BREATHING & EXERCISE

ARTICLE 3: Exercise-induced breathing fatigue – how it impairs your performance

Introduction

In the first two articles of this series, we considered the structure and function of the breathing pump, the individual demands of swimming, cycling and running, as well as the challenges posed by combining these activities into a single competitive event – the triathlon.

Within the information provided by these articles we saw that fatigue of the breathing pump, specifically the inspiratory muscles, is a 'normal' part of triathlon. In addition, the cycle phase of the event appears to present particular challenges to breathing, due to the increased demands that the crouched body position place upon the inspiratory muscles (see article 1 in this series for more details on this).

We also leant that inspiratory muscle fatigue has wider repercussions than one might think. For example, the increase in breathing discomfort at the cycle-run (CR) transition has been attributed to inspiratory muscle fatigue, which not only increases perceived effort, but also leads to an increase in the metabolic requirements of running, and a decrease in the oxygen diffusing capacity of the lungs.

This all sounds bad enough, but inspiratory muscle fatigue has some other nasty tricks up its sleeve to rob you of your full potential. Although these performance impairments aren't unique to triathlon, they arise more commonly in triathlon because of the uniquely challenging nature of the sport.

Because IMT has only recently been recognised as a limitation to exercise performance, some of the findings that follow are quite literally 'hot off the [sports science] press'.

Inspiratory muscle fatigue – what does it actually do?

There are a number of very serious repercussions of inspiratory muscle fatigue (IMF), and I will discuss each of these in turn:

1. IMF increases breathing and whole body effort perception – makes you feel as though you are working harder;
2. IMF leads to changes in lung diffusing capacity for oxygen – impairs oxygen transport during very heavy exercise;
3. IMF prevents maintenance of deep, efficient breathing – impairs breathing efficiency and comfort;
4. IMF causes blood flow to the exercising limbs to be restricted – impairs oxygen delivery and metabolite removal from the working muscles.

1. ***Breathing and whole body effort perception*****:** As a muscle fatigues, it requires greater effort to achieve the same muscle force output; this is why the final few repetitions of a weight set feel harder than the first. This is also why the end of a race feels harder than the start.

   The underlying physiology is pretty straightforward; as a muscle fatigues, it requires a larger neural drive from the brain to activate the muscle fibres. The brain is very adept at judging the magnitude of the neural drive, and perceives an increase in the required drive as an increase in effort. Conversely, the magnitude of the neural drive to a muscle decreases after its strength has been improved by training.

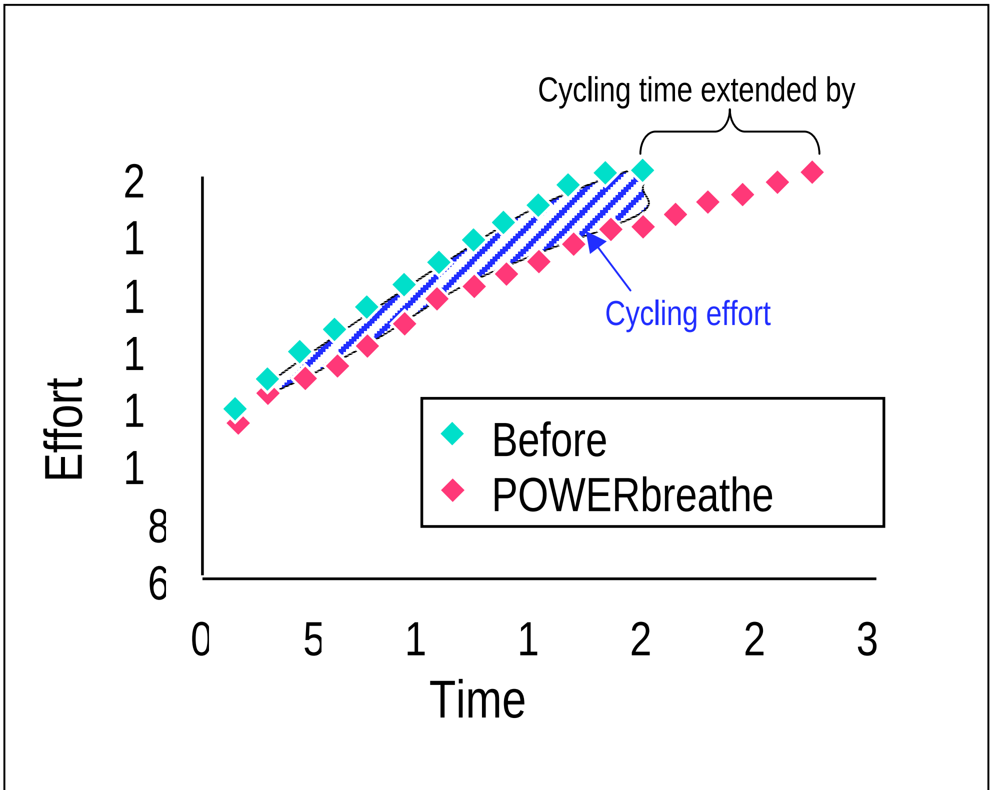
   In this case, the brain perceives the decrease in neural drive as a reduction in effort. The inspiratory muscles interact with the brain in the same way as other muscles, so fatigue is associated with an increase in breathing effort, and improvements in function after POWERbreathe training are associated with a decrease in breathing effort.

A study conducted in the early 1990s showed that fatiguing the inspiratory muscles before a maximal cycle test impaired performance and increased the perceived effort/difficulty of cycling[1]. The good news is that strengthening the inspiratory muscles using POWERbreathe has been shown to decrease effort during rowing, sprint running and cycling after 4-6 weeks of POWERbreathe training[24].

However, breathing effort also makes a big contribution to how hard the exercise feels as a whole, so reducing breathing effort also has a direct benefit upon whole body effort perception. Reduced whole body effort perception is key benefit of POWERbreathe training.

Most people choose a pace that is just the right side of intolerable discomfort; in other words, we work as hard as is tolerable. Because POWERbreathe training reduces effort perception, the limit of tolerability is increased, which means that a faster pace can be maintained for the same effort. Of course, the reverse is also true if the inspiratory muscles fatigue, which has a negative knock-on effect upon whole body effort perception and the tolerable pace. Fortunately, POWERbreathe training has been shown repeatedly to eliminate inspiratory muscle fatigue[4,5], which helps to stave off the escalating increase in effort as the race progresses. Figure 1 illustrates how POWERbreathe training reduced the effort associated with a fixed intensity of cycling, and extended the time to the limit of tolerance by 33%.

Figure 1



From: Caine & McConnell,

2. ***IMF and lung diffusing capacity*****:** A reduction in the diffusing capacity of the lungs for oxygen has been reported following triathlon, and the suggested mechanism relates to the crouched body position during cycling[6], and its effect on inspiratory muscle efficiency (see article 1).

During exercise, the return of blood to the heart from the peripheral muscles is assisted by the drop in pressure that occurs within the chest cavity during inhalation; as well as sucking air into the lungs, this pressure drop also sucks blood back towards the heart. This is important because if the return of blood to the heart is impaired, this also impairs the volume of blood that can be pumped to the lungs for oxygenation, and to the body to support muscular work.

So, if breathing is constrained by a crouched body position, and/or fatigue of the inspiratory muscles, the return of blood to the heart is also impaired, leading to a reduction in the efficiency of oxygen diffusion. Less oxygen spells earlier fatigue, greater perceived effort and impaired performance.

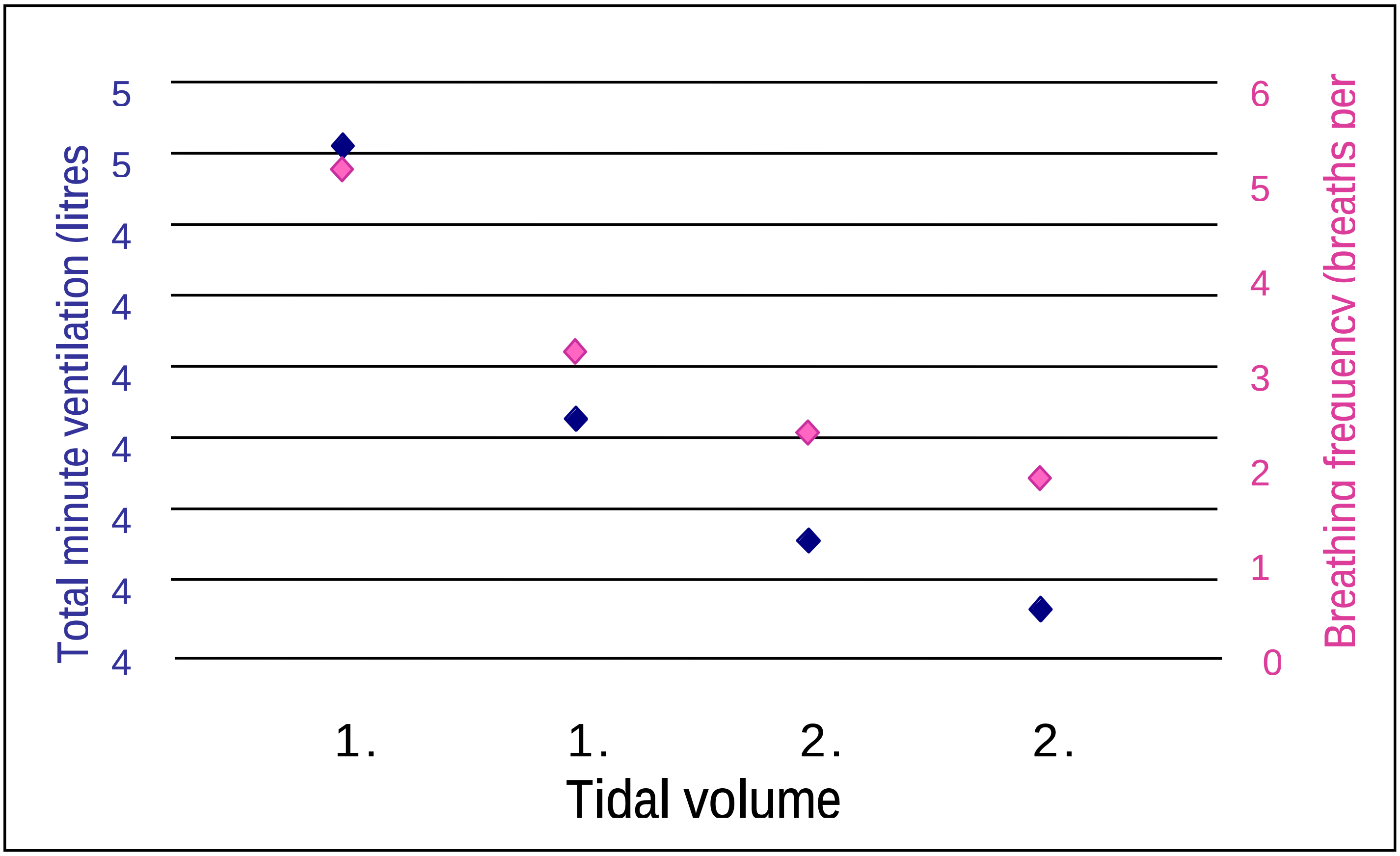
A recent study has shown that inspiratory muscle training increases the oxygen diffusing capacity of the lungs, and the amount of oxygen carried in the arterial blood to the working muscles during treadmill running in conditions of simulated high altitude[7]. The training also reduced the amount of inspiratory muscle fatigue that was induced by the treadmill run.

3. ***IMF and shallow, inefficient breathing*:** Part of each breath that is inhaled is effectively 'wasted', because it sits in the conducting airways (breathing tubes) that direct the air into the parts of the lung that exchange oxygen and carbon dioxide (the alveoli). Because these conducting airways do not contribute to gas exchange, they are known as 'dead space'.

   This dead space has a fixed volume, so irrespective of the size of the breath that is inhaled, the same volume is wasted in the dead space. For example, if you inhale 1 litre, about 20% (200mls) sits in the dead space, but if you inhale only 0.5 litres, 40% (200mls) sits in the dead space. What's more, each new breath that is inhaled is 'diluted' by the unexpired volume of the previous breath (you never completely empty your lungs, plus the dead space air is always inhaled again). This means that with an inhaled volume of 0.5 litres, only 300mls is fresh air, whereas with an inhaled volume of 1 litre, the fresh air component is 800mls. In each case, the fresh air is diluted by the same volume of dead space air, which reduces the amount of oxygen that is carried to the alveoli for exchange with the blood.

   The end result is that in order to supply the alveoli with the required volume of fresh air, you need to breathe much more if your inhaled volume is small than if the volume is large, because the oxygen in larger breaths is less diluted by dead space air. Figure 2 illustrates the effect of different inhaled tidal volumes upon the total breathing requirement (minute ventilation) and breathing frequency. More breathing means more breathing muscle work, and a higher metabolic cost, as well as a greater risk of inspiratory muscle fatigue, and a greater intensity of breathing effort.

Figure 2



Once the inspiratory muscles become fatigued, there is a tendency for inhaled volume to become smaller and smaller, as it becomes more uncomfortable to maintain a high inhaled volume. A good analogy here is what happens when we fatigue during a weight training set – the tendency is to make the movements smaller, because this minimises the associated effort and discomfort. This also happens as our inspiratory muscles fatigue.

One factor that has been found to distinguish professional cyclists from elite non-professional cyclists is the ability of the professionals to maintain a higher inhaled breath volume for longer[8], which contributes to their greater overall efficiency. POWERbreathe training has been shown to reduce inspiratory muscle fatigue, increase inhaled breath volume, whilst simultaneously reducing the oxygen requirement of cycling[2]. So POWERbreathe helps to promote and maintain deep, efficient breathing.

Definitions:
• **Alveoli –** tiny air sacs that make up the gas exchanging portion of the lung tissue; • **Arterial –** the arterial side of the circulation carries oxygenated blood to the tissues (the venous vessels carry blood away from the tissue – this is 'deoxygenated', as the tissue take up oxygen from the blood); • **Breathing frequency -** number of breaths per minute; • **Dead space –** the volume of the lungs that does not contribute to the exchange of oxygen and carbon dioxide; • **Tidal volume -** volume of each breath; • **Total minute ventilation -** tidal volume multiplied by breathing frequency.

4. ***IMF and limb blood flow stealing*:** In order to understand how IMF leads to limb blood flow stealing, we need to understand a little of how blood flow is controlled during exercise. When exercise commences, there is an increased need for oxygen within the contracting muscles, and this is met by increasing blood flow to these muscles. In order to produce the increase in blood flow, the output of the heart must increase, which it does by increasing both the rate and volume of each heart beat.

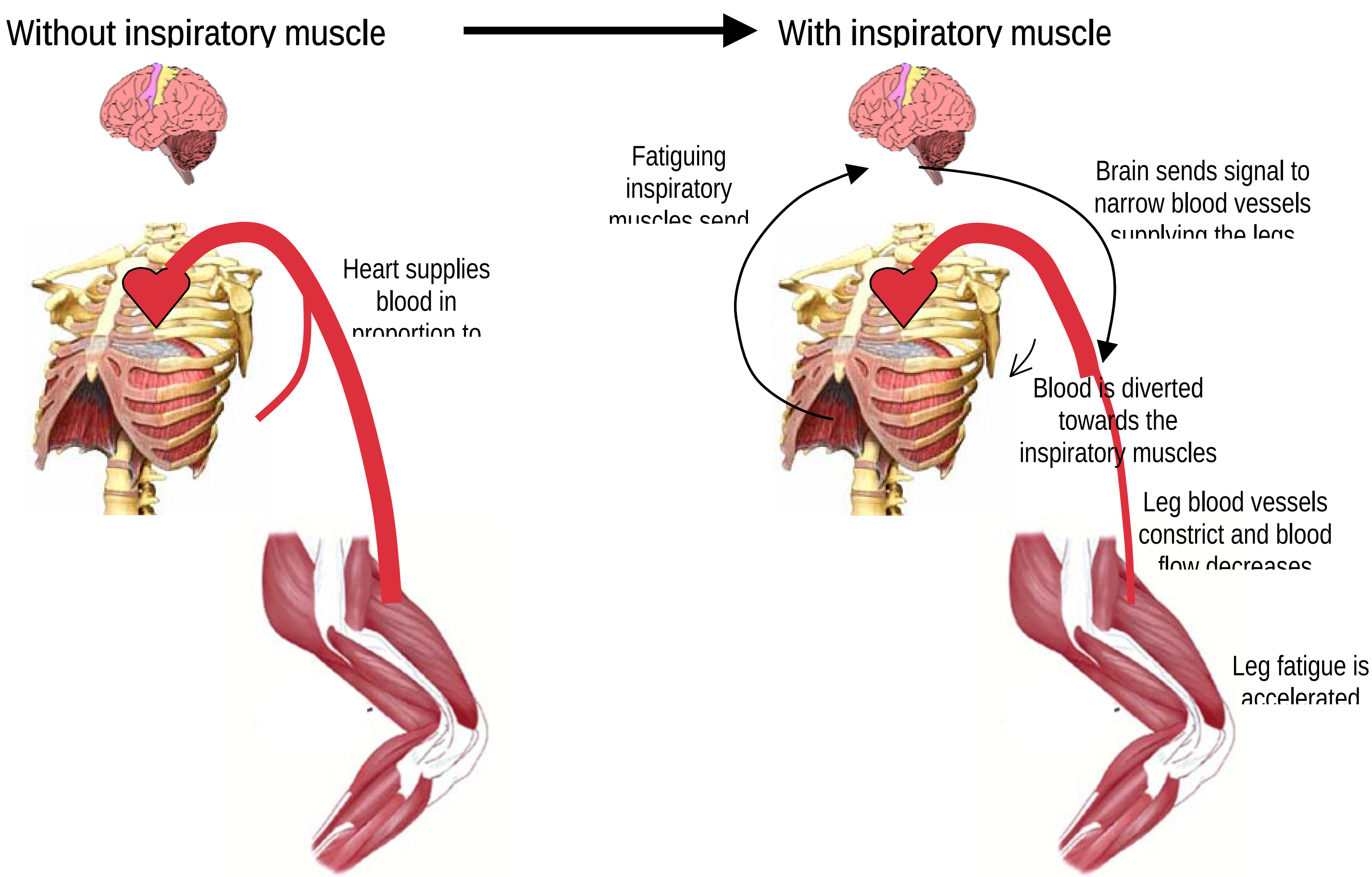
   As exercise progresses, the blood vessels in the working muscles open up (dilate) in response to local factors produced by the exercising muscle. However, during very intense exercise, especially in the heat, the capacity of the heart to pump blood is not sufficient to maintain blood flow to all of the organs of the body, as well as the skin (to dissipate heat) and working muscles (limbs and breathing muscles). So control centres in the brain restrict blood flow to non-essential organs such as the stomach and intestines in order to ensure that the working muscles, skin and the brain continue to be adequately supplied (this is why gastrointenstinal problems sometimes arise during or following exercise).

   The flow of blood to other organs is reduced by causing constriction (narrowing) of the blood vessels supplying them; this narrowing reduces blood flow. Unfortunately, there is also a small amount of constriction in the working muscles too, but this is mostly counteracted by the local metabolic factors that induce dilatation, so the net effect is a small amount of constriction (smaller than in the non-essential organs). This tactic is all ‘fine and dandy’, because the limbs are still getting pretty much what they need. The problem arises when the inspiratory muscles begin to fatigue.

When any muscle works intensely, and with a sub-optimal blood supply, metabolites accumulate inside it. These help to keep the blood vessels open, but they also contribute to failure of muscle contraction (muscle fatigue) and the metabolites stimulate nerve receptors, which in turn trigger a protective reflex.

It’s this reflex that causes the problems for the exercising limbs, because it induces a much more powerful constriction of the blood vessels (see Figure 3). The reflex is so powerful that it is able to over-ride the local dilating effect of metabolites within the working muscles; the net result now is a reduction in limb blood flow. What happens to the blood that was going to limbs? It’s diverted to the inspiratory muscles, in a Robin Hood style ambush that ensures that the ‘poor’ inspiratory muscles get what they need.

Figure 3



This reflex has two benefits from the viewpoint of the inspiratory muscles; firstly (and obviously), it ensures that they get more blood and oxygen (protecting their vital function); secondly (less obviously), by restricting blood flow the working limbs, the supply of oxygen and removal of metabolic by-products is impaired, which leads to an enforced decrease in exercise intensity (or even cessation), which reduces the breathing demand.

Don't worry if you didn't follow all of the physiology, the only thing you need to know is that when the going get tough, your inspiratory muscles steal blood from your legs, and that slows you down!

In a recent study from my laboratory, we've shown that IMF makes limb fatigue occur more rapidly, because of its effects upon blood flow, but we've also shown that POWERbreathe training prevents the blood flow stealing reflex from being triggered[9]. Preventing the reflex from being triggered also prevents the premature limb fatigue. This helps to explain how POWERbreathe training improves performance; we believe that the enhanced inspiratory muscle strength, power and fatigue resistance leads to an abolition, or delay in the triggering of the blood flow stealing reflex.

To summarise, we know that triathlon induces inspiratory muscle fatigue (IMF), and we also know that IMF is bad news for performance from a number of standpoints; its makes exercise feel harder, and leads to changes that impair the efficient delivery of oxygen to the exercising limbs. We also know that training the inspiratory muscles with POWERbreathe prevents IMF, and leads to improved exercise performance.

References

1. Mador MJ, Acevedo FA. Effect of respiratory muscle fatigue on subsequent exercise performance. *J Appl Physiol*. 1991;70:2059-65.
2. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. *J Sports Sci*. 2002 Jul;20(7):547-62.
3. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med*. 2002 Jul;23(5):353-60.
4. Volianitis S, McConnell AK, Koutedakis Y, McNaughton L, Backx K, Jones DA. Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc*. 2001;33(5):803-9.
5. Romer LM, McConnell AK, Jones DA. Inspiratory muscle fatigue in trained cyclists: effects of inspiratory muscle training. *Med Sci Sports Exerc*. 2002 May;34(5):785-92.
6. Galy O, Hue O, Boussana A, Peyreigne C, Couret I, Le Gallais D, et al. Effects of the order of running and cycling of similar intensity and duration on pulmonary diffusing capacity in triathletes. *Eur J Appl Physiol*. 2003 Nov;90(5-6):489-95.
7. Downey AE, Chenoweth LM, Townsend DK, Ranum JD, Ferguson CS, Harms CA. Effects of inspiratory muscle training on exercise responses in normoxia and hypoxia. *Respir Physiol Neurobiol*. 2006 Sep 20.
8. Lucia A, Carvajal A, Calderon FJ, Alfonso A, Chicharro JL. Breathing pattern in highly competitive cyclists during incremental exercise. *Eur J Appl Physiol Occup Physiol*. 1999;79(6):512-21.
9. McConnell AK, Lomax M. The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue. *J Physiol*. 2006 Sep 14.

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