Lab 04: Oxygen Consumption, Energy Expenditure, and VO_2 Max Testing

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SPSC 3275 - 002 Advanced Physiology of Exercise & Training

Presented to: Mr. Ryan Cook

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1. Introduction

Oxygen is required by the body to produce energy from food in the form of adenosine triphosphate (ATP) (Plowman & Smith, 2014). As the intensity or the duration of the exercise increases, the body's requirement for oxygen also increases; the respiratory system works in conjunction with the cardiovascular system (2014). If oxygen is being delivered to the muscles, then the aerobic energy system is predominantly active.

The body's ability to not only deliver oxygen to muscles, but also to use said oxygen, is called aerobic power (Giles, 2015). The volume of oxygen consumed by the muscles while exercising at a maximal capacity can be measured, the result being aerobic power. Once considered the golden number for athletes, a $\dot{V}O_2$ max indicates aerobic power, and represents the maximum volume of oxygen consumed per unit of time (2015), generally expressed in relative terms which considers body weight ($ml/min^{-1}/kg^{-1}$). Cycling ergometres and treadmills are among the most common exercise modes for measuring $\dot{V}O_2$, and a metabolic cart is most often used to measure and analyze the expired gases (2015).

2. Results

2.1. Task 1 was a walking test on a treadmill performed at 3 miles per hour (mph); it was conducted by a female subject. There were two conditions: condition 1 was wearing a backpack weighing 15 kilograms (kg), condition 2 was without the backpack. Both conditions of task 1 are a sub-maximal short-term aerobic exercise, which is defined as 5 to 10 minutes in duration, and at 50 percent to 80 percent of maximum HR (Bott, 2016). The subject's heart rate (HR) and METs were measured every 60 seconds, and blood lactate measured at 2 minutes and immediately post-exercise. The calories expended were recorded immediately post-exercise as well.

The HR results of condition 1, seen in Figure 2.1.1, show an overall increase as expected given that any movement requires an expenditure of energy which requires oxygen (Plowman & Smith, 2014). Initially the HR likely increased due to increase of intensity in exercise – from standing still to walking at 3 mph. The small decrease in HR at 3 minutes may be the result of an increase in stroke volume (SV), the volume of blood pumped per beat, since cardiac output ($\dot{Q}$) (not measured in Task 1) is a result of HR multiplied by SV ($\dot{Q}$ = SV*HR) (Bott, 2016).

The $\dot{V}O_2$ results for condition 1, seen in Figure 2.1.2, show an immediate plateau. The values for the $\dot{V}O_2$ were converted from the Metabolic Equivalent (METs) readings from the treadmill; the METs were multiplied by a factor of 3.5 to produce the $\dot{V}O_2$ equivalent (Giles, 2015). A large change in $\dot{V}O_2$ was not expected given the intensity of the exercise – the speed set at 3 mph, and the mass of the load at 15 kg – remained constant, and that the duration was short, 5 minutes.

The HR results of condition 2, seen in Figure 2.1.3, show an increase from 118 beats per minute (bpm) to 122 bpm before decreasing to 121 bpm and reaching a plateau. The initial rise in HR is an acute cardiovascular response to aerobic exercise (Plowman & Smith, 2014). The mild decrease in HR to plateau is the steady state, a condition which requires a balance between the energy provided during exercise and the energy requirements of the exercise (2014).

The $\dot{V}O_2$ results of condition 2, seen in Figure 2.1.4, show an immediate plateau at the same values of condition 1. The values for the $\dot{V}O_2$ were converted from the Metabolic Equivalent (METs) readings from the treadmill; the METs were multiplied by a factor of 3.5 to produce the $\dot{V}O_2$ equivalent (Giles, 2015). Little to no change was expected in the $\dot{V}O_2$ values given the intensity and speed of the exercise remained constant for a short-term aerobic modality.

While the HR and $\dot{V}O_2$ values between condition 1 and condition 2 of the walk test were similar, the energy expenditure differed. Figure 2.1.5

The HR results of the 1.5 mile test, seen in Figure 2.1.6, rise sharply over the duration of the exercise, from 154 bpm to 210 bpm. A plateau is reached at minute 8 of the exercise. Short-term light to moderate intensity sub-maximal exercise means that $\dot{Q}$ reaches a plateau within the first 2 minutes (Plowman & Smith, 2014). The subject's predicted maximum HR was calculated at 188 (220 – 32 [age of subject]), which means that the subject reached very close to his maximum HR. Reaching the maximum HR means the exercise changed from sub-maximal to maximal, and from light-to-moderate to heavy (>85 percent of $\dot{V}O_2$ max, and 95 percent to 100 percent of HR) (Bott, 2016).

The $\dot{V}O_2$ results of the 1.5 mile test, seen in Figure 2.1.7, show an increase to a plateau at the 8-minute mark. The results of the $\dot{V}O_2$ were converted from METs values from the treadmill. During maximal aerobic exercise, the $\dot{Q}$ is 25 litres per minute (L/min^{-1}), with 88 percent of that flow going to the skeletal muscles (2016). Typical values of $\dot{Q}$ at rest is between 5 and 6 L/min^{-1} (2016). The subject was instructed to "push the pace" for the 1.5 mile run; the final 0.5 miles were at a pace of 10 mph. Figure 2.1.8 shows the subject's reported Rate of Perceived Exertion (RPE) as the exercise bout continued, there was a steady increase in the RPE until the subject felt maximal exertion as the distance of 1.5 miles was completed. As the intensity of the exercise increased, the demands for oxygen increased as well (Plowman & Smith, 2014) in order to create more ATP. The subject's increased $\dot{V}O_2$ values were expected as the duration of the exercise bout increased, and it was expected that he reach $\dot{V}O_2$ max.

The criteria for reaching $\dot{V}O_2$ max includes: blood lactate levels greater than 8 to 9 mmol/L, a HR that is within 12 bpm (plus or minus) of the predicted max HR (220 minus subject's age), a respiratory exchange ratio (RER) of 1.0 or 1.1, and a plateau in oxygen consumption (2014). As seen in Figure 2.1.9, the subject's blood lactate levels were measured approximately every 150 seconds, and rose to a level of 12.7 mmol/L, achieving the first criteria for $\dot{V}O_2$ max. The subject's HR was predicted at 188, and reached a peak HR of 210 bpm, achieving the second criteria. As there was no mask with gas exchange sensors, the subject's RER could not be determined. As seen in Figure 2.1.7, the subject's oxygen consumption reached a plateau at the 8-minute mark, achieving the fourth criteria for reaching $\dot{V}O_2$ max.

2.2. There was no cycling ergometre $\dot{V}O_2$ max test performed, therefore there are no differences to be seen. However, the different modalities can produce different results among the same individual; a cycle ergometre may produce localized muscle fatigue which limits the test, but it also allows for a quantified power output (Giles, 2015). On the other hand, a treadmill requires the subject to utilize more muscle mass to ensure stability (Anderson & Parr, 2013), which makes it difficult to quantify the power output but reduces the chances for localized muscle fatigue (Giles, 2015).

Care must be taken to ensure the correct modality is selected based on the athlete's background, needs (2015), and modality-familiarity. Draper, Wood, and Fallowfield (2003) found that $\dot{V}O_2$ max – defined as the highest $\dot{V}O_2$ reached any of the tests – did not differ between running and cycling modalities. However, the subjects observed by Draper et al. (2003)

were all aerobically trained, but not specifically for running or cycling; the subjects were familiarized with the equipment and procedures prior to testing. Draper et al. (2003) also found that a $\dot{V}O_2$ response is influenced by exercise intensity and mode.

The subject for task 3 reported familiarity with distance running a few years prior, and mentioned that he had performed a $\dot{V}O_2$ max test on a cycling ergometre earlier in the year. He also mentioned that between the two modalities, the treadmill felt like a better test; his cycling $\dot{V}O_2$ max results was 54.7 (K. Perkins, personal communication, November 16, 2016), which is within the average range for trained men (Giles, 2015). The subject's $\dot{V}O_2$ max test on a treadmill produced results in the "Superior" range (2015). The findings from the subject are difficult to correlate to literature; most researchers find subjects who are trained individuals or untrained individuals; there is no cross-over where individuals may be trained in one modality but unfamiliar with the other but perform both tests. Caputo, Mello, and Denadai (2003) had four groups: untrained runners, untrained cyclists, endurance runners, and endurance athletes; there was no cross-over between groups.

2.3. Cardiovascular responses to exercises can shift from acute to chronic, this shift normally takes 8 to 12 weeks of training (Bott, 2016). Such a training regimen would result in several physiological adaptations including: an increase in myoglobin, an increase in mitochondrial density, an increase in oxidative enzymes, and an increase in capillarization (Plowman & Smith, 2014).

Myoglobin is an oxygen transporter in the muscle cells (2014). Myoglobin moves to the cell membrane to transport oxygen through the cell to the mitochondria resulting in an increase in ATP production via oxidation (2014). Oxygen is required in the aerobic energy system to produce ATP (2014).

There is an increase in the number of mitochondria in a muscle cell as an adaptation due to aerobic training, as well as an increase in the size of mitochondria (2014). This means more oxygen can be utilized in the production of ATP via oxidation (2014). More ATP allows for more energy to be used for muscular contraction, allowing the working muscles to contract for a longer duration (2014).

An increase in oxidative enzymes such as pyruvate or lactate dehydrogenase (LDH) (2014). Pyruvate metabolises glucose into pyruvic acid, which creates ATP in the Kreb's Cycle when oxygen is present (2014). LDH catalyzes and converts lactate ($C_3H_5O_3$) to pyruvic acid in order to convert NAD^+ to NADH (2014). The NAHD can then be used in the Kreb's Cycle for production of ATP during aerobic respiration (2014).

An increase in capillarization creates a greater cross-sectional area between the vascular system and the muscle (2014). This increase in surface area allows for oxygen to be exchanged between the blood and the muscle through passive diffusion and partial pressure (2014). With more oxygen able to diffuse into the muscle, the myoglobin can more readily transport oxygen to the mitochondria for ATP production (2014).

The respiratory muscles – consisting of the scalenes, intercostals, diaphragm, transverse abdominus, and quadratus lumborum – can hypertrophy with an appropriate training regimen (2014). Such a hypertrophy will also see the physiological adaptations listed and explained above.

If a subject performed a $\dot{V}O_2$ max test, underwent 6 months of endurance training, and performed a second $\dot{V}O_2$ max test at the end of the endurance training, the physiological adaptations should allow for an increase in the $\dot{V}O_2$ max results.

2.4. A $\dot{V}O_2$ max test typically requires a subject to wear a gas retrieval mask containing sensors to analyze the expired gases (Giles, 2015). The sensors are calibrated and sensitive enough to detect the mix of gases, including oxygen and carbon dioxide. Quercetin, a bioactive flavonoid found in foods such as apples, grapes, capers, and onions, or liquids such as red wine and black tea, has been shown to have anti-inflammatory, anti-carcinogenic, and cardioprotective properties (Dumke et al., 2009), and has a direct effect on skeletal and cardiac muscle mitochondria. Dumke et al. (2009) found that quercetin has the ability to increase mitochondrial capacity and oxidative enzyme capacity; such increases could potentially allow for a greater $\dot{V}O_2$ max result without chronic physiological training adaptations.

If a subject took a properly regimented dose of quercetin prior to a $\dot{V}O_2$ max test, that subject may see an increase in their $\dot{V}O_2$ max results which would not be due to chronic physiological training adaptations. A re-test of their $\dot{V}O_2$ max without prior consumption of quercetin would likely provide lower but more accurate results for the subject.

3. Conclusion

Once used as the golden standard for athletic testing, the $\dot{V}O_2$ max test is now only one of several tests used to determine athletic performance. Some caution is needed when delivering a $\dot{V}O_2$ max test to ensure proper specificity for the subject undergoing testing, certain athletes – bodybuilders as an example – are not concerned with their aerobic endurance (K. Anderson, personal communication, September 9, 2016). However, $\dot{V}O_2$ max testing can reveal pulmonary and cardiovascular pathologies that might have otherwise remained hidden (Giles, 2015). Further research is also required for dietary supplementations that may provide an acute cardiovascular response to improve the results of a $\dot{V}O_2$ max test (Dumke et al., 2009).

References

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Appendix

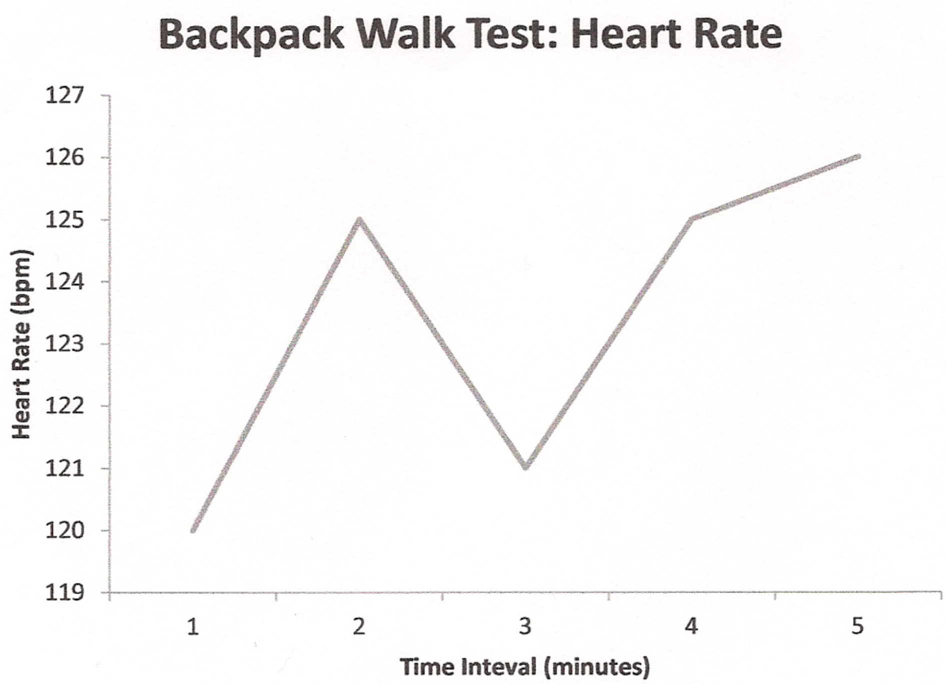

Figure 2.1.1. Heart rate over time, with weighted backpack.

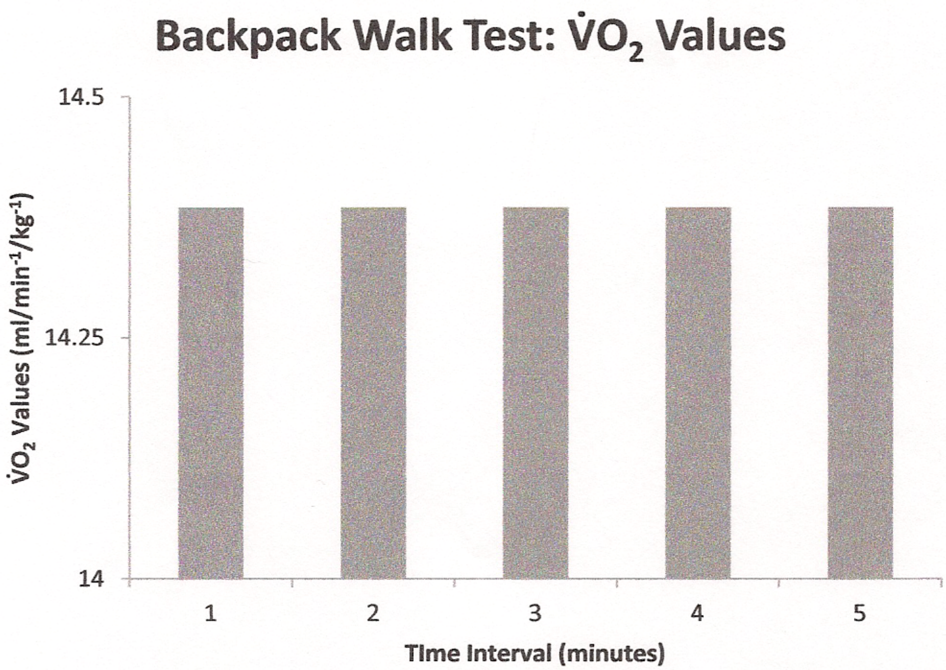

Figure 2.1.2. $\dot{V}O_2$ values, converted from METS, over time, with weighed backpack.

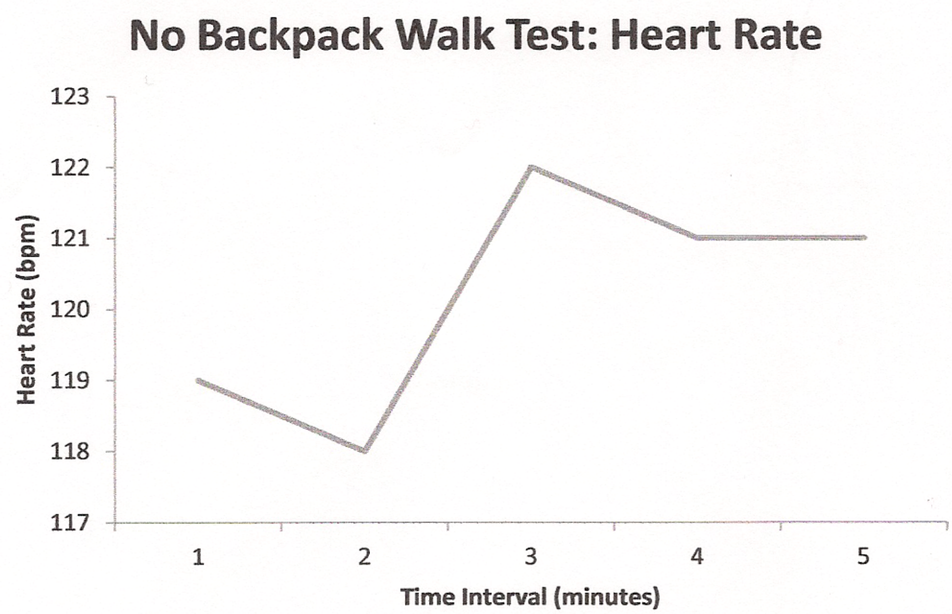

Figure 2.1.3. Heart rate over time, without extra backpack weight.

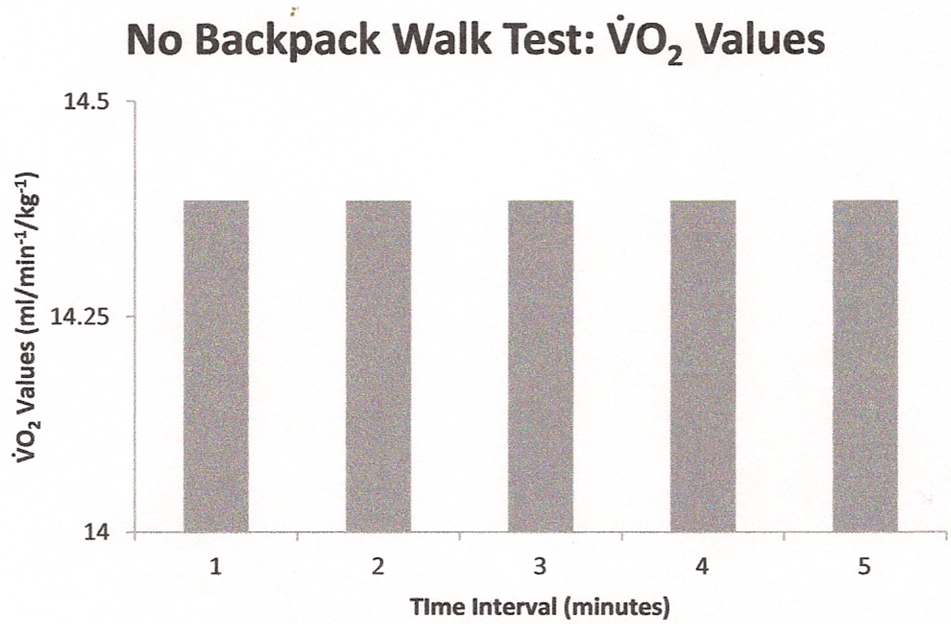

Figure 2.1.4. $\dot{V}O_2$ values, converted from METs, over time, without extra backpack weight.

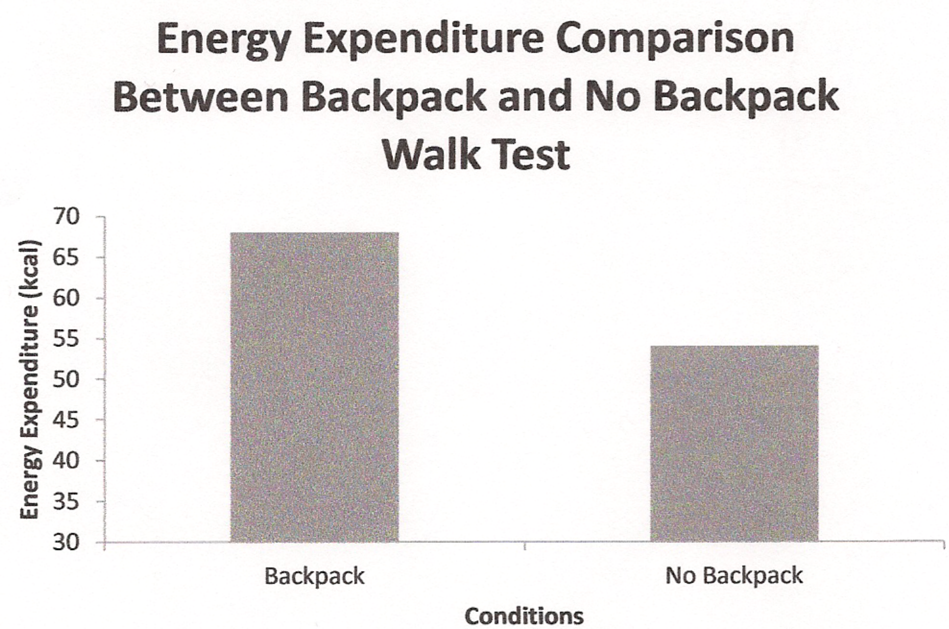

Figure 2.1.5. Energy expenditure between condition 1 and condition 2.

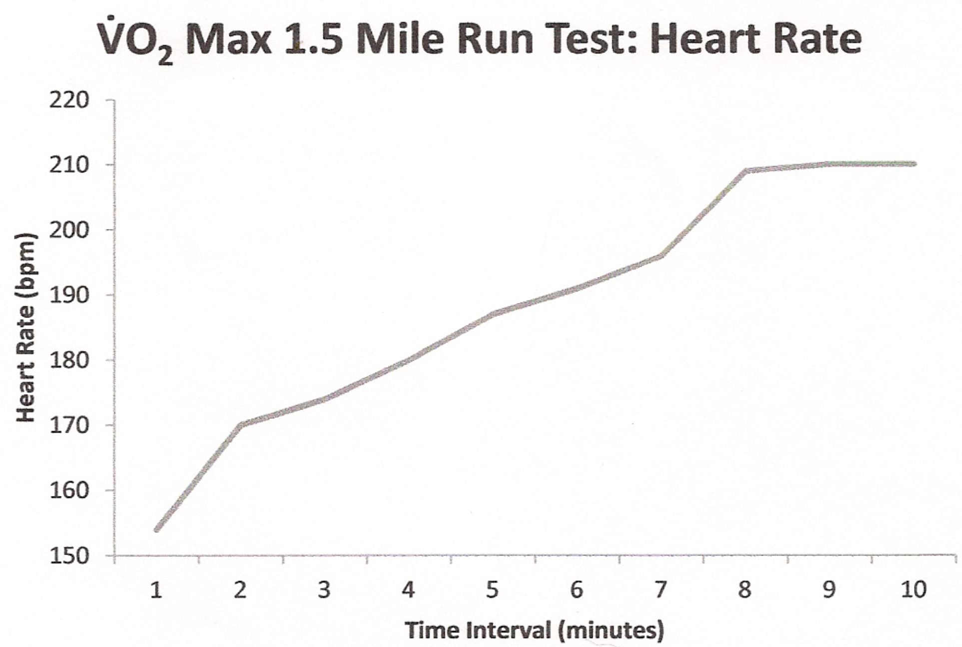

Figure 2.1.6. Heart rate over time for 1.5 mile run test.

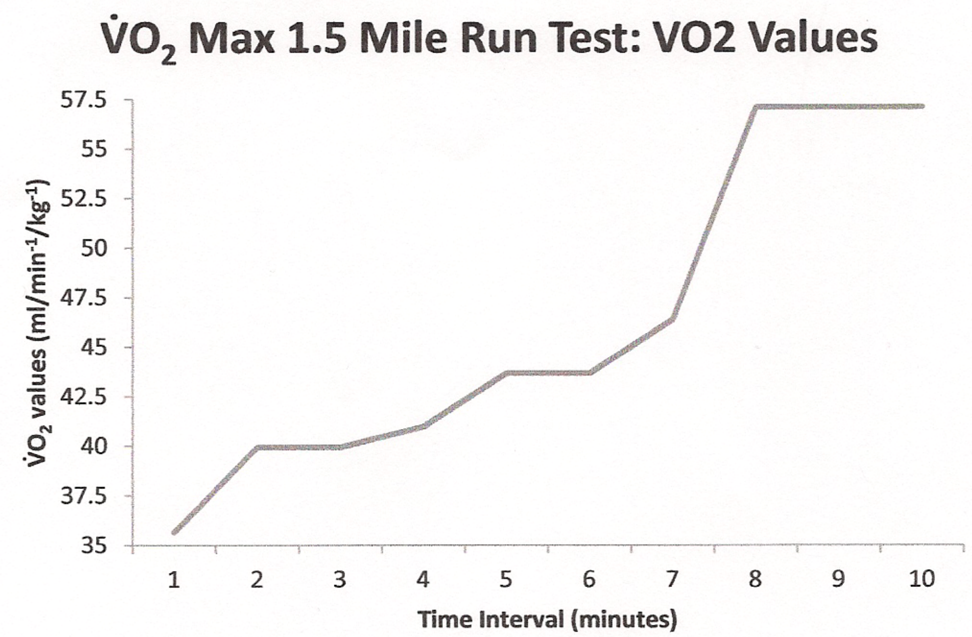

Figure 2.1.7. $\dot{V}O_2$ values over time for 1.5 mile run test.

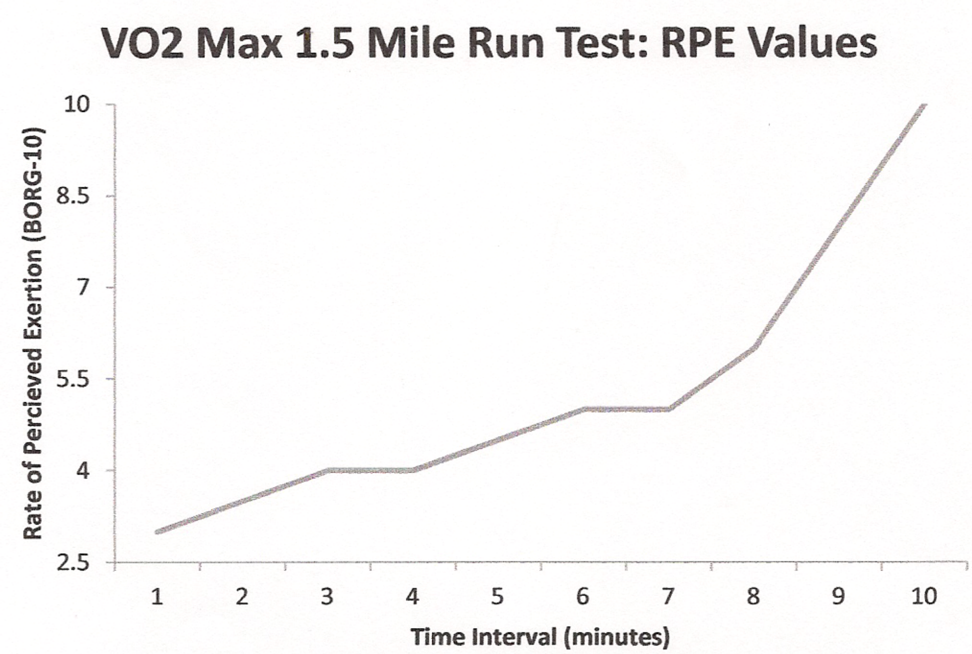

Figure 2.1.8. Rate of Perceived Exertion on a BORG-10 scale for the 1.5 mile run.

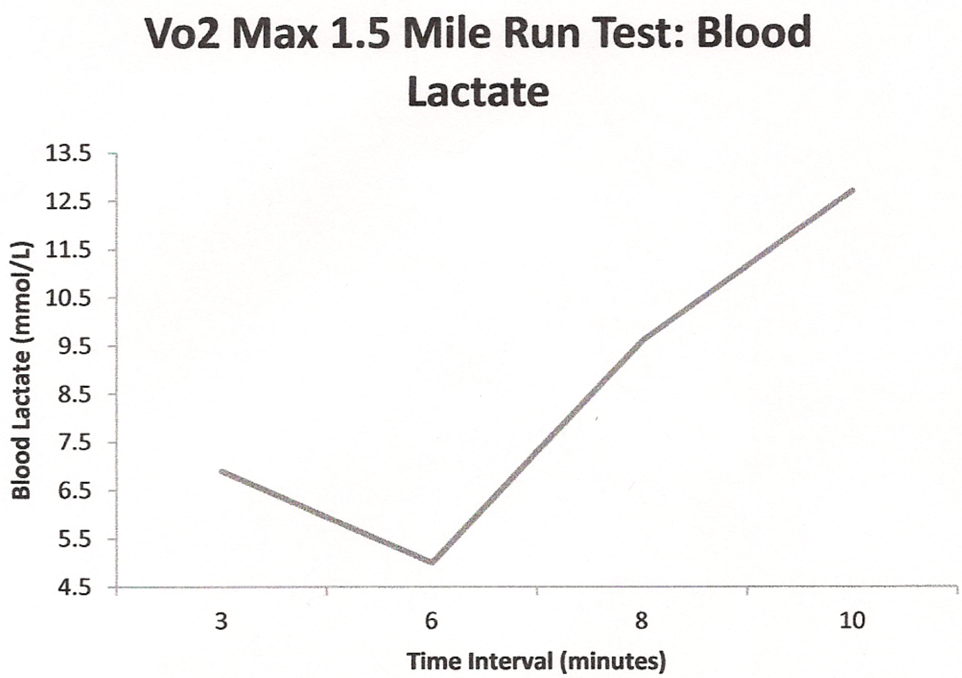

Figure 2.1.9. Blood lactate values during the 1.5 mile run test, taken approximately every 2.5 minutes.