Leicestershire & Rutland Coaches Club
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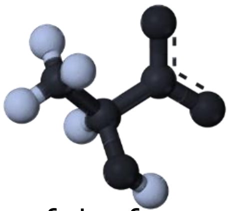
LEICESTERSHIRE RUNNING & ATHLETICS NETWORK

Energy Systems – The science



For those who sit on the "coaching is science" side of the fence and following on from my article some time ago entitled "The wheels are off" which tried to explain in simple terms how the lactate system worked I have produced the following, more detailed and technical description which was promised in the earlier article. I have though also tried to link the technical parts to real life situations which might make things easier to digest. As with many of these things nomenclature may be different to what you may have read elsewhere. For the "coaching is an art" people please look through it and see how the science backs up what you already know!

How is energy produced?

As we all know energy is produced from the food we eat, however, in order to release the maximal amount of energy, the molecules of Carbon, Hydrogen, Oxygen and Nitrogen which make up our food are stored as a high energy molecule known as ATP or Adenosine Triphosphate
When energy is needed, ATP is broken down using an enzyme (known as ATPase) into ADP (Adenosine Diphosphate). This process breaks the high energy Phosphate (P) bond and so provides energy for use by the body so a simple equation might be ATP = ADP + P +Energy. The body is also capable of resynthesising ATP to allow it to continue producing energy. To do this it must use energy to reverse the equation shown above, and this is known as an endothermic reaction as it requires energy. The breakdown of ATP is called exothermic as it produces energy, the process of breaking down and resynthesising ATP is efficient at producing energy as less energy is required to resynthesis the ATP than is made to break it down. Energy + ADP +P = ATP. The body can only store a very small amount of ATP which you might look at as the" spark plug of your engine". If you imagine standing up and walking a few steps that would be the limit of the stores within your body and is enough to allow time for the resynthesising process. A good example here is that you may have seen body builders or weight lifters lift a heavy weight and then strut around for 2-3 minutes. They are not "posing " but allowing the ATP stores to build up again which, depending upon the individual, can take up to three minutes as this is the energy system that they are most likely to want to train.

What are the energy systems?

There are two energy systems, the aerobic energy system, meaning 'with oxygen' which is used for long-term, steady paced exercise and day-to-day activities and the Anaerobic energy system or 'without oxygen' which produces fast bursts of energy for short, powerful bursts. The Anaerobic system can be divided into two further systems, ATP-PC and Lactic acid. It is important to remember that all energy systems work together, but the intensity and type of activity will determine which system is predominant.

Aerobic system
Anaerobic system
ATP-PC system
Lactic Acid System
The aerobic energy system

The aerobic energy system produces the largest amounts of energy, although at the lowest intensity, so at the start of exercise the body cannot deliver oxygen to the muscles fast enough to initiate the complex chemical reactions which occur during aerobic metabolism. Therefore the body relies on the anaerobic processes for the first couple of minutes. For those of you who don't warm up or find "it always takes me a few minutes to get into my race" please take note that this is why you struggle early on whilst racing or training!

The aerobic system can be broken down into three sections:
Glycolysis
Kreb's Cycle
Electron Transport Chain (ETC)

Glycolysis is the breakdown of Carbohydrates (in the form of Glucose or Glycogen) into Pyruvic acid which supplies energy to living cells through the Krebs cycle when oxygen is present. Pyruvic ferments to produce lactic acid when oxygen is lacking. The above results in the production of two ATP molecules. A total of 10 chemical reactions are required to convert Carbohydrates into Pyruvic acid which take place in the muscle Sarcoplasm.

Kreb's Cycle
Sometimes also known as the Citric acid cycle, this is the second phase in the process of aerobic metabolism. The Pyruvic acid produced during Glycolysis enters the mitochondria and is immediately converted to Acetyl Conzyme A which combines with Oxaloacetic acid to form a 6 carbon compound, known as Citric acid. Further chemical reactions occur to wield enough energy to resynthesise 2 ATP molecules. Bi-products of these reactions include Carbon Dioxide (CO_2), which is exhaled by the lungs and Hydrogen (H) which is transported to the site of the Electron Transport Chain by carrier molecules NAD+ and FAD. The process is termed a cycle as the starting product of Oxaloacetic acid is also the end product, ready to start the process over again. As we have ascertained the major difference between anaerobic and aerobic conditions is the requirement of oxygen. Anaerobic processes do not require oxygen while aerobic processes do so, the Krebs cycle

however is not that simple. It is a part of a complex multi—step process called cellular respiration. Although the use of oxygen is not directly involved in the Krebs cycle, it is considered an aerobic process.

Electron Transport Chain

The hydrogen mentioned above is transported into the inner membranes of the Mitochondria where it is split into a proton (H+) and an electron (H-). The electrons are then subject to a series of redox reactions which release a large amount of energy in order to resynthesise ATP. The protons also create energy by moving back through the inner membrane of the Mitochondria because of the redox reactions. This causes an imbalance of H+ and so they return through the membrane, producing energy. A final exothermic reaction is the combination of hydrogen with oxygen, to form water. The total ATP production during all of the reactions of the electron transport chain is 34, meaning it is by far the highest producing phase of aerobic metabolism.

The anaerobic energy system

As already mentioned the anaerobic energy system provides energy in the absence of Oxygen. This is used in the first few minutes of all exercise, before there is sufficient oxygen available at the muscles for aerobic metabolism. It is also used for fast, powerful bursts of energy, for which the aerobic system is insufficient. There are two systems within Anaerobic metabolism, which are the ATP-PC system and the lactic acid system.

ATP-PC System

ATP as already discussed is a high energy molecule which is broken down to form ADP and release energy. PC or Phosphocreatine is another high energy molecule, found in the Sarcoplasm of muscle fibres. The breakdown of ATP and so increase in volume of ADP triggers an enzyme known as Creatine Kinase to initiate the breakdown of PC into Phosphate and Creatine. Being an exothermic reaction, this provides the energy required to resynthesise ATP at a fast rate. We only have 120g of Creatine within our bodies and so this repeated breaking down of PC in order to produce energy to resynthesise ATP is temporary and can only last a maximum of 10 seconds. Therefore the ATP-PC system is used mainly for bursts of speed.

Note here that although the ATP system can be trained to be more efficient such as with sprints/weights etc it is generally accepted that improvements in technique will far outweigh any improvement gained from training the ATP system.

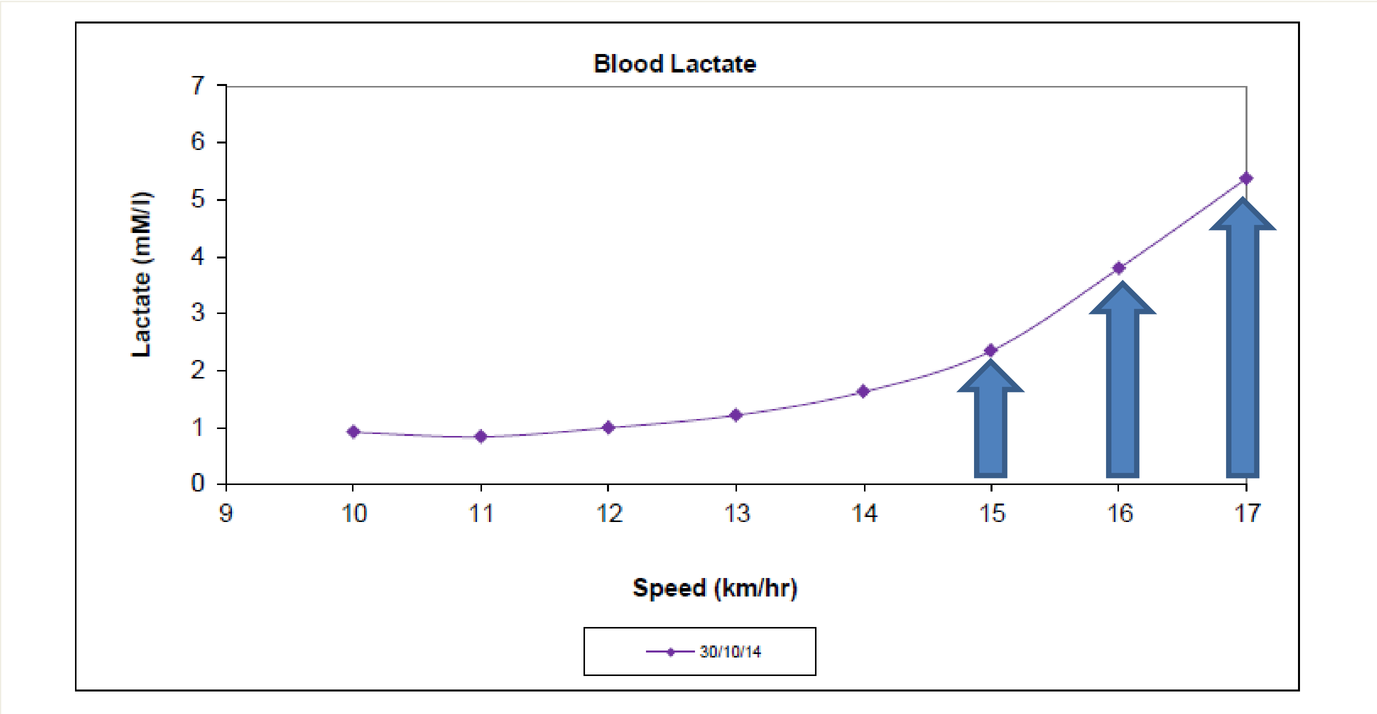
Lactic Acid System

For endurance runners this is the system that they may be most familiar with though often with some misconceptions as Lactate is actually a fuel which when it has sufficient oxygen resynthesises into energy. Sometimes also known as Anaerobic Glycolysis due to the initial process being the same as aerobic glycolysis (as mentioned above), only without oxygen. So, as before 10 chemical reactions occur within the Sarcoplasm which turn Carbohydrate into Pyruvic acid and 2 molecules of ATP. The difference now being the lack of oxygen meaning the carrier molecule NAD+ cannot offload the Hydrogen (H+) by-product of glycolysis causing a build-up in the cell.

To try to prevent an increase in acidity the pyruvic acid accepts the H+, forming Lactic acid. If oxygen was present the H+ would be transported to the Mitochondria for use in the Kreb's cycle. Lactic acid is thought then to interfere with muscle contraction. Acidity also stimulates free nerve endings within the muscle, causing pain. Due to lactic acid production, this energy system can only be predominant for up to 2 minutes. Note though that Lactate is not always a bad thing and indeed it is at aerobic levels resynthesising to produce more energy and without it the PH in the muscles would become too high and would not work at all which is something we sometimes see at the end of a marathon. It is only when there is insufficient oxygen that the hydrogen ions build up and cause that familiar burning sensation!
So now that we have a basic understanding of how the energy systems work it would make sense as coaches to look at how we might be able to train the various systems. As endurance runners much of the work done would aerobically whereas sprinters would lean almost exclusively towards anaerobic work as this would be predominantly their energy system. However we always find that sprinters will use the winter to build up endurance and may do longer reps than they would normally which may even source the aerobic system. As you should have derived from the above technical information all of the energy systems work as an interaction with each other and it is only the type of work that is done that determines the predominant system being used at any one time. In such case it would make good sense to ensure that training is set with sufficient variety to cover all the required bases. A good example would be to look at sessions which may improve the efficiency of the Krebs cycle (sometimes known as lactate shuffle training) which as we have noted above is a complex multistep process which whilst not using oxygen is considered an aerobic process. An example session to work this energy system specifically would be perhaps 10 X150m with walk/jog back recovery. This session being long enough to start touching into the aerobic systems but being predominantly anaerobic also covers lots of bases through the energy systems and if you correlate all of the above information above you will be able to chart directly the energy systems that are used in this session.

Lactate turnpoint

Despite all the possible misconceptions above, the point at which your body starts to begin using carbohydrates as its primary energy source is known as the lactate turnpoint. It is as its name denotes the point at which you have "crossed the red line" in terms of aerobic energy production. The graph below is from a test on a well-trained adult W35 runner and as you will see blood lactate (the volume of lactate that has seeped into the bloodstream) shoots up dramatically at around 16km per hour (around 6mpm). This is termed as the lactate turnpoint and essentially if this was in a race rather than a lab test the end would be very shortly nigh in terms of competiveness. It then makes great sense to train to increase this turnpoint and some practical suggestions of how this could be achieved are detailed below.



__The sessions below are based on the chart which below and is specific to the athlete that was tested,__ so you will need to find a way of ascertaining this point. As with the athlete whose data is shown you could have a physiology test although these are fairly expensive but do give out a huge amount of data. Alternatively you could pursue the strong association between race paces and lactate turn point. __Generally speaking, the lactate turn point is hit at a running pace that is just slightly lower than your 10K pace. For most runners then 10K pace is about 2.5 percent faster than their lactate threshold and their 5K pace is about 5 percent faster.__

LACTATE THRESHOLD (Zone 2 → Zone 3)
ANAEROBIC THRESHOLD (Zone 4 → Zone 5)

		Duration	Heart Rate (b/min)	Speed (km/hr)	Speed (min/mile)	Exertion	Adaptations
Zone 1	Recovery	30 mins	< 158	< 12	< 08:03	<11	Increase blood flow
Zone 2	Easy	1 - 5 hrs	158 - 166	12 - 13	08:03 07:26	11 - 12	Increase fat burning
Zone 3	Steady	30 mins -2 hrs	166 - 172	13 - 14	07:26 06:54	12 - 13	Improve aerobic base
Zone 4	Fast Steady	**20 - 40mins** e.g. 3 x10, 1min recovery, 2 x 20min 2min recovery or 1 x 30min	172 - 178	14 - 15	06:54 06:26	14 - 15	Quality mileage for aerobic development - shift the LTP up from below
Zone 5	Tempo	**15 - 25mins** e.g as one run session or included within a longer run	178 - 182	15 - 16	06:26 06:02	16 - 17	Pull the LTP up from above.
Zone 6	Intervals / VO_2 max	**Short: 20 - 60s**, e.g 20 sprint, 40 recovery, or 60 on, 60 off. **Long: 1 - 4mins**, e.g. 3/4mins on 1:30 off, 2mins on, 2mins off.	> 182	> 16	> 06:02	18 - 20	Increase VO_2max

Tempo runs and runs in the higher end of the “steady” zone are ideal for improving this threshold. You may initially find that it may be a struggle to do more than 3 or 4 miles at this place in such case breaking down the run into for example 3 miles followed by a rest and then 1-2 miles more would be an ideal starting point. You could play with durations, aiming to total around 30-45 minutes of tempo running, breaking the reps down into 10 minutes+ blocks. For example, doing to X3 miles, 1X4, 1X3 miles et cetera. Some other options are :

- A progressive tempo whereby you start in the steady zone and get faster aiming to be in the tempo zone for the last part of the run (as you progress you would be able to do more in the tempo so) or a total duration of, say, 20-30 minutes.

- Long reps-7.5 minutes effort at a heart rate 1-3% above lactate turnpoint with 2.5 minutes easy jog recovery. You would look initially to do 3-7 reps of this building up the number as you or your athlete gets fitter and adapts more to the training.
- 2X 10 minutes in the tempo zone, with two minutes recovery between reps. Building up to 3 reps, and then gradually extending the duration of each rep again as fitness improves
- Short reps 30 seconds effort at 3-5% above lactate turn point heart rate with 7-10 seconds walk recovery. This is a deceptively tough session and you would look at starting at around 20 reps building gradually up to a maximum of 60. For this session you would make sure that you or your athlete didn't go off too fast which is very tempting as the effort isn't very long. Running too fast in the early stages will mean that you will struggle to maintain the quality of the session and not accumulate enough time above the lactate turn point.
- Finally a really high quality tempo session is five minute intervals at tempo pace with one minute recovery between reps - you should be able to do 20-25 minutes in volume.

Improving Lactate threshold

Of course to raise our lactate turn point we also need in turn to improve the threshold which sits just below that point. In order to shift your lactate threshold you would need to firstly look to ascertain where this threshold is and build up mileage around this speed. Using the chart above as an example long runs of 60 minutes or more would be done in zone two (easy zone) while runs of 45-60 minutes can be done a little over lactate threshold, so in zone three-steady. It is easy to be carried away with the sessions however it is really important that once you have ascertained the threshold that you don't go too fast as in turn you won't get the required adaptations. Other sessions to improve lactate threshold are as follows:

- Long reps. These reps should be done at a heart rate a little over lactate threshold (2-3%) higher and should last for 5-20 minutes and increasing the duration as you or your athlete gets fitter, with the recovery being half the duration of the rep and at a heart rate about 15% lower than lactate threshold. Ideally 2-5 reps should be completed. To progress this training you would reduce the number of reps but increase their duration as you get fitter
- Short reps. These are very short reps but you do lots of them to accumulate time spent at/above lactate threshold. These sessions are best done on a track or somewhere you can assess speed accurately. Reps are one minute long, with 10 seconds walk recovery. Heart rate should be 4-5% higher than lactate threshold during the rep. You should aim to complete 20-50 reps depending on fitness. This is a deceptively hard session to complete.

The idea with these above sessions is to drag lactate threshold up from above, so to run a little above lactate threshold intensity, then allow your body to recover (clear the lactate that has started to build up) and then repeat. So while the long runs below are a little above lactate threshold they are improving your endurance at lactate threshold (improving how long you can run at that pace whilst still using predominantly fats as an energy source), the sessions are about trying to get your body better at using fats at slightly higher speeds.

So there we are, a mixture of technical information about how our energy systems operate and hopefully some good examples of how to turn this knowledge into practical training areas. When setting your sessions it would always be a really good idea to briefly look through the systems that are being used during that session which might challenge your thinking about changing some of the sessions that you actually do.

Having looked at all of the above technical information as coaches do we need to understand every scientific angle and term of what is happening? **Probably not**. However to enable us to provide the best training schedules for our athletes and to understand how they react to the training that we give them we should get to know and understand in at least the most basic of terms what is happening in their bodies so that training can be adapted to suit the individual.

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