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VARIABILITY OF SUBSTRATE UTILIZATION DURING EXERCISE RELATIVE
TO VO_2VT AND VO_2MAX

By

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Thesis

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Variability of substrate utilization during exercise relative to $\text{VO}_{2\text{vt}}$ and $\text{VO}_{2\text{max}}$

Chairperson: Steven E. Gaskill

PURPOSE: The purpose of this study was to determine to the stability of ventilatory threshold (VT) as a set point for prescription of exercise intensity. **METHODS:** Fifty-eight healthy adults (males $n = 28$, females $n = 30$) performed $\text{VO}_{2\text{max}}$ and steady state testing. The $\text{VO}_{2\text{max}}$ test used a treadmill ramp protocol to determine $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{vt}}$. The results were used to determine workload exercise relative to $\text{VO}_{2\text{vt}}$ and $\text{VO}_{2\text{max}}$ ($70\% \text{VO}_{2\text{vt}} \approx 40\% \text{VO}_{2\text{max}}$, $90\% \text{VO}_{2\text{vt}} \approx 50\% \text{VO}_{2\text{max}}$, $125\% \text{VO}_{2\text{vt}} \approx 65\% \text{VO}_{2\text{max}}$). During the steady state test, subjects walked for 4 minutes at each of the workloads associated with the six exercise intensities. These stages were sequentially completed in the order of increasing intensity. Ventilation (VE), respiratory gas-exchange ratio (RER), VO_2 , and VCO_2 were measured continuously and heart rate and rate of perceived exertion (RPE) were collected each minute. **RESULTS:** The mean overall variance of RER at the $\% \text{VO}_{2\text{vt}}$ intensities was significantly less than at the $\% \text{VO}_{2\text{max}}$ intensities ($\% \text{VO}_{2\text{vt}} = 0.030 \pm 0.025$, $\% \text{VO}_{2\text{max}} = 0.041 \pm 0.029$, $p < 0.001$). The mean RER variance was not different between genders relative to $\% \text{VO}_{2\text{vt}}$ ($p > 0.05$). For males and females, the variance in RER was significantly less when evaluated at 70% and 90% of $\text{VO}_{2\text{vt}}$ than at 40% and 50% of $\text{VO}_{2\text{max}}$ respectively ($p < 0.001$). When the RER mean variance values were compared at the $125\% \text{VO}_{2\text{vt}}$ vs. $65\% \text{VO}_{2\text{max}}$, RER variance values within subjects (males, females and overall) were not different ($p > 0.05$). Similar patterns in RER variance were seen when compared by body mass index (BMI) or fitness. **CONCLUSIONS:** Using $\% \text{VO}_{2\text{vt}}$ is a viable method to prescribe exercise intensity during research and/or training, with overall lower RER variance, especially when the intensity of exercise is below the ventilatory threshold.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements	iii
Table of Contents	iv
Chapter 1: Statement of the Problem	
- Introduction	1
- Problem	1
- Purpose	2
- Hypotheses	3
- Significance and Rationale	3
- Limitations	3
- Delimitations	4
- Definitions	4
Chapter 2: Literature Review	
- Introduction	6
- Training	6
- Genetics	7
- Training relative to % VO ₂ vt and % VO ₂ max	8
- RPE	10
- RER	11
- Summary	12
Chapter 3: Methods	
- Setting	13
- Subjects	13
- Research Design	
o Descriptive Data	13
o VT Determination	14
o Intensity and % Grade Determination for Steady State	15
o Statistical Analysis	16
Manuscript for Medicine and Science in Sports and Exercise	
- Introduction	18
- Methodology	20
- Results	23
- Discussion	25
- References	32
- Figures	37
- Tables	39

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CHAPTER ONE

STATEMENT OF THE PROBLEM

Introduction

Common markers utilized to determine cardiorespiratory fitness levels have included VO_2max (15,21,29) ventilatory threshold (11,12,18,21,22,33), lactate threshold (11,21,22,33), substrate utilization at a given $\% \text{VO}_2\text{vt}$ or $\% \text{VO}_2\text{max}$ (23,26) and rate of perceived exertion (RPE) at a given $\% \text{VO}_2\text{vt}$ or $\% \text{VO}_2\text{max}$ (14,20)). However, the values of these measurements vary greatly.

Maximal oxygen uptake (VO_2max) is the common method used for prescription of exercise intensity in exercise research or fitness training. However, due to factors such as age, gender, training, health and genetics, ventilatory threshold (VT) may be a more stable measure. Ventilatory threshold is defined as the exercise intensity at which the increase in ventilation becomes disproportional to the increase in power output (PO) or speed of locomotion during an incremental exercise test. VT generally correlates well with the first rise in blood lactate (LT) (21,22,33). With training, an individual increases exercise tolerance (11) by decreasing lactate production at a given moderate-intensity PO, increasing lactate clearance at a high relative PO (5), and shifting the velocity-time curve to the right (21). Additionally, training increases LT and VT at the same VO_2max (11,12,18,22) and individuals with similar VO_2max do not have the same VT or LT (9).

Results from the HERITAGE family study, a large heterogeneous, biracial, and sedentary population, found that age, sex, race, and initial fitness level had little influence on the response of VO_2max to a standardized 20-wk exercise training program (29).

Additional data from this study found that with training there was a strong familial contribution to the response of VT and $\text{VO}_{2\text{max}}$ (7,8,13,16) and a decrease in HR at the same absolute intensity (PO in watts) but no difference in HR at the same $\% \text{VO}_{2\text{max}}$ (29).

Submaximal measure as a percent of $\text{VO}_{2\text{vt}}$ may be a more appropriate method of cardio respiratory endurance capacity than $\% \text{VO}_{2\text{max}}$ (11,29). Endurance performance has been highly correlated with VT (30). Strong test-retest relationships in work rate and $\% \text{VO}_{2\text{vt}}$ have been reported and reliability of the method is enhanced if test conditions and personnel are kept constant (17,28).

The Problem

Individuals respond differently at a given exercise intensity. In the past few years $\% \text{VO}_{2\text{vt}}$ has been proposed as a more appropriate basis than $\% \text{VO}_{2\text{max}}$ for prescription of exercise training for a wide variety of individuals. However, to our knowledge, no previous research has examined the stability of exercise intensity of $\% \text{VO}_{2\text{vt}}$ versus $\% \text{VO}_{2\text{max}}$. The University of Montana Human Performance Laboratory is interested in determining the validity of using ventilatory threshold as the standard for prescribing exercise intensity during research. This study will examine the variability of the respiratory gas-exchange ratio (RER) and the rate of perceived exertion (RPE) at a given $\% \text{VO}_{2\text{vt}}$ versus $\% \text{VO}_{2\text{max}}$ at similar relative exercise intensity.

Purpose

To determine the stability of ventilatory threshold as a set point for prescription of exercise intensity in exercise research.

To determine the variability of RER at a given % VO_2vt versus a relative % VO_2max intensity.

To determine the variability of RPE at a given % VO_2max versus a relative % VO_2vt intensity.

Research Hypotheses

1. The variability of RER relative to VO_2vt will be significantly smaller vs. relative to VO_2max at similar absolute exercise intensity.
2. The variability of RPE relative to VO_2vt will be significantly smaller vs. relative to VO_2max at similar absolute exercise intensity.

Significance and Rationale for Study

Most current research prescribes subjects' exercise intensity relative to % VO_2max . Since research has shown individuals respond differently to % VO_2max , % VO_2vt may be more appropriate to ensure similar metabolic stress across a variety of fitness levels and subjects. This study was conducted to determine the stability of ventilatory threshold as a set point for exercise intensity prescription during research using a heterogeneous population.

Limitations

1. Determining ventilatory threshold is an indirect method using gas exchanges values. Indirect methods increase measurement error; however, all personnel were trained.
2. There is an inherent error with any instrumentation. To limit this error, all equipment was carefully calibrated and all testers adequately trained.
3. The sample was non-randomized. The University of Montana HHP 499 Senior Project Class recruited subjects for the study.

Delimitations

1. The subjects in this study were delimited to sedentary or active groups.
2. The mode of exercise was limited to the treadmill.

Definition of Terms

Active: An individual who meets the Surgeon General's recommendation of 30 minutes of physical activity most days of the week.

Rate of Perceived Exertion (RPE): Subjective level of intensity an individual feels the body is exerting during exercise. The rating is on a scale of 6-20, where 6 is sitting and 20 is maximal effort (6).

Respiratory Gas-Exchange Ratio (RER): The ratio of CO₂ production over O₂ consumption used for estimating the contribution of carbohydrate or fatty acid to overall metabolism.

Sedentary: An individual who does not meet the Surgeon General's recommendation of 30 minutes of physical activity most days of the week.

Ventilatory Threshold (VT): The exercise intensity at which carbon dioxide output (VCO₂) increases more rapidly than oxygen uptake (VO₂) during a progressively increasing workload. For this study, VT will be evaluated using a combined method determined by Gaskill et al., 2001.

VO₂max: The maximal amount of oxygen an individual can consume during a graded exercise test.

CHAPTER TWO

REVIEW OF LITERATURE

Ventilatory threshold (VT) is defined as the point reached during a progressively increasing workload at which carbon dioxide output begins to increase more rapidly than oxygen uptake. At this point, ventilation increases in a nonlinear fashion with continual increases in workload. The importance of VT is multimodal: it appears to be an excellent measurement to identify changes in aerobic conditioning, especially when evaluating the ability to sustain aerobic capacity for extended periods (11,12,18,19,22,31); is well related to the first lactate threshold (17,21,33); has been shown to be better related to aerobic performance than is $VO_2\text{max}$ (2,27,31); results in a more homogenous response to training than % $VO_2\text{max}$ (12); is more strongly related to the incidence of chronic disease, especially CVD and diabetes than is low $VO_2\text{max}$ (Hanna et al., in print); and is non-invasive.

The relationship between VT with the first lactate threshold (LT) is not perfect, although most researchers have found it to be quite consistent. With consistent aerobic activity over time, VT and LT generally occur at the same workload (17). However, endurance training can induce a greater increase in LT than VT (11,25) and there seems to be a period of time before VT and LT again equalize (25).

Ventilatory threshold measurement has been found to be reliable if test conditions and personnel are kept constant (17,28). Additionally, using a combined method of

ventilatory equivalent, excess carbon dioxide and modified V-slope, more data is decipherable, accuracy of VT determination is improved and reduction of errors is achieved when compared with individual methods of determining VT (17).

Training

Ventilatory threshold and lactate threshold have been shown to be sensitive markers of aerobic training improvements, even without improvements in VO_2max . Research has demonstrated that training increases ventilatory threshold in individuals of all fitness levels, gender, age and race (11,12,18,22). In a meta-analysis of 34 studies, Londeree, 1997, found training at or near the lactate or ventilatory threshold improves the thresholds in sedentary subjects, but a higher intensity may be needed for conditioned subjects. Also, detraining will occur if training intensity is reduced (22). Henritze et al., 1985, found similar results in a 12 week training study using LT. Thirty three college women were divided into three groups: 1) above LT (workload associated with 69 watts above LT), 2) at LT (workload associated with LT) and 3) control group. Post training they found the above LT subjects had significantly higher VO_2max , VO_2lt and $\% \text{VO}_2\text{lt}$ ($\text{VO}_2\text{lt}/\text{VO}_2\text{max}$) compared to the control group. However, overall, no group significantly changed their VO_2max as result of training. The above LT group showed significant increase in VO_2lt and both the near LT and above LT showed a significant increase in $\% \text{VO}_2\text{lt}$ (19). Edwards et al, 2003, found significant improvements in LT ($p < 0.01$) and VT ($p < 0.05$) with training in professional soccer players, while finding no change in VO_2max .

In the HERITAGE family study, using a large, heterogeneous, sedentary population, increases in VT were related to the intensity of training relative to VT. If the intensity of the training was above VT, subjects showed the largest increase in VO_{2vt} and if the intensity was below VT, subject elicited smaller improvements. These results were similar across age, gender and race (18).

Genetics

Ventilatory threshold and VO_{2max} are influenced by genetic and environmental factors (7,8,13,16). Additional data from the HERITAGE family study found differences in VT in a sedentary state are influenced by a gene or a few genes that have low-frequency alleles (in whites not blacks) and contribute to VT in sedentary state, but did not appear to influence trainability of VT (13). Also, they found significant familial resemblance for both maximal and submaximal aerobic performances (7,17). Furthermore, the results showed a strong familial contribution to VO_{2vt} in the sedentary state and to the response of training (17). In summary, genetics appears to be a strong influence on VO_{2max} trainability but a lesser influence on changes in VO_{2vt} which are more related to the intensity, frequency and duration of training.

Training relative to % VO_{2vt} and % VO_{2max}

The American College of Sports Medicine recommends a training heart rate (HR) of 50 to 85% of VO_{2max} and/or HR reserve (1) and prescribing training as a percentage of VO_{2max} has long been the recommended standard for fitness. VO_{2max} , adjusted for body weight, is the most common measure of aerobic fitness and is often used to monitor

changes during aerobic training. However, VO_2max has a large genetic contribution (8) restricting potential improvement and reduces its efficacy as a measure of aerobic training fitness. Elite athletes, with already well-developed aerobic exercise capacity, may improve race performance without increases in VO_2max (30). While VO_2max provides a useful indication of aerobic capacity, it may have limited value for monitoring changes in the training state (11). It has been proposed that values associated with ventilatory threshold may be a better method for aerobic exercise prescription (32).

Ventilatory threshold, as a marker for aerobic fitness and exercise prescription, takes into account specific metabolic stress, resulting in more homogeneous response to training than $\% \text{VO}_2\text{max}$. Additionally, VT differs as a function of age, gender, physical fitness, health, etc., making it more individualized. In a study conducted by Fabre et al, 1997, sixteen elderly subjects were divided into two groups; one group trained at the intensity of VT and the other group at ACSM recommended intensity for this age group of 50% heart rate reserve (HRR estimating 50% of VO_2max). Mean training heart rate (HR) for the VT group was 129 ± 14.2 bpm and for the HRR was 115 ± 7.9 bpm. Results showed VO_2max improved significantly in the VT group, while the HRR group showed no significant improvements. Submaximal ventilation and HR decreased more in the VT than in the HRR group. The authors concluded training at VT is significantly more effective than training at 50% of VO_2max for this age group in terms of improving VO_2max and submaximal cardiorespiratory adaptations. Additionally, the authors concluded that VT is an individualized variable for exercise prescription inducing improvements in aerobic capacity and in submaximal exercise tolerance (12).

Using the ratio of $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$ ($\%\text{VO}_{2\text{vt}}$) indicates the sustainable utilized aerobic power as a percentage of maximal power while performing work at VT (11). Both $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{vt}}$ decrease with age, but $\%\text{VO}_{2\text{vt}}$ increases with age as a result of the more rapid decrease in $\text{VO}_{2\text{max}}$ than in $\text{VO}_{2\text{vt}}$ (15). When individuals train at similar percentages of $\text{VO}_{2\text{max}}$, there is a wide variance in their intensity of training relative to VT (10). These differences are due to widely different values of VT which are not accounted for in training design. When exercise is prescribed at similar $\%\text{VO}_{2\text{max}}$ to a number of individuals, as is commonly recommended (1), the perceived exertion of individuals may vary greatly and their metabolic substrate contribution may vary widely. Across a large number of studies, VT appears to be an excellent method by which to set intensity of training.

RPE

Rating of perceived exertion (RPE) has been described as the 'single best indicator of physical strain' (6). During exercise it provides a psychological compliment to the physical responses to exercise. RPE at the ventilatory threshold has consistently been found to be in the range of RPE = 11 (somewhat easy) to RPE = 13 (somewhat hard). Feriche et al, 1998, investigated the use of a RPE fixed value of 12-13 for determination of the workload associated with VT. Eleven trained cyclists used ramp protocol on cycle ergometer to collect gas exchange data to determine VT. The data suggested that using the fixed value of RPE = 12-13 might be used to detect the exercise intensity corresponding to VT (14). In a study by Hill et al., 1987, the researchers determined at

VT the value of RPE = 13-15 (hard). After 17 college students completed six weeks of 18 interval training sessions, they found the greatly increased work rate at VT remained at an RPE = 13-15. In the same study, RPE at fixed percentages of VO_2max decreased with the training unlike RPE at VT, which remained stable (20). RPE appears to remain constant at VT across a wide range of fitness within individuals, while RPE at fixed percentages of VO_2max is quite variable.

RER

The respiratory gas exchange ratio (RER) indicates what substrates are being oxidized during exercise. While the RER remains constant between genders (26), with training, the RER decreases (enhanced lipid oxidation) when measured at the same $\% \text{VO}_2\text{max}$ (4,23). Additionally, individuals with similar VO_2max values will vary in the metabolic response to exercise above and below LT (9,10). Coggan et al., 1992, studied 14 subjects with similar VO_2max . In seven of the subjects, LT occurred at a relatively high intensity ($65 \pm 2\%$ of VO_2max), while in the other seven subjects, LT occurred at a relatively low intensity ($45 \pm 2\%$ of VO_2max). They found individuals with high LT have lower RER than those with lower LT at a given $\% \text{VO}_2\text{max}$.

In contrast, RER at VT appears to remain stable across aerobic training. After 20 weeks of training in the HERITAGE family study when measured at VT pre- and post-training, RER remained unchanged at 0.91 ± 0.02 across race, age and gender in over 400 subjects. While RER has been shown to change with training relative to VO_2max and has been

shown to remain stable at VT, little data has been reported on RER at intensity levels relative to VT.

Summary

Prescribing aerobic exercise intensity relative to VT (%VT) or LT (%LT) has long been used in the prescription for aerobic athletes. Additionally, it has long been accepted that training above the ventilatory or lactate threshold is appropriate for high intensity training to increase performance and training studies have documented the efficacy of athlete training relative to ventilatory and lactate breakpoints. However, exercise prescription for research and general recommendations for aerobic fitness training remain focused on the use of %VO₂max as the gold standard (1). In studies evaluating different populations such as fit vs. unfit, males vs. females, young vs. old, or even race differences the use of exercise intensity at fixed values of %VO₂max has consistently resulted in differences in RPE, RER and training effect between (and within) these groups. However, limited data, such as the large HERITAGE family study data set, indicate that RPE and RER at VT are quite constant across different groups. Thus, it has been proposed by a number of researchers and coaches that using % VO₂vt may be a more appropriate basis than % VO₂max for prescription and for research evaluating the effects of aerobic training, especially when evaluating across a wide variety of individuals.

CHAPTER THREE

METHODOLOGY

Setting

All testing took place at the University of Montana Human Performance teaching lab in McGill Hall, room 131.

Subjects

Fifty-eight healthy adults served as subjects. Twenty-eight males and thirty females were recruited by the Health and Human Performance (HHP) 499 Senior Project Class. Prior to participation all subjects completed an IRB approved informed consent form.

Descriptive data is found in Table 1.

Research Design

Descriptive Data

After signing the consent form, subjects were assigned a subject number and descriptive data were collected (Table 1). In addition, a three site skin fold measurement (males - chest, abdominal and thigh and females - tricep, suprailiac and thigh), was repeated three times on the right side of the body, by the same investigator, to determine body fat percentage utilizing the equations of Jackson-Pollock (1). Once collected, subjects put on a heart rate monitor (Polar, Port Washington, NY) and proceeded to the VO₂max test.

VO₂max Test

VO₂max was measured while subjects walked and ran using a Quinton Treadmill (Seattle, WA) during a ramp protocol. After a five minute warm-up, subjects self-selected a “brisk” walking speed and began walking at a 0% grade. The grade increased 1% each minute until an RER \geq .97 and/or RPE \geq 15 was reached. The speed was then increased one mile per hour (mph), while grade was maintained, until volitional exhaustion was achieved. The observation of three of the four criteria was necessary to assume the subjects had reached their VO₂max: (1) stability of VO₂ in spite of increase in workload; (2) RER > 1.10; (3) RPE > 19; and (4) the inability of the subject to maintain the running speed. Heart rate and RPE were collected each minute. Expired gases were collected during the test using a calibrated metabolic cart (Parvomedics, Inc., Salt Lake City, UT) and analyzed at 15-second intervals. The results from this test were later used to determine intensities for steady state exercise relative to VO₂vt and VO₂max.

VT Determination

To determine VT for each subject, a combined method of ventilatory equivalent (VEQ method), excess carbon dioxide method (ExCO₂) and modified V-slope method (V-slope) (Gaskill) was used. The ventilatory equivalent method is defined as the intensity of exercise which causes the first increase in the VE/VO₂ without a concurrent increase in the VE/VCO₂. The excess CO₂ method is defined as the intensity of exercise which causes the first sustained rise in excess CO₂ production. ExCO₂ is calculated as $((VCO_2^2 / VO_2) - VCO_2)$. The modified V-slope method is the exercise intensity corresponding with the increase in the slope of the VO₂ - VCO₂ plot. In addition, RER

and RPE were used to help determine VT. Two trained investigators independently picked each VT. After analysis if there was no agreement between the investigators, the subject was retested and data from the repeated test was used.

Intensities and % Grade Determination for Steady State Exercise

Light intensity was defined as 70% VO_{2vt} and 40% VO_{2max} , moderate intensity was 90% VO_{2vt} and 50% VO_{2max} and vigorous intensity was 125% VO_{2vt} and 65% VO_{2max} , even though the resulting MET values after steady state exercise indicate higher achieved intensity (light ≈ 6.0 , moderate ≈ 7.5 and high ≈ 9.5 , respectively). These intensity pairs were determined from prior research data (15).

Regression equations found the best linear fit between subject's VO_2 and % grade with each subject's self-selected walking speed during the VO_{2max} test. They were calculated in order to determine the % grade associated with the VO_2 at the three % VO_{2vt} and three % VO_{2max} intensity pairs to be compared during steady state activity.

Steady State Exercise Testing

After a 5 minute warm up, the treadmill speed was adjusted to the subject's self-selected walking speed from the VO_{2max} test. Once established, the subject exercised in 4 minute increments under the following conditions: a) VO_{2max} exercise at a % grade associated with 40, 50, and 65% \dot{V}_E , respectively, and b) VT exercise at a % grade associated with 70, 90, and 125% VO_{2vt} , respectively. These stages were sequentially ordered such that the stages were completed in the order of increasing intensity. During exercise ventilation (\dot{V}_E), RER, VO_2 , and VCO_2 were measured continuously using the

same metabolic cart as used during the VO_2max test. Heart rate and RPE were also collected each minute. The last two minutes of each stage were averaged for the steady state values.

Statistical Analysis

Means and standard deviations were calculated for all descriptive variables overall and by gender. Gender differences in descriptive variables were evaluated using an independent t-test. Descriptive variables having more than two levels, such as activity, were evaluated using a 1-way, between groups, ANOVA. Additionally, many variables were separated into tertiles (BMI, VO_2vt , VO_2max and $\text{VO}_2\text{vt}/\text{VO}_2\text{max}$) and evaluated using 1-way, between groups, ANOVA.

The main purpose of this research was to compare the variability around the means of a number of variables (RER and RPE) at similar absolute intensities relative to VO_2vt and VO_2max . The apriori planning, based on prior data, suggested $70\%\text{VO}_2\text{vt} \approx 40\%\text{VO}_2\text{max}$, $90\%\text{VO}_2\text{vt} \approx 50\%\text{VO}_2\text{max}$, and $125\%\text{VO}_2\text{vt} \approx 65\%\text{VO}_2\text{max}$. Absolute work ($\text{VO}_2 \text{ L}\cdot\text{min}^{-1}$) and dependent variables (RER and RPE), within subject, at each of these intensity pairs was evaluated using dependent t-tests. Gender differences across each intensity pairing for absolute work and dependent variables was evaluated using a 2 x 2 mixed design, (gender, between groups) x (intensity, within individual) general linear model analysis.

The individual variance in RER and RPE (absolute value of the {mean – individual value}) at each of the six steady state intensities was calculated. A dependent t-test was then used to assess significant differences in the mean variance of RER or RPE

at the three intensity pairings (70%VO₂vt vs. 40%VO₂max, 90%VO₂vt vs. 50%VO₂max, 125% VO₂vt vs. 65%VO₂max). To evaluate gender differences in variance across the two methods of determining relative intensity (%VO₂vt vs. %VO₂max) independently at each of the three intensities, a 2 x 2 mixed design, (gender, between groups) x (intensity, within individual) general linear model analysis was used. Statistical significance was set at p<0.05 for all analyses.

INTRODUCTION

Paragraph Number 1 Prescribing aerobic exercise intensity relative to ventilatory threshold (VT) or the associated lactate threshold (LT) has long been used in the prescription for aerobic athletes. Additionally, it has been accepted that training above the ventilatory or lactate threshold is appropriate for high intensity training to increase performance (18,19). A number of training studies have documented the efficacy of athlete training relative to ventilatory and lactate breakpoints (11,12,18,22,25). However, exercise prescription for research and general recommendations for aerobic fitness training remain focused on the use of percentages of maximal aerobic capacity ($VO_2\max$) as the gold standard (1).

Paragraph Number 2 The use of exercise intensity at fixed percentages of $VO_2\max$ ($\%VO_2\max$) has consistently resulted in within group differences in ratings of perceived exertion (RPE) (20), respiratory exchange ratio (RER) (4,23) and training effect within and between studies evaluating different populations such as fit vs. unfit, males vs. females, young vs. old, or race (10,11,18,19,22,30,31). This may be due in part to the large genetic contribution to $VO_2\max$ restricting potential improvement (8). Additionally, elite athletes, with previously well-developed aerobic exercise capacity, often improve race performance without increasing $VO_2\max$ (30). While $VO_2\max$ provides a useful indication of maximal aerobic capacity, it may have limited value for monitoring changes in the training state (11). It has been proposed that values associated with VT and/or LT may be both a better indicators of training effect and as a method for aerobic exercise prescription (32).

Paragraph Number 3 Ventilatory threshold, as a marker for aerobic fitness and the set point for exercise prescription, takes into account specific metabolic stress, and may result in a more homogeneous response to training than using %VO₂max. Additionally, absolute VO₂vt and VT as a percentage of VO₂max (VT%VO₂max), differ as a function of age, gender, physical fitness, health, etc., making it more individualized (11,12,15,18,22,33). Both VT and LT have been shown to be sensitive markers of aerobic training improvements (12), even without improvements in VO₂max (11,18,19). Furthermore, when individuals train at similar percentages of VO₂max, there is a wide variance in their intensity of training relative to VT (10). These differences are due to widely different values of VT which are not accounted for in training design. When group exercise is prescribed using %VO₂max per common recommendations (1), the perceived exertion of individuals may vary greatly and their metabolic substrate contribution may vary widely (4,9,10,15,23). In contrast, while seldom specifically reported, when exercise intensity is set relative to VT or LT, there appears to be greater homogeneity in RER and RPE suggesting that it may be an effective method by which to set training intensity.

Paragraph Number 4 A limited number of researchers have specifically reported the constancy of RER and RPE at VO₂vt across different groups (14,15,20). Thus, it has been proposed by a number of researchers, agreeing with the majority of elite coaches, that using % VO₂vt or % VO₂lt may be a more appropriate basis than %VO₂max for exercise prescription and for research evaluating the effects of aerobic training, especially when evaluating across a wide variety of individuals and groups including both males and females. Therefore, the purpose of this study was to determine the stability of RER

and RPE at intensities relative to the VT compared to similar absolute intensities relative to VO_2max and evaluate the use of VT as a set point for aerobic exercise intensity.

METHODS

Paragraph Number 5 Subjects. Fifty-eight healthy adults served as subjects (males $n=28$, females $n=30$) (Table 1). Prior to participation all subjects completed an IRB approved informed consent form. All testing took place at the University of Montana Human Performance teaching lab in McGill Hall, room 131.

Paragraph Number 6 Descriptive Data. Descriptive data, including height, weight, age and gender were collected (Table 1). Skin fold measurements (males - chest, abdominal and thigh and females - tricep, suprailiac and thigh), were repeated three times on the right side of the body, by the same investigator, to determine body fat percentage utilizing the equations of Jackson-Pollock (1).

Paragraph Number 7 VO_2max Test. VO_2max was measured while subjects walked and ran using a Quinton Treadmill (Seattle, WA) during a ramp protocol. After a five minute warm-up, subjects self-selected a “brisk” walking speed and began walking at a 0% grade. The grade increased 1% each minute until an $\text{RER} \geq .97$ and/or $\text{RPE} \geq 15$ was reached. The speed was then increased one mile per hour (mph), while grade was maintained, until volitional exhaustion was achieved. The observation of three of the four criteria was necessary to assume the subjects had reached their VO_2max : (1) stability of VO_2 in spite of increase in workload; (2) $\text{RER} > 1.10$; (3) $\text{RPE} > 19$; and (4) the inability of the subject to maintain running speed. Heart rate and RPE were collected each minute. Expired gases were collected during the test using a calibrated metabolic cart

(Parvomedics, Inc., Salt Lake City, UT) and analyzed at 15-second intervals. The results from this test were later used to determine VT and the intensities for steady state exercise relative to VO_{2vt} and VO_{2max} .

Paragraph Number 8 VT Determination. To determine VT for each subject, a combined method of ventilatory equivalent (VEQ method), excess carbon dioxide method ($ExCO_2$) and modified V-slope method (V-slope) was used (17). The ventilatory equivalent method is defined as the intensity of exercise which causes the first increase in the VE/VO_2 without a concurrent increase in the VE/VCO_2 . The excess CO_2 method is defined as the intensity of exercise which causes the first sustained rise in excess CO_2 production. $ExCO_2$ is calculated as $((VCO_2^2 / VO_2) - VCO_2)$. The modified V-slope method is the exercise intensity corresponding with the increase in the slope of the $VO_2 - VCO_2$ plot. In addition, RER and RPE were used to help determine VT. Two trained investigators independently picked each VT. After analysis if there was no agreement between the investigators, the subject was retested and data from the repeated test was used.

Paragraph Number 9 Intensities and % Grade Determination for Steady State Exercise. Light intensity was defined as 70% VO_{2vt} and 40% VO_{2max} , moderate intensity as 90% VO_{2vt} and 50% VO_{2max} and vigorous intensity as 125% VO_{2vt} and 65% VO_{2max} , even though the resulting MET values after steady state exercise indicate higher achieved intensity (light ≈ 6.0 , moderate ≈ 7.5 and high ≈ 9.5 , respectively). These intensity pairs were determined from prior research data (15). Regression equations found the best linear fit between subject's VO_2 and % grade with each subject's self-selected walking speed during the VO_{2max} test. They were calculated in order to

determine the % grade associated with the VO_2 at the three % $\text{VO}_{2\text{max}}$ and three % $\text{VO}_{2\text{vt}}$ intensity pairs to be compared during steady state activity.

Paragraph Number 10 Steady State Exercise Testing. After a 5 minute warm up, the treadmill speed was adjusted to the subject's self-selected walking speed from the $\text{VO}_{2\text{max}}$ test. Once established, subjects exercised in 4 minute increments under the following conditions: a) $\text{VO}_{2\text{max}}$ exercise at a % grade associated with 40, 50, and 65% $\text{VO}_{2\text{max}}$, respectively, and b) VT exercise at a % grade associated with 70, 90, and 125% $\text{VO}_{2\text{vt}}$, respectively. These stages were sequentially ordered such that the stages were completed in the order of increasing intensity. Ventilation, RER, VO_2 , and VCO_2 were measured continuously using the same metabolic cart as used during the $\text{VO}_{2\text{max}}$ test. Heart rate and RPE were also collected each minute. The last two minutes of each stage were averaged for the steady state values.

Paragraph Number 11. Statistical Analysis. Means and standard deviations were calculated for all descriptive variables overall and by gender. Gender differences in descriptive variables were evaluated using an independent t-test. Descriptive variables having more than two levels, such as activity, were evaluated using a 1-way, between groups, ANOVA. Additionally, many variables were separated into tertiles (BMI, $\text{VO}_{2\text{vt}}$, $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$) and evaluated using 1-way, between groups, ANOVA.

Paragraph Number 12 The main purpose of this research was to compare the variability around the means of a number of variables (RER and RPE) at similar absolute intensities relative to $\text{VO}_{2\text{vt}}$ and $\text{VO}_{2\text{max}}$. The apriori planning, based on prior data, suggested intensities of $70\%\text{VO}_{2\text{vt}} \approx 40\%\text{VO}_{2\text{max}}$, $90\%\text{VO}_{2\text{vt}} \approx 50\%\text{VO}_{2\text{max}}$, and $125\%\text{VO}_{2\text{vt}} \approx 65\%\text{VO}_{2\text{max}}$. Absolute work ($\text{VO}_2 \text{ L}\cdot\text{min}^{-1}$) and dependent variables (RER and RPE),

within subject, at each of these intensity pairs was evaluated using dependent t-tests. Gender differences across each intensity pairing for absolute work and dependent variables was evaluated using a 2 x 2 mixed design, (gender, between groups) x (intensity, within individual) general linear model analysis.

Paragraph Number 13 The variance in RER and RPE (mean – individual value) at each of the six steady state intensities for each individual was calculated. A dependent t-test was then used to assess significant differences in the mean variance of RER or RPE at the three intensity pairings (70%VO₂vt vs. 40%VO₂max, 90%VO₂vt vs. 50%VO₂max, 125%VO₂vt vs. 65%VO₂max). To evaluate gender differences in variance across the two methods of determining relative intensity (%VO₂vt vs. %VO₂max) at each of the three intensities, a 2 x 2 mixed design, (gender, between groups) x (intensity, within individual) general linear model analysis was used. Statistical significance was set at p<0.05 for all analyses.

RESULTS

Paragraph Number 14 Table 1 lists descriptive data for all subjects. The data are shown for the subjects overall and separated by gender and activity (sedentary individuals were those not meeting the Surgeon Generals 1996 guidelines of 30 minutes or more of moderate intensity activity most days of the week vs. active individuals who did meet the guidelines). Furthermore, the population was separated by BMI, VO₂ at the ventilatory threshold (VO₂vt), maximal aerobic capacity (VO₂max) and by the ratio of VO₂vt / VO₂max (a measure of their sustainable fitness as a percentage of maximal aerobic fitness) tertiles, with the highest and lowest tertiles reported and compared.

Paragraph Number 15 Males and females were different in height, weight, %body fat and $\text{VO}_{2\text{vt}} / \text{VO}_{2\text{max}}$. There were differences between the sedentary and active individuals in % body fat, $\text{VO}_{2\text{vt}}$ and $\text{VO}_{2\text{max}}$. Individuals with higher BMI values weighed more, had higher body fat and lower aerobic fitness, both sub maximally ($\text{VO}_{2\text{vt}}$) and maximally ($\text{VO}_{2\text{max}}$), but were not different in $\text{VO}_{2\text{vt}} / \text{VO}_{2\text{max}}$. Additional differences between subject grouping are shown in Table 1.

Paragraph Number 16 We attempted to match the intensities across % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$ and balance pairs of % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$ intensities to estimate the lowest range of the aerobic training zone (70% $\text{VO}_{2\text{vt}}$ vs. 40% $\text{VO}_{2\text{max}}$), a moderate intensity in the aerobic training zone (90% $\text{VO}_{2\text{vt}}$ vs. 50% $\text{VO}_{2\text{max}}$), and a vigorous intensity (125% $\text{VO}_{2\text{vt}}$ vs. 65% $\text{VO}_{2\text{max}}$). Table 2 details the achieved intensities and values for physiological and perceived variables within each exercise intensity pair. Significant differences were found between pairs for each intensity level, light (70% $\text{VO}_{2\text{vt}}$ vs. 40% $\text{VO}_{2\text{max}}$), moderate (90% $\text{VO}_{2\text{vt}}$ vs. 50% $\text{VO}_{2\text{max}}$) and vigorous (125% $\text{VO}_{2\text{vt}}$ vs. 65% $\text{VO}_{2\text{max}}$) for all of the variables.

Paragraph Number 17 The stability of RER within each method of determining exercise intensity (% $\text{VO}_{2\text{vt}}$ or % $\text{VO}_{2\text{max}}$) was evaluated by calculating the variance from the mean for each individual and then comparing the mean variances of each intensity pairing. When the data across all three intensities was pooled, the mean variance of RER at % $\text{VO}_{2\text{vt}}$ intensities was significantly less than at the % $\text{VO}_{2\text{max}}$ intensities (0.030±0.025 vs. 0.041±0.029 for % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$ respectively, $p < 0.001$).

Paragraph Number 18 When the variance values for RER were compared by gender, the mean variance was not different between genders at any % $\text{VO}_{2\text{vt}}$ intensity. However, for

both males and females, at both the light and moderate intensity the variance in RER was significantly less when evaluated at 70% and 90% of $\text{VO}_{2\text{vt}}$ than at 40% and 50% of $\text{VO}_{2\text{max}}$ respectively (Figure 1a & 1b). When the RER mean variance values were compared at the vigorous intensity (125% $\text{VO}_{2\text{vt}}$ vs. 65% $\text{VO}_{2\text{max}}$), RER variance values within subjects (males, females and overall) were not different ($p>0.05$).

Paragraph Number 19 When the variance of RER was compared within subjects by highest and lowest BMI tertile, a significant difference was found between % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$ for both light intensity ($p<0.001$) and moderate intensity ($p<0.01$) (Figure 2a & 2b). However, at the vigorous intensity, RER variance between % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$ was not different ($p>0.05$). Between BMI tertiles, RER variance was similar for all three intensity pairs ($p>0.05$).

Paragraph Number 20 When the variance of RPE was compared across the pairs of intensity (% $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$) by gender, BMI, fitness level, % $\text{VO}_{2\text{vt}}$ and % $\text{VO}_{2\text{max}}$, no significant differences were found within subjects and between groups for all three intensity pairs.

DISCUSSION

Paragraph Number 21 Both the lactate threshold (LT) and the ventilatory threshold (VT) have been used by coaches and researchers to evaluate the effectiveness of training programs as summarized by Londeree, 1997, but most research studies and fitness training continue to define aerobic training intensity in terms of % $\text{VO}_{2\text{max}}$. The major aim of this study was to determine the metabolic stability of prescribing aerobic exercise

training as a percent of ventilatory threshold (%VO₂vt) compared to the gold standard %VO₂max during research, or training for performance or fitness.

Paragraph Number 22 A number of researchers have previously shown that VT increases with training (11,12,18,22) and can vary greatly depending on fitness level (33) ranging from $17.6 \pm 4.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in sedentary individuals (18) to over $50 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in elite endurance trained athletes (22). In the current study, the differences in VT between sedentary and active individuals was significant ($p < 0.05$) though small (active = 30.7 ± 5.4 , sedentary = $27.4 \pm 4.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). The overall mean VO₂vt for this study was 29.8 ± 5.2 . Thus, while it was the intent of the researchers in the present study to sample a heterogeneous population across a broad range of fitness levels this goal was not achieved. Subjects were asked to self report their physical activity; sedentary individuals were selected as those who reported less than 30 minutes of moderate physical activity most days of the week. Our data would suggest that these subjects were not truly sedentary when evaluated for VT. Further, the majority of the current subjects were college students who, while not athletes, tended to be physically active. Previous unpublished data from our lab has shown that the average VT for college students in the Health and Human Performance Department averages $28.2 \pm 5.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and males and females are not different even though males have higher VO₂max values ($43.2 \pm 6.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) compared to females ($37.2 \pm 6.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Thus, while we did not achieve a heterogeneous fitness sample, the current are still valuable in showing the differences in stability of RER when evaluated as a % VO₂vt compared to a %VO₂max.

Paragraph Number 23 For this study we attempted to determine a priori equivalent intensity pairs of %VO₂vt and %VO₂max. The prescribed exercise intensities were

adapted from HERITAGE family study data (15), which consisted entirely of sedentary individuals and suggested relative intensity pairings of $70\%VO_{2vt} \approx 40\%VO_{2max}$, $90\%VO_{2vt} \approx 50\%VO_{2max}$ and $125\%VO_{2vt} \approx 65\%VO_{2max}$. Our sample was considerably more active and more aerobically fit as determined by the higher mean VO_{2vt} (HERITAGE = 17.6 ± 4.1 , current = 29.8 ± 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$) and VO_{2max} (HERITAGE = 32.9 ± 8.3 , current = 46.3 ± 9.4 $ml \cdot kg^{-1} \cdot min^{-1}$). These fitness differences resulted in differences in VO_{2vt}/VO_{2max} in the current study compared with HERITAGE data ($65.2\% \pm 9.1\%$ vs. $54.8\% \pm 9.1\%$ respectively). This higher VO_{2vt}/VO_{2max} for the current study, compared to HERITAGE data, resulted in the significant differences in absolute work (METS) between our intensity pairings reported in Table 2 (11-15% higher for the %VT intensity for each pairing). While we were unable to match the % VO_{2vt} and % VO_{2max} intensities as desired, the chosen work loads were reasonably similar and represented intensities at the low end, middle and upper ranges of the accepted aerobic training zone.

Paragraph Number 24 The current study achieved a balance of males and females in order to evaluate differences in RER stability comparing % VO_{2vt} and % VO_{2max} work intensities. It has been previously reported that gender specific differences of RER and RPE during exercise intensity relative to LT or VT do not exist (24). The current study found similar results. RER was similar across gender at 70%, 90% and 125% VO_{2vt} (Table 3). The consistency of similar RER at % VO_{2vt} , independent of other evaluations, suggest that VT is a stable set point for prescribing exercise when comparing genders.

Paragraph Number 25 The respiratory exchange ratio (RER) has been shown to change with training relative to VO_{2max} (23) and has been shown to remain stable at VT

(0.91 ± 0.02 across race, age and gender and training status (pre- and post- 26 weeks of training) in over 400 subjects (15). Data from the current study found RER at $\text{VO}_{2\text{vt}}$ to be 0.91 ± 0.04 .

Paragraph Number 26 Little data has been reported on the stability of RER at intensity levels relative to VT as done in the current study. Prior researchers have found individuals with similar $\text{VO}_{2\text{max}}$ values do not have similar metabolic response above and below LT (9). The current study found RER values at 70 and 90% of VT to be very tightly grouped (0.89 ± 0.038 and 0.93 ± 0.034 , respectively) and to have significantly smaller mean variance values than comparable intensities of 40 and 50% $\text{VO}_{2\text{max}}$. Further, when the pooled % $\text{VO}_{2\text{vt}}$ variance was compared with the pooled % $\text{VO}_{2\text{max}}$ variance, RER variance was significantly small around % $\text{VO}_{2\text{vt}}$. Importantly, there were no gender differences between males and females in RER or the variance of RER at the two lower % $\text{VO}_{2\text{vt}}$ intensities. These data support the hypothesis that setting training and exercise intensity relative to VT results in an overall more stable metabolic substrate use and thus provides a superior method to balance exercise substrate use across genders than does using % $\text{VO}_{2\text{max}}$.

Paragraph Number 27 We were surprised to find that RER was not more stable at 125% $\text{VO}_{2\text{vt}}$ than at 65% $\text{VO}_{2\text{max}}$. We believe this was due to our methodology in calculating 125% $\text{VO}_{2\text{vt}}$ ($125\% \text{VO}_{2\text{vt}} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 100\% \text{VO}_{2\text{vt}} * 1.25 (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$). Since $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$ varied in our subjects this resulted in subjects with low $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$ values using less of their $\text{VO}_{2\text{vt}}$ to $\text{VO}_{2\text{max}}$ reserve ($\text{VO}_{2\text{max}} - \text{VO}_{2\text{vt}}$) than did subjects with high $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$ values. We now believe that a better method to calculate 125% $\text{VO}_{2\text{vt}}$ would be to use $\text{VO}_{2\text{vt}} + 25\%$ of the $\text{VO}_{2\text{vt}}$ to $\text{VO}_{2\text{max}}$ reserve

[i.e. $125\% \text{VO}_{2\text{vt}} = \text{VO}_{2\text{vt}} + (\text{VO}_{2\text{max}} - \text{VO}_{2\text{vt}}) * 0.25$]. This hypothesis remains untested and further research is needed to evaluate the stability of RER using this method.

Paragraph Number 28 In the current study we evaluated if the stability of RER was consistent across a range of individuals by comparing differences in RER variance across activity level, by BMI, by gender and fitness ($\text{VO}_{2\text{vt}}$, $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{vt}}/\text{VO}_{2\text{max}}$). When stability of RER was compared across gender at the three intensity levels (light, moderate, vigorous), a significantly lower RER variance was found for light and moderate intensity ($p < 0.001$). However, no difference was found for vigorous intensity when comparing $\% \text{VO}_{2\text{vt}}$ with $\% \text{VO}_{2\text{max}}$, probably for reasons discussed in the previous paragraph. RER was similar between genders for all three intensities, consistent with previous data (26). Similar stability results were found when RER was compared across BMI with RER being more stable at lower exercise intensities relative to $\% \text{VO}_{2\text{vt}}$ than to $\% \text{VO}_{2\text{max}}$. The same patterns were found when RER stability was compared by all methods of evaluating fitness. There was no difference in RER between groups at any intensity, however the variability of RER at the lower $\% \text{VO}_{2\text{vt}}$ intensities was smaller than at the comparable $\% \text{VO}_{2\text{max}}$ intensities, but not at the vigorous intensity. These data again support that at intensities below $\text{VO}_{2\text{vt}}$, setting aerobic exercise intensity relative to $\text{VO}_{2\text{vt}}$ is a metabolically more stable method than using $\% \text{VO}_{2\text{max}}$.

Paragraph Number 29 In the present study we support using $\%$ ventilatory threshold as a viable method to prescribe exercise intensity during research and/or training, especially when the intensity of exercise is below the ventilatory threshold. Below VT, using $\% \text{VO}_{2\text{vt}}$ is a more stable measure of substrate utilization across a broad range of

intensities. Above VT, while the variance in RER was less using %VO₂vt, the difference in variance with %VO₂max was not significant. Further, gender, fitness, and body composition did not cause changes in RER or the variance in RER, when exercise intensity was set relative to VT. This stability of RER, when evaluated as a % VO₂vt, strongly suggests that VO₂vt is an excellent set point for exercise intensity.

Paragraph Number 30 RPE is a subjective interpretation of exercise intensity. Research has shown that an RPE of 12-13 (14) or 13-15 (20) corresponds to the intensity at which VT occurs. Findings in the current study are consistent with these data at VO₂vt during the VO₂max test (RPE = 13.8±1.4). Additionally, during the steady state protocol, at the intensity near VT (90% VO₂vt), RPE was found to be 13.6±2.0. Even though RPE was consistent with previous research, we found no significant differences in RPE between exercise intensity pairs relative to %VO₂vt and %VO₂max. These data conflict with previous data in sedentary individuals evaluated in the HERITAGE Family study (15) where RPE was more stable (smaller standard deviation) around VT than 50%VO₂max, a very comparable workload in a sedentary population. It is possible that instructions for describing how to report RPE were not clearly given to participants in the current study, or the larger participant number in the HERITAGE family study better differentiated the subjective RPE ratings between exercise intensities. Also, in the HERITAGE family study, the data for the 50% VO₂max was collected during steady state exercise, similar to the current study, while the RPE data for VT was estimated for each subject by linear regression. Based on our data, RPE does not appear more stable as a % VO₂vt or % VO₂max.

Paragraph Number 31 Further work needs to be completed to determine the best methods to control exercise intensity when prescribed above VT. The current investigators propose that using percentages of VO_{2vt} reserve ($VO_{2max} - VO_{2vt}$) would improve the metabolic stability for exercise above VT, but that work remains to be completed.

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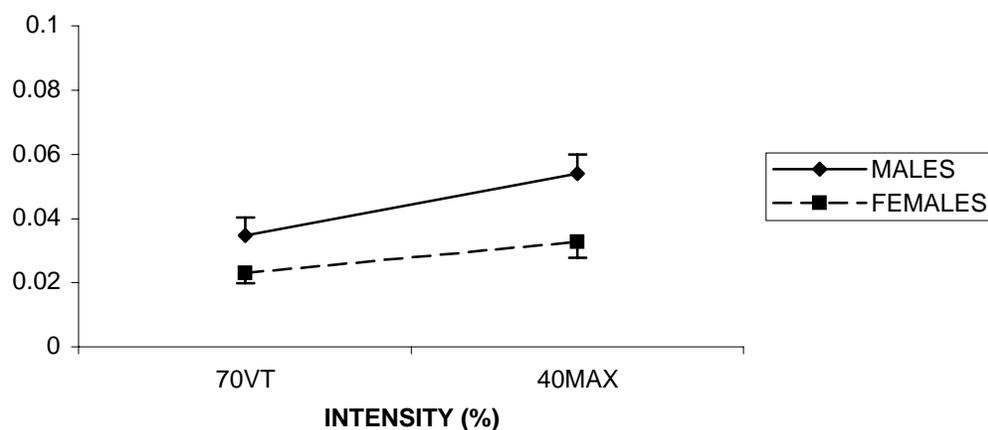


Figure 1(a). Average RER variance for light intensity (70%VO₂vt [70VT] vs. 40% VO₂max [40MAX]). Error bars show the standard error of the variance.

*** Main effect; overall variance at 70% VO₂vt < 40% VO₂max, p<0.001

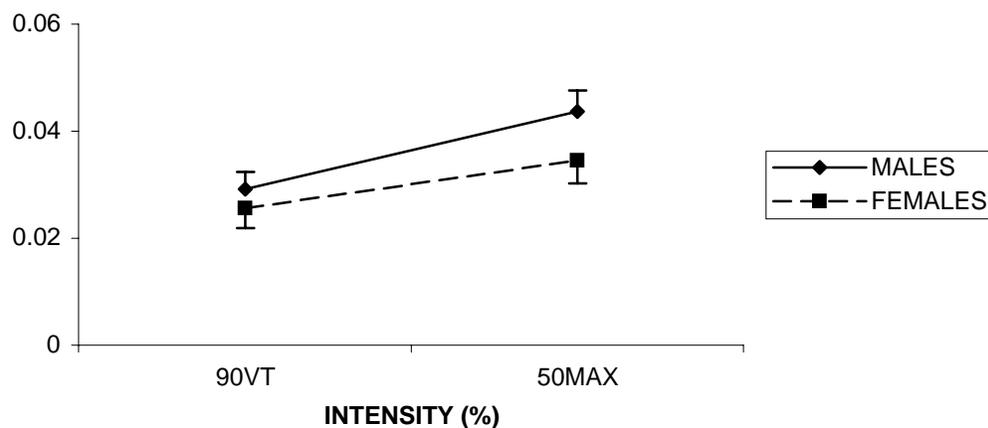


Figure 1(b). Average RER variance for moderate intensity (90%VO₂vt [90VT] vs. 50% VO₂max [50MAX]). Error bars show the standard error of the variance.

*** Main effect; overall variance at 90% VO₂vt < 50% VO₂max, p<0.001

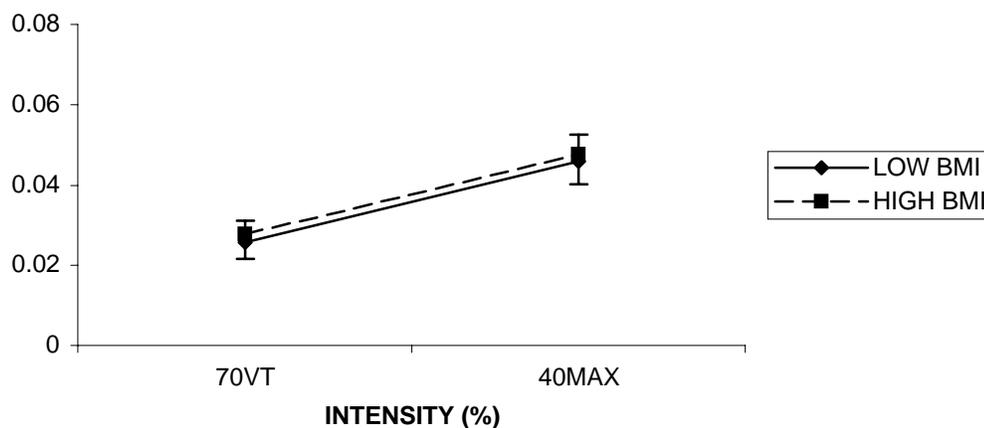


Figure 2(a). Average RER variance for light intensity (70%VO₂vt [70VT] vs. 40% VO₂max [40MAX]) separated by the highest and lowest BMI tertile. Error bars show the standard error of the variance.

*** Main effect; overall variance at 70% VO₂vt < 40% VO₂max, p<0.001

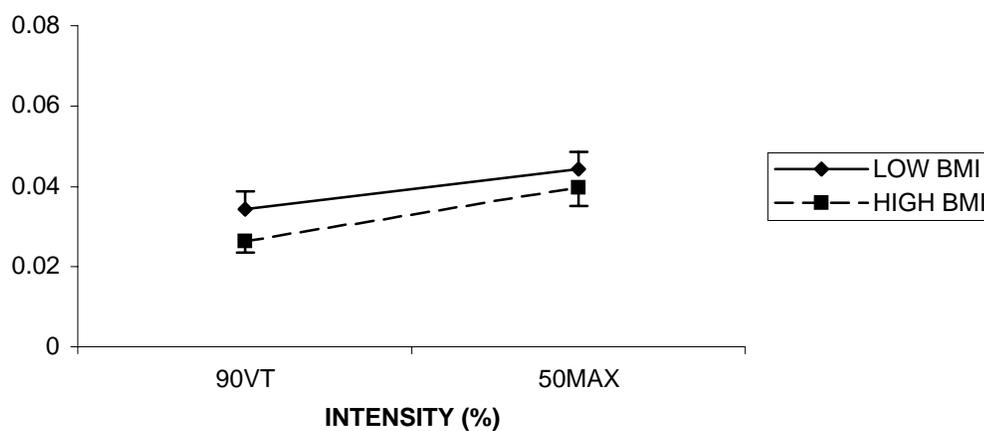


Figure 2(b). Average RER variance for moderate intensity (90%VO₂vt [90VT] vs. 50% VO₂max [50MAX]) separated by the highest and lowest BMI tertile. Error bars show the standard error of the variance.

*** Main effect; overall variance at 90% VO₂vt < 50% VO₂max, p<0.01

Table 1. Descriptive Variables. For BMI, VO₂vt, VO₂max and VO₂vt/VO₂max comparisons are between the highest and lowest third in the sample population for that variable. Data are presented as mean ± SD

	N	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg·m ⁻²)	Body Fat (%)	VO ₂ vt (ml·kg ⁻¹ ·min ⁻¹)	VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	VO ₂ vt/VO ₂ max (%)
Overall	58	26.9±7.3	174.4±9.1	73.2±14.8	24±4	19±9	29.8±5.2	46.3±9.4	65%±9%
Gender									
Male	28	27.4±7.9	181.3±6.2***	81.7±14.9***	24.8±3.8	14.6±9.4***	29.2±5.8	48.3±11.3	61.1±9.1*
Female	30	26.6±6.8	167.9±6.2	65.3±9.5	23.2±3.4	23.6±6.2	30.4±4.7	44.5±6.9	68.9±8.2
Activity									
Active	42	27.9±7.9	174.1±9.6	71.7±12.5	23.6±3.2	17.2±7.9**	30.7±5.4*	48.2±9.6*	64.6±10.0
Sedentary	16	24.5±4.6	175.2±8.1	77.2±19.5	24.9±4.6	24.9±4.6	27.4±4.3	41.5±6.9	66.6±7.8
BMI									
Lower Tertile	20	26.5±6.7	171.0±8.3*	62.2±6.5***	21.2±1.0***	17.2±6.2*	30.1±5.4*	46.7±8.3*	64.9±9.0
Higher Tertile	20	27.9±7.4	177.5±9.5	86.6±15.8	27.4±4.1	23.3±10.5	27.2±4.4	41.9±8.1	65.5±7.9
VO₂vt									
Lower Tertile	20	27.5±6.3	173.9±9.1	75.6±14.8	24.9±4.1	22.9±8.5	24.6±2.0***	39.4±8.7***	64.3±11.5
Higher Tertile	20	26.2±8.4	175.1±7.3	73.6±16.2	23.9±3.9	15.4±10.9	35.4±3.9	53.2±8.0	67.2±8.6
VO₂max									
Lower Tertile	20	27.2±6.1	171.4±8.1	72.9±14.5	24.7±4.1	24.7±7.1	25.6±2.9***	37.0±4.6***	69.4±7.3***
Higher Tertile	20	26.9±8.2	176.6±7.8	74.1±16.4	23.6±4.1	13.7±10.1	33.3±5.1	56.1±7.1	59.2±8.9
VO₂vt/ VO₂max⁻¹									
Lower Tertile	20	24.3±4.5	176.9±9.9	75.8±18.1	24.0±4.1	16.3±11.1*	29.4±5.7	52.7±9.7***	55.3±6.1***
Higher Tertile	20	28.0±8.1	170.3±7.2	69.1±9.7	23.9±3.8	24.4±7.2	30.1±5.3	40.4±7.1	75.0±4.6

* Significant difference within pairing (p<0.05)

** Significant difference within pairing (p<0.01)

*** Significant difference within pairing (p<0.001)

TABLE 2. Comparisons of data at the paired (%VO₂vt vs. %VO₂max) light, moderate and vigorous intensities. Data are presented as mean ± SD.

Planned Intensity		Achieved Intensities						
		%VO ₂ max	%VO ₂ vt	VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	METS	RER	RPE	HR (bpm)
Light	VT70	48.0±6.0*	73.8±5.5*	21.9±3.6*	6.3±1.0*	0.892±0.038*	10.8±1.7*	124.9±13.7*
	MAX40	42.7±3.3	66.9±12.6	19.7±4.0	5.6±1.2	0.870±0.054	9.4±1.7	115.7±12.8
Moderate	VT90	60.7±7.9*	93.2±5.8*	27.7±5.8*	7.9±1.4*	0.929±0.034*	13.6±2.0*	145.7±15.0*
	MAX50	52.0±3.5	81.5±15.4	24.1±5.2	6.9±1.5	0.907±0.047	11.9±1.9	131.1±13.1
Vigorous	VT125	75.1±6.6*	116.2±10.9*	34.6±6.5*	9.9±1.8*	0.994±0.045*	16.4±1.8*	167.8±12.5*
	MAX65	66.6±4.2	104.4±19.5	30.9±7.0	8.8±2.0	0.951±0.051	14.8±2.0	155.2±13.2

*All pairings within intensity (light, moderate, and vigorous) were statistically different (p<0.05) for each variable.

Table 3. Shows gender differences in RPE, RER and HR at 70, 90 and 100% of VO_2vt and at 40, 50 and 65% VO_2max . Data are presented as mean \pm SD

	RER	RPE	HR
100%VO_2vt			
Males	0.917 \pm 0.036	13.7 \pm 1.2	148.3 \pm 13.5
Females	0.902 \pm 0.034	14.1 \pm 1.5	153.2 \pm 12.3
70%VO_2vt			
Males	0.891 \pm 0.046	10.5 \pm 1.7	122.3 \pm 11.9*
Females	0.893 \pm 0.030	11.0 \pm 1.7	127.3 \pm 15.1
40%VO_2max			
Males	0.876 \pm 0.055	9.9 \pm 1.6*	117.8 \pm 13.7
Females	0.864 \pm 0.053	8.8 \pm 1.7	113.7 \pm 11.8
90%VO_2vt			
Males	0.931 \pm 0.035	13.0 \pm 1.6*	141.4 \pm 12.3
Females	0.928 \pm 0.033	14.2 \pm 2.1	149.8 \pm 15.8
50%VO_2max			
Males	0.914 \pm 0.044	12.4 \pm 1.4*	132.8 \pm 13.0
Females	0.901 \pm 0.049	11.4 \pm 2.2	129.6 \pm 13.2
125%VO_2vt			
Males	0.998 \pm 0.048	16.1 \pm 1.6	164.1 \pm 10.3
Females	0.991 \pm 0.043	16.6 \pm 2.0	170.6 \pm 13.9
65%VO_2vt			
Males	0.965 \pm 0.050*	15.0 \pm 1.9	155.4 \pm 11.9
Females	0.938 \pm 0.048	14.6 \pm 2.1	155.01 \pm 14.6

* Significant gender differences within intensity ($p < 0.05$)

