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 ($P<0.05$).

Differences were only noted between the highest and lowest VO_{2max} 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 VO_{2max} 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.

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 overall 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 + 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).

<u>Pre-test Preparation</u>

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.