

11) VENTILATION AND ENDURANCE PERFORMANCE

Do our lungs limit how fast we can go?

So far, on the MAPP I have devoted a lot of attention to two major organ systems that are intimately linked in exercise performance, the skeletal muscles and the cardiovascular system. Now I want to factor a third, equally important system into the equation, the pulmonary system. I am going to discuss breathing and exercise.

The term ventilation is used in physiology circles exclusively in reference to gas exchange in the lungs. You will also see the word respiration, but exercise physiology types often like to reserve this word for use in a cellular metabolism context, so I will try to use ventilation when I mean breathing. Now, when you hear a non-smoker trapped in a smoke-filled room gasping something about "this room needs better ventilation," she means that the room does not have very rapid air-exchange with the outside, smoke-free air. Conversely, in a room that is well-ventilated, the air always seems fresh even when lots of people are crammed together in a small enclosed space, sucking in oxygen and blowing out lots of "waste-products." You non-physiologists prefer to call this situation "a party."

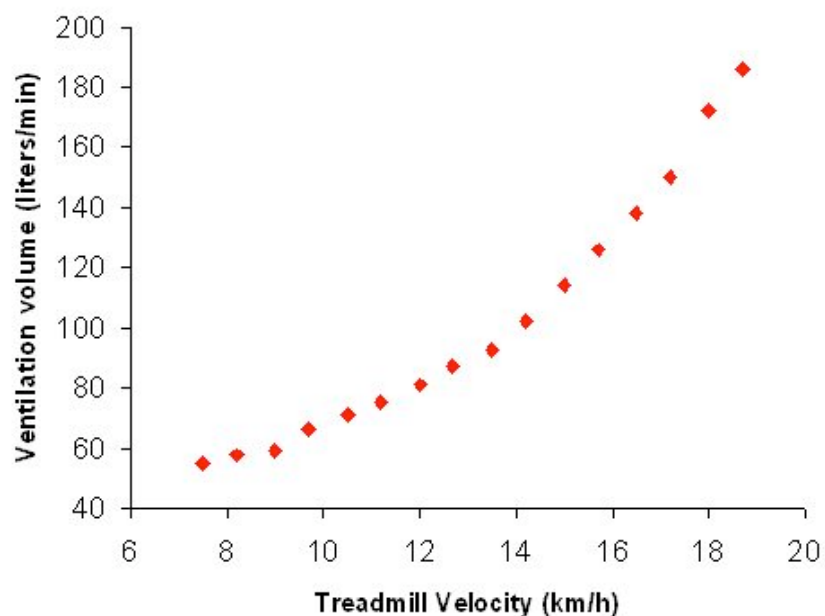
Rooms depend on air-conditioning systems, or big windows and a breeze for ventilation. Our body depends on the lungs, the diaphragm and several intercostal muscles, and a sensitive feedforward/feedback controlled regulatory system to control them. The purpose of the lungs is to ventilate the blood. Blood is the transport vehicle that carries oxygen to all of our cells, and carts off the constant production of CO₂ that is produced as a by-product of both metabolism and pH buffering. The lungs are the site of pickup from and delivery to, the atmosphere. The greater the demand for oxygen delivery and CO₂ removal, the greater the air volume that must circulate in and out of the lungs each minute. All animals of any size at all have had to come up with a ventilation system to get oxygen from the atmosphere down to the most hidden of the cells via the blood. Fish have gills. Insects have a system of air tubes called trachea. We mammals own beautiful pink lungs.

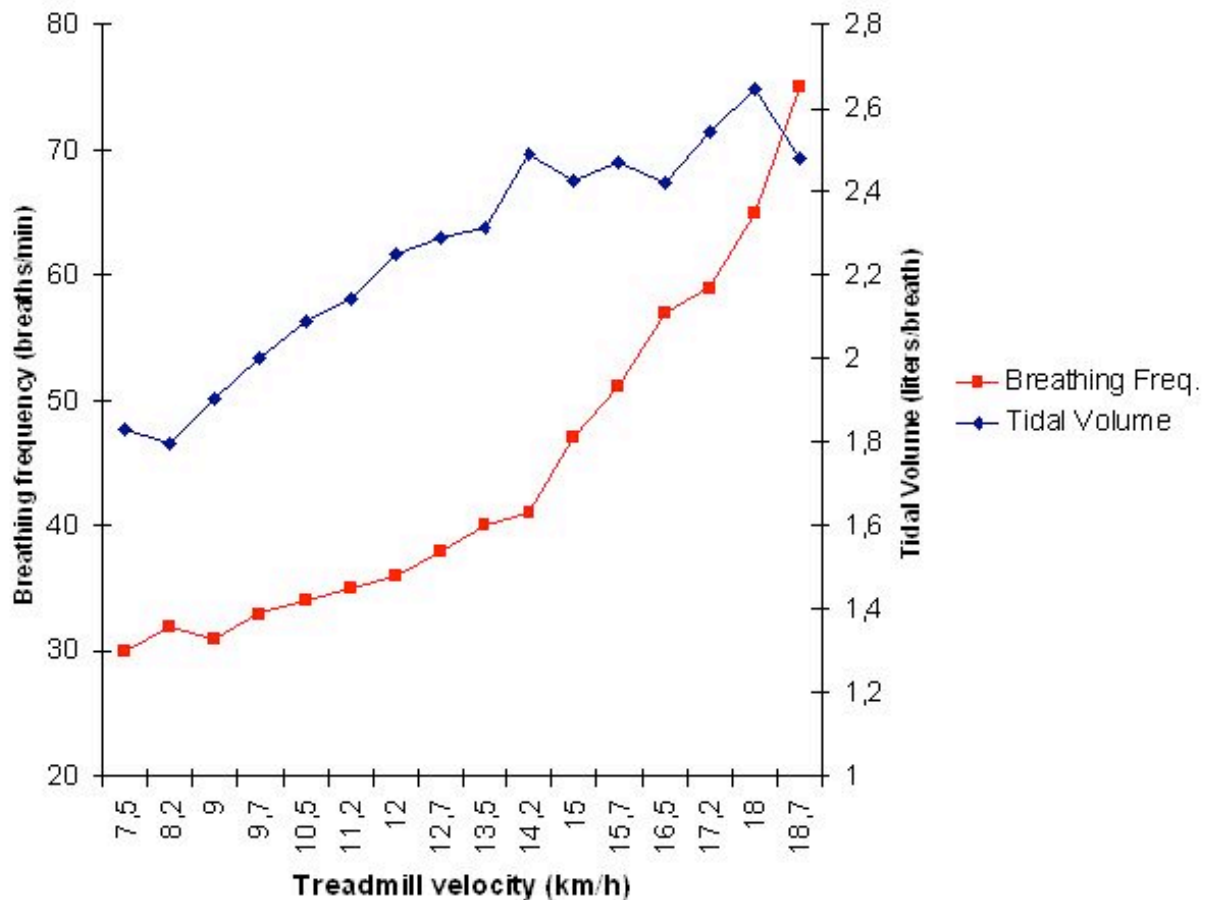
Three aspects of ventilatory function: air exchange, O₂/CO₂ exchange, and blood-gas carrying capacity

1. Air Exchange: Moving air in and out of the lungs

Sitting here in front of my computer, I am breathing about 12 times per minute (although if I try to count my own breathing rate, it will change because I am thinking about it). So my ventilatory frequency (Vf) is 12 breaths/min. Each breath has a volume of about 0.75 liter. This is my resting tidal volume, the volume of air flowing in and out of my lungs each breath. Multiplying ventilatory frequency (Vf) times tidal volume (TV) gives me ventilatory volume (VE), which is 9 liters/min in my example. This is the volume of air moving in and out of my lungs each minute. Somewhere in my files, I have the data from one of the VO₂ max tests I did as a graduate student. During that test, my ventilatory volume (liters/min) peaked at 187 liters/min. That is over 20x greater than at rest. How do our lungs meet the demands of exercise?

Ventilation is regulated in much the same manner as cardiac output. The heart increases cardiac output by increasing both stroke volume and beating frequency. The respiratory nerves control ventilation similarly. At low exercise workloads, the dominant ventilatory adjustment is an increase in tidal volume, the volume of air being moved in and out of the lungs each breath. At high workloads, an increase in breathing frequency is the primary adjustment. The two figures below visualize this. The first figure shows the overall ventilatory response during a treadmill test with progressive increases in velocity every 60 seconds, and a constant incline of 5%. The second figure breaks the ventilatory response above into breathing frequency and tidal volume. This is real, unsmoothed data collected during a test of a well trained runner.





Unlike heart function, ventilation is under considerable voluntary control (with involuntary override mechanisms!). So, you might ask the question, "Can I control my breathing to make it more efficient?" For example, you could decrease the breathing frequency and take bigger deeper breaths to achieve the same total ventilation volume. Studies have indicated that normally the body spontaneously balances the depth of ventilation and the frequency of breathing so that ventilation is optimally efficient. You may also have noticed that at low exercise intensities, you can "play" more with your breathing, by varying its rate and depth. However, as the workload gets high, especially at workloads above the lactate (and ventilatory) threshold, the body assumes much tighter control on breathing and there is far less room for variation in breathing "strategies."

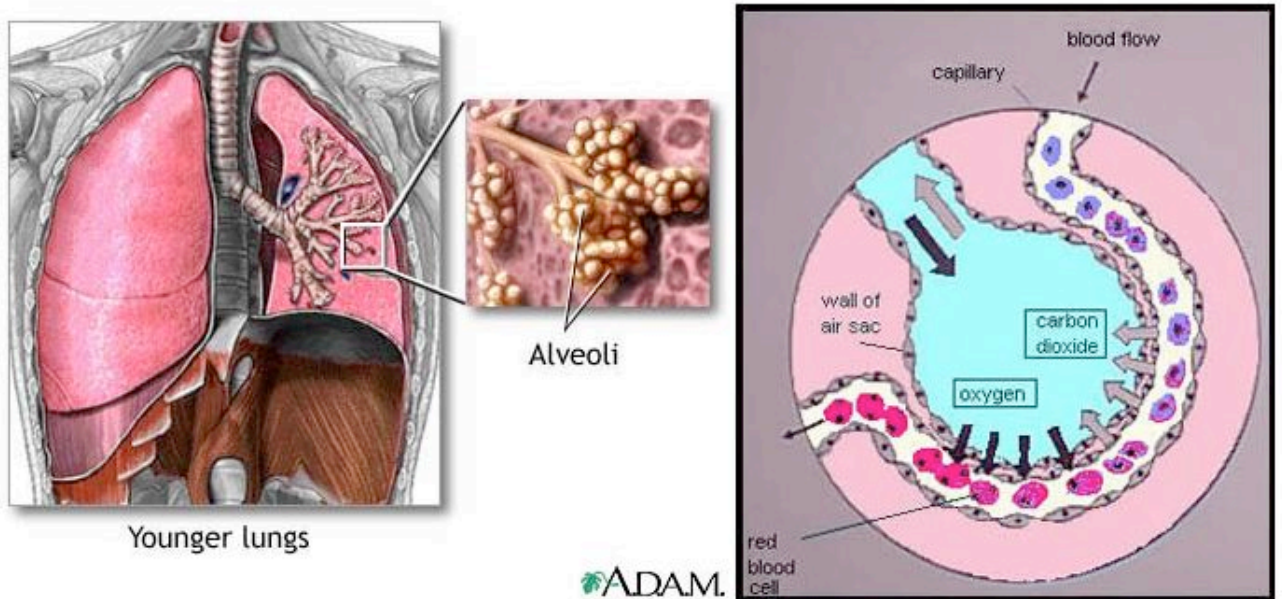
The actual act of moving air in and out of the lungs is accomplished in much the same way that a bathroom plunger works. Since the thorax is "sealed,"

expanding its volume causes air to rush into the lungs to fill the relative vacuum. When we inspire air, we do so by contracting the diaphragm, pulling it down (similar to pulling up on the plunger). If you are breathing "correctly" at rest, the main movement you will notice is your stomach bulging out a bit during inspiration. This is because the diaphragm is pressing down against the abdominal cavity. You are "belly breathing." At rest and low ventilation volumes, this is enough. However, when we need to move a lot of air in and out of the lungs, we not only increase the force of diaphragmatic contraction, we also contract muscles attached to the rib cage. This pulls the ribs up and out, further expanding the thorax and allowing more air to rush into to the lungs. All of this takes muscular work, so inspiration is an "active process." Expiration, or blowing the air back out, is basically a matter of relaxation when we are at rest. The elasticity of the muscles and tissues is sufficient to push the air out. The process becomes more demanding as we exercise harder. During heavy exercise we exhale more forcefully and deeply in order to ensure more rapid and complete exhalation of the old air. This process also takes energy in the form of muscular work. So, the bottom line is that breathing is not free to the body. And, it gets more energetically expensive at high workloads. I will come back to this point later.

2. Gas exchange: Moving oxygen and carbon dioxide on and off the red blood cells.

OK, now that we are moving the air in and out of our body, let's turn our attention to the lungs, and "get cellular" in our thinking. The lungs do some pretty cool stuff. The lung's challenge is to mix air and blood thoroughly and rapidly so that gas exchange can occur. Here comes another analogy. Let's say you have a gallon bucket (4 liters) of paint sitting with the lid open. How long will it take that bucket of paint to dry out? Days and days. But, if we spread the paint as a very thin layer over a very large wall, it will be dry in no time. By spreading the paint out we increase the total area of exposed surface between the paint and the air thousands of times and the water in the paint is quickly evaporated. At any given instant at rest, the lungs spread about 70 ml of blood (less than half of the volume of a coke can) in a "sheet" of capillaries with a total surface area of 70 square meters. That is like spreading a gallon of paint thin enough to paint a football field! The capillaries are so narrow that the red blood cells actually have to squeeze through. This also insures that the gas exchange across the red blood cell and capillary membranes is lightning fast. Simultaneously the lungs move the inspired air down a system of 23 branches of air passages terminating with about 300 million tiny spherical alveoli that form the terminal exchange tissue in the

bronchial system. These two exchange systems, the alveoli for air, and the capillaries for blood, are intertwined so microscopically close that oxygen and carbon dioxide molecules diffuse across the membranes and equilibrate almost instantaneously. Blood passes through the capillaries in about 0.8 seconds at rest and as little as 0.4 to 0.5 seconds during hard exercise. It is during this very brief exposure period that all the gas exchange between each red blood cell and the air in the lungs must take place before each return trip to the body!



Now perhaps one of you physiology student types is doing some analytical thinking that does like this: If resting cardiac output is 5 liters per minute, and maximal cardiac output were say, 25 liters/min, that would mean that 5 times as much blood passes through the lungs (and back to the heart and then to the body) and those capillaries per minute at max. Why doesn't the lung capillary transit time for each blood cell decrease from 0.8 secs at rest to $0.8/5$ or a really fast 0.16 seconds during maximal exercise? Here is the answer. Normally, the lungs only use a fraction of the total capillary volume available. Small arterioles can regulate the entry of blood into portions of the lungs. During exercise this restriction is gradually removed and the capillary volume can increase by over 3 fold to about 250 ml. This helps to minimize the decrease in capillary transit time. It does not eliminate it though. How important is that? This is another point which we will hit on again.

3. Blood-gas transport: Delivering oxygen to the muscles

Now let's think about how the blood fits into all of this. Blood serves several important functions during exercise (heat removal, deacidification, glucose delivery, hormone communication to name a few), but the one I want to focus on is its role as a delivery truck for oxygen. About 40 to 50% of the total volume of blood is made up of red blood cells (RBCs). For example, if your "hematocrit" is 43, then 43% of your total blood volume is RBCs. More than anything else, RBCs are just tiny, flexible sacks of hemoglobin. Each RBC contains hundreds of hemoglobin molecules, and each hemoglobin molecule has room to carry exactly 4 oxygen molecules. When I say "carry" I mean "bind" in chemistry lingo. There is some very fancy chemistry going on here that we would be in deep trouble without, but I will not try to explain it other than to say that hemoglobin molecules are engineered to hold on to oxygen tightly enough to carry it out of the lungs, but loosely enough to release it in the capillaries feeding the skeletal muscles (and other organs of course). This whole process is designed to function best when the atmospheric pressure is near sea level. If we get 1500 meters or more higher than that, the system begins to break down, and hemoglobin leaves the lungs without a full load of oxygen. This is why it is more difficult to breathe and exercise at altitude.

The capacity for blood to deliver oxygen can be summed up using an equation:

Hemoglobin concentration X oxygen binding capacity of hemoglobin (ml O₂/g hb) X percent saturation of hemoglobin = oxygen carried in a given volume of blood.

Hemoglobin concentration is expressed in grams of hemoglobin per deciliter of blood (g/dl). Typical values range between 12-14 for women and 14-16 for men. The binding capacity of hemoglobin for oxygen is a constant and equals 1.34 ml O₂/g hemoglobin. Finally, the percent oxygen saturation of hemoglobin when it leaves the lungs is normally about 96% (it is not 100% largely because the lung tissue has its own blood supply and this small volume of deoxygenated blood mixes in with the fresh stuff).

So, for an average person with a hemoglobin of 15, the oxygen volume contained in each liter of delivered blood will be:

15g/dl x 1.34 ml O₂/g hgb x 0.96 saturation x (10dl/l) = 193 ml O₂/ liter blood.

If we substitute in 12 for the hemoglobin concentration (someone with anaemia) and 18 (a very high value occasionally seen in trained athletes at high altitude), we see that for the same cardiac output, the volume of oxygen carried by the blood would vary between 154 and 232 ml per liter, depending on the hemoglobin value. It is not hard to see how the blood oxygen carrying capacity affects the VO₂ max. Remember, the muscles can only use what the heart can deliver.

If hemoglobin concentration is higher, the blood can carry more oxygen. This is an important point with relevance to altitude training, illegal EPO use, gender differences in VO₂ max, anaemia etc. *(I should note here that there is a downside to increasing haemoglobin concentration in the blood and that is increased blood viscosity. The body normally maintains an appropriate balance. If the blood becomes too thick, flow resistance increases and the risk of blood embolism increases, hence the dangers of EPO use.)* Second, when the blood leaves the lungs it is normally fully saturated with oxygen. This means that the lungs are very effective at ventilating the blood, even in untrained folks. This is one of the reasons why in the big scheme of things we basically disregard lung function as an area for improvement in the athlete's endurance machine. But, this issue is worth taking a closer look at.

Ventilation Issues in Endurance Performance

Is ventilation volume a limiting factor to maximal endurance?

Sometimes you hear people say "I ran out of wind." Is that really possible? Can we reach a point in exercise when ventilation just can't keep up with demand? The answer is no, assuming you don't have acute asthma or some other severe pulmonary dysfunction. We can measure a person's maximal voluntary ventilation (MVV), the maximal volume of air they can breath in and out while at rest, and compare it with their maximal ventilation during exercise. What we see is that untrained people only use about 60 to 85% of their maximum ventilatory capacity even at maximal exercise. For example the MVV for an average male might be nearly 200 l/min. However, during a treadmill VO₂ max test, they reach a peak ventilation of only 140 l/min. Highly trained athletes use more of their capacity, perhaps over 90%, but ventilation capacity is still not a limitation on performance. Unlike the story with cardiac output, even during maximal exercise, the ventilatory capacity is not maxed out.

By the way, the highest ventilation volume I have read about in a human was 263 l/min recorded on a really big male rower with a chest about the size of a beer keg. Ventilation volumes in excess of 200 l/min have also been recorded in elite female oarswomen. Understandably, rowers get most of the big ventilation prizes because they are really big for endurance athletes, at least among humans. The highest ventilation rates I have heard about in any athlete, irrespective of species, was in a racehorse. They have ventilation volumes of about 1500 liters/min!

Does ventilation performance decline as we get older?

Data from Åstrand presented in his Textbook of Work Physiology addresses this question. He compared ventilatory parameters in a group of male and female physical education students when they were in their 20s, again when they had reached their 40s, and a third time when they were in their 50s. The longitudinal study covered 33 years in all. While other aspects of the students' capacity declined, basic lung function was very stable. Total Lung Capacity was unchanged. Maximal Tidal Volume was unchanged and Maximal Ventilation during exercise was only decreased a few percent in 33 years. One change that does seem to occur consistently due to aging is an increase in the "residual volume" as a percentage of total lung capacity. This means that less of the actual lung volume is dynamically used during ventilation. This age-related change can be accounted for by loss of lung elasticity with age. Overall though declining lung capacity does not seem to be a big factor in the performance limitations of the aging athlete. Lung function is not the weak link in endurance performance, assuming you stay away from the cigarettes.

Uncomfortable Positions- Can body position influence ventilation capacity?

Now, one issue that needs to be considered when we discuss ventilation is body position. In most sports situations the chest is very free to expand. Running and cycling do not impose any mechanical limitations on ventilation. Even down in the aerodynamic position, maximal ventilation in cyclists does not appear to be compromised. However, swimming adds resistance to breathing because we have to move both the ribs and the water surrounding the body when expanding the chest. Coupling this with the problem of coordinating breathing with the brief periods of time the mouth is out of the water probably results in a relative under-ventilation in swimming.

Ventilation during rowing: Special Problems?

Another sport that has gotten some special attention from the ventilation folks is rowing. This I know more about, so I will elaborate a bit. During rowing, the body is squeezed up with the chest against the knees over 30 times a minute, limiting diaphragmatic excursion. That might create some breathing problems, but it is not the biggest issue. The real issue is the fact that rowers also use the same abdominal and intercostal muscles used for breathing to support the back during the powerful extension employed each stroke. Rowers isometrically contract all of these muscles to apply a high interthoracic pressure at the moment of the catch, when the oars take the water, to reinforce the connection between oar, back and legs. It is impossible to breathe and constrict all the abdominal and thoracic muscles at the same time.

The consequences of this competition are debated. The results of several, but not all studies suggest that elite rowers are not able to achieve the same ventilation volume at max during rowing as they achieve during cycling. The differences are not huge, but they may be significant. For example in one recent study elite rowers achieved a peak ventilation of 198 l/min during a VO₂ max test cycling, but only 171 liters/min during rowing. The VO₂ max values for the rowers were not different between rowing and cycling (5.03 l/min vs 5.09 l/min). This suggests that the small degree of under-ventilation at max experienced in rowing does not limit maximal oxygen consumption. However, some physiologists interpret these results differently. It is generally accepted that elite endurance athletes achieve their highest values of VO₂ max when they are performing the sport that they train for. In other words, elite runners excel most during treadmill tests. Elite cyclists max out slightly higher on cycling tests etc. In several studies national class rowers have demonstrated the same VO₂ max while rowing as they did while running, or even cycling. This has not been a unanimous finding, but it appears that VO₂ max for highly trained oarsman during rowing is lower than it "should be", when consideration is given to their training specificity and the very large muscle mass employed in rowing. A mechanism for this problem may be a slight ventilatory limitation imposed by the unique demands of rowing. Personally, I am inclined to believe that VO₂ max is limited in rowing for a different reason. The muscle contraction frequency is too slow and at too high intensity to allow optimal blood flow to the working muscles, and muscle pump action by the working muscles. If this is true, then higher stroke rates might produce increased aerobic power. This is consistent with the trend in elite rowing to move toward higher stroke rates, but it is not proven. But, now

that I have mentioned stroke rates, that brings up another interesting ventilation issue.

Breathing to the beat: Entrainment of ventilation rate to movement rhythm

If my wife joins me at the rowing club for a workout on the rowing machines, an interesting phenomenon occurs. Hilde is not a rower, so she always seems to adjust her rowing cadence so that it matches mine. I don't think she does it on purpose, but her rowing rhythm naturally entrains onto mine. This is problematic when I am doing intervals and she is rowing steady state! Our ventilatory system does the same thing. Ventilation tends to match with running, cycling or rowing cadence in a consistent pattern. For example, in cycling, we sometimes see athletes exhale in unison with the downward kick of the same leg, every 2nd or third stroke. This entrainment process does not seem to be a bad thing. In fact, since it is more prevalent in experienced athletes, it is probably an adaptation that promotes efficiency by minimizing the mechanical constraints to breathing created by limb movements.

Breathing pattern seems to be an especially important issue in rowing. Steinacker et al (1992) investigated ventilatory responses during incremental rowing exercise and observed two distinct breathing patterns. Type 1 was one complete breathing cycle per stroke cycle, with expiration occurring during the drive and inspiration during the recovery phase. Type 2 was two complete breaths per stroke, one during the drive and one during the recovery. When the intensity reached a certain point, the rowers automatically switched from type 1 to type 2. All these elite male rowers entrained their breathing to the stroke rate. Another study found the same patterns in elite female rowers. Untrained subjects tested during rowing only rarely exhibited this pattern. To make things more interesting, it appears that the breath during the stroke is "smaller" than the breath during the recovery phase.

Now if we extrapolate those findings to a racing situation at a high 40 strokes per minute, what we would expect is a ventilation rate of 80 breaths per minute. This is very high! In running or cycling max tests we usually see maximum ventilation rates of about 50 to 60. In contrast, ventilation rates as high as 88 breaths per minute have been observed during competitive rowing, accompanied by a relatively low tidal volume. All of this data suggests that the mechanics of rowing place unique demands on ventilation. Well trained rowers adapt to these demands by developing very strong ventilatory

muscles and adapting a unique breathing rhythm which makes the most of the brief periods of relaxation during the stroke.

The Great Arterial Desaturation Debate

New topic. Earlier in this breath-taking novel of mine, I discussed the issue of hemoglobin saturation with oxygen. I said that the lungs were so good at oxygenation that the blood always leaves the lungs saturated with oxygen, even during hard exercise when cardiac output is high. This means every RBC picks up a full load of oxygen before leaving the lungs. Now I am going to contradict myself a bit.

Here is the central issue. The blood returning from the periphery must eliminate its carbon dioxide load and fully re-saturate with oxygen during the brief time it passes through the lung capillary network on the way back through the heart and out to the body again. Normally this is not a problem. It only takes about 0.45 seconds for the hemoglobin to become fully saturated during its passage through the twisting capillaries. It takes even less time to unload the CO₂. Since the transit time is 0.8 seconds, there is time to spare. Even during exercise there is enough time, unless.....you are a really fit athlete with a very high cardiac output and VO₂ max.

Recent studies with highly trained endurance athletes (VO₂ max over 70 ml/kg/min) have shown a significant degree of arterial desaturation. This means that for the guys with the really big cardiac outputs, the blood is rushing through the lungs so fast that hemoglobin hasn't taken on a full load of oxygen before leaving for the muscles. The result is that instead of being 96 or 97% saturated with oxygen, the blood leaving the lungs may only be 89 or 90% saturated in the athletes with very high cardiac outputs and VO₂ max. Clifford et al. (1990) reported a drop in arterial saturation from 105 mm Hg at rest to 88 mmHg during the last minute of a maximal rowing test in elite rowers. This means that the arterial blood was becoming slightly hypoxic when they reached very high workloads. All other things being equal, VO₂ max might be up to 5 % higher or so in the elite types if the lungs could fully saturate the blood at maximal cardiac output. Support for this assumption comes from the fact that when well trained athletes breathe a higher concentration of oxygen while performing in a lab, they reach a slightly higher VO₂ max.

What does this information mean in regards to how we train? Nothing. There is nothing we can do to prevent this desaturation in folks with the really high

cardiac outputs, short of having them wear an oxygen tank while performing. Unless you have a VO₂ max of about 5 liters/ min or higher, it is not really an issue anyway. Consider arterial desaturation a small physiological tax on the "cardiovascularly endowed."

The Rising Cost of Breathing

The ventilatory muscles, like all muscles need oxygen to support continuous exercise. It turns out that the diaphragm is one of the body's best endurance muscles, perhaps even in second place behind the heart. It has a high percentage of type I fibers, a high capillary density, and high concentration of oxidative enzymes, compared to skeletal muscles. Animal studies have demonstrated that the diaphragm improves its endurance capacity (mitochondrial enzyme concentration) with training, but not more than about 20-30%, because it is already pretty well equipped for chronic work. However, with high intensity training, other muscles involved in breathing like the internal and external intercostals and the abdominal muscles become more active and also improve their endurance capacity. Since these muscles are less trained to begin with, they respond more to endurance training. These accessory breathing muscles are not trained at low exercise intensities but become active when we really start moving a lot of air.

From the above, plus your own experience, you can figure out that breathing becomes more demanding when ventilation rates get very high. There are studies which have actually measured the oxygen cost of breathing at different intensities. You might think of this as the tax on oxygen delivery. The body has to deliver blood to the ventilatory muscles so that they can help the lungs supply oxygenated blood to the rest of the body. To make things worse, this "tax rate" increases when you are working at very high intensities. The oxygen cost per liter of ventilation (VE) doubles from low to very high exercise intensities.

The bottom line is that while the oxygen cost of breathing is only perhaps 3-6% of total VO₂ at low intensities, it can be as high as 10 to even 15% of total VO₂ in young adults with greater than average VO₂ max. In the fit older athlete, a high oxygen cost of breathing may occur at lower ventilation rates due to the increased stiffness of the chest wall.

Because physical training results in a reduced ventilatory response (at any given level of CO₂ production) during intense exercise, in the highly trained, the high cost of breathing is somewhat reduced. One interesting physiological

question is whether or not the respiratory muscles “steal” blood flow from the skeletal muscles at intensities near VO₂ max. The scenario goes like this. Cardiac output has already maxed out, but hyperventilation is still climbing, so the respiratory muscles need more oxygen. Physiologists have predicted that the respiratory muscles would get their share of blood flow at the expense of skeletal muscle blood flow, but direct experiments are lacking. Does this mean VO₂ max would decrease? No, it would be the same. However, the peak work rate achieved at VO₂ max would be reduced, because more of the consumed oxygen is going to supply “supporting organs” instead of the skeletal muscles.

When you add this to the problem of desaturation, we see that there are some additional limitations on maximal performance that enter into the picture when we start dealing with extremely well trained endurance athletes. These guys have such high cardiac outputs and work capacities that the ventilation machinery starts to demand a lot of the total available oxygen in order to keep the machine running.

Do the Breathing Muscles Fatigue?

The final issue I want to discuss brings us back to a common theme in endurance performance, muscular fatigue. We know the skeletal muscles fatigue (lose force generating potential) during endurance exercise. Do the breathing muscles get tired?

To make things short and sweet it appears that they do fatigue. Tests of maximal ventilatory function after a hard endurance session show a temporary drop in, for example peak expiratory force. This is an indirect way of measuring how much force the diaphragm can generate.

But, does fatigue of the ventilatory muscles limit performance?

To date the best technique for answering this question is to unload the ventilatory muscles and observe whether performance improves. These techniques have included using helium oxygen mixtures and breathing assist devices. Unfortunately, the methodology is not perfect. For example, using lighter than air helium may make the hoses and mouthpiece easier to hold in the mouth and actually decrease the cost of rowing. The results are unclear. At workloads below 85% of VO₂ max it appears the respiratory fatigue has no influence on performance. However, the results of some studies suggest that at intensities approaching VO₂ max respiratory fatigue may contribute to

performance limitations. The scientific jury has not reached a verdict on this question.

Can I Apply Any of This to My Training?

So, if you made it to the end of this novel, you may be disappointed to learn that there are no secret breathing tricks that will push you over the top. In general the lungs are wonderfully equipped for doing their job. Training does improve the ventilatory system in some ways, but it is not the weak link in healthy athletes. In recent years, there have been a handful of studies published where the impact of inspiratory muscle training on various aspects of pulmonary and endurance performance have been investigated. This involves essentially weight training for the breathing muscles, where resistance is generated by using some kind of device that reduces airflow during inspiration and forces the inspiratory muscles to work harder against greater resistance. Neither peak pulmonary function nor maximal oxygen consumption have been shown to change with this form of training. However, a couple of studies have shown modest increases in either time to exhaustion or time trial performance during cycling, using placebo controlled designs. How does this work? Perhaps stronger inspiratory muscles allow high ventilation to be achieved at lower breathing frequencies. This would decrease the oxygen cost of breathing and free up some blood flow for the working muscles. Perhaps.

If there is another area where we can benefit from attention to breathing, it would be the issue of entrainment. Good athletes develop breathing “rhythms” that tune in to the rhythms of their movements. This probably promotes efficiency. When you feel yourself performing at your physiological redline, your breathing may be a place to turn your attention. If you are a runner or cyclist, focus on the diaphragm and the abdominal muscles for moving the air in and out, instead of the intercostals attached to the chest. Heaving the chest more than necessary costs extra energy. “Belly breathing” makes sense. If you are a rower “belly breathing” doesn’t work too well. We just have to learn how to breathe between the strokes.