Explanation of Lactate Threshold and Vo2max

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Lactate Threshold (or anaerobic threshold)

When increasing running pace or workload there is a point at which lactic acid begins to accumulate. This is a crucial workload, as lactic acid can inhibit muscle contraction and energy production and cause pain and a burning sensation. The point (heart rate or running pace) at which lactic acid begins to accumulate is called the **Lactate Threshold**. This measurement is also sometimes called the anaerobic threshold or onset of blood lactic acid.

The lactate threshold measurement is very valuable as it is one of the more sensitive indicators of fitness level. For example, if training is ineffective the lactate threshold will be reached at a relatively low running speed; with more effective training the threshold will be achieved at a higher speed. Elite athletes reach the lactate threshold at a much higher running speed than sub-elites. The threshold is, once again, a function of effective training and also genetics. Many scientific studies indicate that the lactate threshold is one of the best predictors of distance running performance.

The lactate threshold is also very valuable relative to training and competition. Training at the threshold has been found to improve performance and the capacity of the aerobic system. Interval training and "overdistance" training should thus consider the running speed at which the lactate threshold is attained. The lactate threshold is one of the more important measurements that will be obtained during testing of an endurance athlete.

The lactate threshold for most males is between 165 and 180 beats per minute, with females being slightly higher, at about 175 to 185 beats per minute. Of all the measurements obtained during testing, the speed and heart rate at which the lactate threshold is obtained are probably the most important to remember when planning training.

The lactate threshold can also be 'roughly' estimated by graphing VO2 (l/min) on the x-axis against Ve (l/min) on the y-axis and 'looking' for the ventilation breaking point. Which would generally be 2/3 of the way up the graph. The most accurate way would be to take blood lactates throughout the VO2max test, but if this is not available this graphing technique can work quite well.

For comparison purpose, in competitive regional and national level distance runners, the lactate threshold is reached at speeds of 6:00 to 5:00 pace per mile. A higher speed at the threshold is desirable. The threshold represents a point where the accumulation of metabolites detrimental to performance may begin; thus, a faster threshold speed indicates that the athlete may perform at this speed for a fairly long period of time (possibly up to a marathon) without experiencing undue fatigue. However, when speed or workload exceeds the threshold, the accumulation of lactic acid and depletion of muscle fuels can lead to more rapid fatigue and a slowing of pace.

The lactate threshold is perhaps the best and most sensitive indicator of distance running performance. An individual who reaches the threshold at a speed of 10 mph (16.1 km/hr) would most likely defeat an individual who reaches the threshold at any lower running speed. It is thus desirable to increase the speed at which the threshold is obtained; this can be accomplished by methods outlined below.

1) Training at speeds/heart rates near or at the threshold. The above information has provided you with the approximate speed and heart rate at which the lactate threshold is achieved. Of the two, training at this given heart rate is probably the most effective method for monitoring training intensity relative to the threshold. This knowledge may greatly improve training effectiveness as training near or at the threshold provides a very effective stimulus for improving factors associated with endurance performance.

For example, it was found that when highly-trained distance runners added a weekly 20 min run at the lactate threshold the speed at which the threshold was reached increased after 14 weeks of such training (Sjodin et al., Eur. J. Appl. Physiol. 49:45, 1982). This research also demonstrated that the addition of this single weekly run significantly improved many of the enzymes, which produce energy in muscle. Thus, steady-state training (i.e., longer distance, continuous runs) at the lactate threshold will improve the metabolic capacity of skeletal muscle even in well-trained athletes. It was also found that the addition of the 20 min run improved running economy. Thus, relatively long-duration runs (15-30 min) at the speed or heart rate of the lactate threshold should be considered when designing an effective endurance-training program.

The "theory" behind these adaptations is that at a speed greater than the lactate threshold, lactate acid begins to accumulate in the muscle. The accumulation of lactate then results in a slower running speed and/or shortens the length of the workout where a high speed is attained. By keeping training intensity at the lactate threshold, the muscle and cardiovascular system can be optimally stressed for a relatively long period of time. In other words, the lactate threshold appears to be the "red line" of training intensity; going above this workload results in fatigue, while going below it does not adequately stress the systems involved. It is this "stress" on the cardiovascular and muscular systems, which provides the stimulus for positive adaptations to occur. Such adaptations then lead to enhanced endurance performance.

2) Interval work. Relatively high-intensity, short rest period interval work has also been found to improve the lactate threshold. Cycles of 2-3 minutes of work with 1-2 minutes of rest have been found to reduce lactate accumulation during exercise. As with VO_2max, the principal is that skeletal muscle and the heart adapt when the level of exercise is close or above VO_2max. Unfortunately, this is quite intense exercise, which cannot be maintained for a long period of time (5-15 minutes) due to the accumulation of lactic acid. The lactic acid diffuses out of the skeletal muscle by allowing a "recovery" period of walking or slow running between intense work bouts. Intervals thus allow a high workload to be maintained over a longer time period which results in maximal adaptations. With shorter, intense intervals, the stress is even greater. The endurance athlete and coach should thus not shy away from the performance of relatively "sprint" type work with an active recovery between each bout. Such work has been found to increase the lactate threshold, which is a very sensitive and accurate indicator of performance potential in endurance events.

Knowledge about the lactate threshold can also help in designing workloads/heart rates for various types of training. General recommendations are listed below (from Coen et al., Int. J. Sports Med., 12:519-524, 1991). Implementation of these guidelines may help prevent overtraining and staleness and also provide a maximal stimulus to the muscle and cardiorespiratory systems for development. Please keep in mind that these recommendations are based upon treadmill data under room conditions; different environmental conditions (i.e., heat) and terrain (hills) can alter the relationship.

1) Overdistance runs and "easy" or recovery days should be performed at 80 to 90% of the lactate threshold.

2) Intensive, continuous distance runs (15-30 min duration) can be performed at approximately 100% of the lactate threshold, as discussed above. No more than one of these workouts should be performed per week.

3) Longer interval work (i.e., 800-1000 m repeats) should be performed at approximately 110-120% of the lactate threshold.

4) For shorter, intense interval work the lactate threshold is usually not considered. Keep in mind that such work, although commonly considered "anaerobic" can maximally stimulate the aerobic systems if adequate sets are performed with rest between the sets.

This discussion has emphasized the importance of the lactate threshold to the endurance athlete. A key question for the coach/athlete is how to monitor if the threshold is changing over the course of a month or years over training. Unfortunately, measuring the lactate threshold can only be effectively performed in a laboratory setting. However, the design of my research is to find out possible means of estimating the lactate threshold without having to use the laboratory setting. In the next few months I will have a better idea of which of these estimation formulas most accurately estimated the lactate threshold. I will be glad to share that information with you at that time.

VO_2max (maximal aerobic power)

Maximal oxygen consumption, also known as VO_2max, has long been considered the "gold-standard" for determining cardiorespiratory fitness level. Your VO_2max value is dependent upon several factors:

1) the ability of your muscle to use oxygen to produce energy
2) the ability of your lungs, heart, and circulatory system to transport oxygen to the muscle
3) your body composition, which is the amount of fat and muscle you have.

The measurement of VO_2max is important, as in many athletic events a large amount of the energy needed to perform the exercise is produced through the use of oxygen. For example, it is estimated that approximately 25% of total energy comes from oxygen in short events which last 40 to 60 seconds. In events lasting 100 to 120 seconds about 50% of energy comes from oxygen and in events lasting 3-4 minutes about 65% of the energy comes from oxygen. Longer events such as distance running require greater than 90-95% of their energy from aerobic sources. A high VO_2max is indicative of an enhanced ability of the aerobic systems to provide this energy to the working muscle. Thus a measurement of the capacity of the aerobic system to produce energy is vital to assessing athletic performance. Successful athletes which participate in sports lasting more than 1 minute generally possess a higher VO_2max then sedentary individuals or those in more short-duration, high-intensity oriented sports such as weightlifting or sprinting.

VO_2max value is measured ‘relatively’ in the units of ml/kg/min or ‘absolutely’ in l/min. The VO_2max value in ml/kg/min is adjusted for your body weight while the value in l/min is your absolute maximal oxygen consumption. In many sports, such as running, the commonly used value is ml/kg/min, since the mass of the body must be moved against gravity. Absolute VO_2max is more appropriate for non-weight supported events such as swimming and cycling.

Maximal oxygen consumption is determined by training and genetic endowment; the contribution of each is not known. VO_2max can indicate the **potential** of an athlete for participation in endurance-oriented events. VO_2max can also help determine if a specific training program is efficient in developing the aerobic system.

How does your VO_2max compare to values in other athletes? Keep in mind that any one variable that is being measured as part of your evaluation does not predict athletic performance. However, there are ranges of VO_2max for many different sporting endeavours.

Ranges of VO_2max reported for international athletes in a variety of sports.

Sport	Range (ml/kg/min) Males	Females
Nordic Skiing	69-95	56-74
Middle-distance running	70-86	55-70
Distance running	65-80	55-72
Rowing	58-74	48-68
Cycling	56-72	47-57
Swimming	54-70	48-68
Soccer	50-70	-----
Basketball	45-65	42-54
Baseball	40-60	-----
Untrained	38-52	30-46

From: Physiological Testing of the High-Performance Athlete, Human Kinetics, 1991 and Physiology of Exercise, Human Kinetics, 1994.

VO_2max values of some athletes (ml/kg/min):

Steve Prefontaine, middle distance runner, American record holder	84.4
Lance Armstrong, Tour de France Cycling Champion	83.8
Alberto Salazar, world record holder, marathon	78.0
Bill Rodger, world class marathoner	78.0
Grete Waitz, world class female distance runner	73.5
Frank Shorter, Gold Medalist, Munich Olympic Marathon	71.3
World Class male long-distance runners	78.7
World Class female long- and middle-distance runners	65.6
World Class male marathon runners	74.1
Elite middle-distance and male distance runners	76.9
Good national class male distance runners	69.2

It is evident from the above information that a high VO_2max (greater than 68-70 ml/kg/min in men and 60-65 ml/kg/min in women) must be attained for international success in many athletic events involving endurance, such as distance running. However, there is very little "separation" between VO_2max values in terms of performance; for example an athlete with a VO_2max of 70 will not always run faster than an athlete with a VO_2max of 68. Thus, for your athletic event, you should optimally be in the ranges listed in the presented tables and figures. Generally, a nationally competitive male distance or middle-distance runner will have a VO_2max of approximately 70 ml/kg/min or greater; a nationally competitive female distance runner will have a VO_2max greater than 65 ml/kg/min. To increase VO_2max many factors must be considered by the coach and athlete.

There are four considerations when attempting to **improve maximal oxygen uptake**.

1) Training. One way to improve maximal oxygen consumption is by stressing the aerobic system. Thus, workouts must overload the heart and skeletal muscle. This can be accomplished by performing repeated intense work bouts (intervals or repeats) lasting > 2 min in duration. Maximal stress is induced by the performance of interval work (i.e., exercise lasting 2-4 minutes or longer) with minimal rest (i.e., 30 sec to 1 minute) between sets. Interval training increases VO_2max as more total work can be performed at a higher intensity due to the recovery period between sets. The combination of high intensity and a high amount of total work then stimulates the cardiorespiratory and muscle systems to adapt which increases VO_2max. The "magic" combination of work and rest which will induce optimal improvement is, however, specific to the athlete and must be discerned by the athlete and coach.

It is generally accepted that the incorporation of interval work into a training program or a modification of existing interval work is the most effective way to improve aerobic capacity. However, any type of training which stresses the aerobic systems can improve VO_2max, although to a lesser degree. For example, the incorporation of endurance work may increase VO_2max if an athlete has a low endurance base. However, interval work must ultimately be performed to attain the highest values for a given individual.

2) Genetics. Each athlete has a "ceiling" for VO_2max due to his/her genetic makeup. If training is already optimal, i.e., there are sufficient, regular, and well-planned interval workouts, it is virtually impossible to increase VO_2max any further. This should be kept in mind, as obviously not all individuals can become world-class athletes due to genetic limitations. Thus an alteration in training may not increase aerobic capacity, particularly if the training program is already optimal. On the other hand, individuals with a high VO_2max and low training volume may be genetically predisposed toward endurance events.

3) Body composition. A high VO_2max is associated with a minimal amount of body fat. Adipose tissue (body fat) is essentially dead weight during exercise and leads to a lower oxygen consumption relative to body mass. Since body fat (adipose tissue) does not utilize oxygen, increased body fat reduces the oxidative energy available to move each kg of body weight during exercise. Examine the normative values for body fat outlined in this report; if body fat content is too high then a loss of fat may benefit the athlete. However, most competitive athletes already possess a minimal amount of body fat; thus weight loss is not recommended as a means of increasing aerobic potential for many competitive athletes. To the contrary, an extremely low amount of body fat may actually impede performance. Again, communication between the coach and athlete should be performed prior to implementing any possible weight gain/weight loss program.

4) Event Specificity. (your VO_2max is sufficient for your athletic event) If your VO_2max is within the ranges published for your athletic event, then you may have maximally trained the aerobic system. This would most likely be the case if you have been training intensely for a prolonged period of time and have been incorporating the proper amount of interval and endurance work. It is possible that VO_2max may change slightly with subtle alterations in training; however, this may only be determined by repeated laboratory tests over time.

In summary, VO_2max is a good indicator of fitness level and may change with training. However, if training is already optimal then genetic factors may limit the VO_2max obtained. This test must thus be interpreted in relation to your training and performance potential.