ABSTRACT

The purpose of the present investigation was to examine the ratio between total CO₂ expiration and O₂ consumption to VO₂ max. Twenty-six male (VO₂ max: 55.4 ± 8.3 ml O₂/kg*min) and thirty-five female (VO₂ max: 44.1 ± 8.1 ml O₂/kg*min) recreationally active adults volunteered. The participants underwent a custom ramped treadmill protocol (GXT) with expired gases monitored. Third order polynomial regression was undertaken for the VO₂ and VC0₂ by time (r>0.950). Regression equations were integrated from 60 seconds after the start of the test (to negate any initial hyperventilation) until VO₂ max. This area under the curve calculation was equal to the total accumulated expired CO₂ and consumed O₂. The ratio of total CO₂ to O₂ was calculated (AUC ratio). Data analysis was undertaken using multiple linear regression analysis. The model included gender, RER at VO₂ max and AUC ratio as predictors and relative VO₂ max as the outcome. The model was significant with predictor variable gender (b =0.582, p<0.001) and AUC ratio (b=-0.298, p=0.019) significant in the model. Based upon these results it would appear that individuals who are more fit relying more heavily on oxidative pathways throughout the course of a GXT.

Key Words: Endurance, Performance, Exercise Testing Aerobic Capacity, Graded Exercise Test
INTRODUCTION

Maximum oxygen uptake (VO₂ max) is commonly studied among both recreational and athletic populations and is widely held to be the criterion measure by which cardiovascular fitness is judged. The determination of maximum aerobic capacity has been studied in conjunction with performance among athletes in different sports for many years [7,15,19,21]. Specifically for many endurance athletes VO₂ max testing is a usefully tool to examine changes in physiological response to training stimuli [10]. While much is known in regard to outcome of maximum aerobic capacity, particularly in athletic populations, less is known about the differences in expired and inspired gases during the test.

Some information has been brought forth regarding the slow and fast components of VO₂ kinetics [23]. This suggests that some trends in the data collected during graded exercise tests contain valuable information. Though maximum aerobic capacity is primarily concerned with oxygen consumption, expired carbon dioxide has been shown to play an important role in performance in these tests. Hermiston and Faulkner [13] reported the ability to predict maximum oxygen capacity in young men using a stepwise regression technique that included the fraction of carbon dioxide in expired gas. Duncan, Howley and Johnson [9] argued that a plateau in oxygen consumption was not a necessity in determination of maximum aerobic capacity, and that secondary measures such as a respiratory exchange ratio of greater than or equal to 1.15 might suffice. Given that during a graded exercise test it is common knowledge that the subject will increasingly rely on carbohydrates as work output increases, it is not shocking that expired CO₂ can be linked to the maximum workload and maximum oxygen use during a VO₂ max assessment. Furthermore, markers such as RER 1.0 [4] and the Respiratory Compensation point [5], the V-slope method to determine the anaerobic threshold [3] and the PEC [6] have all incorporated expired carbon dioxide into a marker within an exercise test that can be used for predicting athletic performance.

Further, carboxyhemoglobin levels above 4.3% have been shown to impair the ability to achieve maximum aerobic capacity [14]. It is clear that carbon dioxide has a role in determination of a subjects maximum aerobic capacity. Given that higher starting percentages of carboxyhemoglobin impair the attainment of higher levels of oxygen use, it can be suggested that individuals who have higher maximum aerobic capacities might show a different pattern of carbon dioxide production during a test of maximum aerobic capacity. However, given the large number of studies that suggest RER as a plausible marker for VO₂ max [2,9,18] and a recent study that found nearly 75% of surveyed exercise physiologist used a pre-identified value of RER as a criteria for the determination of VO₂ max [20] it would appear that ultimately maximum aerobic capacity tests end with similar absolute
ratios of expired carbon dioxide to consumed oxygen. However, overall ratios of expired carbon dioxide to oxygen consumed through an entire graded exercise test have yet to be investigated and may offer some insight as to the end point aerobic capacity. Based upon the association between higher carboxyhemoglobin levels and reduced aerobic capacity, and the likelihood of a higher absolute value of expired carbon dioxide near the end of a graded exercise test it can be hypothesized that persons with higher maximum aerobic capacity might maintain a lower overall ratio of expired carbon dioxide to consumed oxygen in a maximum aerobic assessment independent of RER at the conclusion of the test.

MATERIALS AND METHODS

Participants

Twenty male (age: 20.0±1.0yrs, weight: 71.3±9.7kg, VO₂ max: 56.6±8.6 ml O₂/kg*min, RER at VO₂ max 1.18±0.08, HR at VO₂ max 187.5±9.6) and eighteen female (age: 21.1±0.6yrs, weight: 55.8±7.2kg, VO₂ max: 44.8±9.9 ml O₂/kg*min, RER at VO₂ max 1.17±0.08, HR at VO₂ max 191.2±8.8) college aged students who were recreationally active volunteered for the present investigation. (see Table 1). All subjects gave informed consent prior to participating.

Table 1: Participant characteristics given in Means ± SD for male (n=26) and female (n=35) participants.

Graded Exercise Testing

Participants were asked to report to the Human Performance Lab for a graded exercise test to determine VO₂ max. The subjects ran on a Track Master TMX 425 treadmill (Full Vision Inc., Newton, KS.) during the assessment. Participants expired air was sampled and analyzed with a ParvoMedic TrueOne 2400 metabolic measurement system (ParvoMedics, Sandy, UT.) The system utilizes a mixing chamber and was set to sample expired air every 20 seconds. The system was
calibrated prior to each test according to the manufacturers specifications. Drift in the sensors was not appreciable during testing (<1.5%). Listed accuracy for the gas sensors in the unit are: paramagnetic O₂ analyzer ±0.1%, infrared CO₂ analyzer ±0.1%, pneumotach ±2%.

For the assessment a custom ramp protocol was used [4,6]. The test was concluded when the oxygen consumption was determined to have reach a plateau, or the participant volitionally quit exercise. In the present investigation most subjects demonstrated a plateau in oxygen consumption at the conclusion of the test. For the remaining subjects a VO₂ peak was determined from the best stage completed at an RER values of greater than 1.15. Heart rate during the test was determined through a Polar Wear Link heart rate sensor (Polar Electro Inc., Lake Success, NY.) that was linked to a receptor on the metabolic measurement system.

**Area Under the Curve (CO₂/O₂) Determination**

Third order polynomial regression was undertaken for the VO₂ (see example, Figure 1) and VCO₂ (see example, Figure 2) by time (r>0.950). Regression equations were then integrated from 60seconds after the start of the test (to negate any initial hyperventilation) until the point at which maximum oxygen consumption was determined to have occurred. This area under the curve calculation was equal to the total accumulated expired CO₂ and consumed O₂ during this time period. The values for carbon dioxide were then divided by the values for oxygen and a ratio score was created (AUC ratio). This ratio was then compared against the results of the VO₂ max test.

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\text{AOC Ratio} = \frac{\int_{V\text{O}_2_{\text{max}}}^{60\text{sec}} 3\text{rd order polynomial VCO}_2}{\int_{V\text{O}_2_{\text{max}}}^{60\text{sec}} 3\text{rd order polynomial VCO}_2}
\]
Figure 1. Example third order polynomial regression for VO₂ by time.

Figure 2. Example third order polynomial regression for VCO₂ by time.
**Statistical Analysis**

AUC ratio score was analyzed for normality via a Shapiro-Wilks test. Linear regressions (with for gender and RER at VO2 max) were used to compare AOC ratio to the VO2 max. Statistical significance was set a priori at alpha < 0.05. A modern statistical software package was utilized for all analysis (JMP 12.0 Pro).

**RESULTS**

The analysis for normality of the AOC ratio data suggested a normal distribution, as the Shapiro Wilks test was non-significant (p>0.05). Additionally, analysis for problems of multicollinearity were not revealed during analysis (VIF<1.5).

**Area Under the Curve Analysis**

Data analysis examining the relationship between the AOC ratio and VO2 max was undertaken using multiple regression analysis with gender as a descriptive variable. The results of the analysis showed a significant model (F=12.81, p<0.001) where AOC ratio was a negatively associated with VO2 max (b=-0.298, p=0.019), gender was a significant predictor in the model (b=0.582, p<0.001) but RER at VO2 max was non significant (b=0.043, p=0.731).

**DISCUSSION**

The data from the present investigation suggest that individuals who achieve higher maximum aerobic capacities produce less carbon dioxide per unit of oxygen during a VO2 max test independent of the final RER. In general, increases in expired CO2 during exercise precede changes in blood lactate concentration but manifest the same trend of increasing with increased anaerobic metabolism [1]. Based upon this understanding, the smaller AOC ratio in higher fitness subjects might be attributed to a lesser amount of anaerobic contribution to exercise performance during the graded exercise test. Some evidence exists for this as it is known that the lactate threshold occurs at a higher percentage of VO2 max in endurance-trained populations [17]. The findings from the present study expand upon the understand of a anaerobic threshold at a greater oxygen consumption in high fit individuals by suggesting that a lesser percentage of anaerobic metabolism contributes to the totality of an exercise test in high fit persons. This is further evidenced by the fact that RER at the conclusion of the GXT was not associated with aerobic fitness.
Past research has demonstrated that training induces changes in expired CO$_2$ at submaximal exercise intensities. Davis et al. [8] found that after training a submaximal exercise bout resulted in lower expired CO$_2$ without a concomitant decrease in VO$_2$. This again suggests that as people adapt to endurance training, the role of anaerobic metabolism in submaximal exercise is reduced.

There are known changes in VO$_2$ max that occur with aging [11,12,22]. However, it has been found in athletes that performance can increase through time even in the face of declining maximum aerobic capacity [16]. Future studies will need to be conducted to examine the change in AOC ratio during exercise testing longitudinally. Given the decline in VO$_2$ max with age, and the potential to increase exercise performance with continued training [16] there may be changes in the AOC ratio that can contribute to the explanation for the observations.

The present study is limited in scope based upon the modality of exercise, and the population that took part in the experiment. The results may not be generalizable to populations other than young adults, and may not be similar to data from exercise tests conducted on ergometers, nordic trainers or other common exercise modalities employed during exercise testing.

**CONCLUSIONS**

For those individuals engaged in exercise testing or training of healthy young adults the present study demonstrates that in aerobic exercise that is not maximal in intensity fit persons will use less anaerobic metabolism. Therefore, as a person’s aerobic fitness increases even exercise at match intensities via percentages of VO$_2$ max will elicit less respiratory by product associated with anaerobic metabolism. Overall, individuals who are more fit will need to work at higher relative intensities as compared to less fit persons in order to engage in submaximal training that targets anaerobic bioenergetics.

**REFERENCES**


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