VO_2max and the Endurance Athlete

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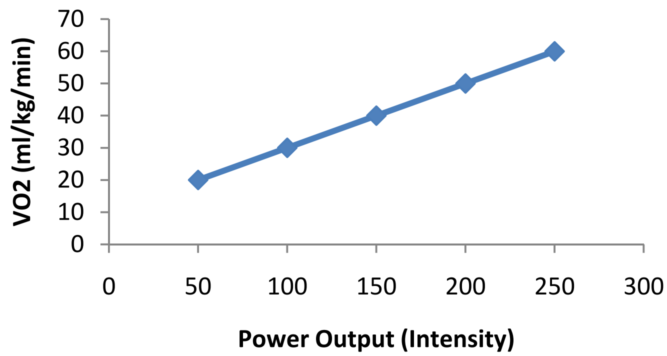
What is VO_2max?

VO_2max is the maximal rate of oxygen use by the body. The 'V' signifies that rate is being expressed. Oxygen is required for aerobic energy processes in practically all the cells of the body. Much of the oxygen is used by muscles and the amount required in muscles increases from rest to exercise. The higher the intensity of exercise, the higher will be the VO_2. At rest, the rate of oxygen use is relatively low as the oxygen-demanding muscle cells are inactive. During exercise, oxygen requirements increase and during maximal aerobic exercise, the body has achieved VO_2max.



An individual's VO_2max depends on several factors including training, gender, age and genetics (see table below).

How is it measured?

VO_2max can be measured in a human performance laboratory and is considered to be the best objective measurement of cardiorespiratory endurance. To measure VO_2, expired air must be analyzed for oxygen and carbon dioxide volumes. To collect the expired air, the individual must breathe through a 2-way valve that allows expired air to be routed through a hose into a metabolic system that contains oxygen and carbon dioxide sensors. These measurements can be performed while an individual is resting in order to measure resting metabolic rate or during exercise. To measure VO_2max, the individual must be exercising at his or her aerobic capacity. The most reliable and valid way to measure VO_2max in most individuals is to have them run on a treadmill during a graded exercise test (GXT). The GXT begins at low to moderate speed and the intensity (speed or grade) is increased every 1-3 minutes until the person achieves exhaustion and can no longer continue. Tests like these can be performed on cycle ergometers, elliptical machines or rowing ergometers. These modes of exercise are more appropriate to their respective athletes. Thus, a cyclist would achieve his or her true VO_2max during a cycle ergometer GXT. As a rule, to determine VO_2max, treadmill is best for non athletes and a sport-specific mode is best for athletes.

What is the advantage to having a high VO_2max?

VO_2max sets a limit to the exercise intensity or pace one can sustain for a prolonged period of time. Refer to the table below and note the VO_2max values for the untrained person before and after 8 weeks of training, compared to an athlete who has been training for years. Running pace or exercise intensity can be expressed as a percentage of VO2max and as an example, 75% is illustrated here. Because of the athlete's higher VO_2max, he or she is capable of running at a faster pace at a given percent of VO_2max. Note that 8 weeks of training can improve VO_2max, and thereby increase the running pace sustained for a period of time.

	Untrained	Trained for 8 weeks	Athlete
VO_2max (ml/kg/min)	45	54	70
75%VO_2max	34	41	53
Running pace (mph) at 75% VO_2max	5.7	7.0	9.2

What physiological adaptations result in a higher VO_2max?

Physiologically, VO_2max is determined by the combination of the cardiorespiratory system's ability to deliver oxygen to the muscle and the muscle's ability to use the oxygen. Exercise can increase VO_2max through adaptations that occur in the heart, blood, blood vessels, and the skeletal muscle cells themselves. Here is a list of some of these adaptations:

Increase left ventricular chamber size	Increase contractility in the heart	Increase oxidative enzymes	Increase capillaries supplying blood to the muscle
Increase red blood cells	Increase blood volume	Increase number of oxidative muscle fibers	Increase mitochondria in muscle cells

How can I increase my VO_2max?

An athlete is specifically interested in optimizing VO_2max and using the best training strategies to do so. Thus, just simply exercising is not enough. Training studies that have measured physiological adaptations to aerobic exercise include 2-6 mon training protocols involving running or cycling 5-6 days per week for 30-60 minutes per session. From these studies, we have learned that endurance training increases both the ability to deliver oxygen to the muscle and the muscle's ability to use the oxygen. An important concept in all this is *specificity of training*. An athlete will only achieve his or her optimal VO_2max by training specifically for his or her sport. Some benefits can be gained from other activities, but these are not optimal for improvements in one's sport. Training strategies for improving VO_2max include the following:

1. Long, slow distance– 50-75% VO_2max or 60-80% max heart rate. This is also known as"conversation" exercise; in other words, you can carry on a conversation during exercise. Adaptations improve cardiovascular and thermoregulatory function, increase aerobic capacity of the muscles & improve use of fat for fuel. Athletes can increase VO_2max with this type of training but only following a period of detraining. An athlete doesn't want too much of this type of training because it does not stimulate the neurological patterns of muscle fiber recruitment required during a race. To continue increasing VO_2max, athletes must train at higher intensities.
2. Pace/tempo, continuous – (85-95% max heart rate). The pace is continuous at an intensity that corresponds to lactate threshold for about 20-30 min. The goal is to develop a sense of race pace and enhance the body's ability to sustain the pace. The muscle's recruitment pattern required for racing is stimulated during this type of training. The cardiovascular system is stressed significantly during high intensity exercise and thus, will greatly improve its ability to deliver oxygen to the muscle. And because more muscle fibers are being recruited at this high intensity, more muscle fibers will improve their aerobic capacity.
3. Intervals – (>90% VO_2max). By doing very high intensity intervals, one can train at an intensity close to max for a longer period of time with regular rest periods compared to continuous

exercise. For instance, at an intensity corresponding to VO_2max, an athlete can exercise continuously typically no more than 5-10 minutes. By performing the same intensity in 2-min intervals followed by 2-min recovery periods, an athlete can conceivably double his or her time spent at that intensity, which will result in greater adaptations. Among the adaptations that come with interval training is the enhanced oxidative capacity of the most powerful muscle fibers. These fibers are recruited only during very high intensities and to improve their aerobic capacity, they must be recruited. Not only does interval training improve VO_2max, but it also enhances an athlete's tolerance to anaerobic exercise. The athlete will be able to recovery from high intensity exercise more quickly. This means that an endurance athlete will be more capable of incorporating sprints during a long distance race. Interval training is very stressful on the body and if performed too often, can increase an athlete's risk of injury and overtraining. It should be performed only with a firm base of aerobic training and followed by adequate recovery periods. Typically, no more than 2 days per week should be devoted to interval training.

Who benefits from a high VO_2max?
A high VO_2max contributes to aerobic or endurance performance typically associated with long distance running, cycling, rowing and swimming. However, a high VO_2max is important for anaerobic-type sports such as soccer or ice hockey that are played over long periods of time and involve intermittent high intensity exercise. A high VO_2max will help this type of athlete by enhancing his or her resistance to fatigue and ability to recover quickly, both of which are critical to game performance.

Can an athlete's VO_2max decrease?
It can if the athlete stops training. Detraining studies have demonstrated that VO_2max begins to decline within the first week of complete detraining. The quick decrease is due to loss of plasma volume accounting for a 10% reduction in VO_2max. If this type of detraining continues for months, loss of muscle adaptations will result, furthering the decline. Classic bedrest studies (the most extreme form of detraining) showed that the length of time to recover VO_2max was 3 times the length it took to lose it. Such information applies more to an athlete's off season experience. However, many athletes continue some form of training during this time and will not experience a dramatic decrease in VO_2max. Athletes who are in training should not be concerned with losing adaptations if a few days of training are missed. In fact, an athlete can decrease his or her training frequency from 6 days to 2-3 days per week and maintain VO_2max as long as training intensity is maintained. Perhaps the greatest threat to an athlete's ability to maintain performance is overtraining, which can result in a significant decrease in performance. An athlete requires adequate rest, especially following high intensity or vigorous prolonged exercise in order to sustain the level of training required for competition.

Is there another way to increase VO_2max besides training?
Yes, technically, but no, legally. I say this because there is only one method I know of that has been explicitly shown to increase VO_2max. And that method is blood doping. There are several other methods (all legal) including nutritional supplements that have been tested but have not resulted in higher VO_2max values, specifically. Oxygenated water and Optygen are two of these that come to mind. There is some scant evidence that omega-3 fatty acids may lend themselves to improving a muscle's ability to extract oxygen from the blood. Whether or not omega-3 fatty acid supplementation improves VO_2max remains to be seen.

Maximal Oxygen Uptake (ml/kg/min) in Various Population Groups			
Non Athletes	**Age**	**Males**	**Females**
	10-19	47-56	38-46
	20-29	43-52	33-42
	30-39	39-48	30-38
	40-49	36-44	26-35
	50-59	34-41	24-33
	60-69	31-38	22-30
	70-79	28-35	20-27
Athletes			
Baseball/softball	18-32	48-56	52-57
Basketball	18-30	40-60	43-60
Bicycling	18-26	62-74	47-57
Canoeing	22-28	55-67	48-52
Football	20-36	42-60	
Gymnastics	18-22	52-58	36-50
Ice Hockey	10-30	50-63	
Jockey	20-40	50-60	
Orienteering	20-60	47-53	46-60
Racquetball	20-35	55-62	50-60
Rowing	20-35	60-72	58-65
Skiing, alpine	18-30	57-68	50-55
Skiing, nordic	20-28	65-94	60-75
Ski jumping	18-24	58-63	
Soccer	22-28	54-64	50-60
Speed skating	18-24	56-73	44-55
Swimming	10-25	50-70	40-60
Track & field, discus	22-30	42-55	
Track & field, running	18-39	60-85	50-75
	40-75	40-60	35-60
Track & field, shot put	22-30	40-46	
Volleyball	18-22		40-56
Weightlifting	20-30	38-52	
Wrestling	20-30	52-65	

Taken from Wilmore and Costill (2005) (3)