Physiological and perceptual responses at submaximal and maximal capacity in six modes of exercise

by Brian Jerome Sharkey, Jr

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
Montana State University

Abstract:
This study was designed to compare maximum capacity (VO2max) and ventilatory threshold (VT) for leg only and arm plus leg exercise [leg: treadmill (TM), cycle ergometer (CE), stairclimber (SC), and arm leg combined: Schwinn AirDyne (AD), NordicTrack cross-country ski simulator (NT), and NordicRow rower (NR)]. It was anticipated that the inclusion of the increased muscle mass of the upper-body would augment the leg alone V02max, and alter the VT as well.

Eight untrained female volunteers were used as subjects. VO2max was elicited using incremental protocols designed to cause volitional fatigue within 20 minutes. Repeated measures ANOVA was used for data analysis (P<0.05).

Differences were only noted between the highest and lowest VO2max means (AD and NR, 2.62 and 2.33 liters/min respectively). No differences were found in the maximum heart rate or relative perceived exertion (RPE) measurements. Significant differences in oxygen consumption at the VT were: CE (1.31 liters/min) vs TM (1.64 liters/min), AD (1.62 liters/min), NR (1.65 liters/min) and NT (1.79 liters/min). When grouped arm-leg combined VT's were significantly higher than those of the leg alone exercises (1.68 vs. 1.46 L/min respectively). Significant differences noted when VT was expressed as a percentage of VO2max were: CE (53%) vs. TM (64%) and NT(73%); also NT(73%) vs. SC (60%) and AD (62%). There was no statistical difference in RPE at VT.

Results indicate that energy expenditure is higher at VT in combined arm-leg exercise, and would suggest that those higher expenditures could be maintained for a longer time.

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Brian Jerome Sharkey Jr.

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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DEFINITION OF TERMS

Body Mass Index (BMI). A scale used to assess body weight in relation to height, and is calculated by dividing body weight in kilograms by height in meters squared (wt/ht^2). The BMI is considered a good indicator of total body composition (ACSM, 1991).

Non-Specifically Fit. An individual who is fit but not participating in, or concentrating on, any specific training regimen (i.e. cross-training with no specific goal other than general fitness).

Maximum Oxygen Consumption ($VO2_{max}$). The greatest amount of oxygen that can be taken in, transported, and utilized by working tissues in one minute. The VO_{2max} is determined as a peak or plateau in oxygen consumption with further increases in workload (McArdle, Katch, & Katch 1991).

Relative Perceived Exertion (RPE). An exercising individuals subjective rating of psychophysical stress, based on the Borg Scale (6-20) (See Appendix B).

Ventilatory Threshold (VT). Occurs when ventilation and CO_2 expulsion increases disproportionately in relation to oxygen consumption. The VT has been found to correlate very highly with the onset of the anaerobic threshold.

ABSTRACT

This study was designed to compare maximum capacity (VO_{2max}) and ventilatory threshold (VT) for leg only and arm plus leg exercise [leg: treadmill (TM), cycle ergometer (CE), stairclimber (SC), and arm leg combined: Schwinn AirDyne (AD), NordicTrack cross-country ski simulator (NT), and NordicRow rower (NR)]. It was anticipated that the inclusion of the increased muscle mass of the upper-body would augment the leg alone VO2max, and alter the VT as well.

Eight untrained female volunteers were used as subjects. VO_{2max} was elicited using incremental protocols designed to cause volitional fatigue within 20 minutes. Repeated measures ANOVA was used for data analysis ($P<0.05$).

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Results indicate that energy expenditure is higher at VT in combined arm-leg exercise, and would suggest that those higher expenditures could be maintained for a longer time.

CHAPTER I

INTRODUCTION

The variety of exercise ergometers accessible to the exercising individual has increased dramatically in recent years. Today's exercise market presents a wide variety of options, including leg only exercise (treadmill, bicycle, stairclimber) and arm-leg combined exercises (simulated cross-country skiing, rowing machines, and arm-leg bicycle ergometers). Although all exercise leads to increased caloric expenditure and potential weight loss, recent studies have hinted that there may be differences in the human body's response to exercise modes that utilize legs alone, and those that use arms and legs simultaneously (Bart, 1989).

The human body is capable of responding to increases in exercise demand, however each individual is limited by a combination of training/fitness and genetic factors. At a point pre-determined by these limitations, the body will no longer adapt to increases in exercise demanded by generating more energy, this point is referred to as maximal oxygen uptake (VO_{2max}). Differences in VO_{2max}, consequent to exercise mode, have been noted in the exercise science literature. Trained male and female triathletes were noted as having higher $VO_{2max's}$ on a treadmill when compared with a bicycle ergometer (Schneider, LaCroix, Atkinson, Troped, & Pollack 1990; Schneider & Pollack 1991). Other studies have shown slight increases in VO_{2max} with arms contributing up to 30% of the total work output (Berg, Kanstrup, & Ekblom, 1976).

Although the VO_{2max} accurately represents an individual's cardiorespiratory fitness, the percentage of VO_{2max} that can be maintained is ultimately more important for endurance events (Davis, 1985). As exercise intensity increases to approximately 50 to 90% of the VO_{2max} (depending on the training status of the individual) there is a greater reliance on energy obtained through anaerobic metabolism (Walsh & Bannister, 1988). The standard indicators of the anaerobic threshold (AT) are, the onset of blood lactate accumulation (OBLA) and the ventilatory threshold (VT), which generally tend to correspond quite closely (Davis, Vodak, Wilmore, Vodak, & Kurtz 1976).

Differences in the elicitation of the VT have been noted as a consequence of exercise mode. Bart (1989) noted that the VT occurred at a higher percentage of VO_{2max} on a cross-country ski simulator as opposed to a treadmill on well conditioned cross-country skiers. In two other studies that avoided training specificity, Schneider et al. (1990) and Schneider & Pollack (1991) both noted that trained male and female triathletes experienced the VT at a higher percentage of their VO_{2max} on a treadmill as opposed to a cycle ergometer. Compiled training data in these studies showed a rough equivalence in training volume between the bicycle and running.

Due to relative simplicity and accessibility, exercise intensity is frequently prescribed as a percentage of the predicted maximum heart rate (ACSM, 1991). Although this method does give a good indication of the relative metabolic load, the potential for differences in energy expenditure at given heart rates could result in substantial energy cost differences over time.

Berg and Zwiefel (1991) noted higher submaximal energy expenditures in exercise modes that used a combination of arms and legs (simulated cross-country skiing and rowing machine), when compared with modes that utilized legs alone (stairclimber, and stationary bicycle). However, the maximum heart rate response does not appear to be significantly affected until roughly 60% of the total workload is accomplished by the arms (Astrand & Saltin, 1961; Berg, Kanstrup, & Ekblom, 1976; Toner, Sawka, Levine, & Pandolf, 1983).

The purpose of this study was to examine the relationship between exercise intensity and mode of exercise at submaximal and maximal energy expenditures. Currently there is a significant amount of literature on training specificity and its effects on maximum capacity and the VT. Utilizing non-specifically fit young females, this study examined the effects of exercise mode on maximum capacity and VT.

Problem Statement

The following parameters were established for six modes of exercise:

1. VO_{2max}, maximum heart rate, and VT
2. Compare the Relative Perceived Exertion (RPE) with physiological parameters established in the previous statement

The ergometers utilized in this study included the following: treadmill, bicycle ergometer, stairclimber, cross-country ski simulator, rowing ergometer, and Schwinn AirDyne.

Significance

Currently exercise prescription is frequently based on a percentage of predicted maximum heart rate or $VO2_{max}$, these methods are constant across mode. With the potential variance in RPE at submaximal energy expenditures across various modes, exercise prescription should take modal differences into account. The effects of duration of exercise combined with frequency could greatly magnify even small differences in energy utilization, ultimately leading to greater benefits of exercise.

With potential modal differences in the VT and increases in RPE associated with the VT it is important that a knowledge of the VT be incorporated into exercise prescription.

Delimitations

The following delimitations were imposed on this study:

1. The sample population was limited to eight females between the ages of 19 and 27 years of age.
2. The subjects included in this study were classified as average or non-specifically fit individuals; no athletes involved in specific training were included.
3. All subjects participated in each phase of testing.

Limitations

1. It was not possible to completely control subject behaviors outside of the lab, these included dietary, sleep and physical activity.
2. It was not possible to control subjects' motivation level during the data collection period.
3. Although the feminine menstrual cycle has not been shown to cause any major decrements in the performance of physical activity, some females may be detrimentally affected. Specific questions on the Health History Questionnaire were directed at determining menstrual problems, and scheduling was altered. It was impossible to control for the subjects' response to these questions.

Hypothesis

The following hypotheses were tested at the $P < .05$ level of significance on average, non-specifically fit female subjects.

1. There will be no significant difference in the VO_{2max} between exercise modes that use legs alone and those that use a combination of arms and legs.
2. The maximum heart rate will not be significantly different between any of the exercise modes.
3. Differences in the VT as a percentage of the VO_{2max} and gross oxygen consumption at the VT will not be noted across the exercise modes included.
4. There will be no significant differences in RPE at the VT.

CHAPTER II

REVIEW OF LITERATURE

The review of literature will be divided into four sections: Maximum Oxygen Uptake; Ventilatory/Anaerobic Threshold; Heart Rate Response; and the Relative Perceived Exertion. Modal implications will be discussed inclusively within each section.

Maximum Oxygen Uptake

As exercise rate increases the amount of oxygen necessary for energy metabolism increases. At a point pre-determined by genetics and previous physical training, oxygen utilization ceases to increase with increases in workload, that point is referred to as maximum oxygen uptake (VO_{2max}) (Wilmore, 1984). The VO_{2max} has been extensively studied in the exercise science literature, and inter-sport and modal differences have been noted.

In a study conducted by Schneider, LaCroix, Atkinson, Troped, and Pollack (1991), trained male triathletes achieved a significantly higher VO_{2max} while running on a treadmill when compared to a cycle ergometer (75.4 ± 7.3ml/kg/min; 70.3 ± 6.0ml/kg/min, respectively). Schneider and Pollack (1990) had similar results with trained female triathletes (treadmill 63.6 ± 1.2ml/kg/min; cycle ergometer 59.9 ± 1.3ml/kg/min). Compiled training data from the subjects of both studies indicated that the balance of training volume was roughly equal between the cycle and running, possibly indicating that the differences noted were a product of exercise mode. In a study conducted on fifty-five males, Hermansen and Saltin (1969) noted a 7% higher VO_{2max} on a treadmill as opposed to a cycle ergometer. And in a specificity of training study, Pannier, Vrijens, and Van Cauter (1980) noted a 12.8% higher VO_{2max} for runners on a treadmill when compared to a cycle ergometer. Control subjects in the same study (Pannier et al., 1980) showed no significant differences between the treadmill and cycle ergometers.

Energy consumption and VO_{2max} are products of the exercise load and the muscle mass that is accomplishing the work (Astrand & Saltin, 1961). Comparisons of the VO_{2max} between arm alone ergometry and leg alone ergometery are clear, arm musculature produces significantly lower maximum values (Astrand & Saltin, 1961; Bergh, Kanstrup, & Ekblom, 1976; Toner, Sawka, Levine, & Pandolf, 1983; and Nagle, Richie, & Giese, 1984). The current literature however, is not as clear in reference to exercise modes that include a combination of both arms and legs. In a comparison of cycle ergometry, treadmill running, cross-country skiing, swimming, arm crank ergometry, and a combination of simultaneous cycling and arm crank ergometry, Astrand & Saltin (1961) noted that the highest VO_{2max} was generated on the leg alone treadmill exercise, followed closely by cross-country skiing, and combined arm leg cycling. Although not statistically significant, the inclusion of arm crank ergometry with cycling did produce a consistently higher VO_{2max} than did cycling alone. Similarly, Bergh, Kanstrup, and Ekblom, (1976) noted slight increases (not statistically significant) in cycling VO_{2max} with inclusion of arm work, however as in the previous study combined arm-leg cycling did not achieve the levels of treadmill running. Bergh et al. (1976) reached several conclusions regarding

VO_2 during maximal exercise: a) it is affected to a certain degree by exercising muscle mass, b) is lower than the actual oxygen consuming potential of all muscles included, and c) in exercises that include an arm and leg component, both subject fitness for arm work and the ratio of arm to total work rate could effect VO_{2max}. In contrast, Nagle, Richie, and Giese (1984), noted that with an optimal arm-leg combination (10% arms and 90% legs) higher VO_{2max}'s could be achieved. Nagle et al. (1984) concluded that under the optimal load conditions the effective muscle mass was increased and thus VO_{2max} increased, however once past this point, excessive arm load generally occurred, resulting in an insufficient metabolic challenge to the legs, and thus decreased the VO_{2max} response.

In recent years there has been a dramatic increase in the popularity of the cross-country ski simulator and research results included in the body of scientific research. In a study conducted by Allen and Goldberg (1986a) VO_{2max} was compared between a cross-country ski simulator (XC), cycle ergometer (B), and a rowing machine (R). The ski simulator yielded significantly higher VO_{2max}'s than both other ergometers in this study (52.1 ± 2.53 XC; 50.3 ± 2.46 B; 47.9 ± 2.65 R ml/kg/min). Allen and Goldberg (1986a) concluded that exercise with both an arm and a leg component could contribute to a greater cardiorespiratory workout. In another study conducted by Allen and Goldberg (1986b), maximum physiological work parameters were compared between the NordicTrack and Fitness Master cross-country ski simulators. The NordicTrack (NT) yielded a VO_{2max} that was significantly higher than that of the Fitness Master (FM) (52.1+/-2.53 NT; 47.6+/-2.34 FM ml/kg/min). Allen and Goldberg (1986b) concluded that the NordicTrack cross-country ski simulator was conducive to a better cardiovascular training session than that of the Fitness Master. However, in a study conducted by Bart (1989) no significant differences were noted in the VO_{2max} between a treadmill and NordicTrack cross-country ski simulator in competitive cross-country ski racers.

Results similar to those seen by Goldberg and Allen (1986a), were noted by Hagerman, Lawrence, and Mansfield (1989) in a comparison of rowing and cycle ergometers. Significantly lower VO_{2max}'s were found on the rowing ergometer when compared with a cycling ergometer. Low VO_{2max}'s were also accompanied by significantly lower power outputs. Similarly, Mahler, Andrea, and Ward (1987) noted that 12 female collegiate rowers had significantly lower VO_{2max}'s on a rowing ergometer when compared to a cycle ergometer. Interestingly, 17 untrained females in the same study showed no significant differences between the two ergometers (Mahler et al., 1987). It was suggested by Mahler et al. (1987) that compression of the thorax and limbs during the initial phase of the rowing motion could contribute to increased pleural pressure and reduce venous return, ultimately limiting oxygen transport and decreasing the VO_{2max} response.

Ventilatory/Anaerobic Threshold

Although the VO_{2max} is one valid indicator of overall cardiorespiratory fitness, the percentage of the VO_{2max} that can be maintained in relative comfort is ultimately more important (Davis, 1985). During incremental exercise, generally between 50 and 90 percent of the VO_{2max}, depending on the training status of the individual, larger portions of total energy expenditure are acquired through anaerobic metabolism . The point at which the end products of anaerobisis, primarily lactate, begin to accumulate in venous blood is referred to as the anaerobic threshold (Skinner & McLellan, 1980). The anaerobic threshold has also been associated with significant increases in the Relative Perceived Exertion (RPE) (ACSM, 1991), and has been named as one of the primary limiting factors to the performance of high intensity aerobic activities (Yoshida, Chida, Ichioka, & Suda, 1987).

Two methods are generally utilized to determine the anaerobic threshold, 1) the lactate threshold, or onset of blood lactate accumulation (OBLA) and 2) the ventilatory threshold. The lactate threshold (LT) is based on the fact that an exercising muscle produces increasing levels of lactic acid (also referred to as lactate). At steady state submaximal exercise levels the liver and other non-exercising muscles are capable of dissociating the lactate and thus maintaining blood lactate levels. However, as work levels increase at the point generally referred to as the lactate threshold (anaerobic threshold), lactate production exceeds dissociation and muscular and blood lactate levels begin to accumulate (Brooks, 1985). The cutoff point for the lactate threshold is generally established at approximately 4 $mmol \cdot L^{-1}$, nearly twice that of resting levels (Skinner & McLellan, 1980).

The ventilatory threshold (VT) on the other hand is based on the concept that increases in blood and muscular lactate (at threshold levels) will also reflect changes in the respiratory compensation mechanisms (Davis, 1985). The primary buffer for excess lactate is the bicarbonate system: lactic acid + sodium bicarbonate $><$ sodium lactate + carbonic acid $><$ $CO_2 + H_2O$ (Davis, 1985). The increasing levels of CO_2 are thought to stimulate respiration and thus create a "breakaway" effect in ventilation (Brooks, 1985).

Although the VT is considered a good method for non-invasive demonstration of the anaerobic threshold, no "standard" method of determination has been agreed upon. Davis, Vodak, Wilmore, Vodak, and Kurtz, (1976), designated the VT as being the point at which there is a non-linear increase in ventilation (Ve) and the volume of expired CO_2 (VCO_2), and an abrupt rise in the fraction of expired oxygen (FEO_2). Simply stated, when graphed, the lines representing VCO_2 and Ve rise abruptly when plotted against the VO_2, which remains predominantly linear throughout the process. Davis et al. (1976) noted a .95 correlation between methods using gas exchange (VT) and those using venous blood lactates (LT) in the determination of the anaerobic threshold. Using the same methods Simon, Young, Blood, Segal, Case, and Gutin (1986) found no significant differences between the VT and the OBLA in trained male cyclists. In a comparison of gas exchange indices used to detect the anaerobic threshold, Caizzo, Davis, Ellis, Azus, Vandagriff, Prietto, and McMaster (1982) compared four commonly used methods of determining the VT (Ve, VCO_2, R, Ve/VO_2) with blood lactate (LT) methods used to determine the anaerobic threshold. Caizzo et al. (1982) noted the highest correlation between LT methods and VT methods were those that included the measurement of Ve/VO2, which was .93. The Ve/VO2 also provided the highest test-retest correlation of .93 (Caizzo et al., 1982).

Although the concept of the anaerobic threshold is generally accepted throughout the exercise science community, there are critics. In a study comparing gas exchange (VT) methods and lactate (LT) methods Yeh, Gardner, Adams, Yanowitz, and Crapo (1983) monitored arterial and venous blood and gas exchange indices in an attempt to find a threshold. No thresholds were noted in the accumulation of lactate. Arterial lactate increased continuously after the start of exercise, with venous blood lagging about one minute behind. Gas exchange indices, when reviewed by four independent exercise physiologists were subject to large reviewer variability, average range 16%. Based on these results Yeh et al. (1983) reached the following conclusions: 1) the anaerobic threshold is not detectable using either arterial or venous lactates; and 2) the large range in reviewer variability in determination of gas exchange indices is unsuitable for clinical use. In a 1985 review, Brooks had several criticisms of the anaerobic threshold concept (AT): 1) the conditions necessary for bringing about anaerobisis do not exist during submaximal exercise, (enough O_2 for functioning muscles which would keep lactate levels in dynamic balance) which would negate the possibility of a "threshold"; 2) the "theory" of the AT is based on the O2 deficit-debt relationship, which is no longer scientifically accepted; 3) the chain of events necessary for bringing about the VT (i.e. the failure of minute ventilation [Ve] to accurately track changes in blood lactate concentration) do not always hold true, thus rendering the AT concept unusable; and 4) recent invasive studies using isotopic tracers to quantify lactic acid production during rest and graded exercise are in conflict with predictions of the AT, raising serious questions about the concept. Contrasting with Brooks view, Davis (1985) felt that the majority of the criticisms of the AT theory centered on its descriptors and not the fundamental concept, he concluded that the concept would have enduring importance in determining exercise tolerance, and assist in the prescription of exercise for healthy individuals and cardiac patients.

The VT has been found to occur at varying levels of the VO_{2max} in different exercise modes, implying possible differences in the metabolic and exertional characteristics of different exercise modes. In a study conducted by

Davis, Vodak, Wilmore, Vodak, and Kurtz, (1976), the VO_{2max} and "anaerobic threshold" (actually VT) were tested across three different modes of exercise (arm crank ergometer, stationary bicycle, and treadmill). Results from Davis et al. (1976) showed the anaerobic threshold occurring at a significantly lower percentage of the VO_{2max} for the arm crank ergometer (46.5%), as opposed to the stationary bicycle (63.8%) and treadmill (58.6%). Schneider, Lacroix, Atkinson, Troped, and Pollack (1990) used trained male triathletes to compare maximal oxygen uptake and VT between a cycle ergometer and treadmill. Schneider et al. (1990) noted that the VT occurred at a significantly lower percentage of the VO_{2max} on the cycle ergometer (66.8%) when compared to that elicited by the treadmill. Similar VT's were observed by Schneider and Pollack (1991) utilizing female triathletes as subjects, VT expressed as a percent of VO_{2max}: treadmill 74%, and bicycle 62.7%. Review of the training data from both of these studies revealed that both the male and female triathletes had trained equally on both the bicycle and running, indicating that regardless of the specificity of training the VT may be influenced by exercise mode.

The response of the VT to training specificity is evident, specific training results in the VT occurring at a higher percentage of the VO_{2max}. Mahler et al. (1987) noted that trained female collegiate rowers experienced the VT at significantly higher percentages of the VO_{2max} on a rowing ergometer (79%), when compared to a cycle ergometer (69%). Untrained subjects in the same study showed no significant differences in the VT between the two ergometers, both cycle and rowing ergometers were at 61% of the VO_{2max} (Mahler et al., 1987). Simon et al. (1986) noted a significantly higher percentage at which VT occurred in trained cyclists when compared with untrained subjects on a cycle ergometer; trained 65.8%, untrained 51.4%. And in a study on "well-conditioned" cross-country skiers, Bart (1989), noted significantly higher VT's on a cross-country ski simulator (75.4% of VO_{2max} compared to that of the treadmill, 66.7%).

Heart Rate Response

Due to relative simplicity and accessibility, exercise intensity is frequently prescribed as a percentage of the predicted maximum heart rate (ACSM, 1991). Currently, the most common method of establishing heart rate is the heart rate reserve method: maximum heart rate - resting heart rate = heart rate reserve . Prescribed intensities generally range from 60 to 80% of heart rate reserve, which corresponds to approximately 60 to 80% of maximum capacity (ACSM, 1991). Although this method does give a good indication of the relative metabolic load, the amount of muscle mass used in the exercise could perhaps complicate this process.

While working at an equivalent submaximal workrate a small muscle mass will tend to produce higher heart rates. Toner, Miles, Critz, and Knowlton (1980) noted significantly lower heart rates at 60% of aerobic power on a treadmill as opposed to that of a cycle ergometer (treadmill representing larger muscle mass). However, at 80% there was no significant difference. Miles et al. (1980) concluded that the cardiovascular response to these two exercises was similar, however, due to the smaller muscle mass the cycle ergometer did produce greater metabolic acidosis.

The inclusion of arm musculature to an already exercising leg system does not appear to affect submaximal heart rate until a majority of the work is accomplished by the arms. Toner, Sawka, Levine, and Pandolf (1983) studied the cardiovascular and metabolic responses in submaximal leg/arm cycling exercises with 0, 20, 40, 60, and 100% arm inclusion. Workloads were established at 76 and 109 watts. No significant differences were noted in the heart rate response until 60 to 100 percent of the work output was being done by the arms (Toner et al., 1983). Interestingly, heart rate was not significantly affected until the majority of the work was being done by the smaller muscle mass of the upper body (60 and 100% arm inclusion at 76 and 109 watts).

Similarly the heart rate response to maximal exercise appears to depend on the functional muscle mass being utilized, the smaller the muscle mass, the lower the maximum heart rate (Coyle, 1991). Lower maximum heart rates in arm alone exercise when compared with leg alone and leg-arm combination exercise are common in the literature (Bergh, Kanstrup, & Ekblom, 1976; Astrand & Satin 1961; Nagle, Richie, & Giese 1984). However, when the work is distributed evenly between arms and legs, the heart rate response appears to be attenuated, and little or no difference is evident between leg alone and arm-leg combined exercise (Astrand & Saltin 1961; Bart 1989).

Relative Perceived Exertion

As work rate increases during incremental exercise, the bodies' physiological response is accompanied by an increase in the perception of stress. The Relative Perceived Exertion (RPE) was a concept introduced to American scientists in 1967 and 1968 by Gunnar Borg, and has since been extensively used in exercise science literature (Noble, 1982). At present there are two accepted RPE scales: 6-20 with ratings on every odd number; and 0-10 with ratings and categories for each rating (Borg, 1982). During incremental exercise the RPE is considered to be an accurate gauge of impending fatigue (ACSM, 1991).

Many different physiological factors have been associated with increases in RPE (heart rate, ventilation, oxygen uptake, and lactate threshold) (Hetzler, Seip, Boutcher, Pierce, Snead, & Weltman 1991). In fact, any physiological factor which increases linearly throughout incremental exercise will correlate highly with RPE (Noble, Borg, Jacobs, Ceci, & Kaiser 1983). Noble et al. (1983) noted linear correlations between heart rate and RPE all the way to maximum exercise. In the same study, the relationship between blood and muscle lactates and RPE showed an exponential trend. Noble et al. (1983) concluded that RPE and anaerobic metabolism leading to lactate accumulation correspond closely during exercise. Using a cycle ergometer and treadmill Hetzler et al. (1991) studied the effect of exercise modality on RPE at various blood lactate concentrations. It was concluded by Hetzler et al. (1991) that exercise modality did not appear to affect RPE at any lactate concentration, however a strong relationship did exist between blood lactate concentration and RPE. Similarly, Seip, Snead, Pierce, Stein, and Weltman (1991) noted blood lactate concentration as an important determinant of over-all RPE in both runners and non-runners. And finally, in a comparison of exercise modalities that included both an arm and a leg component, Hulme, Barnett, Hale, Hale, and Aicinena (1992), noted that at equivalent RPE's subjects experienced higher VO_2's and heart rates on a NordicTrack cross-country ski simulator (NT) compared to that of a Schwinn AirDyne (AD). It was concluded by Hulme et al. (1992) that greater energy expenditure could be maintained at a lower perceptual cost on the NT as opposed to the AD.

Summary

It appears that the VO_{2max} can be increased by utilizing a larger functional muscle mass (i.e. the difference between upper-body alone and leg alone exercise). However, the literature is still somewhat inconclusive in reference to simultaneous upper and lower body exercise producing larger $VO_{2max's}$ than that of leg alone exercise.

In general, the heart rate maximum of leg alone exercise does not appear to be affected by the inclusion of upper body mass. However, if the proportion of arm to leg work is too great, it appears that upper-body strength limitations may overshadow the maximum heart rate response.

The ventilatory threshold is clearly altered by training specificity. The degree to which exercise mode affects the ventilatory threshold in untrained individuals is not completely clear. Few studies have approached this problem with a wide range of exercise modes.

Varying exercise modes have been shown to produce different oxygen consumptions at similar perceptual costs. The degree to which the inclusion of larger muscle mass affects the perception of exercise stress is not completely clear.

CHAPTER III

METHODS

Subjects

Eight moderately to well conditioned asymptomatic females who were not involved in any sport specific training were recruited as subjects. All subjects were between 19 and 27 years of age. All subjects were required to sign an informed consent and complete a medical history questionnaire prior to testing. All data collection was completed in the Human Performance Laboratory located on the University of Montana Campus. All experimental procedures were submitted to the University of Montana Institutional Review Board for the Use of Human Subjects, and approved. Descriptive data for the subjects are listed below on Table 1.

Table 1. Descriptive Characteristics of Subjects.

VARIABLE	MEAN $\pm$ SD
Age (yrs)	23.0 ± 2.6
Height (cm)	168.0 ± 5.6
Weight (kg)	62.9 ± 5.0
Body Mass Index (BMI)	21.9 ± 2.2

Equipment

Each subject performed a graded maximal exercise test to volitional fatigue on each of the following exercise modes: treadmill (Quinton); bicycle ergometer (Tenturi, Pro Ergometer); stairclimber (Schwinn, SP 300); combined arm-leg ergometer (Schwinn AirDyne); cross-country ski simulator (NordicTrack, Pro model); and rowing ergometer (NordicRow TBX III).

Measures of oxygen consumption, ventilation rate, RER ratio, and heart rate, were taken every 30 seconds. Measures of perceived exertion were taken every minute. Metabolic and ventilatory volumes were determined by open-circuit indirect calorimetry (Beckman cart: LB1 for CO2; OM 111 for O2) and collected through a Hans Rudolph mouth piece and valve (suspended over-head). The metabolic cart was calibrated with known gas concentrations before each test. Heart rates were monitored with a heart rate telemetering device (CIC HeartWatch). Ratings of perceived exertion (RPE) were based on the Borg Scale (6-20) (Borg, 1982) (see Appendix B).

Pre-test Preparation

Subjects were instructed to consume a diet that was the same in nutrient composition three days prior to each test, a dietary recall sheet was provided for subjects to list consumed foods and to duplicate before each procedure (see Appendix C). Subjects were also instructed to abstain from exercise the day prior to each test, and to report to the lab psychologically and physiologically prepared for a maximal test.

Prior to the beginning of data collection the subjects were instructed in the use of each exercise mode. Testing did not begin until each subject felt competent on each exercise mode. Following the initiation phase, subjects were scheduled for testing. Tests were scheduled on a two day a week basis with at least three days and no greater than seven days between each testing period.

Order of Testing

The testing for this study was done in a pre-determined order. The order of testing was first randomly determined for subject number one. Based on the order of subject number one the following trials were ordered so that no sequence was followed (i.e. only one ergometer started twice and finished twice). This ordering was done to minimize the effects of learning from one trial to the next. Compensation for learning was essential in dealing with individuals who were not familiar with VO_{2max} protocols.

Testing Protocol

A five minute warm-up was performed on each ergometer prior to testing. Testing proceeded with workrate increases every two minutes and designed so that each subject reached volitional fatigue in less than 20 minutes. Specific protocols used on each ergometer were as follows:

Treadmill: After a walking no grade warm-up, workload increases were accomplished by increasing grade 2% every two minutes. A constant speed of four miles per hour was used for each test.

Cycle ergometer: After a no load warm-up, workload increases were made in 25 watt increments, with the first workload being established at 25 watts. Once cadence was established (selected by each subject) it was held constant through each test. If subjects had no specific preference for cadence, a preselected cadence of 60 cycles per minute was used.

Stairclimber. Workload increases were accomplished by increasing cadence, with belt resistance constant. Warm-up cadences were established as subjectively easy for each subject. Heart rates were monitored during this period to establish an appropriate starting intensity. Cadence was established by an electronic metronome with the first workload being set at 45 steps per leg per minute. Workload increases were made by increasing the cadence by five steps per leg every two minutes.

AirDyne: Workload was regulated by cadence with this exercise devise. Cadence was monitored by a built in counter on the machine. Warm-up was performed at 25 cycles per minute. The first workload was established at 45 cycles per minute, with workload increases of 5 cycles per minute every two minutes.

NordicTrack: Warm-up was performed with a resistance setting of one on the legs and one quarter of a turn on the arms (any less resistance made balance difficult on the NordicTrack). Workload increases were made by increasing the leg setting one unit on the 1-9 scale, and one quarter of a turn on the arm adjustment spool every two minutes. Tension adjustments were made simultaneously in order maintain a balance between arm and leg resistances. Pilot study results indicated that arm overload began to occur above 1.75 turns on the arm resistance spool, consequently, at six minutes arm workload increases were discontinued. A cadence of 50 cycles per minute was established for the NordicTrack tests. Cadences were maintained via an electronic metronome.

NordicRow: As with the cross-country ski simulator, arm and leg adjustments were independent, so simultaneous adjustments were necessary to maintain balance. Warm-up was performed with a resistance of one on arms and one on the legs (scale of 1 to 9 for both). After a five minute warm-up, workload increases were made by increasing the legs by one and arms by one half. A cadence of 30 strokes per minute was established for all tests for the first eight minutes. At eight minutes workload increases were accomplished by increases in cadence (5 strokes per minute every two minutes) (pilot study results indicated that workloads of four or greater on the legs and two or greater on the arms were strength limited thus reducing maximum capacity if resistance increases continued). The cadence increases consisted of a five stroke per minute increase every two minutes.

Within all protocols hand signals were built in to indicate when subjects were approaching fatigue (hold up a finger to indicate one minute). At that point subjects were encouraged to break away from pre-established cadences and go as hard as possible. This was done to ensure maximum values that were not hindered by the protocol design, and was consistent through all experimental procedures.

Ventilatory Threshold

The ventilatory threshold (VT) was established using two methods. Initial estimates were made plotting ventilation rate (Ve), minute CO_2 production (VCO_2), and oxygen consumption (VO_2), with the point at which Ve and VCO_2 break linearity with VO_2 determined as the ventilatory threshold (Skinner & McLellan, 1980). The method of Skinner & McLellan, was then compared with that of Caiozzo, Davis, Ellis, Azus, Vandagriff, Prietto, and McMaster (1982) in which the break-point in the Ve/VO_2 ratio was plotted against time. Each threshold was determined as the consistent break-point between these methods (examples can be seen in Appendix D). Graphs were generated by Cricket Graph program for Apple Macintosh.

Analysis

Repeated measures analysis of variance (ANOVA) was used to determine potential differences in group means. The independent variables were established as exercise intensities (VT and VO_{2max}), and the dependent variables established as each exercise mode. Analysis was done on the following parameters:

1. VO2max, maximum heart rate, and VT.
2. Comparison of RPE with physiological parameters established in the previous statements.

The *alpha level* was established at the .05 level of significance. All statistical analyses were accomplished using Statview 512K for Apple Macintosh.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The results will be presented in the following order: VO_{2max}; maximum heart rate, VT, VT percent of VO_{2max}, and RPE. Data will show the comparative results for the six ergometers and grouped as leg alone and arm-leg combined.

Maximum Oxygen Uptake

The mean VO_{2max} results for all subjects are listed on Table 2.

Table 2. Maximum Oxygen Uptake, Mean Differences.

VARIABLE	MEAN $^+$ SD (L/MIN)	SIGNIFICANCE
Treadmill (TM)	2.530 ± .35	NS
Bike (B)	2.490 ± .41	NS
Stairclimb (SC)	2.429 ± .38	NS
AirDyne (AD)	2.623 ± .43	Vs. (NR)
NordicTrack (NT)	2.432 ± .37	NS
NordicRow (NR)	2.331 ± .52	**
	GROUPED DATA	
Leg Alone Max	2.483 ± .51	NS
Combined Max	2.462 ± .15	NS

NS = No significance (P<0.05); Significance indicated by Vs. and initials of significantly different means; **=previously stated significance.

Significant differences were noted in the VO_{2max} between the highest and lowest values, AirDyne and NordicRow respectively. When the data were grouped, leg alone and arm-leg combined $VO_{2max's}$ were essentially identical.

Heart Rate Maximum

Heart rate maximums ranged from 190 ± 7bpm on the NordicRow to 194 ± 11bpm on both the Treadmill and the AirDyne, these differences were not statistically significant. When the maximum heart rate data was grouped, no significant differences were noted between leg alone and arm-leg combined exercise (see Table 3).

Table 3. Heart Rate Maximums, Mean Differences.

VARIABLE	MEAN ± SD (BPM)	SIGNIFICANCE
Treadmill (NT)	194 ± 10.57	NS
Bike (B)	193 ± 9.55	NS
Stairclimb (SC)	192 ± 8.70	NS
AirDyne (AD)	194 ± 10.0	NS
NordicTrack (NT)	193 ± 10.26	NS
NordicRow (NR)	190 ± 7.15	NS
	GROUPED DATA	
Leg Alone	192.21 ± 1.14	NS
Combined	192.29 ± 1.73	NS

NS=No significance ($P<0.05$)

Ventilatory Threshold

Significant differences were noted in oxygen consumption at the ventilatory threshold (VT). Table 3 shows that the bike and the stairclimb machines were significantly lower in oxygen consumption at VT in comparison to the other machines. Significant differences were noted in the grouped data as well, with oxygen consumption at VT significantly higher in the arm leg combined group (see Table 4).

Table 4. Oxygen Consumption at the Ventilatory Threshold.

VARIABLE	MEAN ± SD (L/MIN)	SIGNIFICANCE
Treadmill (TM)	1.636 ± .24	Vs. (B)
Bike (B)	1.313 ± .21	Vs. (AD); (NT); (NR)
Stairclimb (SC)	1.435 ± .17	Vs. (NT)
AirDyne (AD)	1.621 ± .32	**
NordicTrack (NT)	1.786 ± .24	**
NordicRow (NR)	1.645 ± .30	**
	GROUPED DATA	
Leg Alone	1.461 ± .16	vs. Combine
Combined	1.684 ± .10	**

Significance indicated by Vs. and initials of significantly different means; **=Previously stated significance (P<0.05)

Ventilatory Threshold

When the VT data was expressed as a percentage of the VO_{2max} significant differences were again noted. Table 5 shows VT percentages

Table 5. Ventilatory Threshold Expressed as a Percentage of Maximum Oxygen Uptake.

VARIABLE	MEAN ± SD (PERCENTAGE)	SIGNIFICANCE
Treadmill (TM)	64.25 + 4.13	Vs. (B)
Bike (B)	52.75 + 2.32	Vs. (NT); (NR)
Stairclimb (SC)	59.5 + 5.32	Vs. (NT)
AirDyne (AD)	62 + 7.87	Vs. (NT)
NordicTrack (NT)	73 + 7.03	**
NordicRow (NR)	68.5 + 4.96	**
	GROUPED DATA	
Leg Alone	58.8 + 6.22	vs. Combined
Combined	67.8 + 8.04	**

Significance indicated by Vs. and initials of significantly different means;**=Previously stated significance (P<0.05).

statistically higher for the NordicTrack, NordicRow, and Treadmill in comparison to the other ergometers. Combined arm-leg exercise VT percentages were also significantly higher than those of leg alone.

Relative Perceived Exertion

No significant differences were found for RPE at the VT. Table 6 shows the RPE values for each machine at the VT. Data were essentially identical when grouped.

Table 6. Relative Perceived Exertion at the Ventilatory Threshold.

VARIABLE	MEAN ± SD (BORG SCALE)	SIGNIFICANCE
Treadmill (TM)	12.13 ± 1.13	NS
Bike (B)	11.00 ± 2.00	NS
Stairclimb (SC)	10.00 ± 2.07	NS
AirDyne (AD)	11.00 ± 2.71	NS
NordicTrack (NT)	12.00 ± 2.67	NS
NordicRow (NR)	10.50 ± 1.93	NS
	GROUPED DATA	
Leg Alone	11.00 ± 7.94	NS
Combined	11.10 ± 2.45	NS

NS=No significance ($P<0.05$)

Summary

In general no differences were noted in VO_{2max} between the six exercise ergometers, except for the highest and lowest means (AirDyne and NordicRow respectively). Arm-leg combined exercise generally resulted in increased oxygen consumption at VT, when compared to that of leg alone exercise, those differences were also noted when VT was expressed as a percentage of VO_{2max}. No differences were noted in maximum heart rate or RPE at VT.

CHAPTER V

DISCUSSION

This study investigated the differences in physiological and perceptual responses to exercise modes that included varying degrees of arm and leg contribution. A discussion of the results follows.

Maximum Oxygen Uptake

A difference in VO_{2max} was found between the AirDyne and NordicRow, the highest and lowest values. Several reasons may explain this difference: 1) the physiological effects of the mechanisms of rowing, 2) upper-body strength limitations, 3) muscular rhythm, and 4) the design of the particular machine used. Lower VO_{2max} readings on a rowing apparatus appear consistent in the literature. Both Rosiello, Mahler, and Ward (1987) and Mahler, Andrea, and Ward (1987) speculated that postural changes that occurred during rowing could effect cardiovascular responses during exercise performance. Rosiello et al. (1987) and Mahler et al. (1987) both speculated that the initial compression of the limbs and thorax may result in elevated pleural pressure, which could reduce veneous return and in turn reduce right ventricular end-diastolic volume. Rosiello et al. (1987) and Mahler et al. (1987) also suggested that involuntary practice of the valsalva maneuver at the beginning of the rowing stroke would also lower ventricular volume, both of which if significant could ultimately limit oxygen transport and the VO_{2max}. Results from the current study would seem to agree with these findings, in that the rowing ergometer did appear to generate lower VO_{2max}'s than the AirDyne, although not significantly lower than the other four ergometers. Jensen and Katch (1990) have also suggested that if there was a possible limitation in strength (e.g. the use of untrained women as subjects) that the subjects could be limited by upper body strength before achieving their true VO_{2max}. The strength limitations suggested by Jensen and Katch (1990) were of concern in this study, and workrate increases on the upper body were regulated in a manner to minimize this potential (see Chapter III).

The higher VO_{2max} on the AirDyne in comparison to the cycle ergometer is also of interest. As stated earlier, Nagle, Richie, and Giese (1984) noted that with an optimal inclusion of arm work (10 to 20% of total work output) the VO_{2max} of leg alone cycling could be increased significantly. Although this study did not quantify the amount, the subjects were able to control the amount of arm work done. During the AirDyne protocols subjects were only required to increase their cycling cadence, no regulation of the amount of arm or leg work could be done. Considering the design of the AirDyne, it must be understood that an individual could complete a maximum exercise protocol with very little arm work, however this is highly unlikely. What appeared more probable was that subjects did a vast majority of the slower cadence work with their legs, however as the cadences began to increase and leg fatigue occurred, the arms were included to increase the cadence, thus augmenting the leg alone VO_{2max}. Similarly Bergh et al. (1976) noted increases in the VO_{2max} of leg cycling alone with an adequate contribution of simultaneous arm work. However, Bergh et al. (1976) were quick to point out that if the arms were working closer to their maximal capacity with respect to the legs, that a greater proportion of the cardiac output could be shunted to the arms. This shunting in turn could result in an inadequate blood flow to the leg musculature and reduce the the VO_{2max}. Perhaps if arm inclusion does not occur until the later stages of exercise, the oxygen consuming capacity of the arms can be fully utilized without compromising that of the legs, thus increasing the oxygen consuming potential of the whole system. This may suggest that the most efficient percentage of arm and leg work combination is controlled by the exercising individual without stopping to make tension adjustments.

Heart Rate Maximum

Maximum heart rate varied little across mode of exercise in this study. Reduced $HR_{max's}$ in exercises that include an arm component have been noted in the literature. The results of Jensen and Katch (1990) revealed that the lower HR_{max} on a rowing ergometer was a reflection of greater strength requirements placed on the upper body. Simply stated, at higher intensities the strength requirements of rowing overshadowed the maximum exercise response (Jensen & Katch, 1990). The results of the current study would appear to indicate that the concerns expressed by Jensen and Katch (1990) were avoided, and true HR_{max} was achieved. Nagle et al. (1984) noted significantly higher $HR_{max's}$ with optimal inclusion of arm work (10%) over leg alone cycling $HR_{max's}$. However, when arm inclusion was 20% or greater of total work output, HR_{max} response began drop back to and below that of the leg alone cycling. It was concluded by Nagle et al. (1984) that whatever the interaction between stroke volume and heart rate in high intensity exercise that the conditions for maximal cardiac output appeared best when leg power output was near maximum. Similar to the results seen in this study, Mahler et al. (1987) and Bart (1989) noted no differences in the HR_{max} between arm-leg combined and leg alone exercise.

Ventilatory Threshold

The ventilatory threshold (VT) did appear to be effected by exercise mode, Table (4). On the average, except for the treadmill, combined exercise modes elicited the VT at a higher oxygen consumption and percentage of VO_{2max} than did modes that used legs alone. Mahler et al. (1987) noted no difference in the VT between a rowing and cycling ergometer in the untrained subject portion of their study, however the trained subjects showed a significantly higher VT on the rowing ergometer. In this study, results appeared more consistent with those of Schneider and Pollack (1990) and Schneider, Lacroix, Atkinson, Troped, and Pollack (1990), in which trained male and female triathletes had higher VT's on a treadmill than that of a cycling ergometer. The current results appeared to indicate that the cycle ergometer elicited the lowest VT in untrained female subjects. Schnieder and Pollack (1990) and Schneider et al. (1990) suggested that although training volumes were very similar between the bicycle and running at the time of the study, that perhaps the amount of training over the previous years had not been as intense on the bicycle, and thus the anaerobic systems were not as well developed, producing the VT at a lower oxygen consumption. In the current study, subjects that were not participating in any specific training were selected as subjects, there was also no subject activity within the past several years that could significantly alter the results (i.e. no subjects had participated in any high intensity aerobic or anaerobic training).

When the data were grouped, the VT was significantly higher in the arm-leg combined exercises. Considering that indications of training specificity have been avoided in the design of this study, modal differences could be indicated in this VT response. Perhaps when the workload is distributed between arms and legs the total energy consumption may remain relatively high between the working muscle groups, while the amount of work being done by any specific musculature (i.e. legs alone) is actually lower, thus reducing the metabolic load, resulting in delayed metabolic acidosis and onset of the VT.

Finally, there were some notable differences in the leg alone data. As discussed previously the VT was significantly higher on the treadmill compared to that of the cycle ergometer. When the treadmill means were compared to those of the stairclimber there was a .2L difference in oxygen consumption, which was approaching statistical significance. Interestingly, on both the cycle ergometer and the stairclimber the upper body was static, while the arms were free to move in opposition during the treadmill protocol. The oppositional arm motion of running may use more musculature from the upper body and trunk than when the upper body is stabilized during cycling and stairclimbing. The increased upper body muscular activity seen during running could in turn increase venous return which would improve the efficiency of aerobic exercise, thus raising the VT.

Perceived Exertion at the Ventilatory Threshold

The VT has been demonstrated to be an accurate non-invasive measure of the level of metabolic acidosis or the lactate threshold (Davis et al., 1976; Caizzo et al., 1982). Several studies have found a direct relationship between blood lactate and RPE (Hetzler et al., 1991; Seip et al., 1991). Therefore a close relationship between the VT and RPE would be expected. This was the pattern found in this study; RPE's at the VT ranged from 10 to 12.13, a non-statistical difference. However, the percentage of VO_{2max} and gross oxygen consumption at which the VT's did occur were statistically different. These results suggest that the perceptual effort may be different at the same submaximal oxygen consumption for different modes of exercise. Or, alternatively stated, it may be possible to expend energy at a more rapid rate with no increased perceptual effort on some ergometers.

Hulme, Barnett, Hale, Hale, and Aicinena (1992) noted no significant differences in VO_{2max} between a NordicTrack cross-country ski simulator (NT) and that of a Schwinn AirDyne (AD). However, when subjects were held at a constant perceptual level, higher oxygen consumptions and heart rates were noted on the NT as opposed to that of the AD. These results concur with those of the current study. Again relating back to the potential metabolic differences indicated by the VT. Of the three combined exercises the AD demonstrated the lowest VT (see Table 4). Although no significant differences were noted between the AD and the NT in the onset of the VT, oxygen consumption was .17 L greater on the NT at the AT. Perhaps the differences noted by Hulme et al. (1992) were a product of increased metabolic acidosis with concomitant increases in RPE produced at lower workrates on the AD, resulting lower energy outputs for equivalent perceptual costs.

The results of this study suggest that the inclusion of a larger functional exercising muscle mass does not increase the VO_{2max} significantly. However, from a metabolic and perceptual perspective it appears that exercises that include an arm and leg component (larger muscle mass) can be maintained at higher oxygen consumptions with no concomitant increases in RPE.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effects of exercise mode on VO_{2max}, maximum heart rate, VT, and RPE. Eight female subjects between 19 and 27 underwent incremental maximum capacity testing (VO_{2max}) on six modes of exercise: three leg only, treadmill, cycle ergometer, and stairclimb; and three arm-leg combined, AirDyne, NordicTrack, and NordicRow. Expired air was measured with a Beckman metabolic measurement cart every 30 seconds. The ventilatory threshold (VT) was determined by plotting ventilation variables, (V_{O2}, Ve, VC_{O2}, VE/V_{O2}) against time, on graphs generated by an Apple Macintosh. Perceived exertion was measured with the Borg Scale (6-20).

A significant difference ($P < 0.05$) in VO_{2max} was noted between the AirDyne (2.62 liters/min) and the NordicRow (2.33 liters/min). There were no significant differences in maximum heart rate.

Significant differences ($P < 0.05$) in oxygen consumption at the VT were found. The modes with the highest VT were: NordicTrack (1.81 liters/min), AirDyne (1.73 liters/min), Treadmill (1.69 liters/min), and NordicRow (1.65 liters/min), in comparison to; Stairclimb (1.43 liters/min), and Cycle ergometer (1.34 liters/min). Arm-leg combined exercise VT was found to be higher ($P< 0.05$) than leg alone exercise. Significant differences were also found when VT was expressed as a percentage of VO_{2max}. Arm-leg combined modes were higher when compared to leg alone modes, 67.8 vs. 58.8% respectively. However, no differences in RPE were noted at the VT.

This study provides evidence that exercise modes which combine an arm and leg component result in higher peak submaximal oxygen consumption (VT) with equivalent perceptual effort.

Conclusions

1. VO_{2max} was statistically unaffected by the amount of muscle mass utilized. However, the VO_{2max} of the AirDyne was O.134 L/min greater than that of the Cycle Ergometer, this result suggests that the addition of arm work may augment the VO_{2max} of legs alone for the same rhythmical leg motion.
2. The inclusion of upper-body musculature appeared to increase VT oxygen consumption and percent of VO_{2max} at which the VT occurred.
3. There was no difference between the six ergometers in the HR_{max}, which approximated age adjusted maximum values.
4. Based on the RPE responses at the VT, it was concluded that similar levels of exertion were experienced at varying oxygen consumptions on different exercise modes.
5. Combined arm-leg exercise appears to result in higher submaximal oxygen consumption at equivalent perceptual costs.

Recommendations

1. The increase in VO_{2max} from the Cycle ergometer to the AirDyne is worthy of further research. A study which compares the same lower body motion (e.g. cycling) with and without calibrated, integrated upper-body contribution, may clarify the influence of muscle mass on VO_{2max} and VT which was suggested by the difference found between the AirDyne and cycle ergometers.
2. A steady state comparison of various types of ergometers is warranted. The question "is energy consumption different at given submaximal percentages of HR_{max} in differing exercise modes" still needs to be answered. A comparison of exercise modes at the same steady state heart rate would provide conformation that arm-leg combined exercise elicits a higher energy consumption.

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APPENDICES

APPENDIX A

RAW DATA

Table 7. Maximum Oxygen Uptake (ml).

SUBJECT	TM	AD	CE	NT	NR	SC
1. KW	2740	2821	2818	2425	2563	2653
2. SE	2893	2638	2848	2745	2561	2619
3. SB	2346	2562	2423	2338	2198	2342
4. AA	2665	2896	2668	2580	2561	2704
5. PC	2489	2447	2185	2501	2302	2135
6. CT	2548	2882	2618	2521	2644	2518
7. MM	1779	1674	1642	1600	1640	1647
8. AF	2781	3067	2716	2749	2690	2816

Table 8. Maximum Heart Rate Raw Data (BPM).

SUBJECT	TM	AD	CE	NT	NR	SC
1. KW	194	191	194	196	190	190
2. SE	176	174	178	176	176	175
3. SB	202	200	200	204	193	203
4. AA	180	190	185	180	185	185
5. PC	195	198	192	194	193	193
6. CT	201	193	190	192	194	194
7. MM	206	209	210	205	200	200
8. AF	196	195	194	195	192	192

Table 9. Oxygen Consumption at Ventilatory Threshold (ml).

SUBJECT	TM	AD	CE	NT	NR	SC
1. KW	1730	1903	1414	2068	2031	1493
2. SE	1888	1796	1432	2000	1783	1495
3. SB	1661	1446	1324	1753	1340	1616
4. AA	1618	2102	1396	1767	1706	1510
5. PC	1779	1520	1113	1668	1578	1333
6. CT	1626	1497	1421	1713	1776	1500
7. MM	1086	1107	885	1317	1125	1061
8. AF	1698	1598	1519	1809	1819	1469

Table 10. Ventilatory Threshold as a Percentage of Maximum O_2 Uptake.

SUBJECT	TM	AD	CE	NT	NR	SC
1. KW	63	67	50	85	79	57
2. SE	65	68	50	72	69	57
3. SB	70	68	55	74	61	69
4. AA	60	73	52	70	67	56
5. PC	71	62	51	67	68	62
6. CT	62	52	54	68	67	59
7. MM	61	66	54	82	69	64
8. AF	67	52	56	66	68	52

Table 11. Relative Perceived Exertion (RPE) at Ventilatory Threshold.

SUBJECT	TM	AD	CE	NT	NR	SC
1. KW	12	8	8	13	8	6
2. SE	13	15	13	12	11	12
3. SB	13	8	10	12	8	12
4. AA	12	14	12	15	13	10
5. PC	13	11	12	16	13	11
6. CT	11	11	10	8	10	11
7. MM	13	11	11	10	11	10
8. AF	10	8	11	10	10	8

Table 12. Subject Information.

SUBJECT	AGE	HEIGHT (CM)	WEIGHT (KG)	BMI
1. KW	24.5	165	57	22
2. SE	22.6	173	68	24
3. SB	20.4	165	63	23
4. AA	23.4	163	68	25
5. PC	26.9	173	61	22
6. CT	19.2	163	60	20
7. MM	20.6	165	54	18
8. AF	24.9	178	64	21

APPENDIX B

PERCEIVED EXERTION, BODY MASS INDEX

PERCEIVED EXERTION

The 15-grade scale for ratings of perceived exertion, the RPE Scale.

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	Maximal

(Borg, 1982)

BODY MASS INDEX

Body Mass Index (BMI) for all subjects was determined using Table 3.4 of the 1992 ACSM Fitness Book (BMI Chart). Determinations for that chart were based on the following formula.

$$\mathbf{BMI = WEIGHT\ (KG)\ /\ HEIGHT\ (Meters)^2}$$

APPENDIX C

SAMPLE FORMS

INFORMED CONSENT

1. *Objective of the Study:* You are volunteering to participate in the study entitled "A comparison of metabolic, cardiovascular, and perceived exertion responses at maximal capacity and ventilatory threshold in six exercise modes." This study is designed to evaluate your bodies' physiological response to exercise and to establish any possible links with the perception of the intensity of the exercise in different exercise modes.
2. *Testing Procedures:* As a subject you will be asked to complete the following:
   a. Fill out a medical history questionnaire and have your height and weight determined.
   b. Perform an incremental maximal capacity test on each of the following exercise ergometers: treadmill, bicycle, stairclimber, Schwinn AirDyne, cross-country ski simulator, and rowing ergometer. These testS will be used to establish your maximal oxygen uptake and ventilatory threshold on each ergometer. The tests will begin at a level that feels easy, and will progress in two minute stages until your oxygen uptake has plateaued or until you are no longer able to maintain the given cadences for each ergometer. You may stop the tests at any time due to feelings of exertional distress.
   c. It is requested that you report to the laboratory in a condition suitable for maximal capacity testing, this includes both food and water. Please eat a suitable diet and be well hydrated before reporting to the laboratory. Please attempt to consume a diet that is

similar in caloric composition three days before each testing period (a dietary recall sheet will be provided for this purpose). It is also requested that you refrain from exercise the day prior to each testing period.

3. *Time Expense for Subjects:* Each maximum capacity test will require roughly one hour of your time.. the whole data collection period will require *six* hours of your time.
4. *Potential Benefits:* Participation in this study will give you an accurate assessment of your aerobic fitness level. Information in the current literature indicates that there is a difference in the response to aerobic exercise that includes varying degrees of arm and leg contribution (both physiological and psychological). Your participation in this study will assist us in answering this question.
5. *Risks and Discomforts:* The overall risks associated with participation in this study are minimal; however, the possibility of certain changes and risks do exist. They include: nausea, dizziness, muscle soreness, fatigue, shortness of breath, abnormal blood pressure responses, irregular heart beats, and in rare instances, heart attack. You will be continually monitored throughout all testing. You may terminate the test at any time if you feel unduly stressed or uncomfortable.
6. *Confidentiality:* The subjects will be identified by numbers which will only be known by the principle investigators. The use of personal information will be strictly relegated for research purposes, including publication. Personal information will only be released through your written consent.

7. *Persons to Contact for More Information:* The individuals below may be contacted if you desire more information regarding this study.

Daniel G. Graetzer, Ph.D.
Health & Human Performance
McGill Hall 121
Missoula, Montana 59812-1055

Brian J. Sharkey
LAB: 243-2117
HOME: 549-8204
OFFICE: 243-2117

In the event that you are physically injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by the negligence of the University or any of its employees you may be entitled to reimbursement or compensation pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the Authority of M.C.A., Title 2, Chapter 9. In the event of a claim for such physical injury, further information may be obtained from the University Legal Counsel.

Your participation in this study is on a strictly voluntary basis. If at any point during this study you wish to end your participation, feel free to do so without fear of reprisal.

I have read this form and I understand the testing procedures that I will perform. I give my consent to participate in this study.

Date:____________________ Signature:________________________

Date:____________________ Witness:________________________

MEDICAL HISTORY QUESTIONNAIRE

Name: ______________________________

Address: ______________________________

City: ______________ State: _____ Zip: __________

Phone: ______________

Name of your physician: ______________________________

Phone: ______________

List the date of your last

Physical exam: __________ Surgery: __________ EKG: __________

1. Have you been told by a doctor that you have or have had any of the following? (Please check each correct response).

YES	NO		YES	NO	
( )	( )	Rheumatic fever	( )	( )	High blood pressure
( )	( )	An enlarged heart	( )	( )	Abnormal EKG pattern
( )	( )	Epilepsy	( )	( )	Diabetes
( )	( )	Heart or vascular	( )	( )	Stroke disease
( )	( )	Metabolic disorders	Specify: ______________		
( )	( )	Heart murmur	( )	( )	Asthma
( )	( )	Lung or pulmonary disorders	( )	( )	Abnormally high blood cholesterol or triglicerides
( )	( )	Thrombo phlebitis (blood clots)			

2. Please list any drugs, medication, or dietary supplements PRESCRIBED by a physician that you are currently taking:

Drug: ______________ for: ______________ Dosage: ______________
Reactions: ____

Drug: ______________ for: ______________ Dosage: ______________
Reactions: ____

3. Please list any SELF-PRESCRIBED drugs, medications, or dietary supplements that you are currently taking:

____

____

____

4. Is there a history of heart disease, heart attack, elevated cholesterol levels, high blood pressure, or stroke in your immediate family (grandparents, parents, brothers, and sisters) *before the age of 55*? If so please explain: ____

____

____

5. Do you smoke? ( ) YES ( ) NO
   a. If yes, how many cigarettes do you smoke per day? ________
   b. If no, have you ever smoked? ( ) YES ( ) NO
   How long ago did you quit? ______________

6. Do you suffer from any menstrual irregularities (i.e. PMS, dysmenorrhea)? ( ) YES ( ) NO

   a. If yes, please explain: ______________________________

   ____

   ____

   ____

   ____

   b. If no, do you feel that your physical abilities are compromised during any part of your menstrual phase, please explain: ______________

   ____

   ____

   ____

   ____

7. Are you currently under a great deal of stress either at work, school, or personally? ( ) YES ( ) NO

8. Do you actively relieve stress through exercise, meditation, or other methods? ( ) YES ( ) NO

9. Are you currently on a regular exercise program? ( ) YES ( ) NO

   Type of exercise you are involved in: ______________________

   Frequency per week: ______________________________

   Duration each day: ______________________________

10. While exercising do you ever feel limited by (if yes, state type of activity you are performing when this arises):

		YES	NO	
a.	breathing	( )	( )	Activity: ____________
b.	chest, arm, or neck pain	( )	( )	Activity: ____________
c.	low back pain	( )	( )	Activity: ____________
d.	pain in leg, relieved by rest	( )	( )	Activity: ____________
e.	side aches	( )	( )	Activity: ____________
f.	lower leg pain front shin pain back achilles	( )	( )	Activity: ____________
g.	extreme long-lasting fatigue	( )	( )	Activity: ____________

I hereby certify that the answers to this questionnaire are true and complete and to the best of my knowledge I am in good health.

Signature: ______________________________ Date: ________________

DIETARY RECALL SHEET

Please list all foods consumed three (3) days prior to each testing procedure. Please attempt to duplicate the nutrient content (i.e. percent carbohydrates, fat, etc.). Each testing session will be marked by a number.

1. FOOD AMOUNT

____
____
____
____
____
____
____
____

2. FOOD AMOUNT

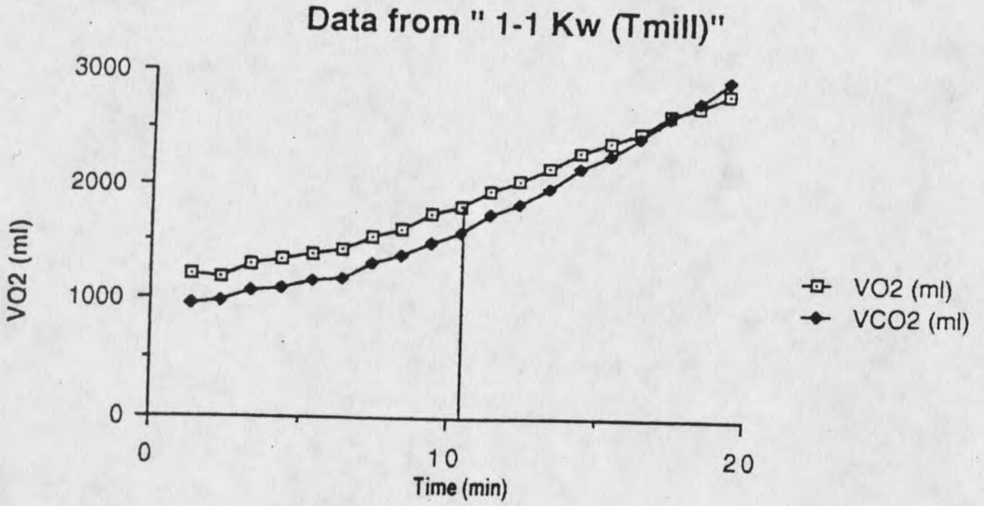
____
____
____
____
____
____
____
____

3. FOOD AMOUNT

____
____
____
____
____
____
____
____

APPENDIX D

DEMONSTRATION OF GRAPHING METHODS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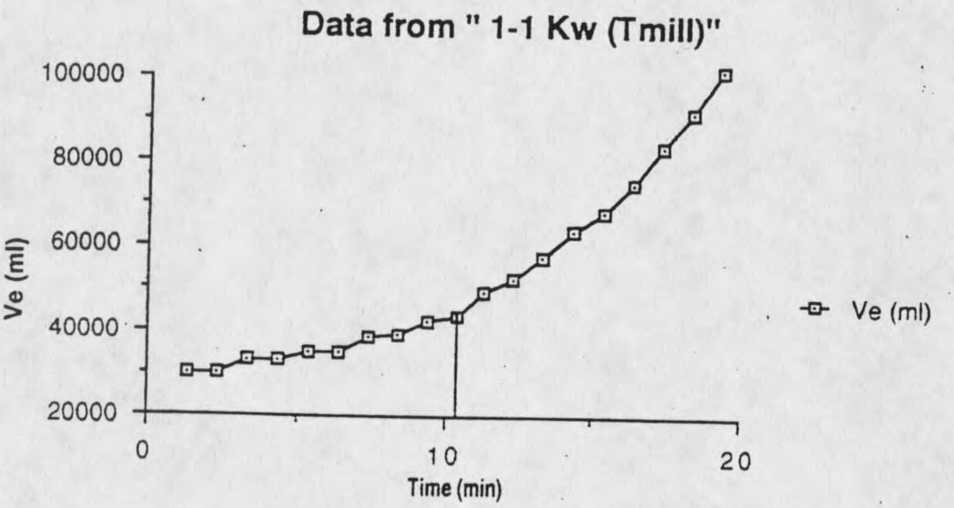
2000
1000
0
VO2 (ml)
0
10
20
Time (min)
VO2 (ml)
VCO2 (ml)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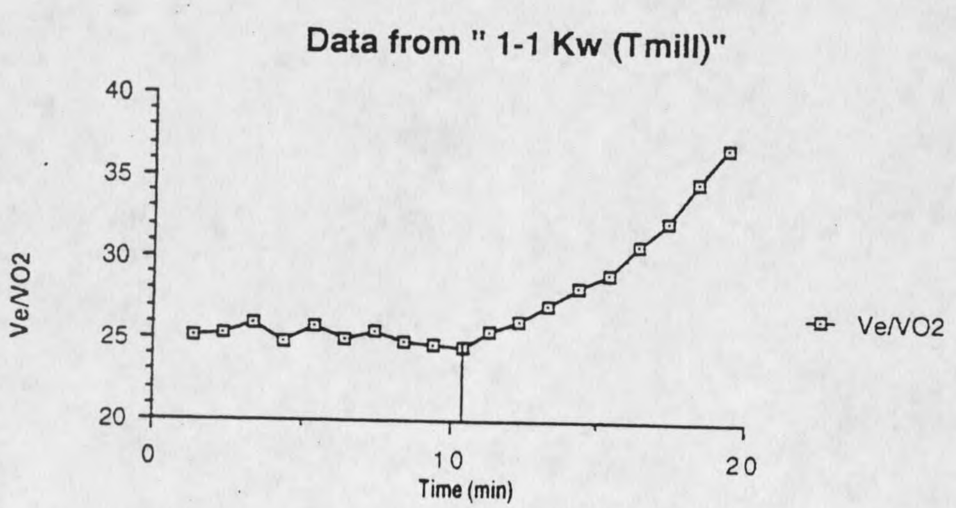
80000
60000
40000
20000
Ve (ml)
0
10
20
Time (min)
Ve (ml)


Data from " 1-1 Kw (Tmill)"
40
35
30
25
20
Ve/VO2
0
10
20
Time (min)
Ve/VO2