VO_{2max}: HOW CAN AN ENDURANCE ATHLETE USE IT TO OBTAIN PEAK PERFORMANCE?

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ABSTRACT

The most critical factor that determines the benefit of aerobic exercise is intensity. Training at the correct intensity for each type of workout optimizes the body's response, giving someone the highest workout efficiency. Whether attempting to improve endurance, lose weight, or increase sustainable speed, almost everyone exercises harder than is ideal. Testing is the only way to learn the most efficient training intensities for one's unique physiology and get the most out of each training session. In this review, I present information about VO_{2max} testing and how it can help an endurance athlete obtain peak performance. Many key points in this review are based on clinical observations in Henry Performance Lab located in Lafayette, Louisiana (USA) where I serve as the Director. Henry Performance Lab is owned and operated by Dr. Barry Henry, Board Certified Orthopaedic surgeon and Board Certified Subspecialist in Sports Medicine.

KEY WORDS: VO_{2max}, lactate threshold, heart rate training

INTRODUCTION

Metabolic profiling is routinely done on endurance Olympic and professional athletes. This metabolic profiling is now more readily available not only to professional and Olympic athletes but to amateur and recreational endurance athletes as well who may be seeking an option to improve their performance on a more scientific level. A simple metabolic profile called a VO_{2max} assessment can determine an athlete's unique metabolic profile which is a body's precise response to exercise. If an endurance athlete has a comprehensive understanding of their VO_{2max} number and how to use this number, the biological changes that occur with incorporating VO_{2max} training in their performance program will in turn help them to obtain peak performance.

WHAT IS VO_{2max}?

The term "VO_2" is derived from V-volume of O_2-oxygen. VO_{2max} is the maximum volume of oxygen that the body can consume during intense, whole-body exercise. As exercise intensity increases so does oxygen consumption. However, a point is reached where exercise intensity can continue to increase without the associated rise in oxygen consumption. The point at which oxygen consumption plateaus defines the $VO_{2\ max}$ or an individual's maximal aerobic capacity. This volume is expressed either as an absolute rate in liters of oxygen per minute (l/min) or as a relative rate in milliliters of oxygen per kilogram of bodyweight per minute (ml/kg/min) (16). The latter expression is often used to compare the performance of endurance sports athletes (16).

While other data are better predictors of current endurance performance, VO_{2max} is one indicator of an athlete's potential (5). Below is normative data for the VO_{2max} assessment and comprises of the following grades: *Very Poor, Poor, Fair, Good, Excellent and Superior*.

TABLE 1

FEMALE NORMATIVE DATA FOR VO2max (values in ml/kg/min) (1)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<25.0	25.0 - 30.9	31.0 - 34.9	35.0 - 38.9	39.0 - 41.9	>41.9
20-29	<23.6	23.6 - 28.9	29.0 - 32.9	33.0 - 36.9	37.0 - 41.0	>41.0
30-39	<22.8	22.8 - 26.9	27.0 - 31.4	31.5 - 35.6	35.7 - 40.0	>40.0
40-49	<21.0	21.0 - 24.4	24.5 - 28.9	29.0 - 32.8	32.9 - 36.9	>36.9
50-59	<20.2	20.2 - 22.7	22.8 - 26.9	27.0 - 31.4	31.5 - 35.7	>35.7
60+	<17.5	17.5 - 20.1	20.2 - 24.4	24.5 - 30.2	30.3 - 31.4	>31.4

TABLE 2

MALE NORMATIVE DATA FOR VO2max (values in ml/kg/min) (1)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<35.0	35.0 - 38.3	38.4 - 45.1	45.2 - 50.9	51.0 - 55.9	>55.9
20-29	<33.0	33.0 - 36.4	36.5 - 42.4	42.5 - 46.4	46.5 - 52.4	>52.4
30-39	<31.5	31.5 - 35.4	35.5 - 40.9	41.0 - 44.9	45.0 - 49.4	>49.4
40-49	<30.2	30.2 - 33.5	33.6 - 38.9	39.0 - 43.7	43.8 - 48.0	>48.0
50-59	<26.1	26.1 - 30.9	31.0 - 35.7	35.8 - 40.9	41.0 - 45.3	>45.3
60+	<20.5	20.5 - 26.0	26.1 - 32.2	32.3 - 36.4	36.5 - 44.2	>44.2

TABLES' REFERENCE

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HOW IS VO_{2max} MEASURED?

One way to determine the maximum amount of oxygen consumed during exercise is through maximal fitness testing. When aerobic fitness is measured at maximal effort, it is called Maximal

Oxygen Uptake (VO_{2max}). To accurately measure VO_{2max}, an athlete would have to put forth a physical effort that would be in sufficient duration and intensity to fully tax their aerobic energy system. These tests can be either direct or indirect. To obtain the most accurate and direct results, the athletic testing would involve a graded treadmill or cycle test in which exercise intensity is progressively increased while measuring the ventilation and oxygen and carbon dioxide concentration of the inhaled and exhaled air via open-circuit spirometry. To begin the exam, the subjects would be fitted with a respiratory mask, covering their mouth and nose, and would be connected to a cardiac monitoring device such as a Heart Rate Monitor or a 12 Lead EKG machine. See sample picture below.

FIGURE 1

PICTURE OF AN ATHLETE BEING MONITORED BY A METABOLIC CART (TREADMILL)

Prior to testing, all vital statistics would be taken to obtain baseline measurements including heart rate, resting respiration and blood pressure. During the test, the subjects would be encouraged to exercise to exhaustion. The workload during the test would increase approximately every minute until maximum exertion is achieved. During the assessment, a small (pinprick) blood sample is taken at regular intervals from either a finger or ear-lobe to test blood lactate concentrations. Essentially, it is believed that as the athlete progresses to higher intensity during the test, the muscles need an increasing volume of oxygen, a process, which is continued until the supply of oxygen becomes limiting or the ability of the muscle to utilize oxygen is exceeded. At this point, there would be no further increase in oxygen uptake. Again, once an athlete reaches their VO_{2max}, intensity and heart rate response increase without the associated rise in oxygen consumption, but this is not always observed (3, 6). A two to three minute recovery time is always included to obtain recovery heart rate. All data is recorded continuously throughout the test period and the test can be stopped by the subject at any time for whatever reason. The average total time for the tests are usually around 90 minutes, including time for a warm-up, the actual assessment, time for a cool down and an overview of the results. However, this can vary depending on the education of the athlete. One problem with direct measurement of VO_{2max}, is that it requires special, expensive equipment and that may not always be readily available to most athletes (10).

Currently, there are over 20 combined different VO_2 max and VO_2 sub-maximal tests that one could find between the internet, books and training manuals to take in order to obtain their VO_{2max} value. The sub-maximal indirect tests that athletes can participate in will "predict" their VO_{2max} values (30). An interesting finding on the accuracy of sub-maximal tests revealed endurance athletes calculated a 14% underestimation of their true VO_{2max} values (10). The most common indirect test conducted to predict VO_{2max} values includes a walking test where the Bruce Protocol is followed (15). The walking test that follows the Bruce Protocol would begin with a warm-up on the treadmill (15). The treadmill would then begin moving at an easy, comfortable pace of 2.7 km/hr at a gradient or incline of 10%. Both the speed and the incline would increase every three minutes, up to a point where the athlete feels unable to continue with the protocol. During this test, an exercise specialist would monitor the heart rate, blood pressure and rate of perceived exertion (RPE). At the point where the athlete can no longer perform the exercise, which would be their peak level of oxygen consumption, the test would then be terminated. A two minute cool-down period would then begin to assess how quickly the cardiovascular system recovers. Since the Bruce Treadmill Test is known as an indirect test, it only estimates VO_{2max} using the following formulas (as opposed to direct tests that use gas analyzers to measure respired gases):

Men*: VO2max = 14.8 – (1.379 * T) + (0.451 * T2) – (0.012 * T3*)

***Women:* VO2max = 4.38 * T – 3.9**

In both cases, "**T**" denotes the time in minutes spent on the treadmill. Before the formula is used, it is important to remember that 10 minutes and 45 seconds would be expressed as 10.75 minutes. Athletes can analyze their performances by comparing past and present test results. The reliability of the test refers to the degree to which a test is consistent and stable in measuring what it is intended to measure. So, the reliability of the Bruce Treadmill Test will depend on how strict the test is conducted and the individual's level of motivation to perform the test. Test validity refers to the degree to which the test actually measures what it claims to measure and the extent to which interferences, conclusions, and decisions made on the basis of test scores are appropriate and meaningful. This test provides a means to monitor the effect of training on the athlete's physical development. As mentioned previously, Tables 1 and 2 (referenced on page 2) are published VO_{2max} tables that can be used by an athlete for comparison.

HOW CAN AN ENDURANCE ATHLETE USE THEIR VO_{2max} VALUE TO OBTAIN PEAK PERFORMANCE?

Each individualized VO_{2max} value can be used by endurance athletes to determine their current functional capacity and as a gauge of their future progress. An athlete can use their VO_{2max} number solely or in combination with their absolute lactate threshold value to determine the optimal energy source usage, caloric needs and heart rate training zones which they can incorporate into a peak endurance training program. It is important to point out that other factors can contribute to an athlete's peak performance as well which include a combination of but not limited to genetics, rest and recovery.

Lactate is a byproduct of exercise. Although the muscular fatigue experienced during exercise often correlates with high tissue concentrations of lactate, lactate is not the direct cause of fatigue. Athletes during exercise, even at low intensity, are always producing lactate and using it as an energy substrate through a process called gluconeogenesis, especially in Type I cardiac muscle fibers. Higher intensity exercises do result in more lactate production by the muscles. However, at low intensity, the muscles easily recycle as much lactate as is produced to turn out more glucose that will in turn contribute to energy production. If the athlete speeds up just slightly, the muscles produce more lactate than it can recycle, it accumulates, and then causes an immediate spike in blood lactate concentration. At this point, the athlete is considered to be at their lactate threshold. Some studies have shown that lactate thresholds are at an average of 4mg/dl for trained endurance athletes (18). It is important for endurance athletes to continue to increase this lactate threshold so that they will consequently improve the efficiency of mitochondrial function at the muscle cellular level and capacity of oxygen to enter the cell membrane. In turn, this allows the athlete to perform at higher levels for longer periods of time more efficiently without the increased risk of injury. This is mainly due to the athlete designing majority of their training at or below their lactate threshold (27). One study revealed that 75% of the sessions or training distances for elite endurance athletes are generally below lactate threshold (4). Once an endurance athlete obtains their VO_{2max} number via direct measurement or predicted, they can then calculate the percentage of VO_{2max} where the lactate threshold occurs. So, the percentage of VO_{2max} at which an athlete can perform is related to the amount of lactate in the blood thus the reason for lactate threshold generally used as a sound predictor of race pace. Subsequently, these athletes can then more accurately design their training programs. For example, if VO_{2max} occurs at 24 km/h on a treadmill test and a sharp rise in blood lactate concentration above resting levels is seen at 12 km/h then the lactate threshold is said to be 50% VO_{2max}.

Previously, it was mentioned that the point at which oxygen consumption plateaus defines the $VO_{2\ max}$ or an individual's maximal aerobic capacity. It was also mentioned that VO_{2max} value can determine an athlete's capacity to perform sustained exercise and is linked to peak performance (5). However, with elite athletes, VO_{2max} is not always a good <u>predictor</u> of performance. The winner of a marathon race for example, cannot be predicted from maximal oxygen uptake (19). While a high VO_{2max} may be a prerequisite for performance in endurance events at the highest level, another marker such as lactate threshold is more <u>predictive</u> of performance (12, 31). One can think of $VO_{2\ max}$ as an athlete's aerobic potential and the lactate threshold as the marker for how much of that potential they are tapping into during an endurance event. This threshold can improve and increase numerically with appropriate training. In theory, an individual could exercise at any intensity up to their VO_{2max} indefinitely. However, this is not the case even amongst elite athletes (13). Again, as the exercise intensity draws closer to that at VO_{2max}, a sharp increase in blood lactate accumulation and subsequent fatigue occurs and the lactate threshold is broken. In world class athletes, lactate threshold typically occurs at 70-80% $VO_{2\ max}$ (7, 13). In untrained individuals it occurs much sooner, at 50-60% $VO_{2\ max}$ (7, 13). In general, if two athletes have the same VO_{2max} value but one has a higher lactate threshold, the one with the higher lactate threshold will more than likely perform better than the other in endurance events. Therefore, the speed (or wattage for cyclists) at which an athlete reaches their lactate threshold is an additional important training indicator versus VO_{2max} value alone (3). Studies have shown that when endurance athletes train at a predetermined percentage of their VO_{2max} on a consistent basis, they are able to train longer at a higher intensity before reaching high blood lactate concentrations (4, 21, 24, 27). In addition, a decrease in heart rate response to the same higher intensity level has been noted (5). For example, the VO_{2max} numbers along with the oxygen cost of running for marathon runners are important factors and has helped to explain the variation between marathon performances (25). Also, one study conducted in 2005 on soccer players demonstrated a significant correlation between laboratory testing of VO_{2max} and performance on the field (8). Training induced improvements in VO_{2max} were reflected in improved performance in these tests and an increase in lactate thresholds was noted (8). If an athlete only has access to indirect VO_{2max} and lactate threshold assessments, they could simply use the predictions from the tests and still formulate a great training program that would reduce the onset of fatigue and injuries if the principles of recovery, intensity and volume are all taken into consideration for such a program. When one increases intensity, they should inversely decrease volume or time of training to prove the reverse truthful.

When an endurance athlete designs their training program, they should have an idea of what their caloric needs are and what energy sources they use at different percentages of their VO_{2max} value to maximize performance (17). The VO_{2max} data is important in calculating caloric expenditure and needs during training and during competition for individualized training plans as opposed to estimations from equations based on height, weight and gender. By directly measuring an individual's oxygen uptake and carbon dioxide production, a more accurate metabolic rate that is sensitive to current fitness levels and physiological changes can be determined. The food source (glucose) that will combine with oxygen in the mitochondria to form ATP during aerobic metabolism can come from fats, proteins or carbohydrates. Nutrients are converted to ATP based upon the intensity and duration of activity, with carbohydrate as the main nutrient fueling exercise of a moderate to high intensity, and fat providing energy during exercise that occurs at a lower intensity. Fat is a great fuel for endurance events, but it is simply not adequate for high intensity exercise such as sprints or intervals (20). If exercising at a low intensity (or below 50% of VO_{2max}), you have enough stored fat to fuel activity for hours or even days as long as there is sufficient oxygen to allow fat metabolism to occur. The major significance of the local adaptations within the muscle may be an increased capacity for use of fat as a fuel, leading to a slower rate of depletion of the limited muscle glycogen stores (16, 20). One study has shown that a major limiting factor to marathon performance is probably the choice of fuels for the exercising muscles (25). Present indications are that marathon runners, compared with normal individuals, have a higher turnover rate in fat metabolism at given high exercise intensities (25). By using optimal intensity for basic endurance training it maximizes this fat burning and minimizes recovery time and risk of injury. Most athletes perform basic endurance workouts at an intensity that is too high (3, 9). Conducting basic endurance workouts at optimal intensity is much more efficient, enabling increased training volume as well as greater frequency and better quality speed workouts. During prolonged exercise at about 50% VO_{2max}, adipose tissue blood flow is increased (20). If an endurance athlete were to train or compete above 50% VO_{2max} continuously, they would then need to subsequently ingest a carbohydrate supplement which may not be always available. Otherwise, glycogen depletion occurs (stored carbohydrates are used up) and if that fuel isn't replaced athletes may hit a wall and will be unable to continue the exercise. In our lab and in clinical practice, we have shown team sports to develop a type of under-diagnosed endurance athlete. We have concluded that these athletes need to spend more time in the off-season improving fat oxidation and aerobic capacity to handle long seasons of competition involving 90-120 minutes of play to improve recovery and avoid fatigue related injuries.

An endurance athlete could use their VO_{2max} numbers easily each day to maximize all biological changes that lead to maximizing their performance by training in the appropriate heart rate training zones. Heart rate monitoring has become the most widely accepted technology for monitoring intensity (1). Heart rate monitoring is a relatively inexpensive, convenient, and effective method of monitoring intensity. The athlete wears a strap around his chest which tracks the electrical activity of the heart and transmits a signal to a wrist unit (or a handlebar mounted unit for cycling) which tells how many times per minute the heart is beating. Heart rate will generally follow a consistent pattern, increasing as intensity rises and decreasing as intensity falls. The athlete then trains by heart rate zones, with each zone keeping him near the optimal intensity for each specific type of training. As with any structured training program, each workout should have a specific purpose. To achieve the ideal response from the body, the stimulation must be specific to the desired adaptation and must allow quick recovery for the next key workout. Intensity, more than any other variable, determines the body's response to the training stimulus.

An athlete should use these heart rate training zones to design their optimal training program that suits the needs of their goals and to avoid overtraining. Once the athlete has their VO_{2max} number and maybe even their lactate threshold number, they should find it easy to plan out their training zones. It is important to note that heart rate cannot be used to identify the anaerobic threshold but it may be used to regulate activity intensity above or below anaerobic threshold (11). After little research, an athlete can find many different interpretations of heart rate training zone descriptions (4, 9, 14). Some of the descriptions of heart rate zones may include the lactate threshold data as well (9, 13, 14, 29). In order to formulate the appropriate heart rate training zones, we need to understand that heart rate maximum (HRmax) closely represents VO_2max (23). So, at a percentage of VO2max, there is a corresponding percentage of HRmax. This relationship has been shown to hold true across sex, age and exercise type (16).

The American College of Sports Medicine (ACSM) suggest that 40% VO_{2max} corresponds to 55% HRmax, 60% VO_{2max} corresponds to 70% HRmax, 80% VO_{2max} corresponds to 85% HRmax and 85% VO_{2max} corresponds to 90% HRmax (26). These target values of % HRmax provide a means of quantifying exercise intensity to optimize training results. So, for example, if the optimal training intensity is 60-80% VO_{2max} then, according to the ACSM, the corresponding optimal training HR is 70-85% HRmax and so on. In order to achieve optimum results, a combination of cardio workout types is recommended. To simplify the heart rate zone descriptions, an athlete can use three main zones as seen in ACSM research articles (2, 22, 28). The zones can be constructed as follows (16, 28):

- ***Zone 1***: below lactate threshold (60-70% HRmax)
- ***Zone 2:*** at lactate threshold (70-80% HRmax)
- ***Zone 3***: above lactate threshold (80-90% HRmax)

Zone 1 may include long, continuous aerobic workouts at a low intensity where distance is generally the driving factor. This zone would build and maintain aerobic endurance. ***Zone 2*** would include tempo workouts where the athlete would train at race pace with intentions on building intensive endurance. Finally, ***Zone 3*** would include interval workouts which are alternate high intensity work periods with low intensity recovery periods.

CONCLUSION

To summarize, a VO_{2max} value will determine the size of an athlete's "engine". Once an endurance athlete has his/her VO_{2max} value, they can then determine their current functional capacity and gauge their future progress. The athlete can also use their VO_{2max} value to determine the right heart rate training zones that will enable their body to not only use the right amount and kinds of fuels but to maximize performance and minimize injury and fatigue. This is primarily due in part to VO_2 and Heart Rate having a linear relationship until the athlete reaches their threshold. The premises by which an endurance athlete incorporates VO_{2max} assessments in their training can be summed up in old adage, "***Why not work smarter?...Not harder!***"

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