The Winning Mindset

Scott Christensen

Understanding VO2 $_{max}$: Part 3 of 3

Purpose:

The purpose of CTCs *The Winning Mindset* is to collect and present articles by accomplished athletes, coaches, and business leaders in an effort to provide our readers with valuable insight into successful training, racing, business, and the characteristics of a high-performance mindset.

Subject:

Coach Christensen was asked to prepare a series on understanding **VO2 $_{max}$** and how to train and improve it. The first and second articles, available on our website, is Scott providing a historical summary of the topic and introducing how VO2 $_{max}$ development applies to runners, how to test for VO2 $_{max}$ fitness, and several training examples.

The third article in the series, presented here, advances the discussion again and finishes the assignment by applying the principles to accomplished athletes at the high school, collegiate, and semi-professional levels.

We are confident that, once an effective coach grasps the concepts discussed in this series – and applies the correct workouts, in the correct order, with the appropriate volume and recovery – the athletes will excel.

Scott Christensen has produced volumes of excellent training presentations that are available for purchase at **CompleteTrackandField.com**.

Coach Christensen's Response:

There is a biological paradox regarding oxygen and life on Earth. In aerobic animals such as humans, oxygen is inflammatory to tissues, damages both cell and mitochondrial membranes, the main cause of cell death, responsible for aging, and is linked to cancer and cardiovascular disease. However, humans absolutely need it for respiration. Homeostasis is largely accomplished by ATP production from aerobic biochemical reactions. Because of the negative effects of oxygens reaction on tissue, the human body does have the capability to store much oxygen. The only place it is found outside of cells is what is dissolved in blood. The quantity of oxygen is kept to a bare minimum in the human body to minimize oxygen damage caused by loose oxygen molecules that escape the system (ROS-Reactive Oxygen Species). That is why oxygen will usually be the limiting factor in human activities that last longer than 1-2 minutes. It also explains why there is a $VO_{2\ max}$ in muscle tissue, as there is not an unlimited supply of oxygen available for muscle contractions.

The $VO_{2\ max}$ system is fully mature by age 20 in humans. As adults, males have a mean 10-15% higher standardized (ml/kg/min) $VO_{2\ max}$ value than females, but in overall oxygen consumption capability, males are nearly double that of females (figure 1). This is due to males possessing a larger body, bigger heart, more miles of capillaries, more blood, less body fat, and more muscle.

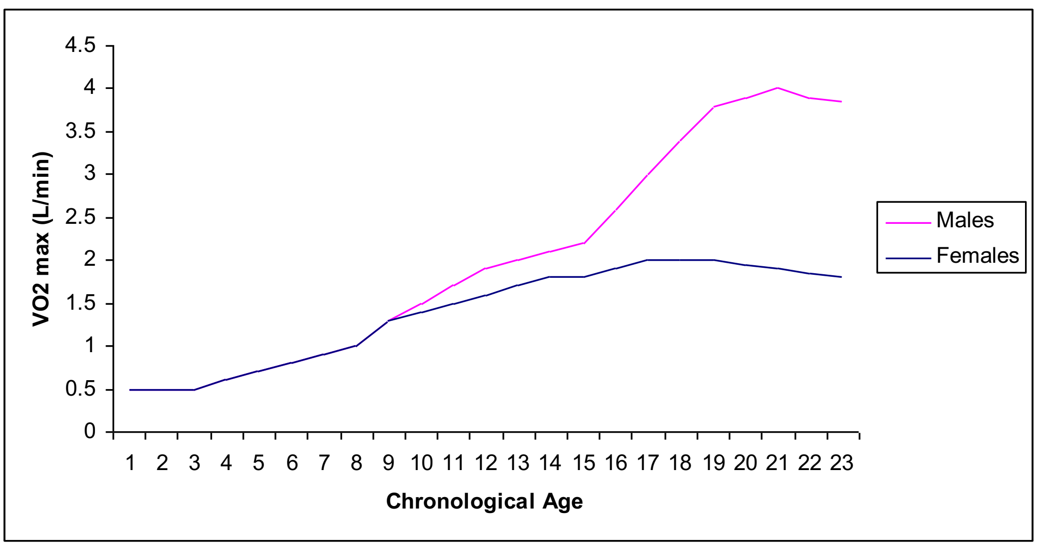

Figure 1. Changes in maximal oxygen uptake with age are shown.

Despite maturity, adaptations to the $VO_{2\ max}$ system can continue to occur through progressive aerobic-based stimuli that target both the central and peripheral aspects and will improve a human's ability to use greater amounts of oxygen even beyond the genetic ceiling.

As an example, American female distance runner Deena Kastor began working professionally with noted distance coach Joe Vigil Ph. D., after graduating from the University of Arkansas. She was already in prime physical fitness after leaving Arkansas as a four-time SEC champion due to her successful training program under Razorback coach Lance Harter. Dr. Vigil continued to train Ms. Kastor for ten years. That time period included Ms. Kastor earning an Olympic Bronze Medal in the marathon and a Silver Medal in the World Cross Country long course race. Upon commencing a training program with Dr. Vigil, he began a series of laboratory $VO_{2\,max}$ tests on her that continued for ten years. Deena Kastor was mature and fit at age 22 when she turned pro. How much more could her $VO_{2\,max}$ improve, even with an additional ten years of 100 mile weeks of training? At the professional level, even a 1-2% improvement could be the difference between making it and not making it. Table 1 indicates the results of Ms. Kastor's $VO_{2\,max}$ test results.

Age	$VO_{2\,max}$
22	77.5 ml/kg/min
27	80.5 ml/kg/min
32	81.1 ml/kg/min

Table 1. Shown are Deena Kastor's $VO_{2\,max}$ test results at different ages during sustained aerobic training.

Deena Kastor improved her already very high $VO_{2\,max}$ by almost 5% in the ten years she worked with Dr. Vigil. The improvement was no doubt equally spread between further central and peripheral development, with much of the percentage explainable by her considerable time living and training at 2400 meters altitude. While $VO_{2\,max}$ is not the only factor in distance racing success, it is a big factor.

Documented training schemes designed to improve both $VO_{2\,max}$, and aerobic power velocity ($vVO_{2\,max}$) in distance runners were first described by the Soviet Sports Institute in the 1970s. Besides the Eastern Bloc countries, one of the athletics organizations to quickly pick up on the training concept was the British Milers Club in the early 1980s. Frank Horwill, and a bit later Peter Coe were two of the coaches that understood the process of improving aerobic power with very specific stimulus applications. Meanwhile, in the United States, David Costill Ph. D., David Martin Ph. D., Joe Vigil Ph. D., and Jack Daniels Ph. D. were all developing distance runners through aerobic power training schemes and detailing and publishing their progress through rigorous application of the scientific method. These pioneers shaped the modern-day field training protocol of addressing improvement in aerobic power through specific stimuli.

Since the early days, it has been well known that aerobic power development is one of the four training domains used in preparing distance runners. Consider the combined energy zone events of the 800 meter race, through the 10,000 meter race. Improvement in the anaerobic glycolytic domain in all of these races hinges on better management of hydrogen/lactate ion presence; while aerobically, the three domains are: improving running economy, shifting the lactate threshold, and boosting aerobic power. These three aerobic domains have a sliding influence based on the distance of the race. The shorter distance races lean more toward aerobic power, while the longer races lean more toward running economy.

Aerobic power training-related sessions done to improve $VO_{2\,max}$ can be either continuous efforts or interval-style in design (table 2). Generally speaking, continuous efforts benefit central development while intervals benefit peripheral development. During interval sessions, the work to recovery ratio in novice and emerging runners is usually seen as a 1:1 ratio. In older, more experienced runners, the work to recovery ratio can begin to drop and will eventually fall to nearly a 1:.50 ratio. Whatever the work to recovery ratio for an athlete is, the goal of the training session is to administer just enough recovery so that the repeated efforts can continue to meet current $vVO_{2\,max}$ pace. There should be no time degradation in performance as the work proceeds. Because interval $vVO_{2\,max}$ work is done at two mile pace, all interval aerobic power training sessions should meet or exceed two miles in total volume and cap out at no more than 8000 meters. Continuous efforts can be 1-3 hours in duration.

Extent of Work Session	$vVO_{2\,max}$ (current 2 mile test)	Work time	Recovery time	Total volume	Percent $vVO_{2\,max}$
14 x 400 meters	(10:52) 5:26	81	80	5600 meters	100%
7 x 800 meters	(9:53) 4:56	2:28	2:30	5600 meters	100%
6 x 1000 meters	(11:43) 5:51	3:40	3:40	6000 meters	100%
4 x 1600 meters	(8:51) 4:25	4:25	4:30	6400 meters	100%
1 x 3200,1 x 1600 meters	(9:14) 4:37	9:15, 4:37	9:15	4800 meters	100%
5 x 1000 meters	(12:00) 6:00	4:10	3:00	5000 meters	90%
1 x 7200 meters	(12:24) 6:12	32:49	NA	7200 meters	85%
1 x 16,000 meters	(11:24) 5:42	87:41	NA	16000 meters	65%

Table 2. Shown are examples of aerobic power related training sessions for distance runners of various abilities.

Table 2 indicates that as $vVO_{2\,max}$ intensity drops below 100%, then the recovery interval and/or the total volume of the session changes significantly. This affirms the contrast in training between interval work (100% $vVO_{2\,max}$) used for peripheral aerobic power development, and continuous steady state work (<100% $vVO_{2\,max}$) used for central aerobic power development.

There are three general categories of skeletal muscle fibers in humans based on the speed of filament (actin and myosin) contraction in movement activities. Every person has a unique blend of the three fibers coded on their genome, and the predominant type becomes fixed in the muscles at about age one in preparation for upright walking. The three types are: a.) Type 1, which are by nature, slow contracting with small force production, but high endurance, b.) Type 2A, which are fast contracting, with high force production and some endurance, and c.) Type 2B which are fast contracting, with very high force production, but little endurance. The speed of a contracting fiber is based on two variables. The first variable is the ATPase enzyme that is found in the specific muscle cell. Type 1, has the slower acting ATPase present and Type 2B, has the quicker acting ATPase enzyme present. Type 2A has a mixture of the two ATPase enzyme types and that is an important factor in aerobic power training activities. The second variable is the number of mitochondria found in the muscle cell. Type 1 has many mitochondria, Type 2B has few mitochondria, and Type 2A has some mitochondria with the ability to generate many more. This is another important characteristic to be used in aerobic power training.

Movement is described as internal force production working against outside forces; chiefly gravity and friction. Walking and jogging utilize Type 1 muscle fibers to a great degree to generate the necessary force. Sprinting 100 meters mainly utilizes Type 2B muscle fibers to get the job done. Combined zone races utilize all three fiber types to a varying degree.

Exercise physiologists suggest that running up to 75% $vVO_{2\,max}$ develops Type 1 fiber to the greatest extent while running over 150% of $vVO_{2\,max}$ develops Type 2B fibers to the greatest extent. Studies have also shown that running at an intensity up to 90% of $VO_{2\,max}$ will transform Type 2A fibers to act more like Type 1 fibers by producing more mitochondria and shifting to the slower variety of ATPase enzyme. Further studies have shown that this transformation in 2A fibers occurs at the highest rate during intensities of 80-90% $vVO_{2\,max}$. If a runner adds additional Type 2A muscle fiber recruitment to the Type 1 fibers present, then aerobic power will improve.

Training pace is the key to effective $vVO_{2\,max}$ based work sessions designed to develop aerobic power. As examples, let's look at a trio of experienced runners and some different workouts they might do to stimulate the development of aerobic power in both the central and peripheral components.

1. Eli is a junior on the track team and has a training age of three. He is also one of the best high school distance runners in the country. Last week, in a mid-season Invitational meet, Eli ran 8:58 for 3200 meters. His goal is to run 8:52 at the state meet which is five weeks away. What might Eli's coach have him do at practice today to stimulate both central and peripheral $vVO_{2\,max}$ system development? Eli has been running 65 miles per week for the past 22 weeks. His central $VO_{2\,max}$ development is nearly complete for this particular macrocycle. If Eli is to find another five seconds (.009%) improvement in his 3200 meter time it will most likely come from further peripheral $VO_{2\,max}$ gains. His coach embraces technology for work session monitoring and frequently pricks Eli's finger for lactate analysis and has Eli wear a heart monitor to measure workout intensity and interval recovery time. All of these gadgets will be used today in Eli's prescribed workout of 5 x one-mile repeats, to be done at $vVO_{2\,max}$, with a work to recovery ratio of 1:1. Since Eli ran 8:58 for 3200 meters last week, his current $vVO_{2\,max}$ is 4:29/mile. That time will be both today's workout pace and his recovery interval. Peer-reviewed studies published by clinical physiologists have helped Eli's coach set up the monitoring of today's work session. Studies on pace and interval recovery for $VO_{2\,max}$ work are well established, and so are heart rate (HR) and lactate levels. Clinical studies suggest that the most effective $VO_{2\,max}$ peripheral work is done at 88% of HR_{max} and at a lactate level of 9.0 mmol/L. Both measured heart rate and lactate should correlate with current $vVO_{2\,max}$ in a well-designed work session. At 17 years old, Eli has an HR_{max} of about 196 bpm using the formula, HR_{max} = 207- (0.7 x age). The work done today should be around 175 bpm. After completing the workout, Eli proclaimed it a success because he ran very close to his $vVO_{2\,max}$ for each of the five repeated miles. Eli's coach withheld judgment, pending his analysis of the data table built in table 3.

Mile Repeat	HR $_{pre}$	HR $_{post}$	Lactate $_{pre}$	Lactate $_{post}$	Time of Repeat
Mile #1	118 bpm	176 bpm	3.1 mmol/L	8.7 mmol/L	4:31
Mile #2	116 bpm	174 bpm	3.6 mmol/L	8.8 mmol/L	4:29
Mile #3	119 bpm	177 bpm	3.7 mmol/L	9.4 mmol/L	4:30
Mile #4	118 bpm	176 bpm	4.2 mmol/L	9.3 mmol/L	4:31
Mile #5	120 bpm	179 bpm	4.9 mmol/L	9.8 mmol/L	4:28

Table 3. Eli's mile interval session data based on a current 3200 meter time of 8:58.

Based on the results shown in table 3, Eli's coach wound up being happy too. Eli completed the workout with all of the variables falling in line with one another. This workout has a 48 hour recovery.

2. Andy is 21 years old with a training age of six. He is a junior on the university track team and specializes in the 5k and 10k. He just ran the 5k at Penn Relays last Saturday and has about three weeks until the important championship meets. He wants to do some kind of full $VO_{2\ max}$ session tomorrow as it is supposed to be 63 degrees with little wind. After talking to his coach, they have decided to go to the physiological edge of $VO_{2\ max}$ work; with outer limits in intensity, repeat work extent, and total session volume. Three days ago, Andy warmed up and then ran a two mile time trial on the track, before adding a nine mile run on the roads at aerobic threshold pace to the same session. His two mile time was 9:12, so his current $vVO_{2\ max}$ is 4:36. Tomorrow's workout will be, 1 x 3200, then 1 x 1600, and then 1 x 3200, all done at $vVO_{2\ max}$ on the levee trail. In essence, Andy's goal is to run 9:12, rest 9:12, run 4:36, rest 4:36, and then run 9:12. For a $VO_{2\ max}$ work session, the pace is correct ($vVO_{2\ max}$), the work/recovery interval is correct (1:1), the extent of each repeat is correct (3200 meters or less), and the total volume is correct (8000 meters). While all variables are correct, they are all pushed out to the farthest limit. This is a very tough workout that is theoretically possible, but the last 3200 meters will be quite a struggle toward the end. If Andy can get somewhat close to 9:12 for the second 3200 meter run, then his $VO_{2\ max}$ fitness is in great shape. The workout has a recovery of 48-60 hours.
3. Sara is a 23-year-old post-collegiate athlete now living in Flagstaff, Arizona. She was mainly a 1500 meter runner while competing in college and living in Florida. Sara moved to the mountains because she has decided to now concentrate on the 5k. She believes living at 2100 meters will speed development of her aerobic energetics. Sara wants to establish her altitude physiological markers so that she can do her long runs, tempo runs, and $vVO_{2\ max}$ runs at the proper pace from her door. For anaerobic themed and some distance work, she will drive 45 minutes to the high school track and scenic trails of Sedona, Arizona, which is 1300 meters altitude. Doing a $vVO_{2\ max}$ test of two miles for a non-altitude native person, even an elite runner will not be accurate at the present time. Sara will do better with a one mile test. Sara's one mile test in Flagstaff will give her an accurate $vVO_{2\ max}$ if she wants to run an aerobic power session down in Sedona, but if she wants to do the same workout in Flagstaff, an exhaustive one mile pace cannot be continued for another mile at altitude so the test data needs to be adjusted. Sara needs to take a percentage of her one mile time at altitude to do $vVO_{2\ max}$ work at altitude. She should begin her

$vVO_{2\ max}$ work at 91% of her one mile test, and work toward 97% as she acclimates over many months. Making this time adjustment will keep the three $VO_{2\ max}$ variables of pace, repeat work extent, and total session volume, the same at altitude as at sea-level. Sara ran her one mile exhaustive time trial in 4:25 on the track in Flagstaff. Her current $vVO_{2\ max}$ is 4:51/mile at altitude. In two days, she will do 6 x 1000 meters on an asphalt trail outside of Flagstaff. Her goal is to run 3:02 for each of the five 1k repeats. Because of her training age and elite skill level, she is lowering her recovery interval to two minutes (work/recovery ratio = 1/.66). This workout has a 48 hour recovery.

Aerobic power training exercises are not done in isolation from the other aerobic domains. Work sessions directed toward $VO_{2\ max}$ improvement also concurrently improve aerobic capacity and running economy. Greater aerobic power can also help shift the lactate threshold to a higher pace. Running economy, which is the efficiency a distance runner consumes food energy and oxygen molecules to facilitate movement, is dependent on aerobic power because the economy too is heavily dependent on greater blood flow to the muscles. Running economy improves with $VO_{2\ max}$ training, as does lactate threshold velocity. Increased aerobic power is evidenced by a bigger heart, greater stroke volume, increased capillary beds, greater total blood volume, and more mitochondria and enzymes. All of these are linked to the improved running economy, which can be thought of as simply the energy cost of movement. In essence, a distance runner completes a greater and greater distance in the same amount of time with increasing improvements to aerobic power and running economy.

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