L and L exercise were equivalent. In both men and women, maximal values for HR, VO_2, V_E, R, mechanical efficiency, workload, and blood LA were similar between A+L and L work (29). These results are consistent with earlier studies reporting that A+L and L work on mechanically braked ergometers (with static contraction of A) elicit similar VO_{2max} responses (5, 56).

Nagle et al. (38) also investigated VO_{2max} responses to A, L, and combined A+L work utilizing an Air-Dyne. Ten males did an incremental maximal test with A, L (with arms at side), and three A+L tests with A contributing 10%, 20%, and 30% to the total work rate on a Schwinn Air-Dyne. Also, four subjects "approximated" conventional cycling by performing L work with their hands fixed to stationary bars (38). When A contributed 10 or 20% to the total power output, VO_{2max} values were similar (4.09 and 3.78 $L \cdot min^{-1}$, $p > 0.05$). However, during L work (A hanging by sides), VO_{2max} (3.58 $L \cdot min^{-1}$) was significantly lower ($p < 0.05$) than when A input was 10%. Eight subjects achieved their highest VO_{2max} with 10% A input and the other two with 20% A input (38). These results, indicating that the percentage of A input that allows the highest A+L VO_{2max} (10 or 20%) varies among individuals agrees with earlier studies (7, 53). Further, these results confirm the view of Bergh (7) and Secher et al. (53) that during A+L exercise the L work should be sufficient to attain maximum leg aerobic power. Interestingly, the L contribution to total power output, when A input was 10%, increased

to 107% of that in the L only protocol. It appears that the A were able to stabilize the L and enable them to attain a greater power output versus L exercising alone. In four subjects, conventional cycling elicited similar VO_{2max} values attained in A+L work (10 or 20% A contribution). These results indicated that the stabilizing effect of hands gripping a bar, as in traditional cycling, contributes 10-20% to maximal power output and thus affects VO_{2max} (38).

Physiological Variables Contributing to RPE

Borg developed the Rating of Perceived Exertion (RPE) scale as a psycho-physiological measure of exercise intensity (8). The original scale uses rankings from 6-20 to approximate the HR values from rest to maximum capacity (60-200 beats $\cdot$ min^{-1}). Therefore, during a incremental test, the scale was designed so that RPE increase linearly with HR. RPE is commonly utilized in exercise physiology laboratories in order to assess perception of effort for various modes of exercise (8, 39). Further, RPE is extensively used for exercise prescription and for evaluating and monitoring subjective effort in athletic, clinical, and occupational settings (39). Various researchers have performed comprehensive reviews of RPE and proven its validity in quantifying subjective exercise intensity (8, 12, 39).

An integration of several physiologic factors is thought to provide input for perception of effort during exercise. Borg proposed that an individual's perception of effort was contingent upon cues from both "the musculature and the system of circulation" (8). In essence, he was referring to central and local factors, which the subsequent literature has supported as the predominant "cues" for RPE (23, 35). Central factors include HR, VO_2, and V_E. Local factors contributing to RPE are: blood lactate accumulation, proprioceptive responses, and general muscle sensations (23, 35). There is a considerable amount of literature examining whether central or local factors are the prominent

contributor to RPE. However, many RPE studies focus on a primary sensory input for the perceptual system that determines an individual's exertion level and fail to acknowledge the mediating influence of such relevant modifying variables as exercise modality, intensity and duration (35).

Sargeant et al. (50) studied RPE responses in six men who performed exercise involving one arm, two arms, one leg, and two legs during submaximal and maximal exercise. There was a significant linear relationship ($p < 0.05$) between RPE and workload, VO_2, V_E, and HR for all modalities. Yet the degree and form of the association was dependent on the type of exercise performed and the degree of muscle mass involvement. Most of these differences could be eliminated by adjusting for the VO_{2max} for each exercise mode. Therefore, these researchers considered that the critical variable for determining RPE as a predictor of exercise stress is the relative workload (i.e. % of VO_{2max}) (50).

Pandolf et al. (40) investigated whether prolonged A or L work produced significant differences in RPE. Local RPE (muscle and joint exertion), central RPE (ventilatory and circulatory RPE), and overall RPE were measured. Nine males performed 60 minutes of A and L exercise at the same absolute and similar relative exercise intensities (% of ergometer specific VO_{2peak}). At the same absolute VO_2, the final mean for each RPE was lower for L than A exercise. Yet, there were no differences between A and L work for all three RPE at the same $\%VO_{2peak}$. Also, local RPE was generally higher than central RPE for both tests. Lactate accumulation (LA) and ventilatory equivalent (VEQ) accounted for most of the variability in differentiated RPE during absolute or relative tests (40).

Borg et al. (8) demonstrated that RPE display a high correlation (r=.85) with HR during an incremental bicycle test. This finding was true regardless of gender, or whether the exercise was continuous or intermittent (8). Yet other researchers have indicated that

when HR is altered through pharmacological intervention, by blocking the influence of the autonomic nervous system on the circulation during submaximal exercise, the correlation between HR and RPE is altered (18, 23). In fact, Ekbolm and Goldbarg (23) reported a better correlation between RPE and blood LA; this was the case regardless if the exercise modality was running, cycling or arm cranking. This result along with the findings of Pandolf et al. (40) indicate that local factors may be the most important determinant of RPE.

Numerous studies have shown that blood LA demonstrates a high correlation with RPE. Borg et al. (9) reported that RPE can be predicted for A or L steady state exercise by combining HR and blood LA data. Edwards et al. (22) found a significant relationship between RPE and blood LA for continuous and intermittent bicycle exercise. It has also been proposed that the lactate threshold (LT) is an important "physiological anchor point" for perception of effort that is unaffected by training state or gender (19). Hetzler et al. (31) found a stable relationship between blood LA and RPE at the LT and fixed blood lactate concentration (FBLC), regardless of exercise mode (i.e., cycle or treadmill). Further, these researchers found that peripheral RPE values between exercise modes at FBLC were almost equivalent, suggesting that blood LA is related to the perception of peripheral effort (31). It has yet to be proven that blood LA can be consciously monitored, yet blood LA rises in association with other physiologic variables during exercise such as muscle strain and increased V_E, which can be perceived or subconsciously monitored. In addition, although many cardiorespiratory variables change linearly with workload, perceived exertion, when ratio-scaling methods are used, increases with a positively accelerating function (35). Blood LA is one physiologic variable which follows the same type of function during incremental exercise. This lends support to the reported relationship between blood LA and perceived exertion (10, 19, 22, 23, 30, 31). These results would indicate that a central factor (i.e., HR) is not the

primary determinant of RPE during exercise; instead a local factor (i.e., blood LA) may be. It is important to note that, although RPE increases throughout incremental exercise, blood LA does not increase appreciably at workloads below 60% VO_{2max}. Blood LA may influence RPE at high exercise intensities, but its contribution at low work intensities would be minimal (23, 35).

Another local factor that has been discussed as a contributor to RPE is local muscular strain. Ekbolm and Goldbarg (23) noted that RPE for cycling is higher than for running at a given submaximal VO_2 but RPE is equal when operating at the same percentage of VO_{2peak}. Further, since blood LA was higher for cycling than running at a given submaximal VO_2, the authors suggested the higher RPE scores may be attributed to the higher muscular strain indicated by the higher blood LA (23). Investigators have also attempted to link RPE with kinesthetic cues including: mechanoreceptor and proprioceptor feedback (33, 41) and Golgi tendon activity (55). Stamford and Noble (55) studied subjects during continuous and intermittent constant power output at pedaling speeds of 40, 60, and 80 rpm. Central factors (VO_2, HR, V_E) did not differ between the pedal rates yet RPE was higher at 40 rpm than 60 or 80 rpm. The authors speculated that the high RPE at low pedaling rates may be accounted for by increased tension concurrent with high resistance and result in fatigue of the Golgi tendon organs (55). Pandolf et al. (41) examined subjects working at various pedaling speeds (40, 60, and 80 rpm) and resistances for equivalent power outputs. Again, central factors (VO_2, HR) were not different between the pedaling rates yet RPE was higher at 40 compared to 60 and 80 rpm. The authors stated that an individual's determination of RPE predominantly involves local factors, which are associated with feelings of strain in the working muscles and joints (41). Löllgen et al. (33) also found that RPE decreased with increasing pedaling rate and stated that RPE is not derived from the strain of exercise but instead may stem from perception of force and speed in the working muscles. Although these

results suggest that local muscular strain sources are a prominent contributor to RPE determination, their contribution were not described in quantifiable terms.

Physiological Variables Contributing to RPE During A, L and A+L Work

It has been consistently shown that VO_{2max} during A work is generally 65-75% of the maximal values achieved during L work (7, 16, 43, 51, 54, 60). Therefore, during A exercise at a given work rate, an individual is working at a higher percentage of VO_{2max} than during L exercise. Not surprisingly, A exercise is accompanied by a higher HR, VO_2, ventilatory volume, tidal volume, respiratory rate, blood LA and O_2 pulse compared to L exercise at the same VO_2 during moderate and heavy exercise intensities (43, 44, 54, 60). These responses have also been shown to persist during long-term endurance situations (60 minutes) (44). Given these results, it is logical to assume that RPE would be higher for A than L work at any given work rate. Borg et al. (9) compared perception of effort for A versus L exercise and reported that at a given power output, RPE was higher for A versus L exercise. In contrast, when Pandolf et al. (40) examined overall RPE during relative exercise intensities (% of ergometer specific VO_{2peak}), RPE was similar for A compared to L work. These results support previous findings in which researchers suggested that the critical variable for determining RPE as a predictor of exercise stress is the relative work load (i.e., % VO_{2peak}) (50).

Researchers have shown that VO_{2max} is equivalent when comparing A+L versus L exercise (5, 21, 29, 38, 56). Hence, it would be logical to postulate that RPE should be equivalent for A+L versus L exercise at the same power output. However, the results of several research studies contradict this apparently logical assumption.

Ekbolm and Goldbarg (23) conducted one of the earlier studies examining RPE during A+L and L work using a maximal work protocol for three subjects. Maximal loads were chosen that would exhaust the individual in five to six minutes. The arm/leg ratio input

was 30/70. Time to exhaustion for A+L work was 5:50 minutes, versus 4:30 minutes for L work. During A+L work, RPE was recorded at the time when L exercise stopped and at the cessation of A+L exercise. The maximal RPE was 19 to 20 for L exercise but only 15 to 16 for A+L exercise. At the conclusion of combined A+L work RPE was 19 to 20. The researchers concluded that exercise should be performed with as large a muscle mass as possible to minimize RPE (23). A problem with this study was the short duration of these exercise bouts; they were probably supramaximal and therefore not applicable to steady-state A+L and L exercise.

Eston and Brodie (24) evaluated RPE, circulatory, and respiratory responses during A+L versus L exercise while subjects exercised at low and moderate work rates (49, 74 and 98 Watts for four minutes) on a Schwinn Air-Dyne ergometer. Nineteen males participated in the study and Borg's 6-20 scale was used to determine RPE. No differences were observed between A+L and L work for any physiological variable or RPE (24).

Duey et al. (21) examined the possibility that differences in RPE for A+L and L exercise were evident only at higher power outputs using a Schwinn Air-Dyne ergometer. Eight male subjects performed a graded exercise test (GXT) using A+L and L. The test began at 98 W and increased 49 W every two minutes until exhaustion. There were no differences between the two modes regarding HR, VO_2, and V_E throughout the test. RPE was about two points higher for L versus A+L work at the exercise intensities of 147, 196, and 245 Watts, ($p < 0.05$) (21).

The literature indicates that at moderately high exercise intensities (147 to 245 Watts) a larger muscle mass (A+L work) causes an individual to perceive the exercise as less stressful compared to using a smaller muscle mass (L work only) during incremental work (21). Few studies have compared the cardiorespiratory and perceptual responses for L versus A+L work during a prolonged exercise bout.

Gutin et al. (27) examined the submaximal and maximal physiologic responses to incremental A and/or L exercise as well as the cardiorespiratory and subjective responses to a 60-minute bout of exercise of A+L and L work. Ten men exercised using Monark L and A ergometers for A+L work. During L work, subjects grasped the handlebars of the A ergometer in order to simulate conventional cycling (27). The incremental and endurance A+L test were performed with either 10 (A-10) or 25% (A-25) of the power output contributed by the A. HR and VO_{2peak} values were significantly lower for A work compare to A+L and L work. When the ventilatory breakpoint (VB) was expressed as a percentage of ergometer specific VO_2 (% of VO_{2peak}), it was significantly lower for A and L compared to A-10 and A-25 ,which agrees with Reybrouck et al. (49). Interestingly, Reybrouck and Gutin used the same ergometry setup for A+L work. Gutin et al. (27) speculated this result would suggest that partitioning the workload simultaneously to the A and L during prolonged work would allow a given workload to result in less blood LA and subjective strain.

In the endurance study, each subject operated at a power output that was approximately 115% of the power output at which the leg VB occurred in the incremental test. The actual power outputs were not significantly different. VO_2 and Q responses were generally higher for A+L work, although not significantly different from L work. The overall cardiovascular response for the three modes was similar. RPE tended to increase over time for all modes. Interestingly, RPE was lower for the A+L modes from 5 to 40 minutes compared to L exercise but from 50 to 60 minutes RPE for the A+L modes was higher although no significance was detected (27).

Sagiv et al. (48) studied the cardiorespiratory and RPE responses in twelve males during 25 minutes of L and A+L (using 1.6 kg wrist weights) exercise at 60 and 75% of their maximal heart rate reserve. No differences were reported between A+L and L work at the two workloads regarding V_E, R, O_2 pulse, VO_2, and blood pressure. In contrast,

RPE and blood LA were significantly ($p < 0.01$) lower during A+L exercise at both workloads. The researchers suggested the addition of arm work to leg exercise distributed the workload to a larger muscle mass leading to a lower reliance on anaerobic metabolism and a lower perceived exertion (48).

CHAPTER 3

METHODS

Selection of Subjects

Eleven males and one female volunteered to serve as subjects in the present study. All subjects routinely participated in cardiovascular endurance exercise at least three times a week for at least 30 minutes per session. The subjects were informed of the procedures involved in the study and each subject signed a statement of informed consent (see Appendix A) and completed a health questionnaire (see Appendix B) in accordance with the Institutional Review Board at the University of Tennessee, Knoxville. The subject's physical characteristics are listed in Table 2.

Table 2. Physical characteristics of subjects (n=12)

	Age (yrs)	Height (cm)	Weight (kg)	Body fat * (%)	VO_{2max} ($ml \cdot kg \cdot min^{-1}$)
MEAN	24.42	177.99	76.88	11.78	51.12
SE	2.23	1.77	3.05	1.35	2.34

*estimated from skinfold thickness (45)

Experimental Protocol

Each subject reported to the laboratory on five occasions. The first visit served as an orientation session to familiarize the subject with the testing procedures, accurate reporting of perceived exertion, and the equipment used. Descriptive information such as height, weight, and skinfold measurements were also obtained. The sum of six skinfold measurements (chest, thigh, ilium, abdomen, triceps, and scapula) were taken for body

composition determination. During their next laboratory visit, the subject performed one of two continuous, incremental maximal exercise tests to exhaustion on an air-braked ergometer (Schwinn Air-Dyne). One test involved the use of A+L input while the other test involved only L input. The ergometer was placed on a treadmill with hand rails for all tests. During L work, the subjects firmly gripped the hand rails for stability and accurate measurement of VO_{2max} as described by Nagle et al. (38). The incremental tests were performed within 5 days of one another and separated by at least 48 hours. Tests were performed in a counter-balanced design in order to minimize any order effect.

The incremental tests began at 74 W and increased 25 W every minute until volitional fatigue and/or the inability of the subject to maintain the required power output. Expired air was analyzed every 30 seconds. HR and RPE was recorded every minute throughout the test. Within 2-3 minutes of test completion, a 50 microliter fingertip blood sample was obtained. Criteria used in the determination of VO_{2max} attainment included: a plateau in VO_2 (an increase of < 150 ml $\cdot$ min^{-1} from the previous stage), peak blood lactate levels > 8 mM, and a $R > 1.10$. Two of the three criteria had to be met in order for the test to be deemed a valid indicator of the subject's VO_{2max}.

The subject then returned to the laboratory on two more occasions to perform a 30 minute bout at 70% of VO_{2max} using A+L or L input, respectively. Again, the tests were performed in a counter-balanced design to minimize any order effect that may have occurred. Expired air was analyzed every minute while HR and RPE's were recorded every five minutes throughout the test. A finger stick blood sample of 50 microliters was obtained at rest and at 10 minute intervals during the endurance tests for a total of four samples. The subjects stopped for 1 minute at 10 and 20 minutes of test performance for blood collection. The tests were separated by a minimum of 48 hours and by no more than one week. To control for diurnal variations (32), all four tests were conducted at the same time of the day.

Metabolic Measurements

V_E was measured using a RAM 9200 air-flow meter (Rayfield Equipment, Waitsfield, VT). The subject's expired air was directed to a 5-liter mixing chamber. Expired concentrations of O_2 and CO_2 were determined using Applied Electrochemistry S3-A O_2 and CD-3A CO_2 analyzers, respectively. These analyzers were calibrated against known gases analyzed by the Scholander method (52). VO_2 was calculated at 30 or 60 second intervals (depending on test performed) by a microcomputer, using the Haldane transformation of the respiratory Fick equation. HR was measured continuously via telemetry from a monitor strapped on the chest (UNIQ Heartwatch).

Ratings of Perceived Exertion

RPE were ascertained using Borg's 6-20 point scale (8). Prior to each test, a standardized set of instructions (37), regarding RPE's was read by and to the subject:

> During the last 15 seconds of each stage you will be asked to estimate how physically stressful you feel the exercise to be; that is we want you to rate the degree of perceived exertion you feel. By perceived exertion we mean the total amount of stress, effort and fatigue. Do not concern yourself with any one factor such as arm pain or shortness of breath, but try to concentrate on your total, inner feelings of exertion. Try to estimate as honestly and objectively as possible. The following scale will be used to evaluate your perceived exertion:

6
7 very, very light
8
9 very light
10
11 fairly light
12
13 somewhat hard
14
15 hard
16
17 very hard
18
19 very, very hard
20

A rating of '6' would correspond to those feelings and sensations you have during the easiest work you can imagine, not unlike sitting in a chair. A rating of '20' corresponds to the feelings and sensations you would have during the most difficult work you could imagine yourself doing, so exhaustive that you could not continue. We will ask you to provide a number corresponding to the verbal anchors which best describe how you perceive the effort during the final 15 seconds of each stage by having you point to an appropriate single number on the scale, held within easy reach by the investigator (37).

Blood Lactate Collection and Analysis

Capillary blood samples were obtained from a fingertip. A 50 microliter capillary tube was used to collect the blood which was immediately plunged into 2.0 ml of cold 7% perchorlic acid and shaken. The samples were then centrifuged for 5-7 minutes, and the supernatant was poured into another test tube, covered with parafilm, and frozen at -20 °C until further analysis.

Lactic acid analysis was performed via the enzymatic lactic acid analysis as designed by Gutmann and Wahefield (28). In the presence of lactate dehydrogenase (LDH), lactic acid and NAD are converted to pyruvic acid and NADH, respectively. In order for the reaction to go to completion, pyruvic acid is removed from the mixture by adding a hydrazine-glycine buffer. The remaining NADH is fluorescent and can be measured using a 15 excitation nm and 60 emission nm slits while utilizing a fluorometer. The simple regression equation from the standard curve line (standards were tested at 0, 1, 3, 5, and 10 mM) was used to calculate the lactic acid concentration based on the amount of fluorescence (28).

Quantification of Percent Contribution of Arms and Legs

The Schwinn Air-Dyne ergometer allows simultaneous work to be done by arms and legs. The pedal crank propels a flywheel fitted with wind blades through a double-increase chain drive. The arm levers allow arm work to be performed as a push-pull

movement and leg work via pedal cranking and can be conducted separately or in combination. As the wheel turns, air is displaced by the fan blades and the resistance is directly proportional to the cube of the wheel's revolutions per minute (rpm). Thus, a specific pedal frequency evokes a given power output. Power output is determined by the load indicator. For example, a reading of 1.0 corresponds to 49 watts (W), a reading of 2.0 indicates 98 W, etc.. Since air displacement is used to measure work, corrections must be made for disparities in air density if barometric pressure and temperature vary markedly from the standards of 760 mmHg pressure and 20°C temperature. Corrections were unnecessary in the present experiment.

In order to partition arm and leg power output, strain gauges were attached to the lever arms of the ergometer as in the work of Nagle et al. (38). The gauges employed a full Wheatstone bridge circuit and were placed approximately 3 inches above the fulcrum of the lever arms. The gauges included two sets of connecting wires, input and output, respectively. The input wires were connected to a 12 volt battery to provide the strain gauges with a power source; while the output wires were connected to a recording device. A calibration of the ergometer was performed on nine subjects which involved a continuous, incremental test with arms only at 49, 98, 147, and 196 W. Force output was determined by integrating the area under the force-time curve for six second intervals (Figure 1, Appendix D). Arm power output was linearly related to the force-time integral ($r=0.907$) providing a simple regression formula which was used to calculate the % A contribution to the total power output during A+L work (Figure 2, Appendix D).

Statistical Treatment

Comparisons for A+L and L work were analyzed using planned contrasts. Planned contrasts were performed at each of the work rates during the incremental test and at five minute interval of the endurance test. Paired student's t-test were used to detect

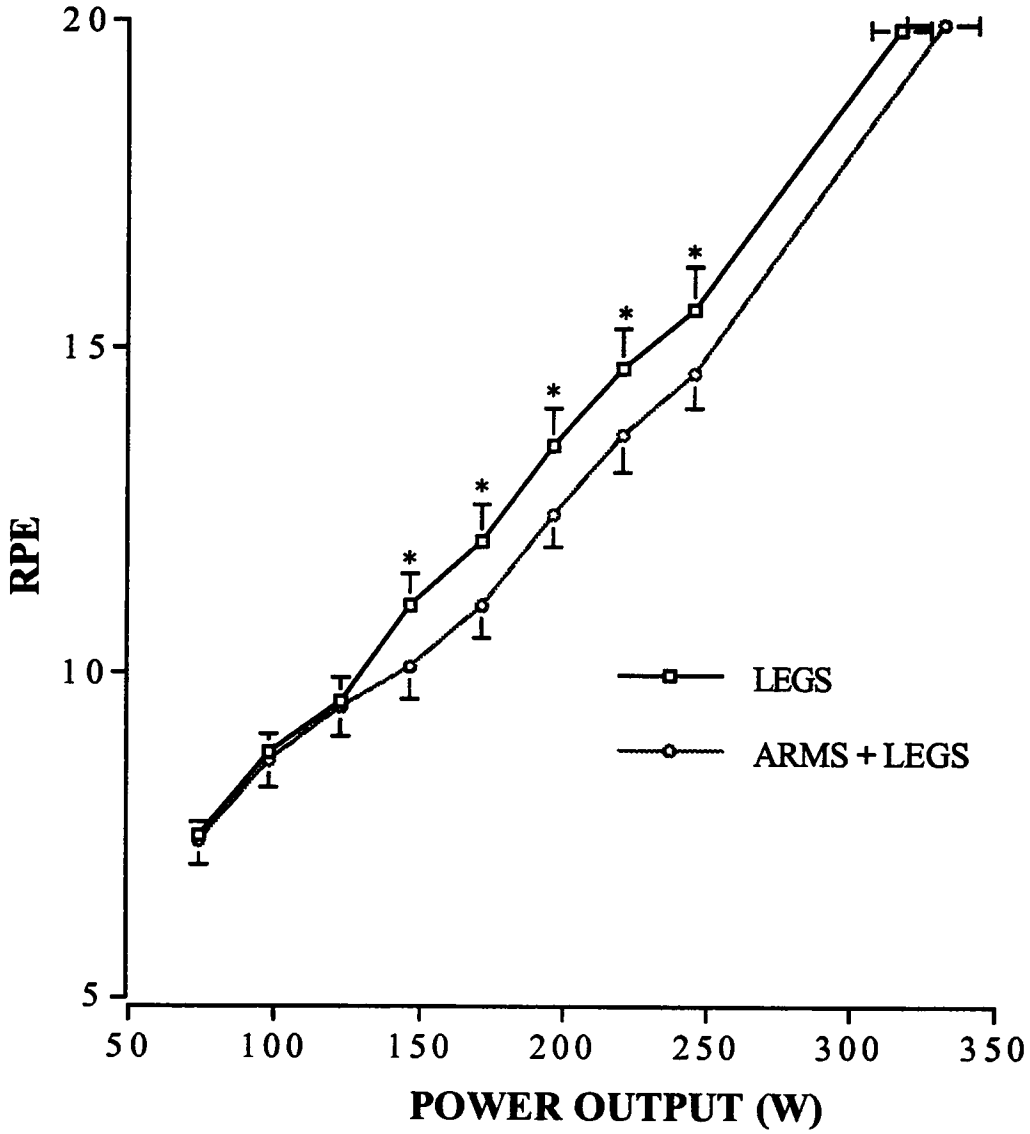
significance in maximal power outputs for A+L and L work for all physiological variables and RPE since maximal power outputs were slightly different (~11 Watts). The level of statistical significance was set at $p < 0.05$ for all comparisons. SuperANOVA software (1) was used for all statistical comparisons. Post-hoc tests are not valid for the within subjects factors in a repeated measures design. This is due to the fact that multiple comparison procedures were developed based on an assumption of independence among the different means being compared, and this assumption is violated by the nature of a repeated measures designs (1). In order to further analyze the between-subjects effects with this model, contrasts were specified for the comparison of interest. Contrasts are applicable when you have specific questions about the effects of a subset of the levels of factors involved in an experiment. Therefore, contrasts were performed at each stage of the incremental test protocols and at five minute intervals of the endurance test for all physiological variables and for ratings of perceived exertion (1).

CHAPTER 4

RESULTS

RPE increased curvilinearly (Figure 3) with power output and was significantly lower ($p < 0.05$) for A+L compared to L work at power outputs of 147, 171, 196, and 221 W (Table E-1, Appendix E). No significant differences were reported for maximal VO_2, V_E, R, and HR, between L and A+L exercise (Tables E-2 - E-5). Overall, VO_2 was significantly higher ($p < 0.05$) for A+L compared to L work. This is a statistical difference derived from the fact that at several submaximal work rates VO_2 for A+L exercise was marginally but significantly higher (~0.05 $L \cdot min^{-1}$, see Figure 4) than L exercise. V_E displayed no significant difference at any work rate for the two modes and the ventilatory breakpoint occurred at 196 W during the incremental test (Figure 5). Although maximal R values (1.17 versus 1.14) were not significantly different, R values for L work were significantly greater ($p < 0.05$) than A+L work at the submaximal work rates from 147 to 245 W (see Figure 6). HR increased linearly (Figure 7) with power output and did not vary significantly for A+L versus L exercise at any work rate. Further, peak blood lactate values were not significantly different for A+L versus L exercise (11.30 versus 11.24 mM, respectively Table E-6, Appendix E). RPE, VO_2, V_E, R, and HR mean values for each work rate of the incremental test are presented in Table C-1, Appendix C.

During the incremental test, subjects chose the amount of A input at each work rate in order to minimize the influence of degree of A training in determining an accurate A+L VO_{2max} (6, 50). The measured A input to total power output for the incremental test is listed in Table C-3, Appendix C. The A input was initially 13.7% and increased linearly with increasing work rate up to 18.5% at the maximal power output of 331 W (Figure 8).



* indicates $p < .05$

FIGURE 3 - RATINGS OF PERCEIVED EXERTION FOR L AND A+L INCREMENTAL EXERCISE

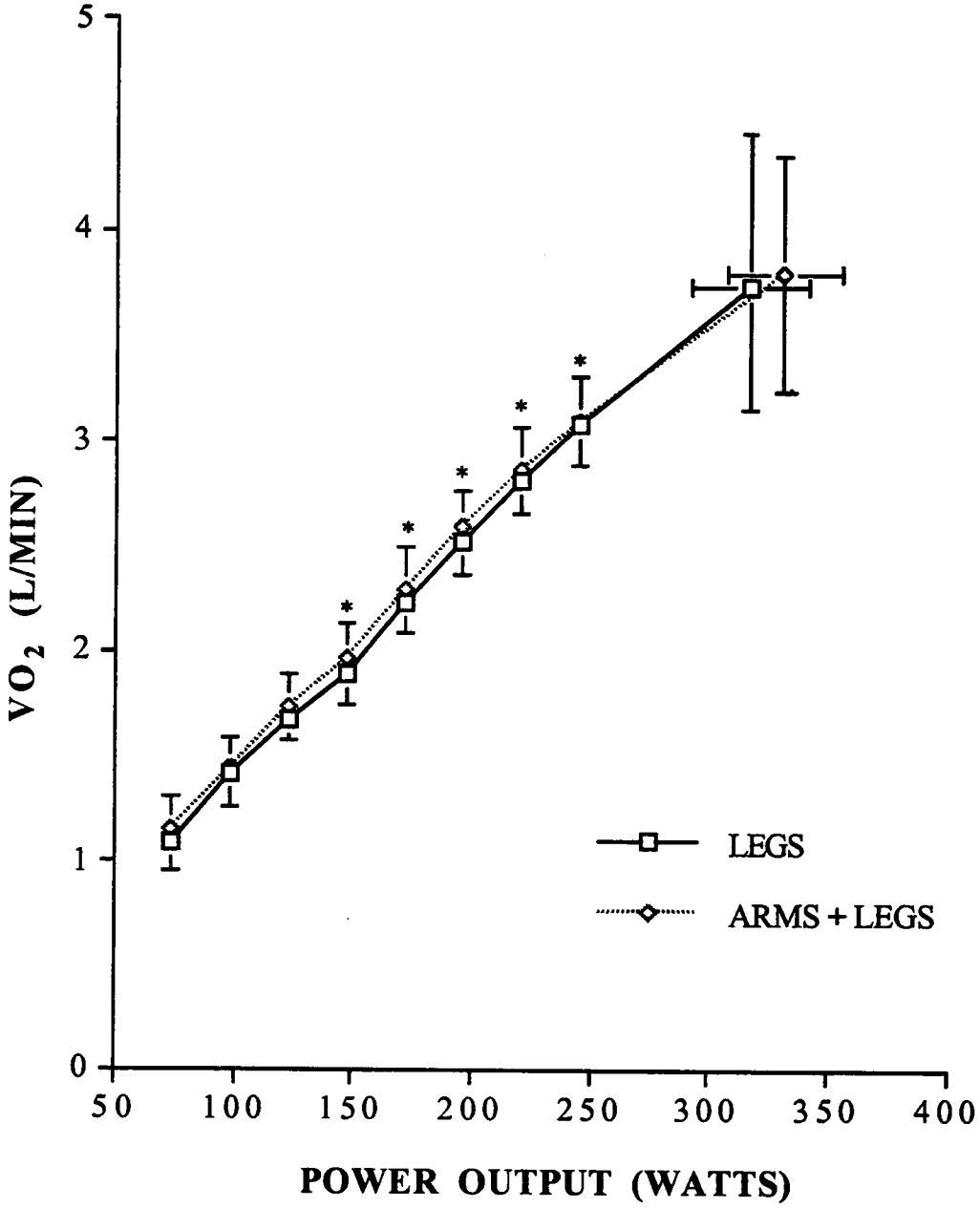


FIGURE 4 - OXYGEN CONSUMPTION FOR L AND A+L DURING INCREMENTAL EXERCISE

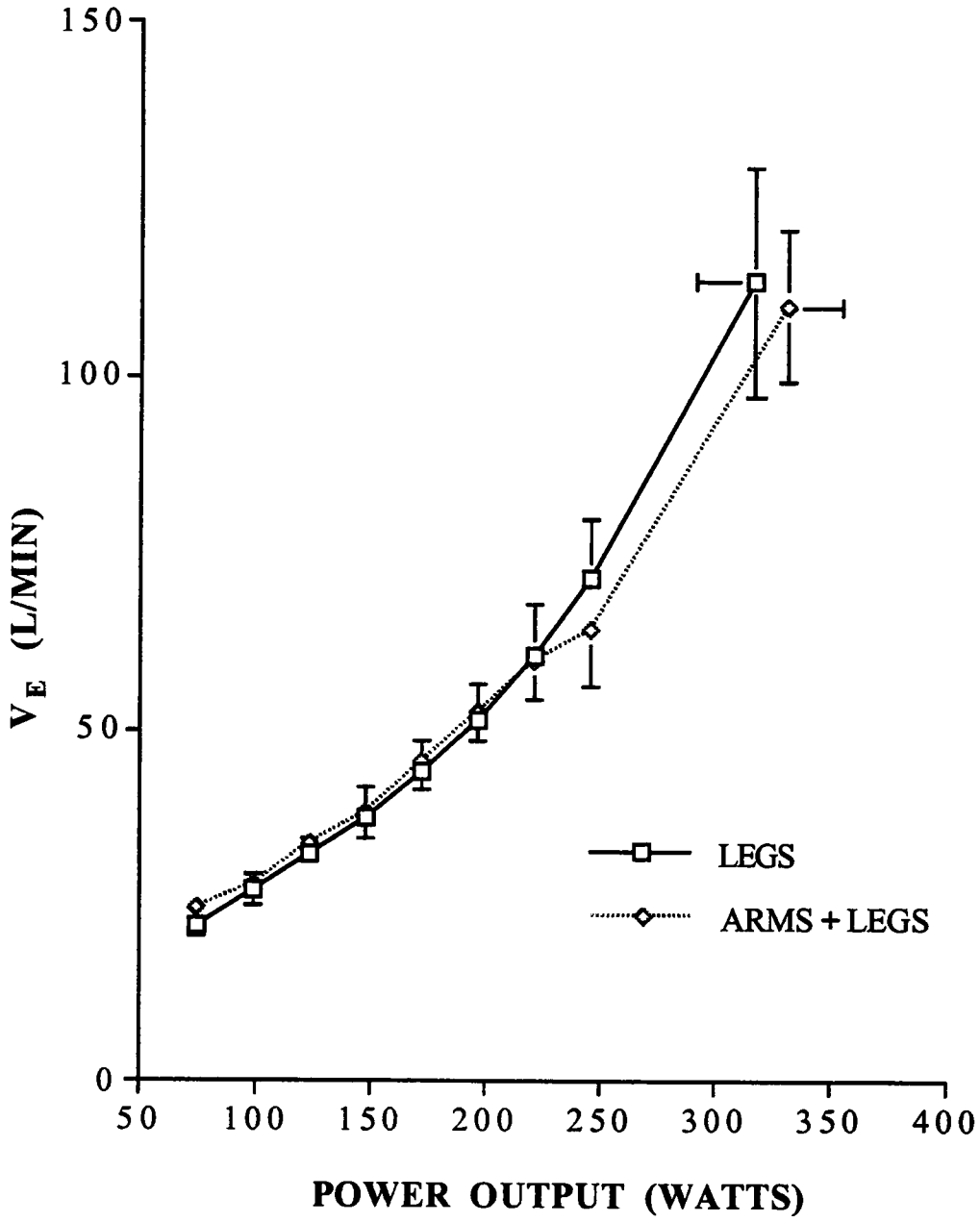


FIGURE 5 - VENTILATION FOR L AND A+L DURING INCREMENTAL EXERCISE

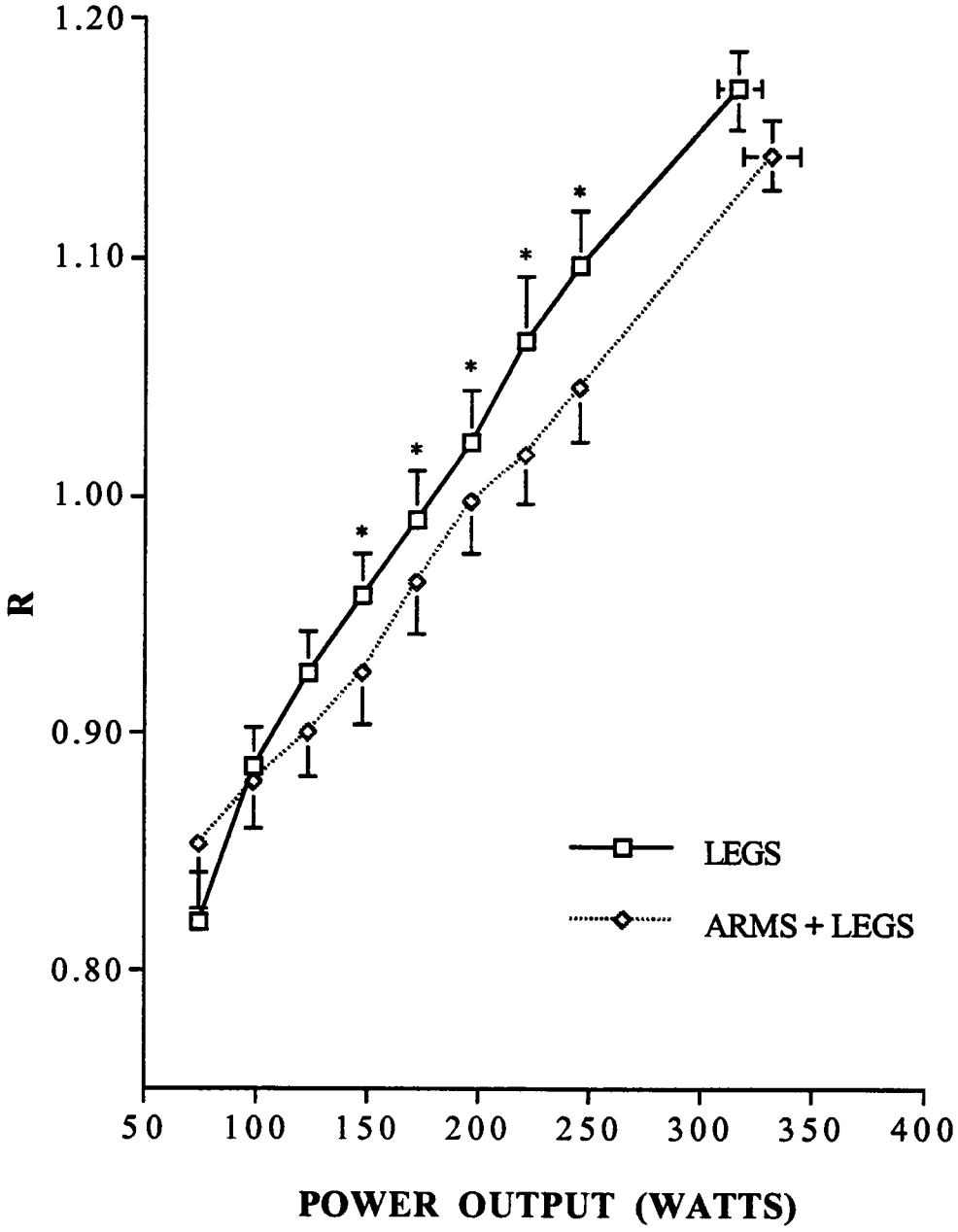


FIGURE 6 - RESPIRATORY EXCHANGE RATIO FOR L AND A+L DURING INCREMENTAL EXERCISE

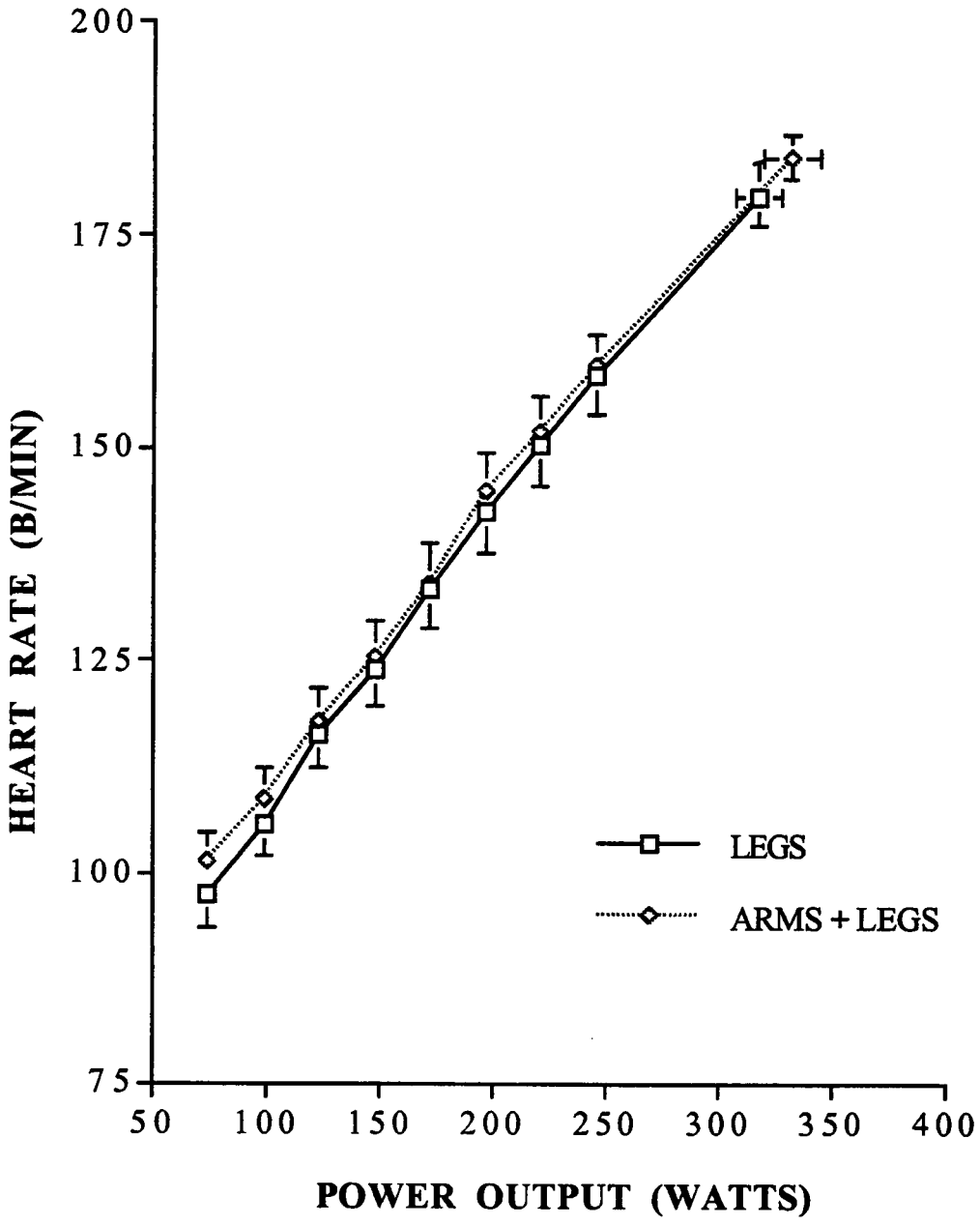


FIGURE 7 - HEART RATE FOR L AND A+L DURING INCREMENTAL EXERCISE

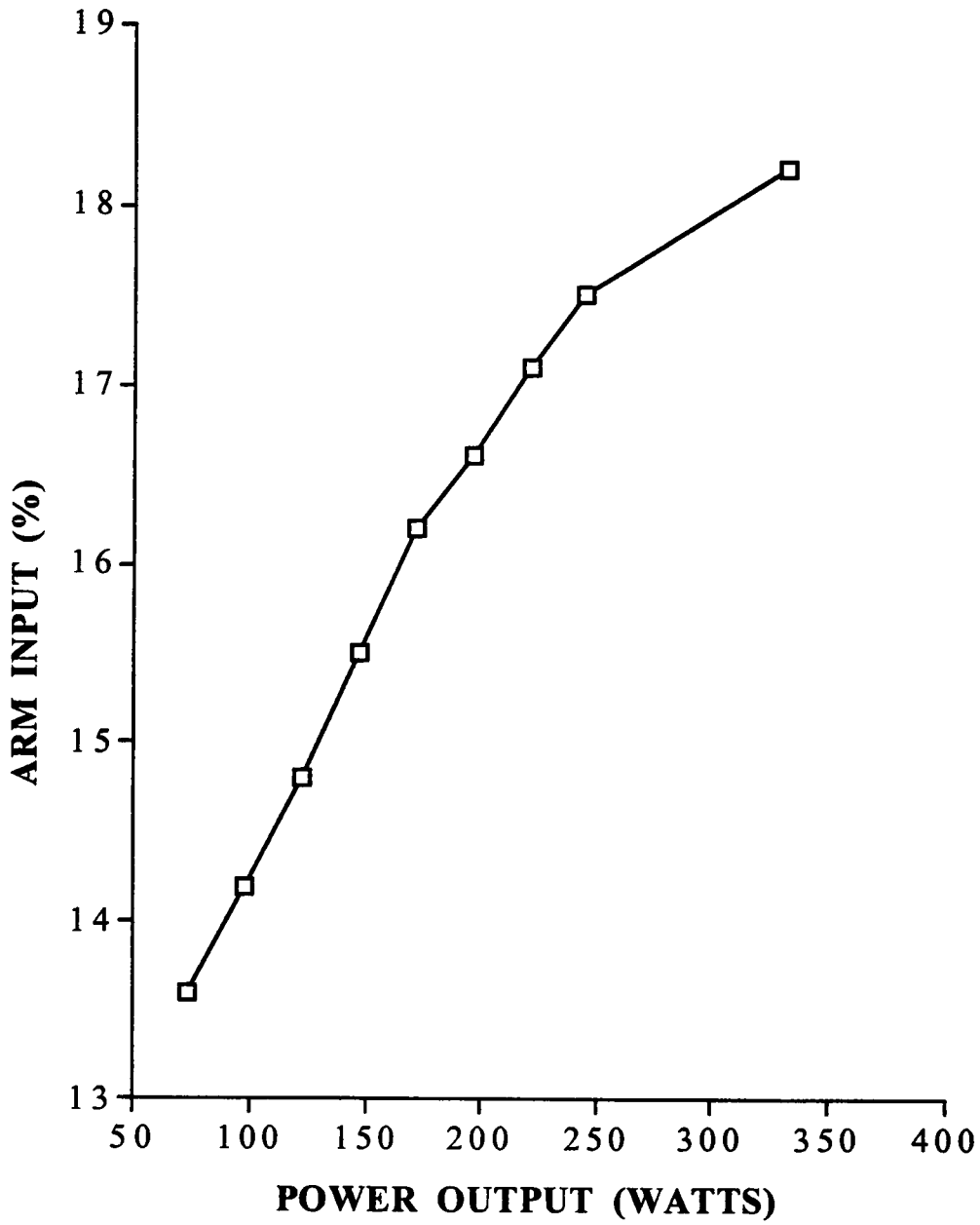


FIGURE 8 - A INPUT (EXPRESSED AS A PERCENTAGE OF TOTAL POWER OUTPUT) DURING A+L INCREMENTAL EXERCISE

In addition, maximal power output and gross mechanical efficiency were not significantly different ($p < 0.05$) between L and A+L exercise (Table E-7 and 8, Appendix E).

During the 30 minute endurance tests, RPE values were significantly higher ($p < 0.001$) at each five minute increment for L exercise compared to A+L exercise (Figure 9, Table E-9, Appendix E). RPE, VO_2, V_E, R, HR, and blood LA values for the endurance test are listed in Table C-2, Appendix C.

VO_2 and V_E values increased minimally over time (see Figures 10 and 11) and were similar for L and A+L exercise throughout the entire endurance test (Table E-10 and 11, Appendix E). HR was significantly higher ($p < 0.05$) for A+L versus L exercise only at 5 minutes (Figure 13 & Table E-13, Appendix E).

R values were significantly lower for A+L compared to L exercise at each five minute interval ($p < 0.05$), (Figure 12, Table E-12, Appendix E). While exercising at a constant work rate, subjects tended to use more fat as an energy substrate during A+L work. Blood LA was similar for both modes at rest but significantly lower at each ten minute interval ($p < 0.02$) for A+L versus L exercise (Figure 14, Table E-14, Appendix E). Blood LA peaked at 20 minutes for both modes and then leveled off for L exercise while A+L values began to decrease (Figure 14).

The measured A input (expressed as a percentage of total power output) for the A+L endurance test is listed in Table C-3, Appendix C. The A input at 3 minutes was 15.4% and remained relatively constant throughout the test.

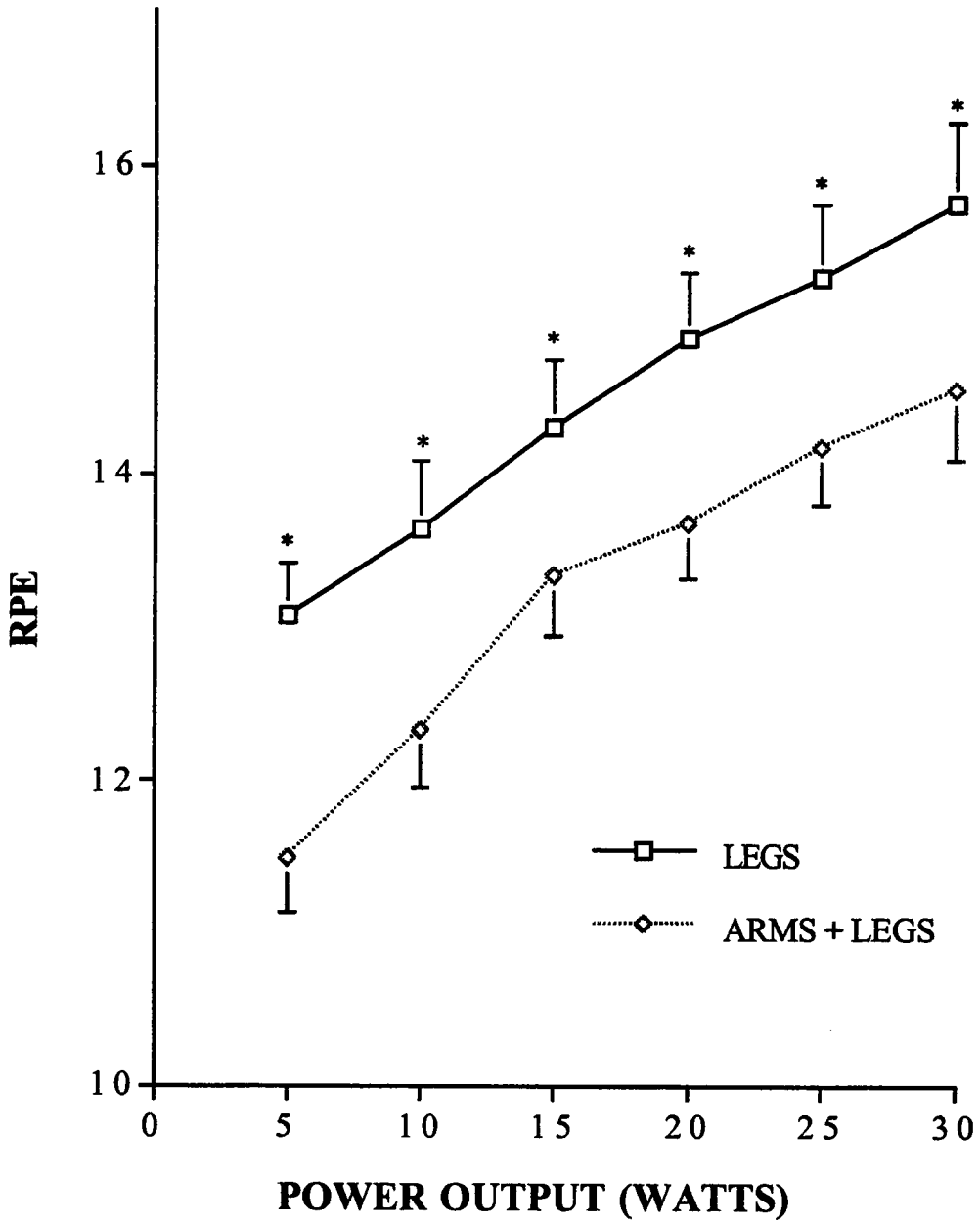


FIGURE 9 - RATINGS OF PERCEIVED EXERTION FOR L AND A+L DURING ENDURANCE EXERCISE

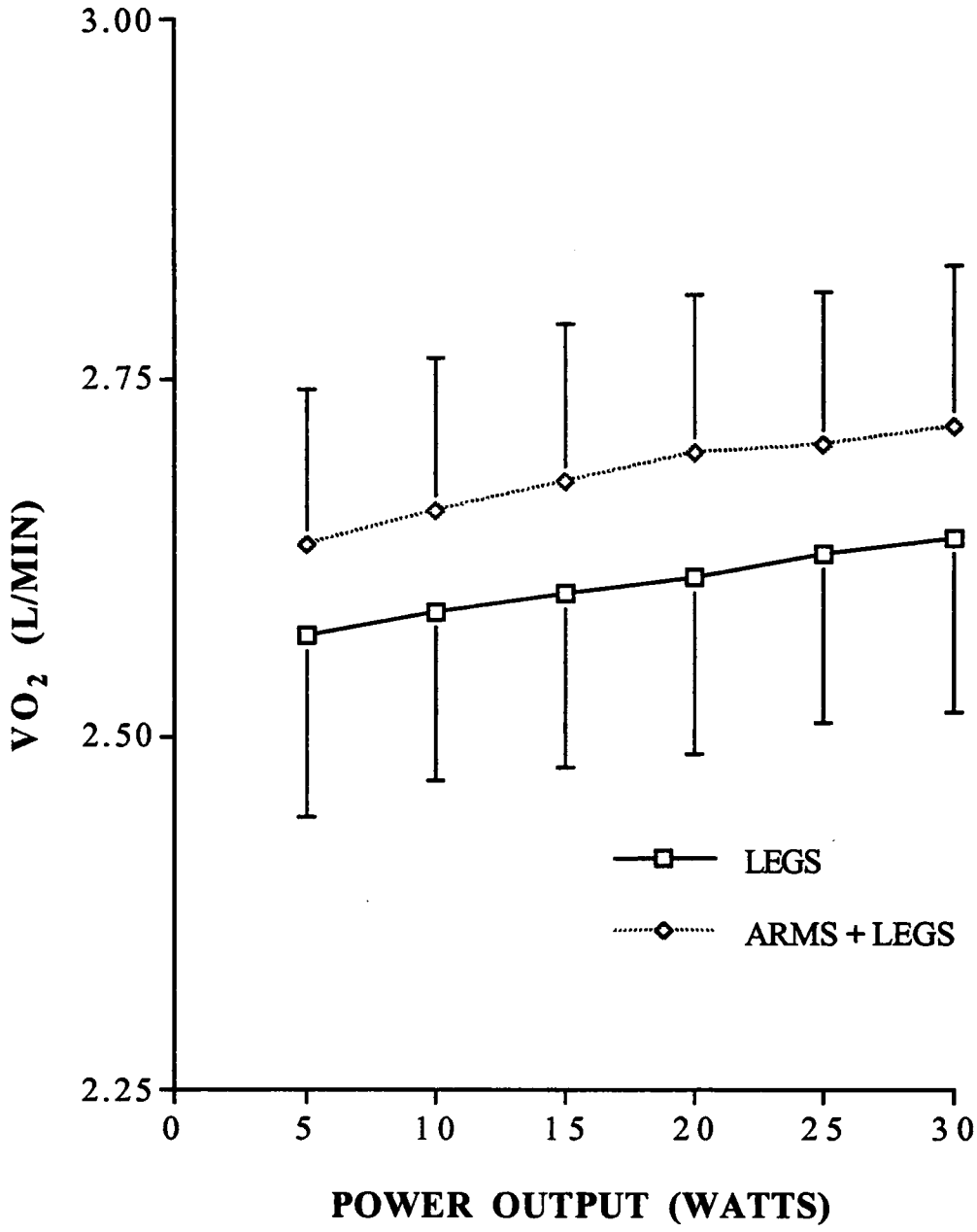


FIGURE 10 - OXYGEN CONSUMPTION FOR L AND A+L DURING ENDURANCE EXERCISE

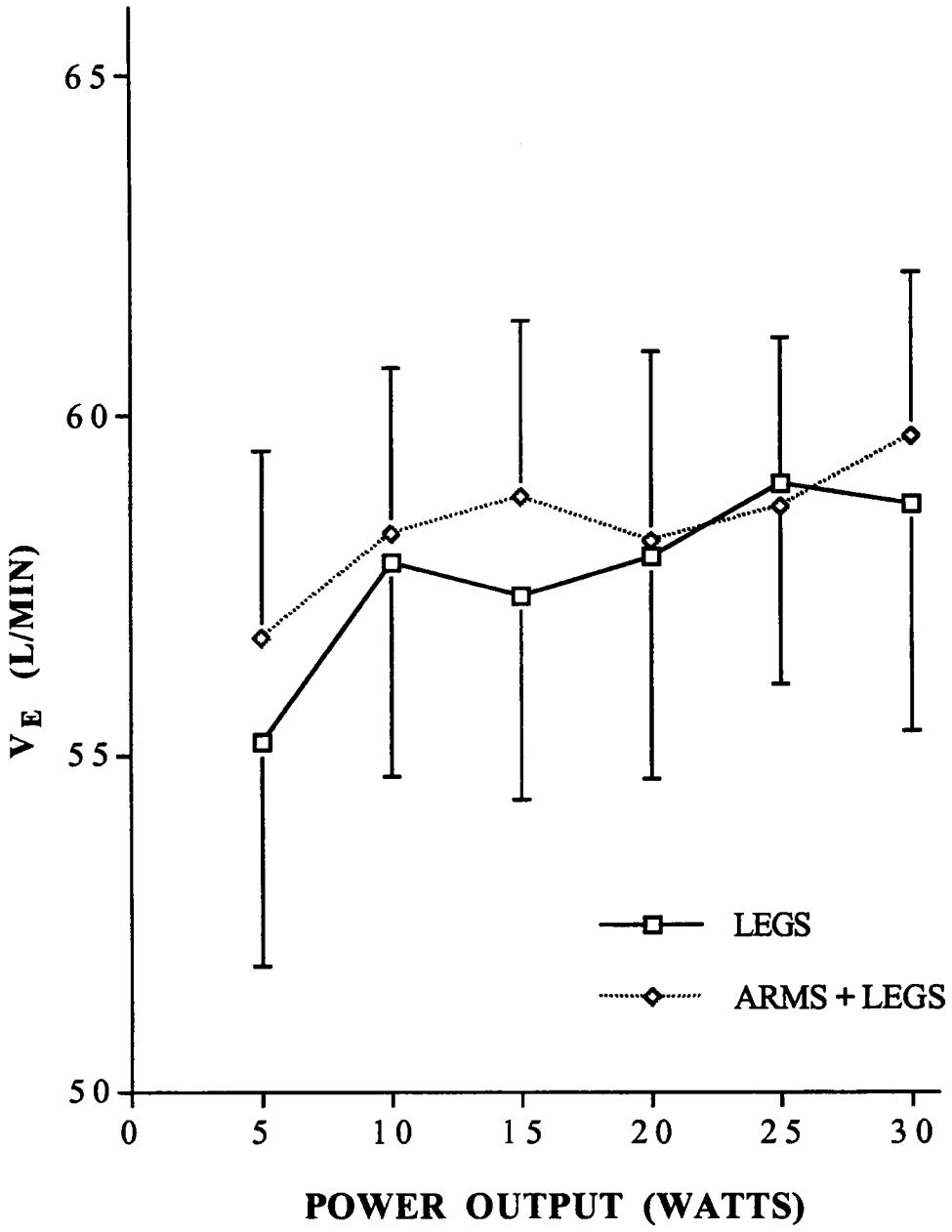
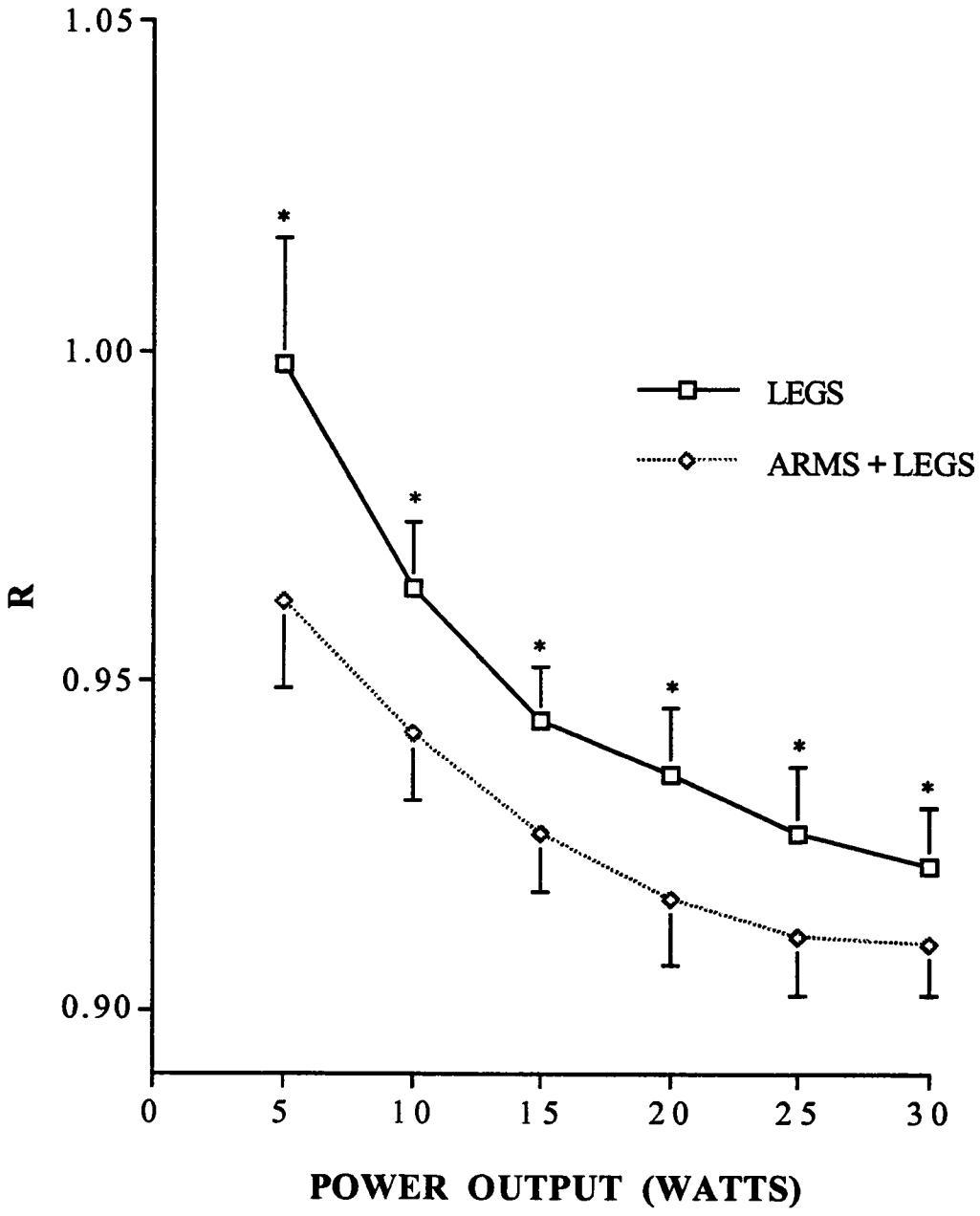
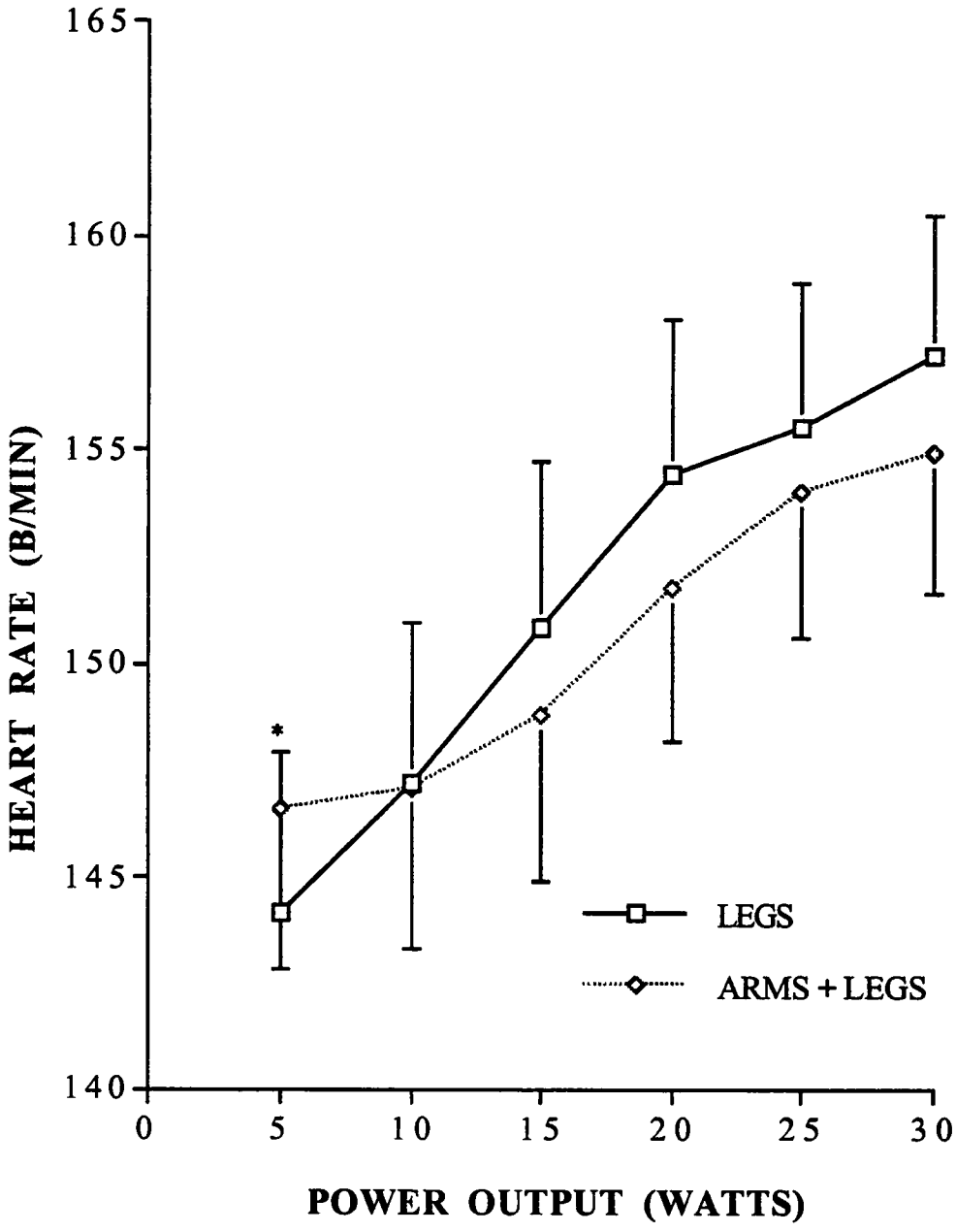


FIGURE 11 - VENTILATION FOR L AND A+L DURING ENDURANCE EXERCISE



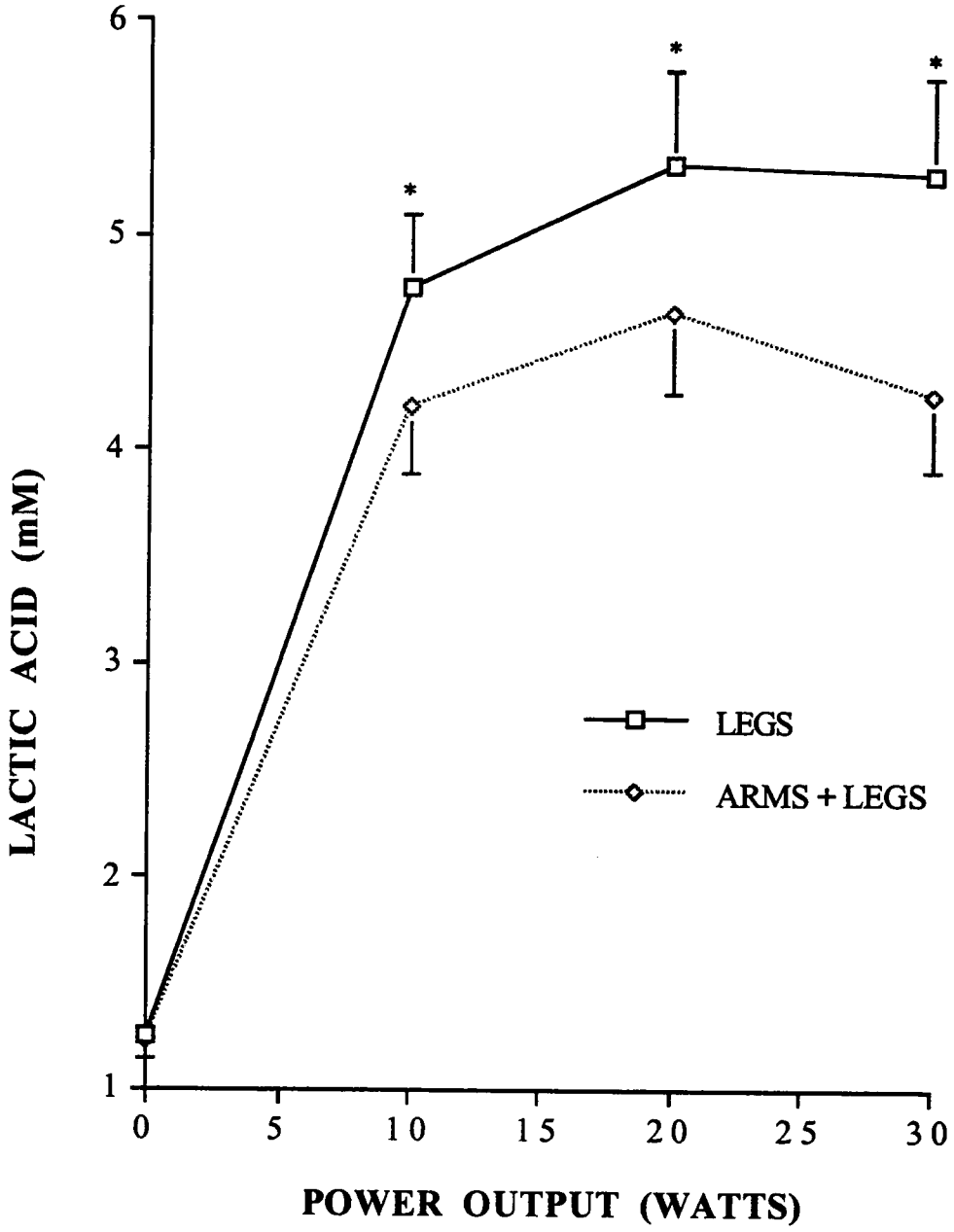
* indicates $p < .05$

FIGURE 12 - RESPIRATORY EXCHANGE RATIO FOR L AND A+L DURING ENDURANCE EXERCISE



* indicates $p < .05$

FIGURE 13 - HEART RATE FOR L AND A+L DURING ENDURANCE EXERCISE



* indicates $p < .02$

FIGURE 14 - LACTIC ACID FOR L AND A+L DURING ENDURANCE EXERCISE

CHAPTER 5

DISCUSSION

The RPE results for the incremental test concur with Duey et al. (21) who reported significantly higher RPE for L compared to A+L exercise at power outputs of 147, 196, and 245 W. Although VO_2 during A+L exercise in the present study was significantly higher than L work, it is important to note that this is a small, statistical difference derived from the fact that during submaximal work, VO_2 for A+L exercise was slightly, but consistently higher (~ 0.05 L · min^{-1}) than L exercise.

The RPE results of the endurance test indicate that when the exercising muscle mass is increased by allowing the arms to perform approximately 15% of the work, perceived exertion decreases. These results are in conflict with those of Gutin et al. (27) who reported that RPE were lower for A+L from 5 to 40 minutes compared to L but from 50 to 60 minutes RPE for A+L work were higher (no significance detected). The differences may be attributable to the methodologies used in the two studies. In Gutin's (27) study, two ergometers were utilized for the A+L test (an A ergometer was mounted on a adjustable table that the subject could reach while pedaling a cycle ergometer). In order to perform A+L work in this manner, subjects must pedal both ergometers simultaneously at a designated rpm, which requires a great deal of coordination and concentration. Although subjects were given a practice session, it is reasonable to conclude that the additional concentration required to synchronize A and L pedaling would elevate A+L RPE values. Second, the test length of 60 minutes may explain why A+L RPE surpassed L RPE after 40 minutes. Subjects were not reported to be notably A trained, thus it is unlikely that any subject was A trained to the extent that they would be able to endure A

work for this length of time without becoming markedly fatigued. Lastly, the subject's A were required to remain in a elevated position when pedaling the two ergometers
simultaneously and could have reduced the gross efficiency of the movement. This could explain why Gutin et al. reported a consistently higher (~0.2 $L \cdot min^{-1}$) VO_2 for A+L work versus L work (27). In the present study, the Air-Dyne allowed subjects to pedal with their L as in conventional cycling while A were positioned at waist level and moved in a fluid push-pull action in concert with L pedaling. These differences in methodology could explain why the present study found A+L RPE to be lower than L exercise throughout the test and Gutin et al. (27) did not.

A study which agrees with the present findings was conducted by Sagiv et al. (48). They studied the cardiorespiratory and RPE responses in twelve males during 25 minutes of L and A+L (using 1.6 kg wrist weights) exercise at 60 and 75% of their maximal heart rate reserve. No differences were reported between A+L and L work at the two workloads regarding V_E, R, O_2 pulse, VO_2, and blood pressure. In contrast, RPE and blood LA were significantly ($p < 0.01$) lower during A+L exercise at both workloads. The researchers suggested the addition of arm work to leg exercise distributed the workload to a larger muscle mass leading to a lower reliance on anaerobic metabolism and a lower perceived exertion (48). This theory concurs with the view of Coyle et al. (16); the amount of muscle mass which participates in the power output influences the relative work rate per muscle fiber. Further, Åstrand et al. (6) has proposed since the 1960s that the subjective feeling of exertion is related to the metabolic rate per square area of muscle.

Zeni et al. (61) compared the rates of energy expenditure at given RPE levels for six different indoor exercise machines. Subjects used a treadmill, cross-country skiing simulator, stair stepper, Air-Dyne, cycle, and rowing ergometer. They performed three

stages of five minutes at self-selected work rates corresponding to RPE values of 11, 13, and 15. At an RPE of 15 the subject's rate of energy expenditure was approximately 400

kcal $\cdot$ hr^{-1} higher on the Air-Dyne compared to cycle ergometry (61). This demonstrates that subjects were able to operate at a higher oxygen uptake at a given RPE, using the Air-Dyne compared to cycle ergometry. Their results are consistent with our finding that combined A+L exercise results in lower RPE at the same power output.

Mihevic (35) conducted a comprehensive review of the literature concerning the various physiological factors that serve as sensory cues for RPE. This review depicts a two-factor model for perceived exertion consisting of central and local factors. Central factors include such physiological factors as: HR, VO_2, and V_E. In the present study, these central factors did not differ significantly between A+L and L exercise, although VO_2 was somewhat higher using A+L than L (2.68 v. 2.61 L $\cdot$ min^{-1}). This result is not surprising since Hagan et al. (29) reported that A work on a Schwinn Air-Dyne is metabolically greater (~25% more) than L work at a given workload. Further, the inverse relationship between VO_2 and RPE during A+L work further undermines the notion that % ergometer-specific VO_{2peak}, a central factor, is the most important determinant of RPE during prolonged exercise. Since central factor responses were consistent during A+L and L work, local factors may account for the disparities in RPE between the two modes of exercise.

Researchers have studied local factors that contribute to RPE including: lactate accumulation (9, 19, 22, 23, 30, 31), and proprioceptive responses (33, 41, 55). A quantifiable local factor that is thought to contribute to perceived exertion is blood LA. Although many cardiorespiratory variables change linearly with workload, perceived exertion, when ratio-scaling methods are used, increases with a positively accelerating function. Blood LA is one physiologic variable which follows the same type of function

during incremental exercise. This supports the view that blood LA is an important determinant of RPE (9, 19, 22, 23, 30, 31).

Ekbolm and Goldbarg (23) presented evidence linking blood LA to RPE. They reported blood LA had the highest correlation with RPE whether their subjects were running or performing exclusively L or A work. At a given submaximal VO_2, RPE was significantly greater for A than L work. However, the RPE for a given blood LA was the same for A or L work. Thus, the relationship between blood LA and RPE remained constant regardless of the mode of exercise. The authors suggested that muscular strain, indicated by higher blood LA, provides feedback which strongly influences RPE (23). Borg et al. (9) reported that RPE can be predicted for A or L steady state exercise by combining HR and blood LA data. It has also been proposed that the lactate threshold (LT) is an important "physiological anchor point" for perception of effort regardless of training state or gender (19). Hetzler et al. (31) demonstrated that RPE was closely related to blood LA in the range of 2.0 to 4.0 mM, regardless of exercise mode (i.e., cycle or treadmill).

A possible explanation for the lower blood LA during A+L work is a decrease in blood LA production. The arm contribution (~15.0 %) to total power output throughout the A+L test reduced the metabolic demand on the L and therefore reduced their lactate production. As opposed to the L test when the L were responsible for 100% of the power output, the L were required to produce approximately 85% of the power output during A+L work. Another explanation for the lower blood LA levels during A+L work may be increased blood LA removal. Skeletal muscle is a major site of lactate oxidation (~75%) during steady-state, submaximal exercise (11). Therefore, during A+L work the A muscles may have oxidized some of the blood LA produced by the L, and increased blood LA removal.

Local factors, including general leg muscle sensations and proprioceptive responses have also be linked to RPE (23, 33, 41, 55). Stamford and Noble (55) studied subjects during continuous and intermittent constant power output at pedaling speeds of 40, 60,

and 80 rpm. Central factors (VO_2, HR, V_E) did not differ between the pedal rates yet RPE was 17% higher at 40 rpm than 60 or 80 rpm. The authors speculated that this may be accounted for by the increased stimulation of Golgi tendon organs at the lowest pedal rate (55). Pandolf et al. (41) examined subjects working at various pedaling speeds (40, 60, and 80 rpm) and resistances for equivalent power outputs. Again, central factors (VO_2, HR) were not different between the pedaling rates yet RPE was higher at 40 compared to 60 and 80 rpm. The authors stated that an individual's determination of RPE predominately involves a local factor, which is associated with feelings of strain in the working muscles and joints (41). Löllgen et al. (33) also found that RPE decreased with increasing pedaling rate and stated that RPE are not derived from the strain of exercise but instead may stem from perception of force and speed in the working muscles. The results of these studies implicate local muscular strain as a prominent contributor to RPE determination.

In the present study, the arms provided about 15% of the total power output during the continuous A+L test. This would have reduced the power output required of the legs by approximately 15%. Additionally, since the velocity of leg muscle contractions was held constant (i.e., equivalent pedal RPM) during the two modes, the force generation required of the legs would have decreased by 15% during A+L work. Thus, during A+L exercise the decreased feelings of local muscle "strain" or tension may have contributed to the reduction in RPE.

Borg stated that the term "perceived exertion" is more appropriate for short, incremental work while "perceived fatigue" may be more applicable for long-term exercise bouts (8). In the present experiment, it appears that peripheral factors (i.e., blood LA and general leg muscle strain) had a marked effect on the subject's "perceived fatigue" during 30 minutes of A+L or L exercise.

The American College of Sports Medicine Guidelines for Exercise Testing and Prescription recommends that the optimal intensity to improve an individual's fitness level is 65-90% of one's maximal HR (3). The proper training intensity for the subjects in the present study would range from 127 to 176 beats/minute. The average HR elicited during the L and A+L endurance tests was 151 and 150 beats/minute, respectively; and therefore, were within the ACSM's guidelines. This study indicates that the subject's "effort sense" was significantly lower throughout test performance for A+L versus L work. Even though energy expenditure was slightly higher for A+L than L work, subjects perceived the A+L work to require markedly less effort than L work. Thus, an individual can accomplish a prolonged exercise bout with less "perceived fatigue" during A+L compared to L exercise. This development could have practical implications in regard to increasing an individual's exercise compliance since Dishman (20) reported exercise compliance is associated with the perceived demands of the activity.

In addition, R values were significantly lower for A+L compared to L work throughout the endurance test indicating that more fat is oxidized during A+L than L exercise (~42% more). We believe that our R values are a valid reflection of substrate oxidation, since Romijn et al. (47) have found that indirect calorimetry accurately measures metabolic CO_2 production/O_2 consumption up to work intensities of 80-85% VO_{2max} in trained subjects (R=.91). Specifically, in the present study subjects oxidized 90 and 62 kcal (10 versus 7 grams) of fat during the A+L and L tests, respectively. Thus,

if the Schwinn Air-Dyne were utilized on a frequent basis it could help to promote fat loss.

In summary, the results of this study demonstrate that RPE is significantly lower for A+L exercise, compared to L exercise, during prolonged cycling. The reduction in RPE appears to be due to decreases in peripheral factors such as blood LA and leg muscle "strain". No significant differences were observed between the two modes regarding central factors (HR, VO_2, V_E) during the endurance test, which are thought to provide input to RPE. Further, R values were significantly lower for A+L compared to L work throughout the endurance test. This study indicates that when the muscle mass is increased to include A+L input, an individual can complete a 30 minute exercise bout with less sense of fatigue than with L work alone. These results may have positive implications for an individual's adherence and compliance to exercise.

CHAPTER 6

CONCLUSION

Ratings of perceived exertion were significantly higher for L versus A+L work at power outputs of 147 to 245 Watts during the incremental test. RPE was significantly greater for L compared to A+L work, at the same relative exercise intensity, throughout thirty minutes of exercise. In addition, blood lactate accumulation was found to be significantly lower for A+L during the continuous test. These results indicate during prolonged work at moderately high intensities, increasing the exercise muscle mass causes RPE to decrease. Further, the decrease in RPE is attributable to a reduction in peripheral variables (blood LA and possibly muscle "strain") during A+L exercise.

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WORKS CITED

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APPENDICES

APPENDIX A

INFORMED CONSENT FORM

Investigator: Michael F. Shipe

Address: Exercise Science Unit
College of Education
University of Tennessee-Knoxville
Room 314 HPSS

Phone: 423/974-5111

Testing Procedure

You are invited to participate in a research study in which the purpose is to compare ratings of perceived exertion (RPE) and mrtabolic responses for arm-leg (A+L) exercise versus leg (L) work using a Schwinn Air-Dyne ergometer. The testing procedure requires participation on four separate days and each test will take approximately 50 minutes per visit to conduct. On two separate days you will perform a maximal exercise test (discussed later) utilizing your arms anf legs (A+L) and the other using legs (L) only on a Schwinn Air-Dyne ergometer. The third and fourth day, a submaximal A+L or L only endurance test will be performed for 30 minutes at 70% of your maximal aerobic capacity. Descriptive information such as height, weight, and skin-fold measurements will also be obtained. Prior to all tests, you will read an instruction form defining and outlining the procedure for obtaining ratings of perceived exertion.

If you consent to participate in the study, you will perform two maximal graded exercise tests at the onset of your participation. One maximal test will involve the use of A+L and the other L work on a Schwinn Air-Dyne. The test involves a progressive increase in work load every minute until exhaustion. A fingertip blood sample will be taken 2-3 minutes after either test completion to ensure that a maximal effort was attained.

Next, you will perform two submaximal 30 minute endurance tests at 70% of your maximal aerobic capacity. One test protocol will use A+L input and the other solely L work on a Schwinn Air Dyne ergometer for 30 minutes. A small blood sample (.05 milliliters (ml) or 2-3 drops) will be obtained at 10 minute intervals (a total of .15 ml) during either test from a fingertip sample. During all tests you will be fitted with a heart rate monitor as well as the proper equipment to measure oxygen uptake throughout the test.

Risks and benefits

The risks of performing these test include musculoskeletal injury and soreness, abnormal blood pressure responses, arrhythmia of the heart, dizziness, and in extremely rare instances heart attacks. In the instance that a medical problem arises, the principal investigator will take the subject to the University of Tennessee Medical Center at Knoxville. In the event that physical injury occurs as a result of test participation in this research study, the University of Tennessee does not automatically provide reimbursement for medical care or other complications. If physical injury is sustained

during test performance or for more information, please contact the project director, Michael Shipe, at 974-5111 or the faculty sponsor, Dr. David Bassett at 974-8766.

Confidentiality

The information obtained in this study, such as your maximal oxygen uptake or lactate threshold, will be provided to you at your discretion. Data from this study will be used in research reports and presentations; however, your name and identity will be kept confidential.

You are invited to participate in the study and may decide to withdraw without prejudices or obligations. You are encouraged to inquire about any aspects of the study you do not fully understand before signing this informed consent from..

Informed Consent Statement:

I, _____, have read the above consent form and have decided to participate in the research project described above. My signature also denotes that I have received a copy of this consent form.

_____ _____
Participant's signature Date

_____ _____
Witness Date

Michael F. Shipe
Room 314, HPSS Building
423/974-5111

APPENDIX B

MEDICAL HISTORY FORM

Name _____ Age _____

Date _____

Previous Medical History
(Check 'X' if yes)

Have you ever had ?

	Yes	No	Uncertain
Rheumatic fever	( )	( )	( )
Heat murmur	( )	( )	( )
High blood pressure	( )	( )	( )
Any heart problems	( )	( )	( )
Varicose veins	( )	( )	( )
Lung disease	( )	( )	( )
Epilepsy	( )	( )	( )
Chronic bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Bronchial asthma	( )	( )	( )
Kidney disease	( )	( )	( )
Liver disease	( )	( )	( )
Hay fever	( )	( )	( )

Present symptoms review

Have you recently had? (within 12 months)

Chest pain	( )	( )	( )
Shortness of breath	( )	( )	( )
Heart palpations	( )	( )	( )
Leg or ankle swelling	( )	( )	( )
Coughing up of blood	( )	( )	( )
Hypoglycemia	( )	( )	( )
Felt faint or dizzy	( )	( )	( )

Do you smoke ? ____ How many cigarettes a day? _____

For how many years? _____

How old were you when you started? _____

In case you have stopped, when did you? _____

Do you engage in sport-type activities? _____

What kind? _____

How often and for how long? _____

Do you have discomfort, shortness of breath, or pain with moderate or maximal exercise?
_____

When was the last time you underwent a physical examination from a medical doctor?
_____

Please list all medications you are presently taking or have taken within the last three months
_____

Do you have any medical conditions that have not been previously listed? If so, please describe them _____

APPENDIX C

Table C-1. Means and standard errors for L and A+L values for incremental test.

Variable	Power output (W)	L	A+L
RPE	73.5	7.50 ± 0.31	7.42 ± 0.19
	98.0	8.75 ± 0.37	8.75 ± 0.35
	122.5	10.25 ± 0.41	10.08 ± 0.38
	147.0	12.42 ± 0.53*	11.50 ± 0.38
	171.5	13.42 ± 0.54*	12.42 ± 0.45
	196.0	14.50 ± 0.56*	13.42 ± 0.50
	220.5	15.67 ± 0.52*	14.67 ± 0.63
	245.0	16.58 ± 0.65*	15.58 ± 0.61
	MAX	19.75 ± 0.13	19.67 ± 0.18
VO_2 (Liters · min^{-1})	73.5	1.08 ± 0.04	1.15 ± 0.04†
	98.0	1.41 ± 0.04	1.44 ± 0.04
	122.5	1.67 ± 0.03	1.73 ± 0.04†
	147.0	1.89 ± 0.04	1.96 ± 0.05†
	171.5	2.23 ± 0.04	2.29 ± 0.06†
	196.0	2.52 ± 0.05	2.59 ± 0.05†
	220.5	2.81 ± 0.05	2.85 ± 0.06
	245.0	3.08 ± 0.06	3.09 ± 0.06
	MAX	3.73 ± 0.17	3.79 ± 0.17
V_E (Liters · min^{-1})	73.5	22.31 ± 0.87	24.70 ± 1.17
	98.0	27.33 ± 0.72	28.13 ± 0.85
	122.5	32.35 ± 0.63	33.86 ± 0.74
	147.0	37.72 ± 0.73	38.13 ± 0.91
	171.5	44.17 ± 0.99	45.48 ± 1.10
	196.0	51.20 ± 1.14	52.28 ± 1.19
	220.5	60.36 ± 1.70	59.68 ± 1.40
	245.0	71.23 ± 2.15	63.88 ± 2.09
	MAX	113.41 ± 6.76	111.07 ± 6.30

* indicates $p < 0.05$

† indicates $p < 0.02$

Table C-1 (Cont.)

Variable	Power output (W)	L	A+L
R	73.5	0.82 ± 0.02	0.85 ± 0.03
	98.0	0.88 ± 0.02	0.88 ± 0.02
	122.5	0.92 ± 0.02	0.90 ± 0.02
	147.0	0.95 ± 0.02*	0.92 ± 0.02
	171.5	0.99 ± 0.02*	0.96 ± 0.02
	196.0	1.02 ± 0.02*	0.99 ± 0.02
	220.5	1.06 ± 0.02*	1.02 ± 0.02
	245.0	1.10 ± 0.02*	1.04 ± 0.02
	MAX	1.19 ± 0.02	1.15 ± 0.02
HR (beats · min^{-1})	73.5	97.33 ± 3.78	101.42 ± 3.26*
	98.0	105.58 ± 3.52	108.58 ± 3.73*
	122.5	116.25 ± 3.87	117.83 ± 3.93
	147.0	123.75 ± 4.14	125.42 ± 4.27
	171.5	133.33 ± 4.72	133.75 ± 4.85
	196.0	142.33 ± 4.74	144.75 ± 4.70
	220.5	150.25 ± 4.80	151.67 ± 4.22
	245.0	158.33 ± 4.47	159.58 ± 3.63
	MAX	181.25 ± 2.47	183.58 ± 3.00

* indicates $p < 0.05$

Table C-2. Means and standard errors for L and A+L values for endurance test

Variable	Time (Minutes)	L	A+L
RPE	5	13.08 ± 0.34	11.50 ± 0.36*
	10	13.83 ± 0.44	12.33 ± 0.38*
	15	14.50 ± 0.44	13.33 ± 0.40*
	20	15.08 ± 0.42	13.67 ± 0.36*
	25	15.67 ± 0.48	14.17 ± 0.39*
	30	16.17 ± 0.53	14.53 ± 0.45*
VO_2 (Liters · min^{-1})	5	2.57 ± 0.13	2.63 ± 0.11
	10	2.59 ± 0.12	2.65 ± 0.11
	15	2.60 ± 0.12	2.68 ± 0.11
	20	2.62 ± 0.12	2.69 ± 0.11
	25	2.63 ± 0.12	2.70 ± 0.11
	30	2.63 ± 0.11	2.71 ± 0.11
V_E (Liters · min^{-1})	5	55.16 ± 3.30	56.72 ± 2.76
	10	57.83 ± 3.15	58.25 ± 2.44
	15	58.34 ± 3.02	58.78 ± 2.60
	20	59.92 ± 3.29	59.01 ± 2.79
	25	60.04 ± 2.94	59.12 ± 2.51
	30	59.79 ± 3.23	59.67 ± 2.40
R	5	0.99 ± 0.02	0.96 ± 0.01*
	10	0.96 ± 0.01	0.94 ± 0.01*
	15	0.94 ± 0.01	0.93 ± 0.01*
	20	0.94 ± 0.01	0.92 ± 0.01*
	25	0.93 ± 0.01	0.91 ± 0.01*
	30	0.92 ± 0.01	0.91 ± 0.01*

* indicates $p < 0.001$

Table C-2 (Cont.)

Variable	Time (Minutes)	L	A+L
HR (beats · min^{-1})	5	141.17 ± 3.78	144.08 ± 2.52†
	10	147.17 ± 3.78	147.08 ± 3.00
	15	150.83 ± 3.87	148.75 ± 2.78
	20	154.42 ± 3.60	151.75 ± 3.03
	25	155.50 ± 3.39	154.00 ± 2.93
	30	156.17 ± 3.31	155.92 ± 3.04
LACTIC ACID (mM)	AT REST	1.25 ± 0.07	1.41 ± 0.09
	10	4.76 ± 0.34	4.20 ± 0.32‡
	20	5.33 ± 0.43	4.64 ± 0.38‡
	30	5.27 ± 0.45	4.11 ± 0.36‡

† indicates $p < 0.05$

‡ indicates $p < 0.02$

Table C-3 - Arm input means and standard errors for the incremental and endurance test

Power Output (Watts)	Arm Input (% of total power output)
Incremental Test	
74	13.6 + 1.1
98	14.8 ± 1.0
123	15.3 ± 1.1
147	15.5 ± 1.1
172	16.2 ± 1.3
196	16.6 ± 1.2
221	17.1 ± 1.3
245	17.5 ± 1.3
332	18.2 ± 1.1
Time (Minutes)	
Endurance Test	
3	15.4 ± 1.3
5	14.9 ± 1.1
8	15.2 ± 0.9
14	15.4 ± 1.1
16	14.8 ± 0.9
19	14.7 ± 1.1
24	14.7 ± 1.0
27	14.2 ± 1.2
29	14.9 ± 1.1

APPENDIX D

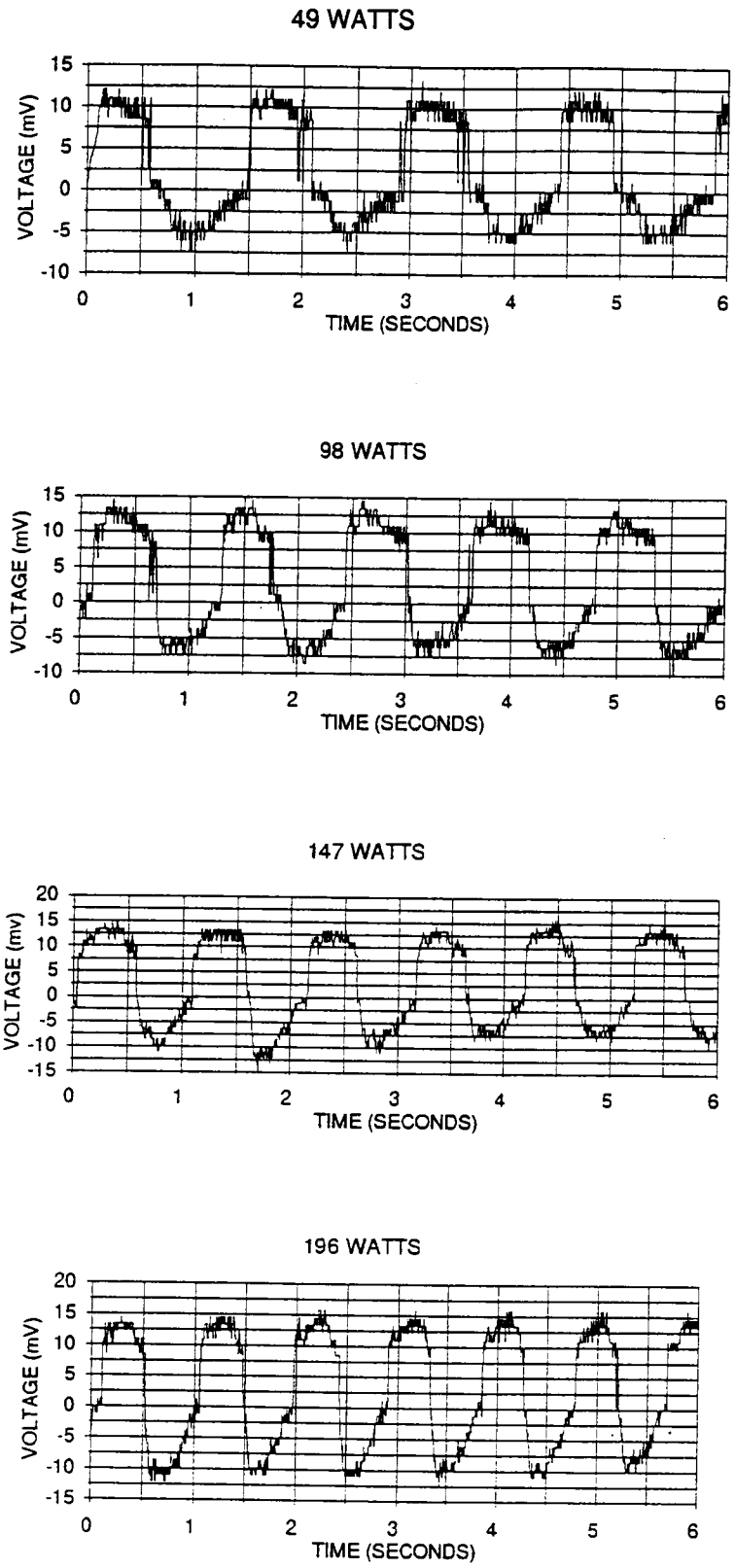


FIGURE 1 - VOLTAGE VERSUS TIME AT DESIGNATED POWER OUTPUTS FOR ARMS ONLY

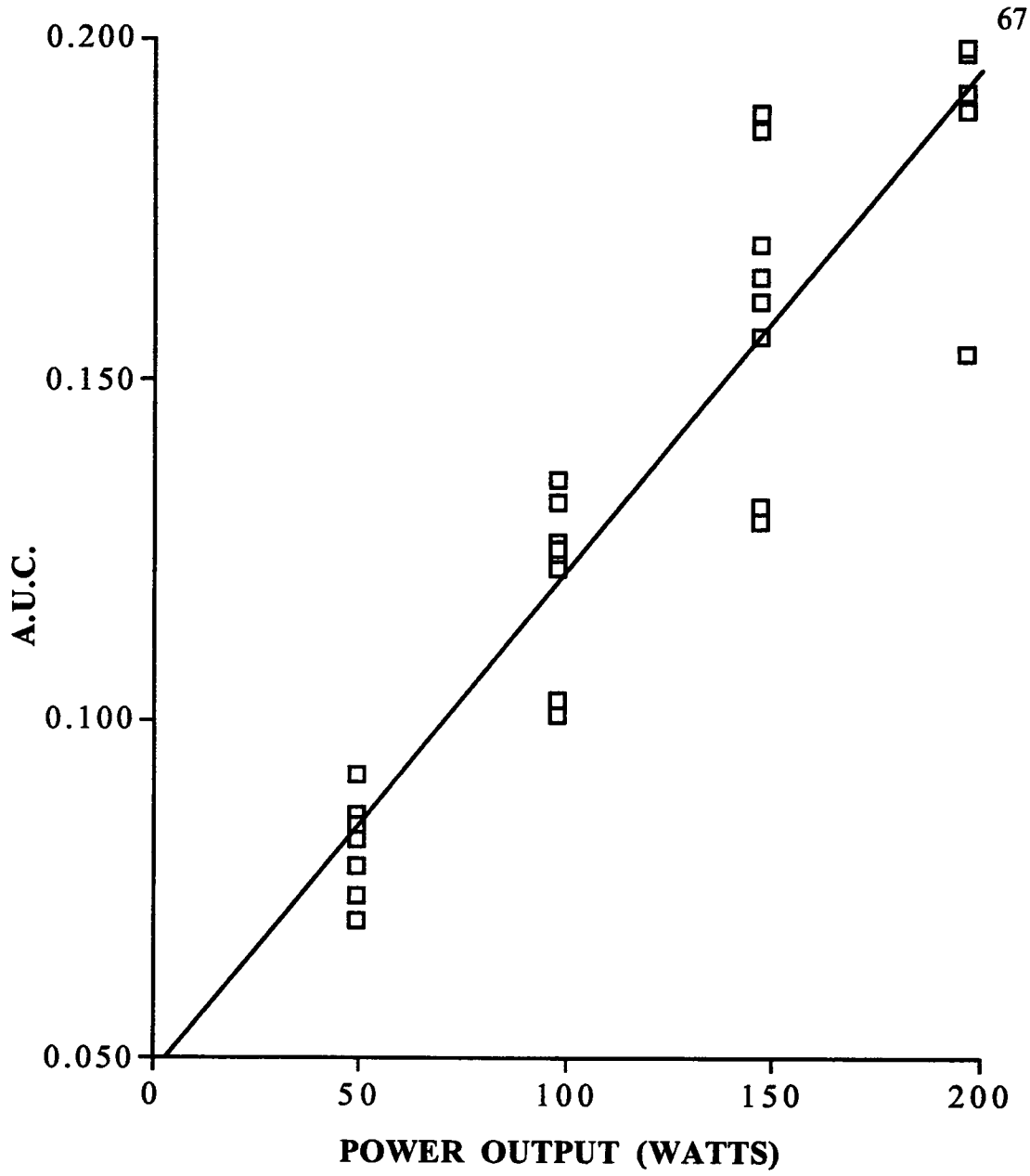


FIGURE 2 - CALIBRATION CURVE RELATING FORCE-TIME INTEGRAL FROM STRAIN GAUGE OUTPUT TO ARM POWER OUTPUT

APPENDIX E

STATISTICAL ANALYSIS

Table E-1. Repeated Measures ANOVA for Ratings of Perceived Exertion between L and A+L Incremental Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	3355.43	32.31		
Condition	1	20.67	20.67	21.88	0.0077
Error	11	10.39	0.95		
Level	8	1581.66	225.95	223.70	0.0001
Error	88	77.77	1.01		
Cond. * Level	8	9.62	1.37	0.010	0.0250
Error	88	997.65	10.97		

E-1a. Paired T-test Analysis for Maximal Ratings of Perceived Exertion between L and A+L Incremental Exercise.

Mean	19.75	19.66
SD	0.45	0.65
Paired Observ.	12	
t-statistic	0.43	Hypothesis
DF	11	H_0: $\mu_1 \neq \mu_2$
Significance	0.67	H_0: $\mu_1 \neq \mu_2$

Table E-2. Repeated Measures ANOVA for Oxygen Uptake between L and A+L Incremental Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	6.513	0.59		
Condition	1	0.23	0.23	9.21	0.0114
Error	11	0.27	0.02		
Level	8	126.90	15.86	289.95	0.0001
Error	88	4.81	0.06		
Cond. * Level	8	0.05	0.01	1.06	0.3982
Error	88	0.50	0.01		

E-2a. Paired T-test Analysis for Maximal Oxygen Uptake Values between L and A+L Incremental Exercise.

Mean	3.72	3.79
SD	0.58	0.57
Paired Observ.	12	
t-statistic	-1.58	Hypothesis
DF	11	H_0: $\mu_1 \neq \mu_2$
Significance	0.14	H_0: $\mu_1 \neq \mu_2$

Table E-3. Repeated Measures ANOVA for Minute Ventilation between L and A+L Incremental Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	2732.80	248.44		
Condition	1	11.07	11.07	0.26	0.6236
Error	11	477.65	43.42		
Level	8	137592.08	17199.01	143.53	0.0001
Error	88	10545.07	119.83		
Cond. * Level	8	430.71	53.84	4.22	0.0003
Error	88	1124.10	12.77		

E-3a. Paired T-test Analysis for Maximal Minute Ventilation Values between L and A+L Incremental Exercise.

Mean	113.41	111.07
SD	26.89	22.27
Paired Observ.	12	
t-statistic	0.92	Hypothesis
DF	11	H_0: $\mu_1 \neq \mu_2$
Significance	0.38	H_0: $\mu_1 \neq \mu_2$

Table E-4. Repeated Measures ANOVA for Respiratory Exchange Ratio between L and A+L Incremental Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	0.60	0.05		
Condition	1	0.02	0.02	3.20	0.1510
Error	11	0.08	0.01		
Level	8	1.92	0.24	93.50	0.0001
Error	88	0.23	0.003		
Cond. * Level	8	0.04	0.005	7.19	0.0001
Error	88	0.06	0.001		

E-4a. Paired T-test Analysis for Maximal Respiratory Exchange Ratio Values between L and A+L Incremental Exercise.

Mean	1.19	1.16
SD	0.05	0.04
Paired Observ.	12	
t-statistic	1.51	Hypothesis
DF	11	H_0: $\mu_1 \neq \mu_2$
Significance	0.16	H_0: $\mu_1 \neq \mu_2$

Table E-5. Repeated Measures ANOVA for Heart Rate between L and A+L Incremental Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	28988.70	2635.38		
Condition	1	280.17	280.17	1.61	0.2302
Error	11	1910.17	173.65		
Level	5	133642.45	16705.31	215.34	0.0001
Error	55	6826.88	77.58		
Cond. * Level	5	93.75	11.72	0.78	0.5723
Error	55	1318.92	14.99		

E-5a. Paired T-test Analysis for Maximal Heart Rate Values between L and A+L Incremental Exercise.

Mean	181.25	183.58
SD	8.56	10.40
Paired Observ.	12	
t-statistic	-1.79	Hypothesis
DF	11	H_0: $\mu_1 \neq \mu_2$
Significance	0.10	H_0: $\mu_1 \neq \mu_2$

Table E-6. Paired T-test Analysis for Maximal Blood Lactate Values between L and A+L Incremental Exercise.

Mean	11.24	11.30
SD	1.26	1.24
Paired Observ.	12	12
t-statistic	-0.11	Hypothesis
DF	22	H_0: $\mu_1 \neq \mu_2$
Significance	0.92	H_0: $\mu_1 \neq \mu_2$

Table E-7. Paired T-test Analysis for Maximal Power Output Values between L and A+L Incremental Exercise.

Mean	318.73	331.89
SD	34.69	38.91
Paired Observ.	12	12
t-statistic	-0.88	Hypothesis
DF	22	H_0: $\mu_1 \neq \mu_2$
Significance	0.39	H_0: $\mu_1 \neq \mu_2$

Table E-8. Paired T-test Analysis for Gross Mechanical Efficiency between L and A+L Endurane Exercise.

Mean	23.13	22.88
SD	1.65	1.74
Paired Observ.	12	12
t-statistic	-0.88	Hypothesis
DF	22	H_0: $\mu_1 \neq \mu_2$
Significance	0.87	H_0: $\mu_1 \neq \mu_2$

Table E-9. Repeated Measures ANOVA for Ratings of Perceived Exertion between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	227.56	20.69		
Condition	1	81.00	81.00	178.20	0.0001
Error	11	5.00	0.46		
Level	5	151.31	30.26	57.34	0.0001
Error	55	29.21	0.53		
Cond. * Level	5	1.42	0.28	1.07	0.3878
Error	55	14.58	0.26		

Table E-10. Repeated Measures ANOVA for Oxygen Uptake between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	20.67	1.88		
Condition	1	0.37	0.37	14.14	0.1332
Error	11	0.29	0.03		
Level	5	0.12	0.02	9.21	0.0001
Error	55	0.14	0.003		
Cond. * Level	5	0.006	0.001	0.73	0.6029
Error	55	0.09	0.002		

Table E-11. Repeated Measures ANOVA for Ventilation between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	11970.87	1088.26		
Condition	1	1.71	1.71	0.02	0.8818
Error	11	810.44	73.68		
Level	5	288.19	48.90	7.53	0.0001
Error	55	292.27	5.31		
Cond. * Level	5	45.89	9.18	2.37	2.3670
Error	55	213.24	3.88		

Table E-12. Repeated Measures ANOVA for Respiatory Exchange Ratio between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	0.12	0.01		
Condition	1	0.02	0.02	6.00	0.0323
Error	11	0.02	0.003		
Level	5	0.07	0.014	30.72	0.0001
Error	55	0.03	0.0004		
Cond. * Level	5	0.002	0.0004	0.16	0.1570
Error	55	0.013	0.0002		

Table E-13. Repeated Measures ANOVA for Heart Rate between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	14195.31	1290.48		
Condition	1	32.11	32.11	.22	0.6489
Error	11	1612.89	146.63		
Level	5	3103.81	620.76	41.48	0.0001
Error	55	823.19	14.97		
Cond. * Level	5	131.56	26.31	3.75	0.0055
Error	55	386.44	7.03		

Table E-14. Repeated Measures ANOVA for Blood Lactate between L and A+L Endurance Exercise

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Subject	11	77.65	7.06		
Condition	1	7.57	7.57	14.95	0.0026
Error	11	5.57	0.51		
Level	5	209.70	69.90	79.99	0.0001
Error	55	28.84	0.87		
Cond. * Level	5	5.37	1.79	10.61	0.0001
Error	55	5.57	0.17		

VITA

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In January of 1994 he entered the Graduate School of the University of Tennessee, Knoxville to begin studies in exercise physiology while employed as a.graduate research assistant in the Department of Human Performance and Sports Studies.