## *6) THE TIME COURSE OF TRAINING ADAPTATIONS*

So far, I have exposed you to some basic physiological variables that are known to 1) bear a strong relationship on endurance performance in every sport and 2) respond to training. By now, I hope you can recite with me the "Big Three" elements of endurance performance:

1. **Maximal Oxygen Consumption**
2. **Lactate Threshold (OBLA - Onset of Blood Lactate Accumulation)**
3. **Efficiency**

**Number 1 is an oxygen delivery issue**. A high maximal capacity for blood delivery means higher oxygen delivery and the potential for more muscle to be active simultaneously during exercise. VO2 is primarily limited by the maximum pumping capacity of the heart, and the specific arterial development to the active muscles.

**Number 2 is an oxygen utilization issue.** The greater the intensity of work we can achieve prior to the point when we begin to accumulate the inhibiting acidity of lactic acid, the faster sustained pace we can tolerate. The limiting adaptations are the capillary density, fatty acid breakdown, enzyme level and mitochondrial density in the specific skeletal muscles used in your sport. Combining elements 1 and 2 gives us the sustainable power output of your "performance engine".

**Number 3 Efficiency,** links sustainable power to performance velocity. The better the efficiency, the greater the achieved velocity at a given level of energy output. Since, ultimately, we have a limited "engine" size, improvements in efficiency are critical to additional improvements in performance time.

In this article I want to discuss the time-course of change in these variables. "How long does it take for my max VO2 to peak out?" "What about lactate threshold?" Understanding the answers to these questions will be important as we try to build appropriate training programs.

**The First Wave of Change- Increased Maximal Oxygen Consumption** ***(see subcategory-(1.a.v) above)***

In a **previously untrained person**, VO2 max is increased significantly after only one week of training! The reason for this early improvement appears to be an increase in blood volume, which results in improved maximal stroke volume ***(see subcategory-(1.a.i) above)***. As training continues, VO2 max continues to increase, for several months, albeit at a slower rate of improvement. We have already discussed the fact that the heart appears to be remodeled by endurance training, developing a greater ventricular volume diameter, and other more subtle adaptations that make it a more effective pump. After about 3-4 months of regular exercise, the improvement in maximal oxygen consumption begins to level off dramatically. At this point, it is common to see about a 15-20% improvement in this variable. For example, a hypothetical male (who I will call Bjorn) with an initial VO2 max of 3.5 liters/min (at a bodyweight of 75kg, that's 47ml/min/kg) may increase to 4.0 liters/min, a 14% increase in **absolute** VO2. If in the process of training, Bjorn also loses 4kg (close to 10 pounds), then his **relative** VO2 max will have increased even more (from 3500/75 or 47, to 4000/71 or 56 ml/min/kg). This is a nearly 20% improvement. Unfortunately, after another 6 months of training, it will have increased little more, if any. If the level of training intensity remained the same after the first 4 months, then no further changes would be expected. If on the other hand, Bjorn continues to intensify his training over the next 6 months, a small additional increase might occur. This increase might be as much as 5 additional percent, bringing our example athlete up from an initial value of 3.5 liters/ min at 75 kg, to 4.2 liters/min at 70kg (he also lost another 1 kg of fat). That's 47 ml/min/kg up to 60 ml/min/kg due to a combination of both increased absolute VO2max (20%) and decreased bodyweight (6.7%), for a total improvement in relative maximal oxygen consumption of 27%. This is actually an unusually large improvement in this variable, but definitely plausible.

If our example subject started at a higher level of VO2 ***(see subcategory-(5) above)***, the relative improvement would almost certainly be less dramatic. The important point to recognize from this is that VO2 max increases fairly rapidly in response to chronic exercise, then plateaus. If our example athlete continues training another 5 years, his VO2 max won't improve any more. It might actually decrease slightly due to age related declines in maximal heart rate ***(see subcategory(1.a.iv) above***. Depressed? Don't be. There is much more to endurance performance then the VO2 max.

**The Second Wave of Change - The Lactate Threshold *(see subcategory-(3.a) above)***

At the same time Bjorn's VO2 max was increasing due to central and peripheral cardiovascular adaptations, changes were beginning to occur in his skeletal muscles (let's assume Bjorn is a runner, so the adaptations of interest are happening in the legs).

Initially, an incremental exercise test on a treadmill revealed that Bjorn began to show a substantial increase in lactic acid concentration in his blood while running at 60% of his maximal oxygen consumption. Remember, his max was 3.5 liters/min. 60% of this is 2.1 l/min. So functionally speaking, **2.1 l/min** was his threshold workload for sustained exercise. If he runs at a speed that elicits a higher VO2 than 2.1, he fatigues quite quickly. However, over time, the overload of training induced quantitative changes to begin occurring in his leg muscles. Mitochondrial synthesis increased. More enzymes necessary for fatty acid metabolism within the muscle cell were produced. And, the number of capillaries surrounding his muscle fibers began to increase. Additional capillaries are being constructed. The functional consequence of these local muscular adaptations is a very positive one. Bjorn's running muscles use more fat and less glycogen at any given running pace. And, the glycogen metabolized to pyruvate is less likely to be converted to lactic acid and more likely to inter the mitochondria for complete oxidative metabolism. Consequently, Bjorn's lactate threshold begins to increase. After 6 months of training, in addition to a higher VO2max, his lactate threshold has increased from 60% to 70% of max, a 17% improvement in an absolute sense, but functionally much more. Why? Because the 70% is relative to an increased max! So, Bjorn has gone from an initial sustainable oxygen consumption of **2.1 liters/min** (60% of 3.5) to a new sustainable intensity of **2.8 liters/min**, a 33% improvement!

Now, the important thing to know is this. While VO2 max plateaus quite rapidly, lactate threshold does not. If Bjorn continues to train, and increase his intensity appropriately, his lactate threshold will continue to improve slowly for a longer period. Of course, improvements in lactate threshold also plateau, otherwise elite athletes that have been training for 15 years would have LT's of 100% of VO2 max! **But, the time course of adaptation is slower**, so the plateau occurs after a longer period of intense training, probably several years.

It is also important to remember that the lactate threshold is even more specific to the mode of exercise than the VO2 max. This was exemplified by a study performed by Coyle et al. and published in 1991. In this study, 14 competitive cyclists with nearly identical VO2 max values differed substantially in their lactate threshold determined during cycling (ranging between 61 and 86% of VO2 max). When the cyclists were divided into a "low" and "high" LT groups (66% vs 81% of maximal oxygen consumption), it was found that the two groups differed considerably in the years of **cycling training** (2.7 compared to 5.1 years on average). However, they did not differ in years of **endurance training** (7-8 years of running, rowing etc.) When the low cycling LT and high cycling LT groups were asked to perform a lactate threshold test while running on a treadmill, the two groups were no longer different. Measured while running, the lactate threshold in both groups averaged over 80% of VO2 max. Similarly, if you are a runner and decide to add swimming and cycling to your training and compete in triathlons, you will immediately recognize that your running fitness does not immediately transfer to the bike, and of course not to the water!

### The Third Wave of Change - Efficiency *(see subcategory(3.b) above)*

The final element of our BIG THREE endurance adaptations is efficiency. I think we all know what it means to be an "efficient" person, or own a "fuel efficient car". But, what does the term mean when applied to endurance performance? It means the same thing, getting more done at lower "cost". Efficiency is defined as MECHANICAL WORK / METABOLIC WORK. For example, one (quite good) cyclist can sustain 300 watts power output for 1 hour on a cycling ergometer at a sustained VO2 of 4.3 liters/min. Another rider performing at the same oxygen consumption, squeezes out 315 watts, a difference in **efficiency** of 5%. Even though both riders have the same "metabolic engine" they have different power output capabilities. You don't do 40k time trials on a lab ergometer, though. So, thanks to my friend the cycling guru, Jim Martin, we can predict their actual performance time in a 40k time trial. If these two cyclists have identical aerodynamics and use aero bars, the times will be 56:10 vs. 55:15. This is only a one minute difference, but probably worth at least 2 or 3 places at the Masters Nationals Time Trial!

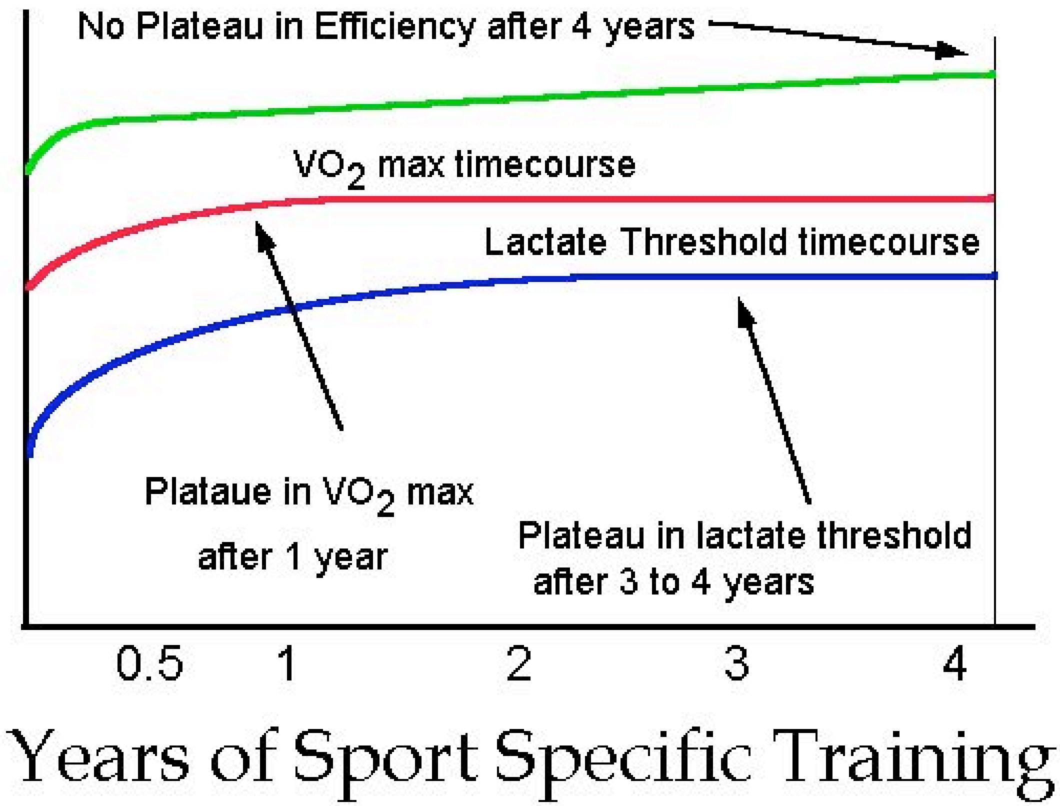
So efficiency makes a difference, often much bigger than the above example. And it also varies among different athletes. That's interesting, but not terribly useful for YOUR training. Your big question is probably "Can **My** Efficiency Improve With Training?". The answer is YES. In highly technical sports like swimming, efficiency differences between beginners and experienced swimmers can be absolutely tremendous! Swimmers already know this full well. In rowing, efficiency also improves dramatically at first, due to gross technical improvements. However, efficiency can also continue to improve after years of training. Dr. Fritz Hagerman followed one group of national class (U.S.) rowers for 8 years, measuring ergometer performance, VO2, lactate threshold, etc. Peak values for maximal oxygen consumption and lactate threshold stabilized after only 2 or 3 years in these hard training athletes. However, performance times on the water and on the rowing machine continued to improve over additional years of training. The reason? Slow improvements in rowing efficiency. One source that is independent of on-water technique may be optimization of workload distribution among the large muscle mass employed in rowing. Ultimately, the rowers who went on to become national team members and have success at the highest levels were more efficient than their peers.

**What about the "less technical" sports like cycling and running?**

For you cyclists, I call cycling less technical only in reference to the act of pushing the pedals, not all of the equipment and aerodynamics! Again there is evidence for significant improvements in efficiency even after years of training. In studies performed on "Good" vs. "Elite" cyclists carried out by Dr. Ed Coyle and colleagues at the University of Texas, it appears that elite riders sustain higher power outputs despite similar physiological values in part by learning to distribute the pedalling force over a larger muscle mass. In running, fomer U.S record holder in the mile, Steve Scott, was shown to have improved his running efficiency even "late" in his career.

**The Bottom Line**

Based on a tremendous amount of both laboratory and "field" data, I would propose to you that the order in which the BIG THREE endurance performance variables reach their peak is 1) VO2max, then 2) lactate threshold, then 3) performance efficiency. Putting it all together, and neglecting for now the negative impact of aging on maximal oxygen consumption ***(see subcategory-(1.a.iv) above)***, we might get something like the figure below. The figure below is obviously very generalized. In reality, all three variables fluctuate during the year (off season vs competitiion period) as a function of training intensity and volume. Peak values after a given period of training will approximate this kind of pattern, though.




Obviously, if you are just beginning in an endurance sport, then all three elements will probably improve dramatically, almost no matter what you do! But, if you have been training in sport for a year or more, you must construct your training program with more and more care to continue making progress in those adaptations that have "room to improve" while maintaining the levels of those that have plateaued or are beginning to. Since for the masters athlete, the option of "just adding another workout" is usually not a viable one, this will often mean finding the right distribution of a limited amount of training time among a variety of workout types. In the next article on my agenda, "Understanding Intervals", I will start to explore some different training methods used by the endurance athlete, from a physiological standpoint. Stay tuned.