The Effect on Ventilatory Threshold in Endurance and Resistance Training

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PURPOSE: With the growing rate of physical inactivity in the United States and around the world, the study of how to improve performance and increase the health benefits that come with exercise is increasing. There are many questions asked about the ventilatory threshold such as what point in time does the ventilatory threshold take place and how long is an individual able to exercise at a certain intensity before major fatigue happens? This brings me to my question, how is the ventilatory threshold affected when doing endurance or resistance exercise training? I looked at $VO_{2\ max}$ stress test data to find where the ventilatory threshold occurs. I wanted to see if there is an increase in the ventilatory threshold of an individual through bouts of resistance and aerobic training. I am looking at the ventilatory threshold through different modes of exercise to see if it is an accurate indicator of one's cardiorespiratory fitness and what is the best method of calculating one's ventilatory threshold. This could also be vital knowledge during rehabilitation for a participant recovering from an injury or a participant wanting to improve their cardiorespiratory fitness level. The second purpose of this study was to determine whether there was a significant difference in the determination methods of finding the ventilatory threshold.

METHODS: Three training groups: Sedentary, highly active Resistance Trained, and highly

Active Endurance Trained performed a CPET on a cycle ergometer, and gas exchange was measured using a metabolic cart. Using the metabolic cart files, the ventilatory threshold was determined using the Ventilatory Equivalent method as the primary determinate with the secondary determinates being the V-Slope method, % $VO_{2\ max}$, and % maximal work rate (w). Once the VT was determined, four methods of determining VT were calculated in GraphPad Prism. The four determining methods that were calculated included the Ventilatory Equivalent, V-Slope, VE, and VCO_2 methods. RESULTS: 59 participants participated in the CPET test and had their VT determined. There was a significant difference when comparing the Ventilatory Equivalent and VE methods for % $VO_{2\ max}$ in the HART group. When comparing the group's % $VO_{2\ max}$, there was a significant difference using the Ventilatory equivalent method between all three groups. There was a significant difference between the Sedentary and HAET groups when doing a group comparison when looking at the % $VO_{2\ max}$ using the $VCO_{2.}$ After comparing the groups using the % maximal work rate, there was a significant difference between all three groups for all four methods of determining the ventilatory threshold. CONCLUSION: The primary findings of the current study after observing the results of comparing the % $VO_{2\ max}$, the HART and HAET group had a higher % $VO_{2\ max}$. When comparing the % maximal work rate between the groups, the HAET group had a higher % maximal work rate compared to the sedentary and HART groups. When comparing what methods of determining VT, there was no significant difference between the methods. This states that any of the four methods could be a viable source to determine one's VT and participating in regular bouts of endurance or resistance training has improvements in $VO_{2\ max}$ and CRF.

THE EFFECT OF VENTILATORY THRESHOLD IN ENDURANCE AND RESISTANCE TRAINING

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List of Abbreviations

1. Cardiopulmonary Exercise Test (CPET)
2. Electrocardiogram (ECG)
3. Body Mass Index (BMI)
4. Highly Active Resistance Training (HART)
5. Highly Active Endurance Training (HAET)
6. Molecular Transducers of Physical Activity (MoTrPAC)
7. Dual X-ray Absorptiometry (DEXA)
8. Chronic Obstructive Pulmonary Disease (COPD)
9. Minute Ventilation (VE)
10. Respiratory Exchange Ratio (RER)
11. Adenosine Triphosphate (ATP)
12. Polymerase Chain Reaction (PCR)
13. End-tidal pressure of oxygen method (PE)

Chapter 1: Introduction

Our population's health and well-being are a major problem today. There is a constantly growing rate of obesity, cardiovascular disease, type 2 diabetes, heart disease, and many other chronic diseases. Whether it is our changing behavior, culture, or lifestyle many health professionals are looking deeper into fixing the big problem within our society. Performing bouts of exercise has tremendous benefits including improving an individual's organ systems, muscular and neuromotor function, disease prevention, and reducing the risk of premature mortality.

When assessing an individual's exercise capacity, healthcare professionals look at VO_2 max. VO_{2max} is the maximum amount of oxygen consumed during a bout of incremental exercise meaning the more oxygen a person can consume throughout an exercise is indicative of an enhanced cardiovascular system. VO_{2max} is the "gold standard" for assessing a person's aerobic capacity (Gaskill and Ruby, 2016). Maximum oxygen capacity tells health care professionals how well the heart can pump blood to the muscles and how well the muscles can extract the oxygen and synthesize adenosine triphosphate (ATP). VO_2 max is typically assessed by a submaximal or maximal exercise test where the participant uses a mouthpiece that is connected to a tube and the individual breaths into the mouthpiece. A machine then takes in the volume of carbon dioxide that a person exhales while measuring the volume of oxygen being consumed.

Endurance exercise poses many benefits to a person's health such as improving one's metabolism and reducing the risk of cardiovascular disease and mortality. Endurance exercise also known as aerobic exercise consists of isotonic contractions in the skeletal muscle done at a submaximal intensity to help improve a person's ventilatory threshold. When increasing the aerobic metabolism, one is trying to increase oxygenated blood while getting rid of metabolic waste (Morici et al., 2016). One measure of cardiorespiratory fitness is the ventilatory threshold. The ventilatory threshold is a specific point during an exercise at which the ventilation rate exceeds the rate of VO_2 (volume of oxygen consumed). The ventilatory threshold occurs between 0.94-0.96 of the respiratory exchange ratio (RER) and 40-60% of an average person's $VO_{2\ max}$.

During successful endurance training, a rightward shift in ventilatory threshold can be accomplished resulting in a higher power output and relative VO_2 max that can be sustained without excessive lactate build-up (Jones, Carter, 2000). Exercising above one's ventilatory threshold can cause a rapid decrease in work output and contractile function thus enhancing the importance of successful endurance training (Jones, Carter, 2000).

Resistance training, also known as strength or weight training is a type of exercise that is performed with some type of resistance acting against the muscle and can increase one's muscular strength, muscular endurance, balance, metabolic rate, joint stability, and muscle size. Resistance training can be done through weightlifting, using resistance bands, or even a person's body weight. Resistance training has many benefits including boosting the metabolism, reduction of body fat, improving balance and stability, increasing bone density, increasing muscle mass, improving muscular strength, and reducing risk of injury (LaMarco, 2022). With resistance training, microscopic tears occur within the muscle fibers, and by the process of anabolism, the muscle is repaired and allowed to strengthen. When the muscle is torn and needs repair, nutrients, growth hormones, and proteins rush to the muscle and begin to repair and strengthen the small tears (Glynn et al 2010). A study by Mate-Munoz, Dominguez, et al, 2016) looked at the ventilatory and lactate threshold during resistance training. Through this study, participants performed a 1 RM test and an incremental load test to locate the lactate and ventilatory threshold. The study concluded that through incremental load tests, the ventilatory and lactate threshold could be found at the same intensity thus the ventilatory threshold could be an accurate assessment in providing an exercise prescription. This study was able to identify two physiological stages, stage 1 being what intensity of exercise depends on aerobic metabolism and stage 2 being when blood lactate levels increase because anaerobic glucose could be broken down at a greater workload (Mate-Munoz, Dominguez, et al, 2016).

Lactate threshold is studied along with VO_2 max and is a good predictor of an individual's aerobic fitness. The lactate threshold is where lactate builds in the bloodstream at a certain intensity where one can exercise for a period without becoming fatigued. Lactate is a product of glucose being used by muscle cells during a bout of exercise. The muscle fibers are activated during a high contractile environment and the production of ATP in skeletal muscle cells increases. During intense bouts of exercise, a high amount of lactic acid is produced which can reduce the pH of muscle and cause acidosis. Lactate is transported through the blood for clearance and can be used as energy throughout the body. Lactate is transferred away from fast-twitch muscle fibers by slow-twitch muscle fibers by an enzyme called Monocarboxylate-4 (MCT-4) and slow-twitch fibers use an enzyme called Monocarboxylate-1 (MCT-1). Once inside the slow twitch fibers, lactate is converted to pyruvate by the enzyme mitochondrial lactate dehydrogenase (mLDH), then made into ATP (Roth, Brooks, 1990).

Exercise physiologists have studied the ventilatory threshold and how it relates to exercise. An individual's ventilatory threshold is the point where the ventilation increases while lactate begins to accumulate within the blood. This is where the oxidative phosphorylation and glycolysis process increase their rates to keep producing ATP at a moderate intensity. While an individual is exercising, VO_2 and CO_2 increase together linearly as bicarbonate acts to buffer the lactate acid that is being produced in the blood. When an individual reaches a certain intensity there is an excessive amount of lactate that has accumulated in the blood and ventilation increases to exhale the CO_2 being produced from the bicarbonate reaction. At this point, the individual may not be able to speak when exercising due to rapid ventilation (Thompson, 2017). At this point, the blood lactate levels are increasing, in turn increasing acidosis causing an individual to become fatigued. At an individual's ventilatory threshold, an individual's ventilation rises disproportionately to the oxygen being consumed. Knowing the intensity of where the ventilatory thresholds happen, a more precise exercise prescription can be made for an athlete or individual who is trying to improve performance while minimizing the risk of injury and being able to exercise without reducing workload. At the ventilatory stage, lactate within the muscle increases, and workload can become reduced because metabolic acidosis cannot be buffered by ventilation (Cerezuela-Espejo et al., 2018).

The bicarbonate reaction that acts as our body's buffering system to help maintain pH is very important when maintaining exercise intensity. This buffering system helps maintain the balance of blood pH and supports metabolic functions. When exercising, the blood can become acidic, and this is where the bicarbonate reaction begins to play a role. A hydrogen proton will be dissolved from carbonic acid thus forming a bicarbonate molecule (HCO_3^-) (Hadzic, Eckstein, Schugardt., 2019). Once this takes place, the bicarbonate molecule begins to bind to a proton in the blood and within the muscle when becoming too acidic producing an H_2O molecule and carbon dioxide (CO_2) molecule. Once this reaction takes place, the ventilation (L/min) begins to become greater to exhale carbon dioxide that is being produced while restoring the balance between acid and base in the muscle. Due to an excessive amount of lactate produced by the muscle CO_2 begins production and increases disproportionately (Hadzic, Eckstein, Schugardt., 2019).

Purpose

Many questions are asked about the ventilatory threshold such as what point in time does the ventilatory threshold take place and how long is an individual able to exercise at a certain intensity before major fatigue happens? This brings me to my question, how is the ventilatory threshold affected when doing endurance or resistance exercise training? I looked at $VO_{2\ max}$ stress test data to find where the ventilatory threshold occurs. I wanted to see if there is an increase in the ventilatory threshold of an individual through bouts of resistance and aerobic training.

Hypothesis

- H_a- Participants who participate in regular bouts of endurance and resistance exercise have a higher ventilatory threshold than those who are sedentary.
- H_n- Individuals who are sedentary and participate in regular bouts of exercise will have roughly the same ventilatory threshold.
- H_a- There will be no significant difference between the methods of determining the ventilatory threshold.
- H_n- The methods of determining ventilator threshold will be significantly different.

Chapter 2: Lit. Review

Problem:

With growing obesity and sedentary rates in the United States and around the world, healthcare professionals are beginning to look deeper into a person's cardiorespiratory fitness and exercise capacity. Scientists have investigated cardiorespiratory fitness and physical activity dating back to Hippocrates over 2000 years ago, and since then have made great strides and discoveries in how physical activity is so beneficial (Paffenbarger, Blair, 2001). Physical activity benefits one's organ systems function, muscular and neuromotor function, and disease prevention, and helps reduce the risk of premature mortality. VO_{2max} has been the gold standard (Gaskill and Ruby, 2001) for measuring a person's aerobic capacity because a health professional can assess how well the heart can function in the means of pumping blood to the muscles, how well the muscles can use the oxygen, and how well adenosine phosphate (ATP) can be synthesized and used.

When exercising, endurance training is very important and poses a variety of benefits such as reducing the risk of cardiovascular disease, reducing risk of premature mortality, and increasing skeletal muscle mass. Endurance exercise is isotonic contractions that are performed at a submaximal intensity. Endurance exercising can increase the amount of oxygenated blood sent to the muscles while being able to get rid of metabolic waste at the same rate (Morici et al., 2016). Endurance training can include jogging, swimming, biking, playing basketball, or hiking. Resistance training is another form of exercise that poses many health benefits. Some benefits include reduction of body fat, increased body density, improved balance and stability, and reduced risk of injury (LaMarco et al, 2022). Resistance exercise is performed with some type of resistance working against the muscle and can include using resistance bands, weightlifting, or one's body weight.

The lowest intensity an individual can exercise before the production of lactate exceeds the body's ability to get rid of the lactate is known as the lactate threshold. As the intensity of the exercise increases the production of lactate increases and exercising above the lactate threshold will increase the amount of lactate resulting in a decrease in work rate. The ventilatory threshold is measured using the amount of oxygen consumed (VO_2) (Breese, 2023). To determine the lactate threshold during an incremental exercise test, blood is drawn from the participant. The lactate threshold in an average person will likely occur around 40-60% of their $VO_{2\ max}$.

Ventilatory Threshold (VT):

The ventilatory threshold is the point at which one's ventilation begins to increase disproportionally as the intensity increases. This emphasizes the importance of exercise training and improving one's ventilatory threshold so a higher-intensity exercise can be sustained longer without a decrease in work output. While increasing the exercise workload, glycolysis operates at a higher rate to produce ATP to keep up with the energy output. While CO_2 production is matched with the ventilation of O_2 in a linear fashion, the increase of lactate initiates the bicarbonate reaction. The bicarbonate reaction is our body's buffering system to help maintain pH. When exercising and the production of lactate increases, our bodies will slowly become acidic, and this is where the bicarbonate reaction comes into play. Once lactate is produced and begins to make pH acidic, a hydrogen proton is dissolved from carbonic acid forming a bicarbonate molecule (HCO_3^-). After this reaction begins to take place, the bicarbonate reaction produces an H_2O molecule and a CO_2 molecule buffering out the acidity in the blood (Hadzic, Eckstein, Schugardt., 2019). Due to this buffering process, the ventilation (L/ min) becomes elevated to exhale the CO_2 while restoring the balance between acid and base in the muscle.

While the excessive amount of lactate is being produced by the muscle, CO_2 gets produced disproportionately to ventilation and this is where the ventilatory threshold happens.

How Ventilatory Threshold (VT) can increase

An individual's ventilatory threshold can be increased through different forms of training. This can be done by training the anaerobic and aerobic metabolic pathways. The anaerobic metabolic pathway can use stored ATP very rapidly for short bouts of exercise such as a 100 m sprint. The anaerobic pathways are not very efficient when providing fuel for extended amounts of exercise because we only have enough ATP stored to last 1-2 seconds. The anaerobic pathway uses phosphocreatine (PCr) that takes place in the sarcolemma to drive the reactions taking place to provide muscles energy to perform an exercise movement. The enzyme creatine phosphokinase is in this reaction to break a high-energy phosphate bond to make ATP. When stored ATP is depleted, glucose becomes the main fuel source to produce energy through anaerobic glycolysis with the product being lactic acid. Lactic acid inhibits muscle contraction by lowering the pH and is directly linked to a decrease in work output in bouts of exercise lasting around 2 minutes.

Another pathway used to produce ATP is the aerobic metabolic pathway. This pathway consists of glycolysis, Krebs cycle, electron transport system, and oxidative phosphorylation. Aerobic metabolism produces a lot of ATP molecules due to the usage of carbohydrates, fats, and protein. The aerobic pathway begins in the mitochondria where glucose is made from a carbohydrate then glucose makes pyruvate. Pyruvate is turned into Acetyl CoA which is the entry point to the Krebs cycle. Acetyl CoA produces CO_2 molecules, FAHD, and NADH molecules. Acetyl CoA attaches to oxaloacetate and begins moving through the cycle. After moving through the Krebs Cycle, the electron transport chain receives electrons from NAHD and $FADH_2$ which will begin to produce more ATP (Gnaiger, 2024).

When lipids are oxidized to produce ATP, beta-oxidation occurs. Fatty acids are metabolized and attached to an Acetyl CoA molecule and begin to enter the mitochondria through CPT-1 (the outer membrane of the mitochondria). After passing through CPT-1 they begin to pass through CPT-2 (inner membrane) and beta oxidation begins to work. Once beta oxidation begins, 2 carbon molecules are taken off the 16-18 long carbon chain which results in substantial ATP production (Schulz., 2013). By training the aerobic metabolic system, one can increase the capacity to supply oxygen to the heart and skeletal muscle, increase capillary size, and increase mitochondrial density.

Investigating the ventilatory threshold throughout a training program is a good predictor of cardiorespiratory fitness. This will also allow a correct and precise exercise prescription to be made that could increase one's performance throughout an activity. Another big reason is due to the ventilatory threshold is such a good predictor of fitness, it can be used as a predictor of cardiorespiratory risk.

Endurance training can impact one's ventilatory threshold. A study by (Ahmadi et al, 1998) looked at interval training at the ventilatory threshold in sedentary older adults. Throughout this study, 22 sedentary older adults were randomized into two groups, one performed interval training and the other was a control group. The training group walked or jogged at their heart rate that corresponded with their ventilatory threshold for an hour twice a week for three months. This study concluded that the $VO_{2\ max}$ and ventilatory threshold were increased by 20% compared to the control group and can increase their maximal aerobic power and tolerance to submaximal exercise.

Another study by (Prada et al, 2018) wanted to see if training intensity relative to one's ventilatory threshold could determine cardiorespiratory fitness improvements in middle-aged sedentary adults. For this study, 76 individuals were divided into two groups where one group would exercise under their ventilatory threshold, and the other group would exercise above their ventilatory threshold. In this study, both groups performed high-intensity interval training for 16-weeks for 43 minutes each session on a cycle ergometer. The results of the study were the $VO_{2\ max}$ of both groups were similar with both groups having the ventilatory threshold increased with a larger improvement in the group who did exercise above their ventilatory threshold. Prada et. al concluded that training over the ventilatory threshold will have a larger impact on one's ventilatory threshold which is fueled by oxidative metabolism.

A study performed by (Hill, Cureton, et al, 1987) investigated the effects of training on the rating of perceived exertion at the ventilatory threshold. This study consisted of 17 college students and was broken up into a training group and a control group where the training group performed 18 interval training sessions on a cycle ergometer for 6- weeks. They cycled for 40 min at 90-100% $VO_{2\ max}$ while being assessed for cardiorespiratory and metabolic variables. Hill and Cureton concluded that the subjects in the training group significantly increased their $VO_{2\ max}$, work rate, and uptake of oxygen at their respective ventilatory threshold while their rating of perceived exertion did not change throughout the program.

Ventilatory Threshold and resistance training

Resistance exercise has not been studied concerning the impact it has on an individual's ventilatory threshold. Resistance exercise has many benefits such as improving muscle strength, improving balance and flexibility, and reducing the risk of an injury. A study by (Mate- Munoz, Dominguez, et al, 2016) investigated the ventilatory threshold in resistance training. For this study, 24 participants performed two half-squat resistance tests, one being a 1 repetition max test and the second test being an incremental load test 48 hours apart to locate the ventilatory and lactate threshold. For the one repetition max test, the participants started at 50% 1RM and did 3-5 reps then moved to 70% and 90% 1RM test with 2-minute rest intervals between sets. The incremental exercise test started at 10% 1RM and went up to 40% 1RM with 30 reps and 2-minute rest intervals between sets. Mate-Munoz and Dominguez found that the ventilatory and lactate thresholds could be located at the same intensity during the incremental load test.

Determining Lactate and Ventilatory Threshold

The point where pulmonary ventilation increases disproportionally to workload and VO_2 is considered the ventilatory threshold. During an exercise bout, the VO_2 and VCO_2 rise proportionally while the body bicarbonate reaction buffers out the lactate that is being produced. Once the ventilatory threshold has been reached, lactate will begin to accumulate faster than it can be buffered, and the body goes into metabolic acidosis (Cerezuela-Espejo et. al, 2018). When determining where the ventilatory threshold occurs the ventilatory equivalent of VO_2 (VE/VO_2), ventilatory equivalent of VCO_2 (VE/CO_2), VO_2, and VCO_2 can be plotted using a variety of methods. One method to determine ventilatory threshold is the V-Slope method which is a visual relative comparison between VO_2 and VCO_2. Another method used is the ventilatory equivalent method which determines the ventilatory threshold by a visual comparison of minute ventilation, time, VE/VO_2, and VE/CO_2. This method determines the VT when there is a distinct rise in VE/VO_2 and little to no rise in VE/VCO_2 relative to time. The ventilatory threshold occurs between 0.94-0.96 of the respiratory exchange ratio (RER) and 40-60% of an average person's $VO_{2\,max}$.

An article by Ghosh, 2004 explains that two variables play a key role in the cardiorespiratory system delivering oxygen to muscle, the first variable being alteration in oxygen delivery such as beta-blocking and blood doping. The second variable is increasing one's $VO_{2\ max}$, the primary result is increasing the cardiac output. With stating these variables, it was concluded that O_2 delivery is the limiting factor when assessing VO_2 in exercising participants. By improving one's lactate threshold through endurance training, mitochondrial enzyme activity improves by increasing fat oxidation and one's buffering system (Ghosh, 2004).

Why I am studying Ventilatory Threshold

I am looking to see if the different modes of exercise compared to sedentary individuals showed a difference in ventilatory threshold. I am also looking at if there was a difference in the different methods of measuring ventilatory threshold. I am looking at the ventilatory threshold through different modes of exercise to see if it is an accurate indicator of one's cardiorespiratory fitness and what is the best method of calculating one's ventilatory threshold. This could also be vital knowledge during rehabilitation for a participant recovering from an injury or a participant wanting to improve their cardiorespiratory fitness level. A major gap throughout the literature is investigating if exercising at the intensity where the ventilatory threshold occurs will improve cardiorespiratory fitness.

Chapter 3: Methods

Participants

To compare the ventilatory threshold of Sedentary vs. Resistance trained vs. Endurance trained, fifty-nine participants were divided into 3 groups based on the amount of exercise they participated in. Forty participants were in the sedentary group. The inclusion criterion for each group included being above the age of 18 years old with a BMI between 19 and 35 kg/m^2. The exclusion criteria included having medical conditions such as diabetes, abnormal bleeding, thyroid disease, chronic obstructive pulmonary disease (COPD), pregnancy, cardiovascular disease, and cancer. Sedentary is defined as exercising no more than 1 day per week, lasting no more than 60 minutes of moderate to vigorous exercise, endurance, and/or resistance exercise. Nineteen participants were included in the highly active group (HART and HAET). Highly active endurance training (HAET) was defined as more than 240 min/week of endurance training for more than a year which results in increased heart rate, rapid breathing, and sweating. Highly active resistance training (HART) was defined as more than 3 resistance training sets of 3 or more upper-body and 3 or more lower-body muscle groups more than 2 times/week for more than a year that is used to increase strength and muscle mass. Endurance training for the HART group could be no more than 90 minutes/week of vigorous endurance training.

All three groups performed a cardiorespiratory fitness test consisting of a cardiopulmonary exercise test (CPET) on an electronically braked cycle ergometer. During the CPET test oxygen consumption and carbon dioxide production were measured using indirect calorimetry along with using a 12-lead ECG recording and blood pressure assessment throughout the test.

How The Ventilatory Threshold was Determined

The ventilatory threshold was determined using the primary method of ventilatory equivalent with supporting determinates being the V-slope method, % maximal work rate, and % $VO_{2\,max}$. The V-Slope method is determined by a visualization of the first point that departs from the linearity of VCO_2 against VO_2 (Caiozzo et. al, 1982). The computer system that MoTrPAC uses automatically calculates the ventilatory threshold after a cardiopulmonary exercise test (CPET) and provides graphing of the ventilatory equivalent and V-slope methods. The ventilatory equivalence method determines the ventilatory threshold when there is an exponential rise in oxygen uptake (VE/VO_2) with no concomitant rise in carbon dioxide (VE/VCO_2). Once the determining the ventilatory threshold using the graphs computed by the metabolic cart (Parvo Medics, Salt Lake, UT), the results were exported to Excel in 10-second measurements. The VE/VO_2 and VE/CO_2 were calculated in Excel by dividing minute ventilation (VE) by VO_2 and then put into graphs where a linear regression line was used to find where the slopes began to change. $\%VO_2$ max was calculated by dividing where the ventilatory threshold occurred by the maximal VO_2 then multiplied by 100. The % maximal work rate was then calculated by dividing the work rate at which the ventilatory threshold occurred by the maximal work rate and then multiplying by 100. To find the ventilatory threshold using the ventilatory equivalent method, a graph was made by comparing the VE/VO_2 and VE/CO_2 to time (minutes). To find the ventilatory threshold, visualization of where there was a deliberate rise in VE/VO_2 with no concomitant rise in VE/VCO_2, is where the ventilatory threshold occurred (Caiozzo et al, 1982). To find the ventilatory threshold using the V-slope method, a visual comparison of VO_2 relative to VCO_2 was used, and the point at which the slopes begin to converge towards each other is where the ventilatory threshold occurred (Caiozzo et al, 1982). The VE method was used to find the ventilatory threshold by comparing ventilation to time and a visual method of where the ventilation begins to rise exponentially, at that point is where the ventilatory threshold occurred (Caiozzo et al, 1982). The VCO_2 method compared the volume of CO_2 (L/min) to time and the point where the CO_2 rises exponentially is where the ventilatory threshold occurs (Caiozzo et al, 1982). The % VO_2 max and % maximal work rate were calculated for each of the four methods to be used for the statistical analyses.

Statistical Analyses

The statistical analyses for this study were measured by using repeated measure ANOVA using Prism GraphPad. The methods for finding and calculating the ventilatory threshold were the Ventilatory Equivalent (V_e) Method, V- Slope Method, VE method, and VCO_2 method. The Ventilatory Equivalent method looked at the ventilation rate (VE L/min) compared to the oxygen consumption (VO_2 L/min) while the V-Slope method compared oxygen consumption (VO_2 mL* min) and carbon dioxide production (VCO_2 mL*min). In Prism GraphPad each participant's % VO_2 max and % maximal work rate (w) for all four methods for each of the three training groups. The calculations were split into comparing if there was a difference in methods of calculating the ventilatory threshold for % VO_2 max and % maximal work rate (w). When comparing the ventilatory threshold of each method to the different training groups for % VO_2 max and % maximal work rate (w). Percent of maximal heart rate was compared between the different training groups using the ventilatory equivalent method. The % heart rate max between the groups was compared using the ventilatory equivalent method.

Chapter 4: Results

Subject characteristics for the study are included in Table 1 (N=59). The sample mean ± SD BMI (kg/m^2) for the Sedentary group was 27.4 ±4.2, 24.9 ±2.8 for the HART group, and 24.9 (5.0) for the HAET group. The Sedentary group had a mean ±SD age (yr.) of 36.9 ± 9.5, 35.6 ±16.7 for the HART group, and 50.4 ±14.1 for the HAET group. Age showed significance with the HAET group being significantly older compared to the sedentary and HART groups. VO_2 max (ml/kg/min) is also included in Table 1 where the sample mean ±SD was 28.9 ±7.6 for the Sedentary group, 40.9 ±6.4 for the HART group, and 44.7 ±9.0 for the HAET group. Significance was found in VO_2 max ($P<0.05$) between Sedentary compared to both HART and HAET with the sedentary group having a lower VO_2 max. Table 1 includes ethnicity and gender with the Sedentary group (N=40) having 28 Caucasian participants (C), 7 African American (AA), 2 Hispanic (H), and 3 Asian (A) participants. The HART group (N=14) had 12 Caucasian participants(C), 1 African American (AA), and 1 Hispanic (H) participant while the HAET group (N=5) had 5 Caucasian (C) participants. Gender was made up of males and females with the Sedentary group (N=40) having 20 males (M) and 20 females (F). The HART group (N=14) had 6 males (M) and 8 females (F) while the HAET group (N=5) had 5 males (M). Isokinetic torque (N) represented in Table 1 had a sample mean (SD) for the Sedentary group of 212.5 ± 73.7, 413 ± 49 for the HART group, and 428 ± 38.2 for the HAET group. No significant difference was found when comparing the % HR max using the ventilatory equivalent method between the groups.

When comparing the % VO_2 max of the different testing groups to the method of calculating ventilatory threshold, there was no significant difference within the Sedentary group as seen in Figure 1. Also seen in Figure 1, for the HART group there was a significance of %

VO_2 max between the Ventilatory Equivalent Method and Ventilation (VE) Method ($P<0.05$) showing that the VE method was lower than the Ventilatory Equivalent method, while in the HAET group, no significance was reported. When comparing the % maximal work rate (w) of the different testing groups to the method of calculating the ventilatory threshold, no significance was reported as seen in Figure 2.

Looking at the comparison between the %VO_2 max of the testing groups within a method of calculating ventilatory threshold in Figure 3A, there was significance using the ventilatory equivalent method with Sedentary having a %VO_2 max less than the HART and HAET group ($P<0.003$). There was also a significance found in the Sedentary having a significantly lower %VO_2 max compared to the HAET ($P<0.0209$) group when using the VCO_2 method also seen in Figure 3D.

When looking at the comparison between the % maximal work rate (w) of the different testing groups vs. the different methods of calculating the ventilatory threshold, a significance was found using the ventilatory equivalent method ($P<0.05$) showing that the HAET group had a significantly higher %maximal work rate compared to both the sedentary and HART groups as seen in Figure 4. Also seen in Figure 4, when comparing the % maximal work rate (w) between the testing groups using the V-Slope method, significance ($P<0.05$) was found in the Sedentary having a significantly lower % maximal work rate compared to HART and HAET groups. Figure 4 also shows there is significance ($P<0.05$) using the ventilation method (VE) showing the % maximal work rate for the Sedentary group is significantly smaller than the HART and HAET group. When comparing the % maximal work rate (w) of the different testing groups using the VCO_2 method, there was significance ($P<0.05$) between the Sedentary vs. HART and HAET groups showing that the Sedentary group % maximal work rate was smaller than both groups.

Chapter 5: Discussion

This study aimed to look at the effects of ventilatory threshold through resistance and endurance training and to see if the different modes of calculating ventilatory threshold would be like one another. The primary finding of the study is that when comparing the % VO_2 max between sedentary, HART, and HAET groups; the HAET group had a higher % VO_2 max. While observing the results of comparing the % maximal work rate between the groups, the HAET group had a higher % maximal work rate compared to the sedentary and HART groups. Moreover, when looking to see if the different modes of calculating ventilatory threshold, there was hardly any significance between the different modes meaning each mode of calculating ventilatory threshold can be a viable mode of calculating ventilatory threshold. Through these findings, the alternate hypothesis can be accepted as the HART and HAET groups had a higher ventilatory threshold when compared to sedentary and there was very little difference in the different modes of calculating ventilatory threshold.

Like previous articles (Cerezuela-Espejo et al, 2018), there was a correlation between highly active endurance training and a greater ventilatory threshold. The benefits of cardiorespiratory fitness can be seen through regular endurance training. In a study by (Jones, and Carter; 2012) endurance exercise results in excellent adaptations to the cardiorespiratory and neuromuscular systems by enhancing the delivery of oxygen to muscles that are in need. With increases in VO_2 max, exercise economy which is defined as the required oxygen uptake at a given exercise intensity, and ventilatory threshold there can be large improvements in exercise performance which is related to the current study with the highly active endurance training group having a higher % VO_2 max and % maximal work rate. Another study looking at endurance training in soccer athletes had similar results to the current study where endurance training promotes improvements in VO2 max while increasing performance (Helgerud et al, 2001).

A novel study by Vainshelboim, et al, 2017, looked at the comparison of methods for determining the ventilatory threshold for implications for surgical risk. The methods or evaluations involved the metabolic system using the V-slope method, the visual method using ventilatory equivalent and the V-slope in 30-second intervals, and the automated computed system methods using ventilation and VO_2. The results found a high correlation of agreement when using a visual method, automated computed method, and metabolic system. After reviewing the previous study, the current novel study has similar results with the different methods of comparison having little variations and agreeing with one another.

Gaskill and Ruby, et al, 2016, studied the validity and reliability of combining three methods to determine the ventilatory threshold. In the previous study, the three methods of determining the ventilatory threshold consisted of the ventilatory equivalent, modified V-slope, and excess CO_2 method. The results showed that each determination method had similar results to one another with very little differences meaning that all three of the methods are a reliable source of measuring one's ventilatory threshold. Comparing the previous study to the current novel study, the result of each study shows similar correlations where each method can be a viable method of determining one's ventilatory threshold with little disagreement.

A study by Visschers et al, 2016 looked at comparing different methods of determining the ventilatory threshold in children with congenital heart or lung disease; the children performed a cardiopulmonary exercise test (CPET) on a cycle ergometer. Visschers et al used the ventilatory equivalent method, V-slope method, End-tidal pressure of oxygen method (PET-O_2), and Respiratory exchange ratio (RER=1). During this study, Visschers et al found that there was no significant difference between the ventilatory equivalent, V-slope, and PET-O_2 methods. Using the RER=1 method showed significant differences when looking at the workload, VO_2, and ventilation compared to the other methods. The validity of using the RER=1 method could not be deemed appropriate or not due to not taking blood lactate concentration samples. With the conclusion of the results, Visschers et al, agree that using the ventilatory equivalent, V-slope, or PET-O_2 method could be an accurate representation of determining the ventilatory threshold. When comparing the results of the previous study to the current novel study, the results came to agree with one another, verifying that using the methods of ventilatory equivalent, V-slope, VE, or VCO_2 method could be used to determine the ventilatory threshold with little disagreement.

In conclusion, participating in regular bouts of exercise has been shown to have health benefits including improved cardiorespiratory fitness, improvements in muscular and neuromuscular function, disease prevention, and decreased premature mortality.
Future studies could include looking at before and after training with participants in similar groups (sedentary, HART, and HAET) while looking at ventilatory and lactate thresholds. Further studies doing such could narrow down how much each type of training protocol could increase one's cardiorespiratory fitness along with other health benefits. This could be proven vital in future research when looking into obesity, cardiovascular disease, and other health conditions. Another area in future studies that could be looked at is how different modes of exercise between men, women, and adolescents affect the ventilatory threshold. Several limitations within the current study include having participants only come from Greenville, NC, having a small age range within the training groups, and only looking at pretest data.

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Tables/Figures

Subject Characteristics

TABLE 1	Sample Size	Age (yr)	BMI (kg/m^2)	VO_2 Max (ml/min)	Ethnicity	Gender	Isokinetic Torque (N)
Sedentary	Mean ±SD N=40	36.9± 9.5	27.4 ± 4.2	* 28.9 ± 7.6	C=28 AA=7 H=2 A=3	M=20 F=20	212.5 ± 73.7
HART	Mean ± SD N=14	35.5 ± 16.7	24.9 ± 2.8	40.9 ±6.4	C=12 AA=1 H=1	M=6 F=8	413 ± 49
HAET	Mean ± SD N=5	*50.4 ± 14.1	24.9 ± 5.0	44.7 ±9.0	C=5	M=5 F=0	428 ± 38.2

Ethnicity Legend
C- Caucasian
AA- African American
H- Hispanic
A- Asian
Gender Legend
M- Male
F- Female
Table 1 represents subject characteristics as Mean ± SD. Body Mass Index (BMI), Age (years), VO_2 max, and Isokinetic torque (N). HART- Highly Active Resistance Training HAET- Highly Active Endurance Training. *Age ($P<0.05$) Sedentary was significantly younger than the HAET group. *VO_2 max ($P<0.05$) was significantly less in the Sedentary group compared to the HART and HAET group.

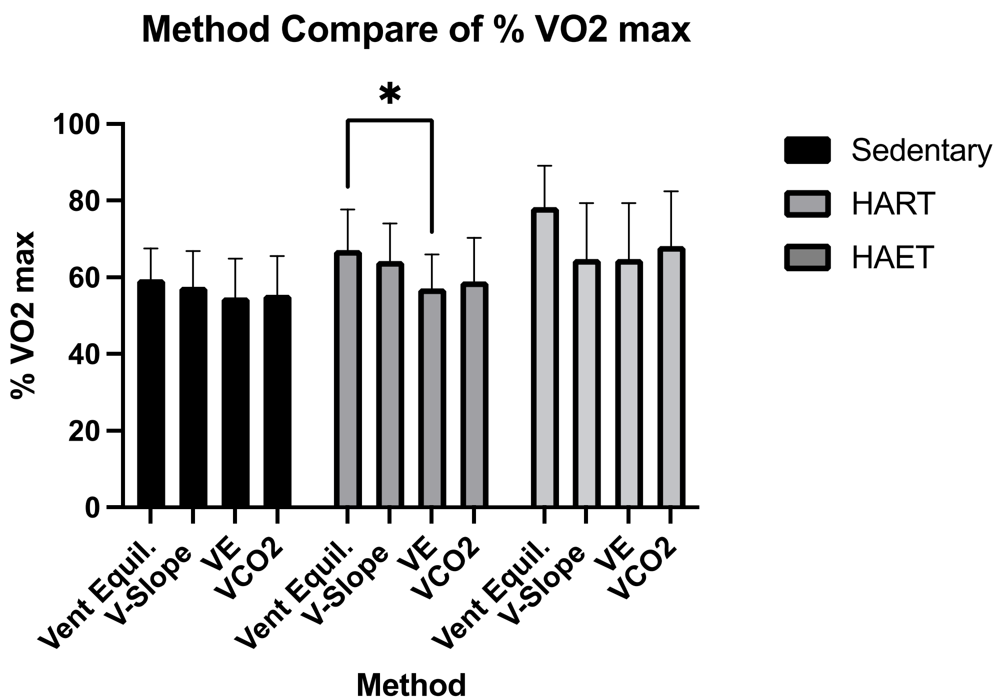

Figure 1 represents the comparison of % VO_2 max of the testing group using different testing methods. * Significant ($P<0.05$) between the Ventilatory equivalent and VE method in the HART group.

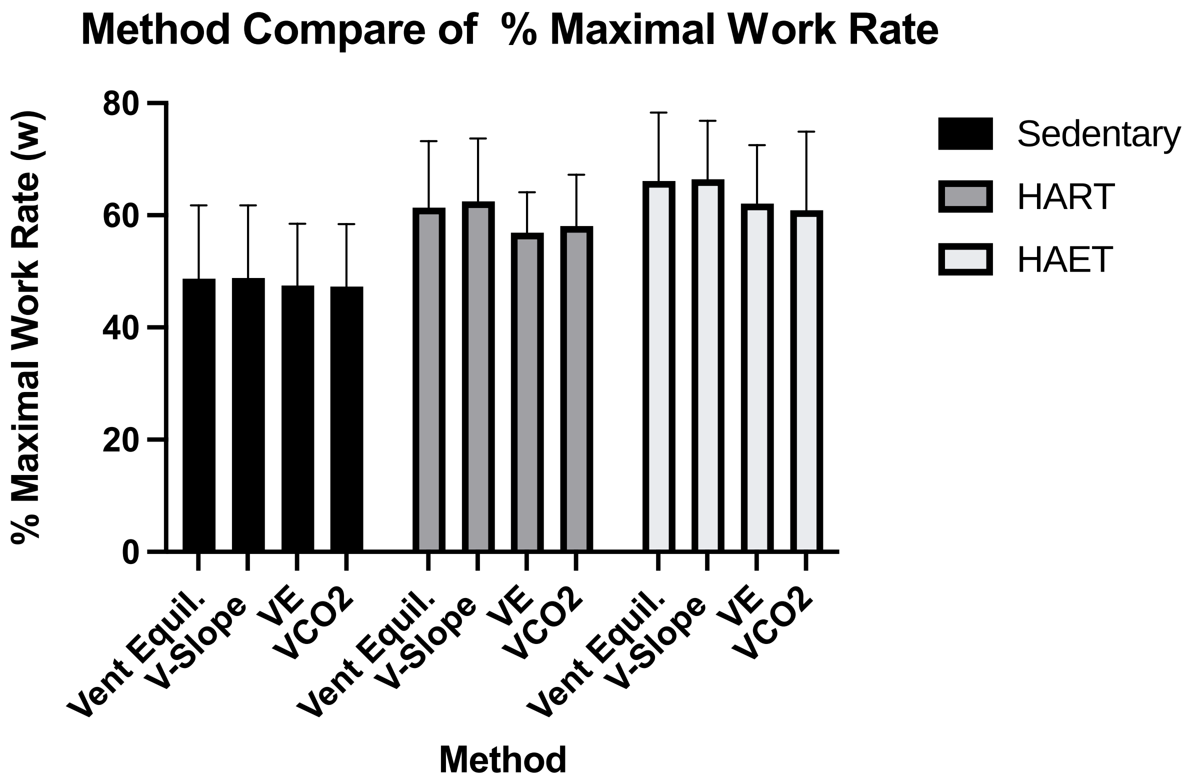

Figure 2 represents the comparison of the % maximal work rate (w) of the testing groups using different testing methods. No significant was found.

Group Compare of Ventilatory Equilvalent Method

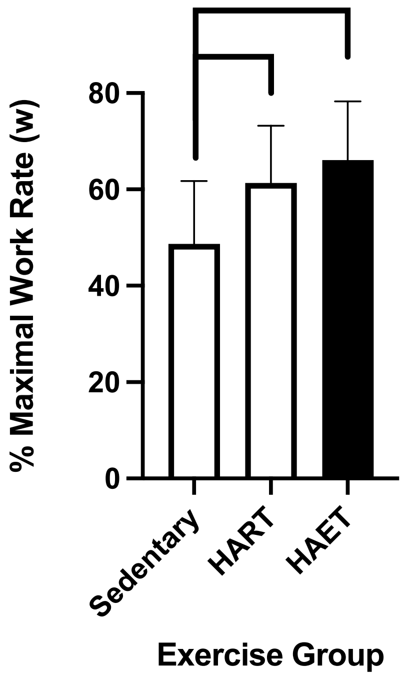

Figure 3A represents a group comparison of % VO_2 max using the Ventilatory Equivalent method. * The Sedentary Group is significantly lower ($P<0.05$) compared to the HART and HAET groups.

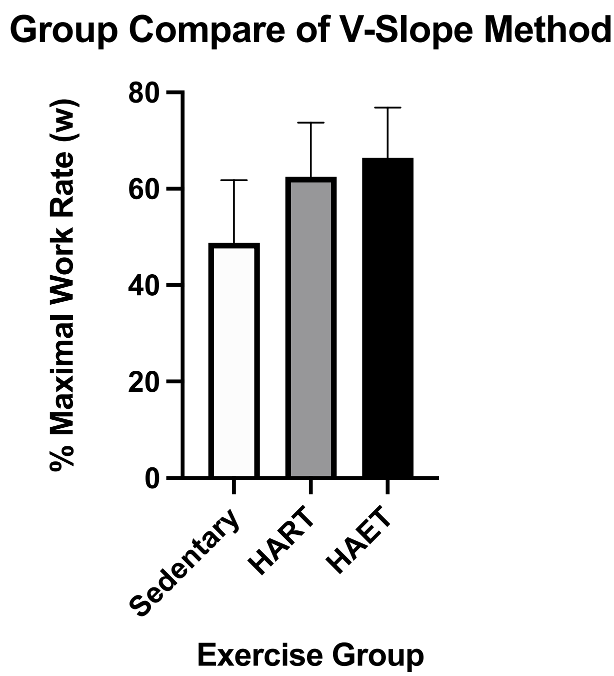

Figure 3B represents a group comparison of % VO_2 max using the V-Slope method. No significant was found ($P>0.05$).

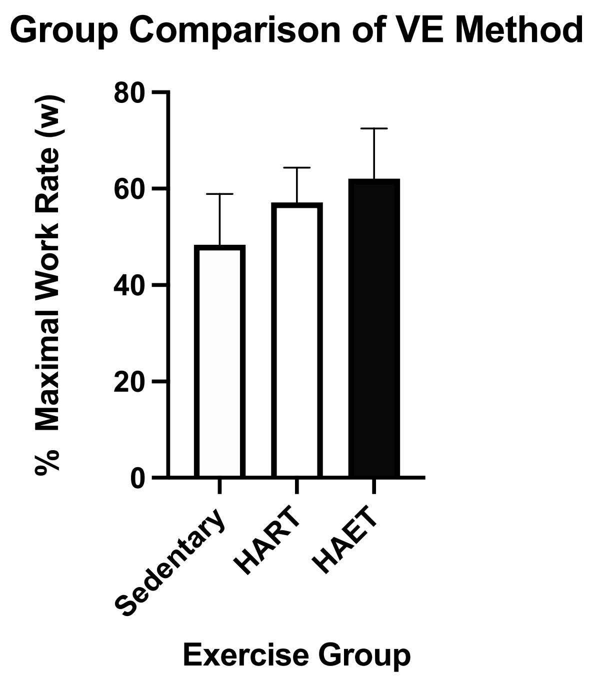

Figure 3C represents a group comparison of % VO_2 max using the VE method. No significance was found (P>0.05)

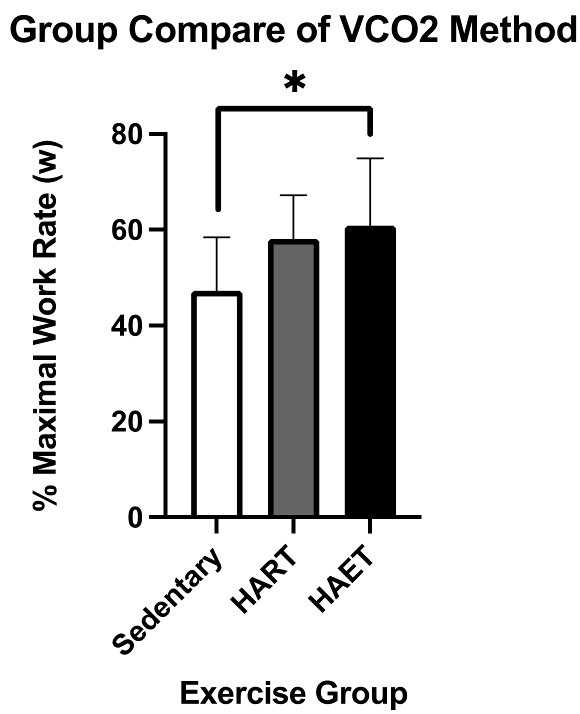

Figure 3D represents a group comparison of % VO_2 max using the VCO_2 method. Significance was found between Sedentary vs. HAET (P<0.05).

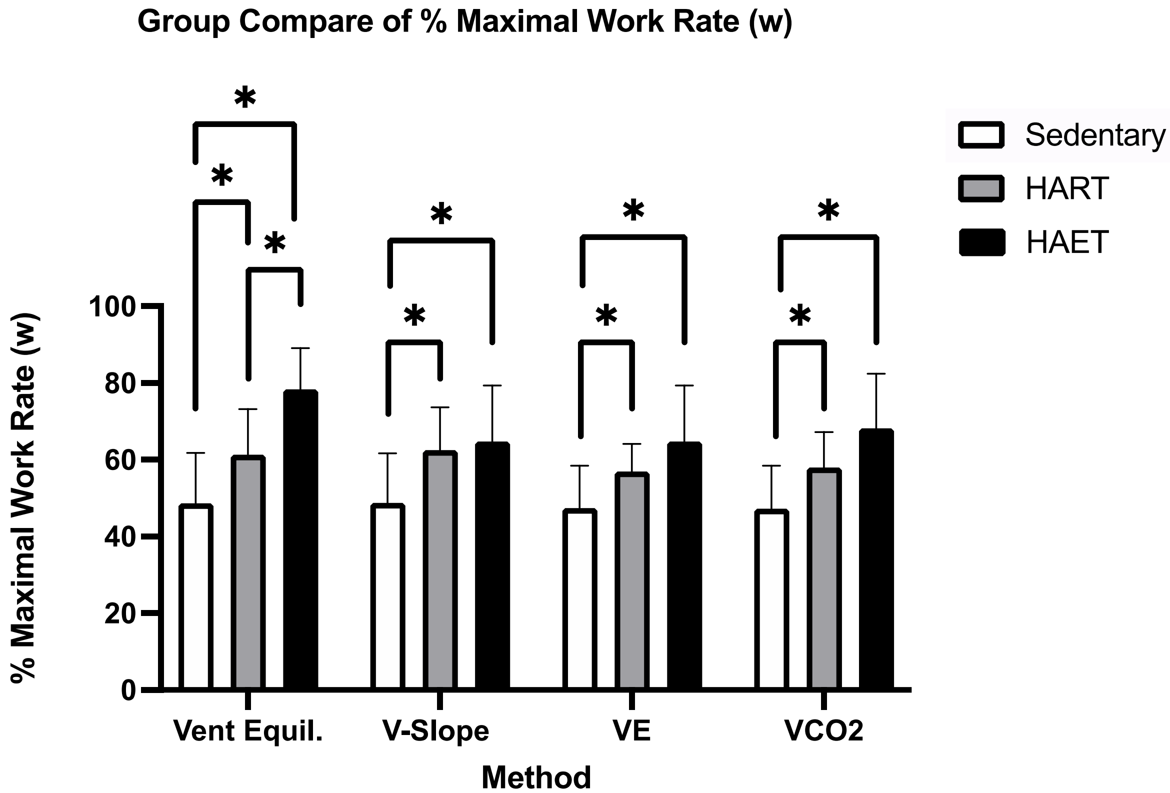

Figure 4 represents a group comparison of the % maximal work rate (w) with the different methods of calculating the ventilatory threshold. * There was significance between the Sedentary group ($P<0.05$) vs. HART and HAET groups in the Ventilatory Equivalent method. *Significance between HART vs. HAET ($P<0.05$) using the Ventilatory Equivalent method. *Significance ($P<0.05$) Between Sedentary vs. HART and HAET group using the V-Slope method, VE method, and VCO_2 methods.

Group Compare Using Ventilatory Equivalent Method

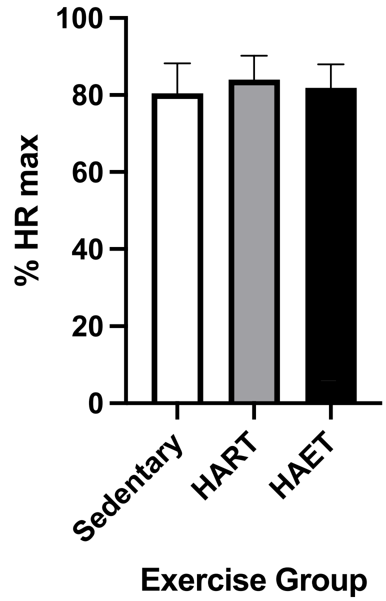

Figure 5 represents a group comparison of % heart rate max using the ventilatory equivalent method. No significance was found (P>0.05)

<u>Appendix-</u> IRB Approval Letter

WAKE FOREST UNIVERSITY
HEALTH SCIENCES

Office of Research
INSTITUTIONAL REVIEW BOARD

MEMORANDUM

To: Michael Miller
Public Health Sciences

From: Jeannie Sekits, Senior Protocol Analyst, Institutional Review Board

Date: 11/30/2023

Subject: Human Protocol: IRB00097219
Molecular Transducers of Physical Activity Consortium (MoTrPAC) Coordinating Center
Amendment 15 for IRB Study #IRB00097219

Study Documents:
Protocol Version: MoTrPAC_Adult Protocol_v3.0_2023-08-22_clean.docx; Informed Consent Version: AdventHlth Orlando[REDCap LC PI Survey]FINAL_Kohrt_IRB00097219_MoTrPAC_Consent_Addendum_v2.1_2023.08.21_AH TRI.docx (approved), AdventHlth OrlandoREDCap LC PI Survey_IRB00097219_MoTrPAC_Site Specific Consent_Adult Sedentary_v2.2_2023.10.02_clean.docx (approved), AdventHlth OrlandoREDCap LC PI Survey_IRB00097219_MoTrPAC_Site Specific Consent_Highly Active_v2.3_2023.11.01_clean.docx (approved), Ball Stat Univ[REDCap LC PI Survey]FINAL_Trappe_BSU_IRB00097219_MoTrPAC_Consent_Addendum_v2.1_2023.08.21_BSU.docx (approved), Ball Stat Univ[REDCap LC PI Survey]FINAL_Trappe_BSU_IRB00097219_MoTrPAC_Master Site Specific Consent_Adult Sedentary_v2.1_2023.08.21_BSU.docx (approved), Ball Stat Univ[REDCap LC PI Survey]FINAL_Trappe_BSU_IRB00097219_MoTrPAC_Master Site Specific Consent_Highly Active_v2.1_2023.08.21_BSU.docx (approved), Cedars Sinai[REDCap LC PI Survey]Musi_MoTrPAC_Consent_Addendum_v2.1_2023.08.21.docx (approved), Cedars Sinai[REDCap LC PI Survey]Musi_MoTrPAC_CSMC Site Specific HIPAA.docx (approved), Cedars SinaiREDCap LC PI SurveyMusi_MoTrPAC_CSMC Site Specific Consent_Adult Sedentary_v2.2_2023.10.2_clean.docx (approved), Cedars SinaiREDCap LC PI SurveyMusi_MoTrPAC_CSMC Site Specific Consent_Highly Active_v2.2_2023.10.2_clean.docx (approved), Colorado_Kohrt_IRB00097219_MoTrPAC_Site Specific Consent_Adult Sedentary_v2.2_2023.10.02_clean.docx (approved), Colorado_Kohrt_IRB00097219_MoTrPAC_Site Specific Consent_Highly Active_v2.2_2023.10.02_clean.docx (approved), Duke Univ[REDCap LC PI Survey]MoTrPAC_Highly Active ICF_Part 2_v2.3_01.NOV.2023_DUKE_clean.docx (approved), Duke Univ[REDCap LC PI Survey]MoTrPAC_ICF Addendum_v2.1_21.AUG.2023_DUKE.docx (approved), Duke Univ[REDCap LC PI Survey]MoTrPAC_Sedentary ICF_Part 2_v2.2_02.OCT.2023_DUKE_clean.docx (approved), East Caro Univ[REDCap LC PI Survey]FINAL_Houmard_IRB00097219_MoTrPAC_Consent_Addendum_v2.1_2023.08.21.docx (approved), East Caro UnivREDCap LC PI SurveyFINAL_Houmard_IRB00097219_MoTrPAC_Master Site Specific Consent_Highly Active_v2.2_2023.10.2_clean.docx (approved), East Caro UnivREDCap LC PI SurveyFINAL_Houmard_IRB00097219_MoTrPAC_Site Specific Consent_Adult Sedentary_v2.2_2023.10.2_clean.docx (approved), FINAL_Kohrt_IRB00097219_MoTrPAC_Consent_Addendum_v2.1_2023.08.21.docx (approved), FINAL_Kohrt_IRB00097219_MoTrPAC_Master Site Specific Consent_Adult