BREATHING & EXERCISE

ARTICLE 1: The individual challenges of swimming, cycling and running

The mechanics of breathing

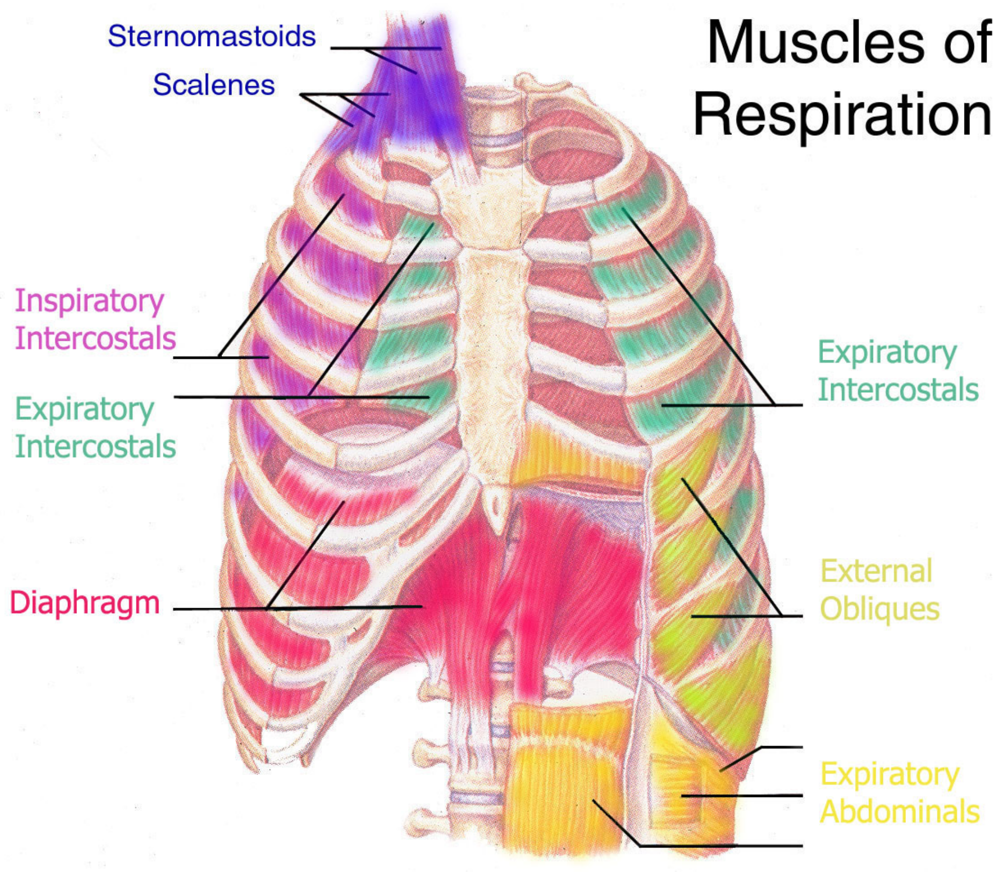
At rest, we breathe approximately 15 times per minute, with a volume of around 0.5 litres (producing a 'minute ventilation' of 7.5 litres per minute [15 x 0.5]). The volume of each breath (tidal volume) depends on body size and metabolic rate (bigger people have larger lungs and take larger breaths, they also require more energy and oxygen to support their metabolism).

During heavy exercise, breathing frequency rises to around 40 to 50 breaths per minute. In 'the man in the street', tidal volume rises to around 3 to 4 litres (minute ventilation = 120 to 160 litres per minute), but in Olympic class male endurance athletes, tidal volume can be over 5 litres, resulting in minute ventilations of 250 to 300 litres per minute. Kilo for kilo, Olympic oarsmen have minute ventilations that are equivalent to thoroughbred racehorses!

We are all familiar with the act of breathing, which is a rhythmic pumping of the chest 'bellows' that sucks and in and out of the lungs. In order to breathe in, the volume of the chest cavity must increase in order to create a pressure gradient into which air moves. Increasing the thoracic volume momentarily creates a slightly negative pressure inside the lungs, which is equalised very rapidly by the movement of air into the lungs.

The 'physics' of this response are exactly the same as those behind a bicycle pump. To draw air into the pump you increase the volume of the pump by drawing the handle out; air flows into the pump to equalise the drop in pressure produced. When breathing out, the volume of the thoracic cavity must be reduced, thereby creating a slightly positive pressure that drives air out of the lungs. These changes in the volume of the thorax are brought about by the action of the breathing (respiratory) muscles (Figure 1).

Figure 1



The breathing muscles are divided into two sets; 1) the inspiratory muscles (diaphragm, inspiratory intercostals, sternomastoids, scalenes), and 2) the expiratory muscles (abdominals, external obliques, expiratory intercostals).

The action of the inspiratory muscles increases the volume of the chest cavity by lifting the rib cage upwards and outwards, and flattening the dome of the diaphragm and moving it downwards (like the handle of the bicycle pump being drawn out of the pump). The action of the expiratory muscles reduces thoracic volume by pulling the rib cage downwards and pushing the diaphragm up into the thoracic cavity.

The lungs and the chest wall (rib cage and associated structures) are elastic structures that naturally ‘spring’ back to their resting positions once the forces acting on them are removed. These forces are brought about by the breathing muscles, and to inhale, the inspiratory muscles must expand the thoracic compartment and stretch the lungs (this stores some elastic energy within the lung tissues. At the start on an inhalation, the inspiratory muscles are relaxed, and any elastic energy stored within the lungs and chest wall has been dissipated. Each intake of breath is therefore initiated from a point where all of the forces acting on the lung are in a state of balance.

When breathing at rest, only the inspiratory muscles are active. Inhalation occurs by contracting the inspiratory muscles, which inflates the lungs, causing them to stretch like a party balloon; to breathe out, all that is required is to relax the inspiratory muscles, and the lungs and chest wall spring back to their equilibrium position using stored elastic energy (like releasing an inflated party balloon).

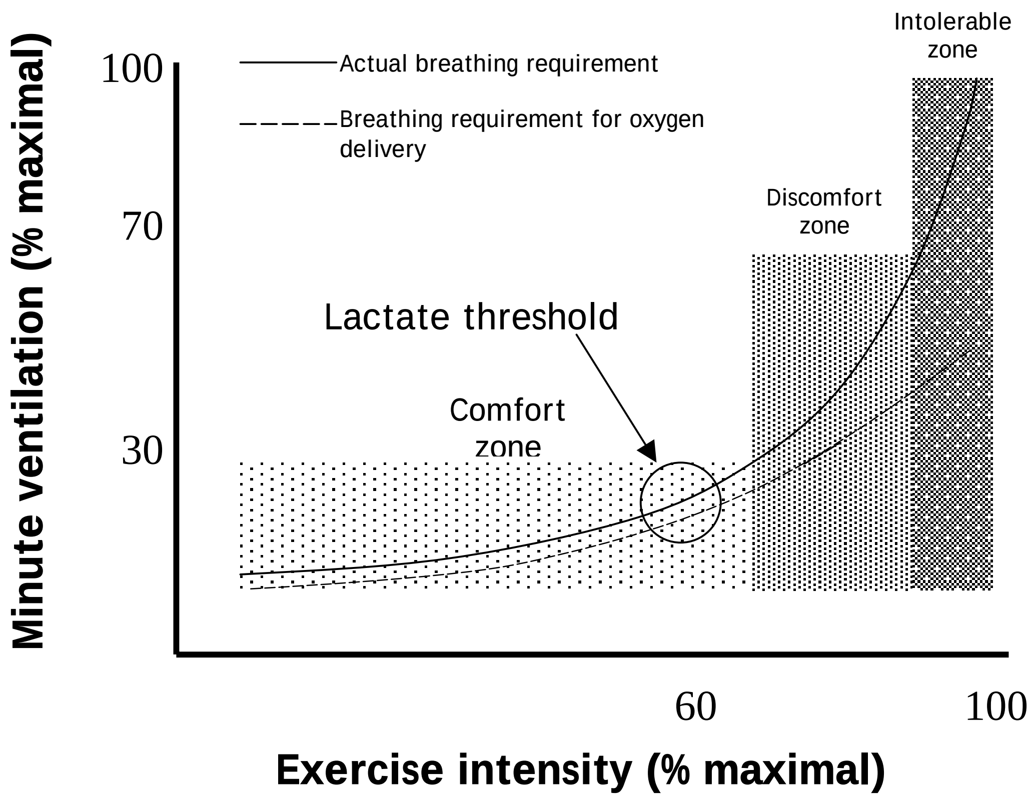
During exercise, the rate and depth of breathing is increased, which requires the respiratory muscles to contract more forcefully, and quickly. The expiratory muscles begin to make a contribution to breathing during exercise, because the stored elastic energy from inspiration is not sufficient to achieve the expiratory flow rates required during exercise.

However, at all intensities of exercise the majority of the work of breathing is undertaken by the inspiratory muscles, because expiration is always assisted to some extent by stored elastic energy that was provided by the inspiratory muscles. Recent studies have estimated that during maximal exercise, the work of breathing demands approximately 16% of the available oxygen, which puts into perspective how strenuous breathing can be.

Exercise intensity and breathing demands

A question that I am often asked is ‘Why are my breathing muscles not already well-trained?’ The answer requires an insight into the relationship between exercise intensity and the associated breathing requirements (minute ventilation). Figure 2 illustrates how breathing is related to exercise intensity, and the first thing that becomes apparent is the fact that it is not a straight line. In other words, the amount of breathing required at 80% of your maximum capacity is not twice the amount required at 40% - more like four or five times greater.

Figure 2



Moderate intensity exercise (activities that can be sustained for more than 30 minutes) are within the 'comfort' zone of the inspiratory muscles; heavy intensity exercise (activities that can be sustained for only 10-30 minutes) are within the 'discomfort' zone of the inspiratory muscles; very heavy intensity exercise (activities that can be sustained for less than 10 minutes, such as walking upstairs as fast as you can) are within the 'intolerable' zone of the inspiratory muscles.

The vast majority of aerobic training occurs within the inspiratory muscle 'comfort' zone, where the training stimulus to the inspiratory muscles is very modest and little training adaptation occurs.

In order to stimulate any muscle to undergo adaptation, the muscle must be overloaded; this means forcing it to do something that it is not accustomed to doing. Unfortunately, the zone that provides the most potent training stimulus to the inspiratory muscles (intolerable zone) is so challenging that it cannot be sustained for long enough to provide overload for long enough to be effective.

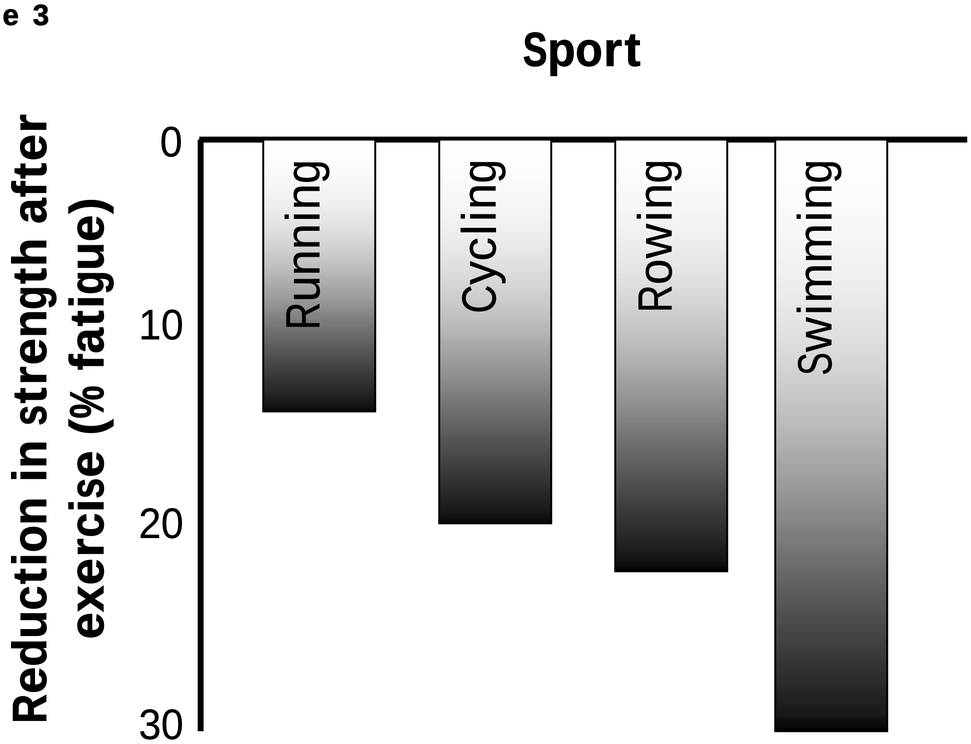
In other words, the intensity of breathing work that’s needed to hone your breathing muscles into optimum shape is the same intensity that makes you so out of breath that you need to slow down – its a ‘Catch 22’. This is why normal training doesn’t optimise the condition of the inspiratory muscles and why they need to be trained specifically with POWERbreathe® in order to ensure that the limits they impose are minimised.

The following sections will describe the specific challenges to breathing during swimming, cycling and running. A theme that is common to all three modes of exercise is that breathing and locomotion must be entrained (synchronised) for maximum comfort and efficiency. In addition, it’s helpful to have an appreciation that although rapid shallow breathing is inefficient, it’s surprisingly common, even in well-trained athletes. It can also be a hard habit to break; you may try to breathe more deeply and slowly, but if your breathing muscles are unaccustomed to this pattern, it can actually make you will feel worse. Strengthening the inspiratory muscles will provide the extra reserve that’s needed to achieve efficient breathing, and can be realised very quickly by using the POWERbreathe® inspiratory muscle trainer (there will be more about POWERbreathe® training in later articles).

The interaction of breathing and swimming

Competitive swimming presents one of the ultimate challenges for breathing. This is exemplified by the fact that our research has shown that swimming induces the most severe inspiratory muscle fatigue of any sport we’ve assessed [7] (29% compared with around 10-20% for terrestrial exercise – see figure 3). Furthermore, that 29% fatigue was induced by a 200m swim at an intensity of 90-95% race pace. The swim lasted just over 2 and a half minutes, and required only 70 breaths (there will be more about inspiratory muscle fatigue and its implications in a later article).

Figure 3



The aquatic environment is innately challenging. Breathing with your chest immersed in water requires more inspiratory muscle force and effort, because in order to expand, the thorax must overcome the extra hydrostatic pressure exerted by the water. Our research has also shown that the inspiratory muscles are around 16% weaker whilst lying horizontal in the water compared to standing upright on dry land.

In order to minimise the detrimental influence of breathing on stroke mechanics, swimmers strive to reduce the number and duration of the occasions when the face is out of the water. This means the swimmer must inhale quickly and take in as large a breath as is comfortable (the latter also helps with maintaining a higher body position in the water due to increased buoyancy).

These demands force the inspiratory muscles to work at the extremes of their capabilities. Getting air into the lungs quickly requires the inspiratory muscles to contract quickly, and all muscles are weaker at high contraction velocities. Furthermore, taking a large breath requires the inspiratory muscles to work against higher elastic loads because a fuller lung is more stretched (think of the lungs as a party balloon; the fuller the balloon the more effort is needed to increase its volume). The inspiratory muscles are also weaker at high lung volumes, so there is a ‘double-whammy’ for swimmers:

1. There is a greater demand for inspiratory muscle work due to the hydrostatic pressure and a higher elastic work of breathing;
2. The inspiratory muscles are weaker because of the horizontal position in the water, and the need for high inhalation rates and volumes.

As if this weren’t enough, swimmers also need to contend with the fact that the muscles that are used to breathe are also engaged during the swimming stroke; the breathing muscles are therefore subjected to the dual demands of breathing and locomotion, which almost certainly contributes to the spectacular fatigue of the inspiratory muscles that we have observed in our research.

The pivotal importance of maintaining inspiratory muscle performance in the face of huge demands makes POWERbreathe® training an essential training adjunct for swimming performance.

The interaction of breathing and cycling

We’ve just considered the fact that during swimming, the synchrony of breathing and stroke is a given. But how many of us actually think about controlling the rhythm of your breathing whilst we’re cycling? Not many if the importance given to good breathing technique in most books on cycling is anything to go by.

A handful of studies have suggested that the efficiency of cycling is improved when breathing and cycling cadence are synchronised[12]. This means that the amount of oxygen (energy) required to cycle at a given pace is slightly lower during synchronised than non-synchronised cycling. Accompanying this is a small decrease in sense of effort (how hard the cyclists feel they are working).

Professional and highly competitive cyclists typically adopt pedal rates of between 90-110 rpm, with breathing frequencies of either 1:3 (1 breath to 3 pedal revolutions) or 1:2. Studies have shown that there is a shift from a breathing/pedalling ratio of 1:3 to 1:2 as exercise intensity and/or duration increase. In other words, breathing frequency tends to increase to meet increased demands for breathing.

A characteristic of professional cyclists is that this shift towards higher breathing frequencies does not occur, and they are able to meet increased demand for breathing by increasing their tidal volume (volume of each intake of breath). It has been suggested that this may be a key factor in minimising the energetic cost associated with breathing, thereby enhancing performance.

Interestingly, it has also been shown that when recreational cyclists (who would typically pedal at 60-70 rpm) attempt to replicate the pedal cadences of elite cyclists (90-110 rpm), their performance is impaired[13]. The ability to sustain high pedal frequencies is likely to be due to a combination of genetic endowment and training, so recreational cyclists should be cautious about trying to emulate the performance strategies of the professionals as they may not possess the genetic 'gifts' that make this advantageous.

The question then arises 'when during the pedal cycle should I breathe'? Exerting downward force on the pedals during the active phase of the pedalling stroke requires the coordination of more than just the leg muscles. The upper body also needs to be coordinated in order to maximise stability and the efficiency of the force production.

For example, if an opposing force is not produced by the upper body during the transmission of force onto the pedal, the body will be pushed sideways (in the opposite direction) and you will fall off the other side of the cycle! The same muscles that we use to breathe are also used to help maintain posture and *'core stability'* These deep 'core' muscles of the trunk are vital for maintaining our upright posture and protecting our spine from injury; some of these core stabilising muscles include breathing muscles such as the diaphragm.

At high pedal rates (>70 rpm) the forces transmitted to the pedals are relatively small compared to the maximum force generating capacity of the muscles involved, so the 'competition' between the postural role of the upper body muscles and their role in breathing is not as problematic as it is in, say rowing.

Because a complete respiratory cycle (breathing in and out) occurs only once every 2 or 3 pedal revolutions, it is inevitable that force will not always be exerted on the pedals during, say, an exhalation. To date, no studies have examined the potential benefits of breathing during particular phases of the pedal stroke, and this is probably because its unlikely to have a large impact upon performance.

One caveat to this is what occurs during hill climbing. During a climb, pedal rate drops and pedal forces increase. During climbing, it may be advantageous to synchronise breathing and pedal cadence; indeed, this tends to occur intuitively, especially on very steep climbs. Notwithstanding this, evidence from elite cyclists suggests that the most important aspect of breathing and pedal synchrony is keeping a steady rhythm for each, and maintaining a 1:3 ratio between them. This ratio will optimise the efficiency and comfort of breathing, but needs to be 'worked at'; the reason that cyclists slip into a 1:2 ratio is because the breathing muscles become fatigued and they can no longer maintain their tidal volume. This is where POWERbreathe® can help, because it gives the inspiratory muscles the ability to achieve and tolerate higher tidal volumes without fatigue.

Cycling posture and breathing

Finally, I want to touch on the topic of upper body posture during cycling. There are 3 main postures that can be adopted during cycling; completely upright, dropped down onto 'drop' handlebars, or crouched forward over 'aerobars'.

Studies suggest that there are differences in the metabolic cost (energy cost) of cycling in these different postures, and that adopting a streamlined body position is advantageous because it minimises the frontal area of the cyclist and thus reduces aerodynamic drag (aerodynamic drag increases the metabolic cost of cycling).

However, there is also evidence that the crouched body position associated with the use of 'aerobars' has some disadvantages. Research suggests that cyclists who are inexperienced in the use of aerobars experience detrimental effects on their breathing and mechanical efficiency compared to cycling in the upright position[14]. For example, compared with upright cycling, aerobars resulted in a lower maximal oxygen uptake and lower maximal ventilation. In addition, breathing appeared to be constrained, such that tidal volume was lower and breathing frequency was higher. This is a very inefficient breathing pattern; indeed, the study found that mechanical efficiency was lower when using aerobars, i.e. the same amount of cycling work required more energy.

The explanation for these findings resides in the influence of a crouched body position upon inspiratory muscle mechanics during cycling. Firstly, crouching forward forces the contents of the abdomen (stomach, liver and gut) upward against the diaphragm. This impedes the movement of the diaphragm during inhalation because the abdominal contents are pushed up against the diaphragm causing it to 'work harder' for each breath.

Secondly, the higher breathing frequency means that inspiratory flow rate must be higher, which means that the inspiratory muscles must work in a region of their force-velocity relationship where fatigue and effort sensation are greater. Since studies appear to show that the aerobar position has fewer detrimental effects in cyclists who have used them for a prolonged period, it is appears likely that the inspiratory muscles adapt to the increased demands imposed by aerobars. A short-cut to this adaptation is to train the inspiratory muscles using POWERbreathe®, so that they are able to cope with the mechanical changes induced by the aerobar posture (see section 5.7 for specific guidance).

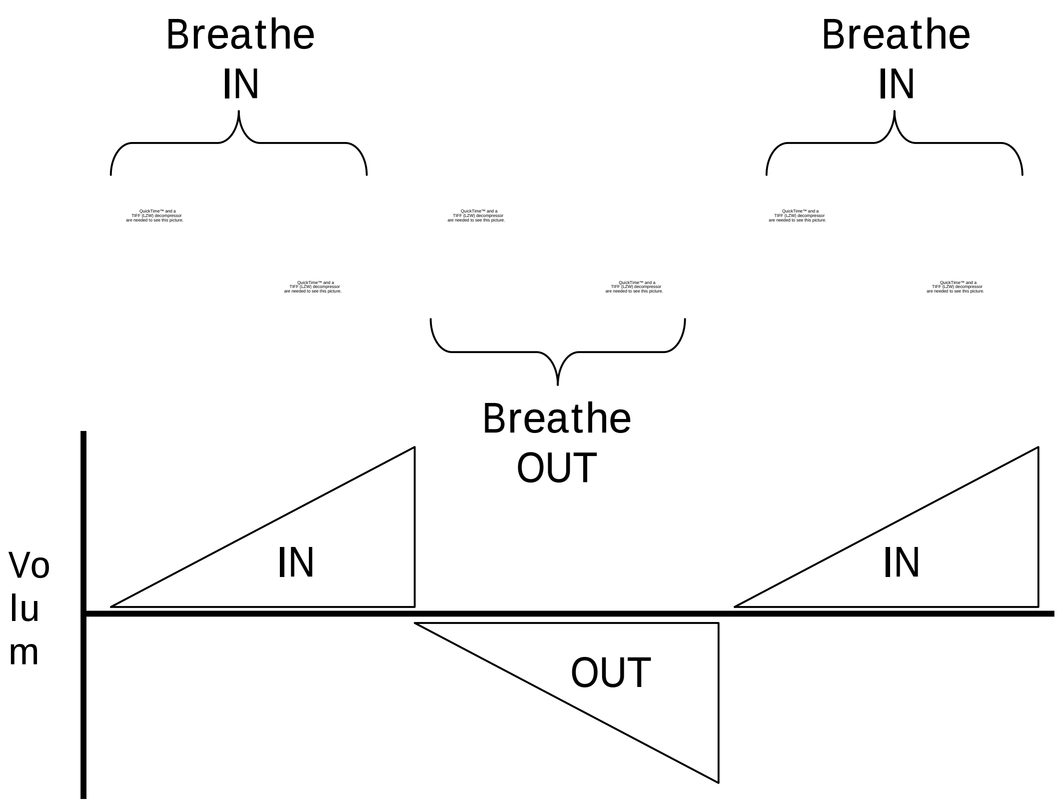
<u>The interaction of breathing and running</u>

Once again, I'm bound to ask the question, how many of us actually think about controlling the rhythm of our breathing while running? You might think that breathing while running was a piece of cake compared to swimming, but holding your upper body upright whilst it's moving through the air and landing unpredictably with each foot fall is hard work for your core muscles. The same muscles that we use to breathe are also used for maintaining an upright posture and 'core stability'.

Each foot strike is accompanied by a huge destabilising force, which is transmitted through the body, and the inspiratory muscles are subjected to competing demands for postural control and breathing. As with swimming and cycling, the key to efficient, comfortable breathing during running is synchronising your breathing with running cadence; this minimises the competition between the stabilising and breathing functions of your breathing muscles.

In addition, you can use gravity to help you to breathe more efficiently. During running the contents of our entire body bounce up and down. This is particularly problematic where the abdominal contents are concerned (stomach, liver, gut). When we breathe in, the diaphragm (the main inspiratory muscle) moves downwards, if it does this at the same time as the abdominal contents are bouncing upwards, diaphragm movement can be impaired, increasing its work (as in cycling with aerobars). But, this ‘visceral pump’ can also be used to your advantage. If you breathe in time with your stride frequency, you can ensure that the diaphragm is assisted by the downwards movement of the abdominal contents. On a steady run you should breathe on every other footfall for the same leg (see figure 3). You’ll know when you’ve got it right, because your breathing will suddenly feel much stronger and easier. You may find it hard to believe, but simply being aware of your breathing and building a steady rhythm can make it feel so much easier.

Figure 4



Common signs of 'bad breathing' include tense shoulders, discomfort that develops around the collar bones and lower neck, and sometimes, discomfort radiating from the collar bone down the biceps (front of upper arm). These are all indications that the inspiratory accessory muscles of the rib cage and neck (inspiratory intercostals, sternomastoids, scalenes) are doing too much of the work of breathing.

The major inspiratory muscle is the diaphragm; it is the largest of the inspiratory muscles and should be doing most of the work. Diaphragm breathing is something that needs to be practiced and learned. Breathing against a small load on the POWERbreathe® is an excellent way to 'feel' your diaphragm working, and to begin to understand how you can focus breathing activity on this major muscle. Once you can focus the work on the diaphragm using the POWERbreathe®, you can practice replicating this during exercise without the POWERbreathe. Breathing with your diaphragm helps to relax your upper body and makes breathing feel powerful, controlled and, most importantly, comfortable.

Summary

In this first article we have considered the individual challenges to breathing that are posed by the individuals disciplines of triathlon. In the next instalment we'll consider what happens when you put them all together.

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