The Lactate Response Curve
or
"The Leaky Bucket Syndrome"

The aim of this note is to explain the Lactate Response Curve, why it is important, how it affects your running or endurance performance and why it might not be a good idea to set off at 5k pace in a Half Marathon, or 1500m pace in a 5k.
Disclaimer: I'm not physiologist, chemist or biologist. There is a whole lot of complex science involved and this is only a simplified explanation of what is going on.

Some Terminology

Firstly, a brief explanation of some of the terminology that is frequently used.

In the diagram below (expertly drawn and photographed) there are two thresholds and in different works and articles these can have different names.

- Aerobic Threshold – also referred to as AT1 or LT1.
- Anaerobic Threshold – also referred to as AT2, LT2 or the Lactate Turn Point.

Mitochondria – These are the "energy factories" in the muscle cells. Most food stuffs get broken down into glucose/glycogen and this is used by the Mitochondria to produce Adenosine Triphosphate (ATP) which is what actually powers the muscles.

VO2max – or maximal volume of oxygen uptake. When you suck in lung fulls of air, VO2max is a measure of the volume of usable oxygen you can extract. This is usually measured in milli-litres of oxygen (O2) per-minute per-kilogram of body mass.

Lactate – What is it?

Lactate is a by-product of one of the body's energy production mechanisms. This is also widely known as Lactic Acid. However, you do not get Lactic Acid in the body, but after years of articles and features which talk about Lactic Acid, the terms Lactate and Lactic Acid have become interchangeable. But if you want to be correct - use Lactate – not Lactic Acid. The burning sensation that you feel in the muscles during intense exercise is not Lactate (or even Lactic Acid!) but is caused by Hydrogen ions which are a by-product of lactate production. The Hydrogen ions cause a lowering of pH in their immediate vicinity in the cells. Recall from School Chemistry that pH=7 is neutral (water), less than 7 is acidic, greater than 7 is alkaline or base, so lowering pH has an acidic effect.

Lactate is always present in our bodies. The level rises with intensity of work but returns to normal levels when the work rate reduces. It also gets recycled into useful fuel that we can use to produce energy.
Lactate level in the blood is usually measured in milli-moles per-litre of blood (mmol/lit).
It was believed that excess lactate caused muscle stiffness and soreness following intense exercise (hard training or races) but more recent research suggests that this may not be the case. and is more likely due to microscopic muscle damage.

Energy Production

Aerobic Respiration

Under normal conditions of low intensity work, our bodies produce energy (ATP) aerobically by burning fuel in the cells with oxygen. There is more than enough oxygen (O2) available and this process is known as aerobic respiration. The waste products of aerobic respiration are carbon dioxide (CO2) and water which mostly get breathed out.
Glucose + O2 --> CO2 + water + ATP

Anaerobic Respiration

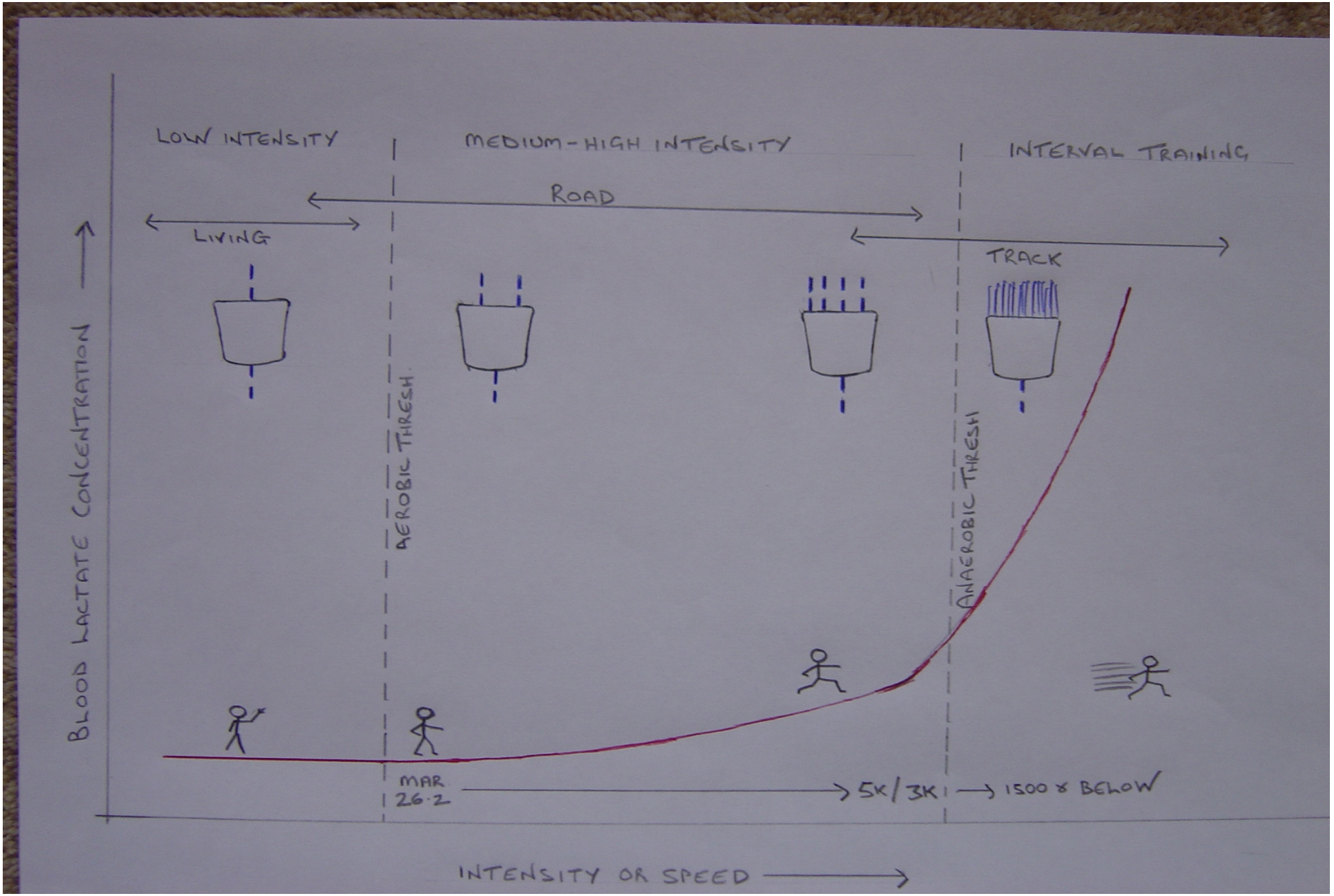
As the work rate or intensity increases, the muscles have to work harder to produce the required energy (ATP). The body may not be able to deliver enough oxygen (O2) to the cells to support the required energy production through the aerobic mechanism. At this point the body starts to provide some of the energy via a process known as anaerobic respiration as this does not require oxygen. As energy demands continue to increase more energy will be produced by anaerobic respiration. The waste product of anaerobic respiration is lactate. As a greater proportion of energy is produced via anaerobic respiration, more lactate is also produced. The excess lactate spills into the blood stream and levels of lactate in the blood begin to rise.
Glucose --> Lactate + ATP

Lactate Dispersal

Lactate is transported to the liver by the bloodstream and can be converted back to glucose for further energy production. However, the rate at which this can occur is limited so unfortunately, we don't have a perpetual unlimited energy supply. When energy requirement drops and more O2 becomes available the lactate can also react with oxygen and breaks down to produce C02 and water

The Lactate Response Curve

The diagram below shows a lactate response curve with blood lactate levels (y-axis) at different running speeds or work intensities (x-axis) shown by the red line.


LOW INTENSITY
MEDIUM-HIGH INTENSITY
INTERVAL TRAINING
ROAD
LIVING
TRACK
AEROBIC THRESH.
ANAEROBIC THRESH
BLOOD LACTATE CONCENTRATION
MAR
26.2
5K/3K
1500 & BELOW
INTENSITY OR SPEED

Pace / Intensity	Lactate (mmol/lit)
Normal Living	<1
Marathon	~2
5k/10k	4-6
1500m	10+

The table left shows typical blood lactate concentrations (milli-mols per-litre) for differing work loads

The "Leaky Bucket"

Lactate is buffered in the bloodstream while waiting to be processed by the liver. This can be thought of as a bucket that is filling with lactate at the top, and the lactate is draining through a hole in the bottom. The liver can only function at a certain rate so the hole or drain rate is effectively a fixed amount. If flow in to the bucket is faster than flow out, the bucket will begin to fill up. The harder of faster you go the faster the bucket will fill. Increasing blood lactate levels begin to inhibit energy production causing you to slow down and very high levels when the bucket overflows will cause you to stop. This prevents you doing serious damage, much like the 'puke response'. (It's very hard to maintain any intensive activity when you have your hands on your knees while reacquainting yourself with your breakfast. The next stage is the 'pass out' response – lying flat on your back usually stops you doing most things!)

Low Intensity

Even at the low intensity of everyday life some lactate is present in the bloodstream. However, the body can adequately cope with this so the flow into the bucket is matched by the flow out of the bucket and there is no accumulation of lactate in the bloodstream.

Medium-High Intensity

As we cross the aerobic threshold and begin running at slower speeds i.e. marathon pace, the body can no longer clear the lactate quickly enough and blood lactate levels begin to increase. Flow into the bucket is now quicker than flow out of the bucket – the bucket is filling up.
(Note for longer distances muscle fatigue is likely to have a greater effect than excess lactate in the later stages of the race.)
As pace/intensity increases further and we begin to rely more on anaerobic respiration, the lactate production rate also increases. The bucket is filling more quickly.

High Intensity / Interval Training

As the work intensity increases further and we approach speeds or distances below 5k/3k we cross the second of the thresholds – the anaerobic threshold. At this point blood lactate levels increase very rapidly and there is only a short period of time before the bucket fills and overflows – game over until you have recovered and the bucket has drained out sufficiently.

OMG – We're Doomed I Tell Ye, We're Doomed

Not quite so fast Private Frazer (Dad's Army). There are several things we can do to help and improve the situation.

Efficiency
Develop good form and posture through core work, conditioning and drills. Avoid flailing arms and legs, rocking and rolling and twisting torsos, as all of these will use energy which is wasted energy not used for driving you forward, yet still comes with the cost of increasing lactate production. At a given speed or intensity an efficient runner will be using less energy than an inefficient runner and so be less reliant on the anaerobic system. Look at top 5k/10k/marathon runners and they all seem to glide along almost effortlessly – they are efficient.

Improve Cardio System and VO2max
An improved cardio system and an increased VO2max will deliver more O2 to the muscle sites. This will enable more energy to be produced via aerobic respiration which does not produce lactate. This will mean you can run faster for the same amount of lactate production.

Lactate Tolerance
Regular training can increase your tolerance of lactate and improve the efficiency with which it is broken down. This is effectively like having a bigger bucket.

Conclusion

if you start a Half Marathon (usually 70mins – 2hours running) at 5k pace (usually 15-30mins), or a 5k at 1500m pace (usually 3:30 to 6:00mins) your bucket is going to overflow way too quickly. This is why pace judgment is essential in any race.
However, correct training can help tremendously by modifying your response curve to help you to run faster for longer and maximize your potential.

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