Using Lactate Testing to Determine your Anaerobic Threshold (AT)

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Introduction:

The building blocks for an optimal performance are many and must be constructed in a proper sequence and must recognize that each individual is different. However, the cornerstone for this building is precise physiological training. That is the main reason an athlete spends so much time in the water, on the bike, on the track or the road, in the weight room or wherever training is best conducted.

Ask yourself; do you know if all those miles/hours of training are paying off?

But what is appropriate physiological training? It is not volume or else those who put in the most hours/miles would be the winners. It is not intensity or else those who pushed themselves the hardest would be the winners. It is not someone's favorite workout or else everyone would be copying the magic workout or training pace. It turns out that each individual has his or her own way of adapting and any smart training plan must recognize this. This is a fact of life. Each has to find his or her own way to the proper balance of the energy systems and peak conditioning on the day that counts, race day.

With proper protocols, a lactate tester enables the coach to measure both the ***aerobic and anaerobic conditioning*** of each athlete. Information about both is necessary for the coach to optimize the conditioning of each athlete: whether they are a 50 metre freestyle swimmer (about 22 seconds plus per race) or in an Ironman triathlon (over 8 hours per race). With information on each energy system the coach can plan, control and monitor the training of athletes with a precision not available before. The lactate tester provides the important information that enables the coach to individualize the intensity of each athlete's workout and control their training so they reach performance objectives.

No over-training and no surprises come race day.

Quite simply, true lactate testing is the gold standard and ultimate form of testing available. It removes the guesswork and estimation that all the other testing methods use and is based solely on the data that your body provides. For example, “anaerobic threshold” prediction tests, “max heart-rate tests” and heart-rate formulas are all based on guesswork and mathematics and as such give very sketchy results. For example, after being lactate tested and comparing the results with those from a heart-rate formula or anaerobic threshold prediction test, it’s not uncommon for some athletes to realize that they’ve been training as much as twenty beats per minute out of their optimal range! Suddenly the athlete can see why they were prone to over-training, underperformance and constant disappointment. Almost always, the athlete improves dramatically following lactate testing, as for many this is the first time that they get accurate data that allows their true athletic potential to be realized.

How does Lactate Testing do this?

Lactate testing is used by sport scientists, coaches and athletes to determine the individual anaerobic threshold (IAT). This is not to be confused with the ‘lactate threshold’. In endurance sports such as triathlon, this information is vital. Numerous studies have shown that the best way to improve performance is to train at or close to your I AT. In the absence of lactate testing, athletes often perform time trials and use heart rate (HR) to determine their IAT. This method can sometimes be unreliable though, as factors such as; wind, fatigue, HR lag, different courses, dehydration etc can affect the results. In addition, it is often impractical in some sports to use HR as a measure of intensity i.e. swimming. In an ideal world, testing for IAT would involve speed, HR and lactate. This is explained in further detail below.

What is Lactic Acid?

Lactic acid is an intermediate product of the metabolism of glucose (glycolysis) for the anaerobic production of energy. Lactate is subsequently oxidised or converted back to glycogen.

What is the Difference Between the Aerobic Threshold and Anaerobic Threshold?

Oxygen (Aerobic) Threshold

Based on the metabolic response to an increasing workload, the aerobic or oxygen threshold can be identified by the first small raise in lactate, indicating the transition between the aerobic state and the uneven aerobic state.
This first rise in lactate can be viewed as the increase of extracellular lactate concentration required to reach the extracellular to intracellular lactate gradient for priming the utilisation of lactate by aerobic muscle fibres. Below this intensity, the great majority of the working muscle fibres are in full aerobic condition.
Above this intensity initially the aerobic fibres, assisted by other body organs, will fully process all the lactate produced by the anaerobic fibres.

Anaerobic Response

If the exercise intensity is increased further the remaining aerobic fibres will also become more dependent on anaerobic glycolysis for their energy production and blood lactate increases rapidly throughout the exercise duration. The exercise intensity is such that oxygen consumption is insufficient to account for the overall energy production. Intracellular and blood lactate and accompanying protons increase while glycogen stores deplete rapidly (Fig 3). As a result, the time spent at this workload (duration) is significantly limited.
There is a point reached where the body cannot remove/buffer all of the lactic acid produced, and the lactate starts to accumulate in the muscle fibres. The athlete is eventually forced to slow down. This point is termed OBLA (onset of blood lactate accumulation). This is normally somewhere between 85% and 90% of your maximum heart rate (MHR). This point is also termed the IAT. This point usually corresponds to race-pace in many endurance sports, as it is the fastest pace that can be maintained for long periods. Due to the fact that this intensity is so high, it can only be maintained for about an hour. This is largely due to the depletion of muscle glycogen stores and emphasizes the importance of replenishing glycogen stores during longer endurance events such as the Olympic distance triathlon and the marathon.

How to use the Lactate Index

Recommendations regarding training intensity based on heart rate zones are much more accurate when heart rate is based on the individual lactate response of the athlete.

Once the five intensity zones have been established according to the lactate index the coach can simply use the related terminology (easy to very hard) when prescribing training intensity. The individual athlete can monitor the prescribed intensity using the five level scale of subjective perception backed by the heart rate monitor readings

When to Use the Lactate Index

The use of heart rate zones based on the lactate index, is especially relevant in the learning stages immediately following lactate testing, to practice the prescribed training intensity zones. It is during this time that the athlete and coach might have to make adjustments to the prescribed training intensity zones based on the subjective perception of the athlete during training. This is the time where the athlete learns to "read the body" using the heart rate monitor for feedback.

During times of structured training monitoring of the heart rate is also useful to ensure that optimum training intensity zones are achieved as accurately as possible. At the same time it is more likely that the athlete will pick up any signs of impending overtraining or illness through a sudden increase or decrease of the heart rate response during training.

When coming back from injury or sickness the use of a heart rate monitor will ensure that the athlete trains within safe limits at all times.

Factors Influencing Lactate Response

A wide variety of factors influence blood lactate and heart rate response to exercise including: training status, carbohydrate intake, caffeine intake, hormonal factors, hydration status and environmental factors. Heat, humidity and altitude all result in an increase in metabolic stress and an accelerated heart rate response.

Training at altitude will also have an effect. Athletes will be unable to train at similar intensities and speed compared to sea level training. It has also been reported that the maximal lactate response of the altitude acclimatisation is blunted at higher intensities, indicating a possible increased dependency on fat metabolism.
Also, some athletes have trouble lifting their lactate levels over 4mmol/L, despite working extremely hard. Therefore it is always good to combine lactate tests with field tests during training to aid in the prescription of training zones (Hellemans, 1993).

Miscellaneous Factors Influencing Lactate Response

Lactate values may differ depending on the sampling site. The most common sampling sites are the forearm vein, the earlobe capillary and the finger capillary.
No significant differences have been observed between venous and ear capillary samples when exercise is performed on a treadmill or exercycle, whereas finger capillary values are higher. Consistency in sampling site is therefore recommended.
Contamination of the sampling site (e.g. sweat and dirt) and a poor sampling technique can also affect the lactate reading.

Lactate Response	
Enhanced	**Inhibited**
Carbohydrate Loading	Carbohydrate Depletion
Excitation (catecholamine)	Fatigue
Over-training (sympathetic)	Over-training (parasympathetic)
Decreased physical fitness	Increased physical fitness
White fibre dominance	Red fibre dominance
Altitude (acute)	Altitude (chronic)
Heat	Insulin

Laboratory Versus Outdoor Testing

Testing needs to mimic training conditions as closely as possible. As an example, the results will differ between a cyclist tested on the road compared to when tested indoors on a wind-load trainer.

Special Considerations

Lactate testing will be of more benefit when repeated over time. An increase in metabolic fitness can be observed by a shift to the right of the lactate curve. If the lactate curve has changed little over time, an increase in pace will indicate improved efficiency

Individual Response

It needs to be made clear that everybody has their own, unique lactate response to increasing exercise intensities. This example deals with endurance athletes only. A clear oxygen threshold cannot always be distinguished on the lactate curve. In these cases the oxygen threshold is established on the heart rate response and the RPE.

Sports Specific Testing

Lactate testing needs to be done specifically for the discipline athletes' train for. Different lactate curves and related heart rate responses are likely for the same athlete when tested in different disciplines (Figure 11, curves A and B). Triathletes for example need to be tested in the three disciplines of swimming, cycling and running.

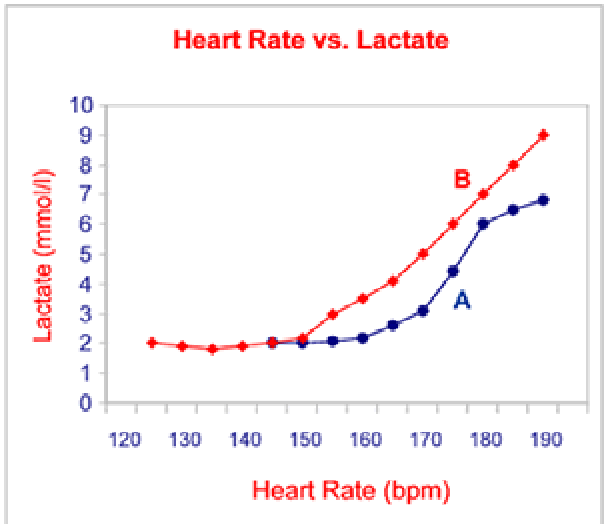


Figure 11

This curve shows the same athlete tested for running (curve A) and cycling (curve B), resulting in different recommended heart rate zones for the two disciplines.

Recommended Heart Rate Zones			
Perceived Exertion	**Heart Rate Zone (A) Running**	**Heart Rate Zone (B) Cycling**	
Easy	**<155**	**<135**	
Moderate	**160-170**	**140-150**	**Oxygen Threshold**
Solid	**170-175**	**150-155**	
Hard	**175-180**	**155-165**	**Lactate Threshold**
Very Hard	**>180**	**>165**	

Even Aerobic Response

At low exercise intensity, all muscle fibres are working aerobically. The pyruvate formed from glycogen is completely oxidised to CO2 and H2O within the mitochondria of the muscle cell (see below).
Lactate production is also minimal because the remainder of the energy production comes from fat oxidation through the Krebs cycle. However, even when all fibres are able to work aerobically there is still some lactate production due to the mass action effect of the LDH enzyme.
This is considered the base line lactate.

Field Testing to Establish the Lactate Index

Instructions to the Athlete

The testing needs to be done under a standardised conditions e.g. at a 20-25 metre pool, a cycling velodrome and a running track. Only controlled aerobic training (easy and steady) for short duration (up to 1.5 hours) is permitted the day prior to testing.
When testing repeatedly the test is best done at the same time of the day. Instructions to the athletes regarding intensity of the different repetitions need to be clear, progressing from easy to steady to moderately hard to hard to very hard.
If a maximum heart rate is known the following guidelines apply:

Easy	Maximum heart rate minus more than 40 beats
Steady	Maximum heart rate minus 30-40 beats
Moderately Hard	Maximum heart rate minus 20-40 beats
Hard	Maximum heart rate minus 10-30 beats
Very Hard	Maximum heart rate minus less than 20 beats

For a first time it is best to start the first repetition at an intensity approximately 50 beats below MHR. A 6th repetition can be added if there is no clear sign of rapid lactate accumulation and the athletes has not perceived the 5th repetition as very hard. The test can be terminated after the 4th repetition of this is perceived as very hard by the athlete and as a significant rise in lactate has been observed (usually more than 4 mmol/l)

Protocols

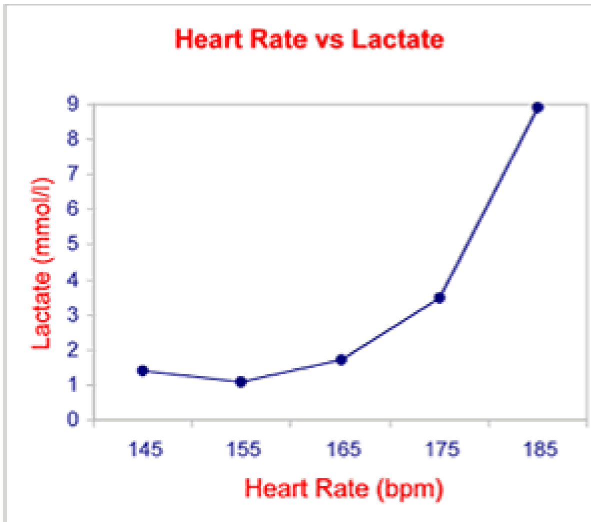
The protocols to establish the lactate index are based on experience with lactate testing and the knowledge that metabolic responses to a certain training intensity stabilise after the first five minutes.

A lactate reading done after this time can be considered to represent and be time reflective of the true metabolic state. The protocols focus on repetitions done at a progressive pace, which take approximately five minutes or more.

For swimming, 300 or 400 metres, for biking 3-4 km and running 1 or 1.6 km (1 mile) repetitions are suggested. The choice of distance depends on the fitness levels of the athlete. Time, heart rate and lactate are recorded immediately following each repetition. The rest period in between repetitions is either determined by the time it takes it takes to do the lactate testing procedure or can be standardised.

Results

The results can be presented to the athlete and coach as shown below, with clear recommendations regarding the training intensity zones.
The results will always need to be verified with the athlete and coach following a trial period, as sometimes recommended heart rate zones need to be adjusted.



Name: Keith Murray		**Date:** 21 September 2001	
Discipline: Running		**Protocol:** 5 x 1600m	
	Time (minutes)	**Heart Rate (bpm)**	**Lactate (mmol/l)**
Resting			
Step 1	**7.23**	**145**	**1.4**
Step 2	**6.55**	**155**	**1.1**
Step 3	**6.15**	**165**	**1.7**
Step 4	**5.43**	**175**	**3.5**
Step 5	**4.14**	**187**	**8.9**

Recommended Heart Rate Zones		
Perceived Exertion	**Heart Rate Zone (A) Running**	**Metabolic State**
Easy	**<155**	
Steady	**160-170**	**Oxygen Threshold**
Moderately Hard	**170-175**	
Hard	**175-180**	**Lactate Threshold**
Very Hard	**>180**	

Hard Zone

In well trained athletes the hard zone represents race pace for shorter endurance events (between 5-30 minutes). Through training, increasing levels of lactate are tolerated for significant periods without the need to slow down. The pace is subjectively perceived as hard and no conversation can be held.

Training in this zone will improve the specific metabolic requirement related to racing, including lactate clearance and lactate tolerance in the muscle and the blood stream. This zone is an important part of training for the competitive endurance athlete during the specific preparation period prior to competition.

In well trained athletes this zone coincides with a heart rate that is usually between 10-30 beats below maximum (See Figure 5).

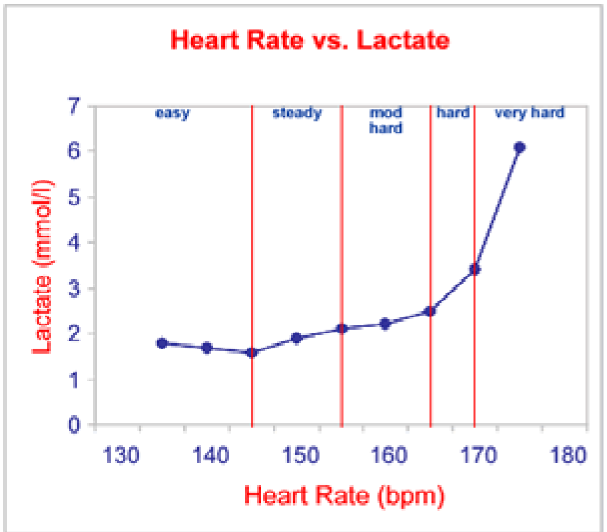


Figure 5
The five training intensity zones based on the lactate curve

<u>Flat Curve</u>

A flat curve expresses an inability to increase lactate levels beyond resting levels that can indicate over-training and or glycogen depletion (Figure 10 - curve A). When there is little or no glycogen available less lactate can be formed. Glycogen depletion can cause symptoms of over training in endurance athletes and a flat lactate curve can confirm the diagnosis.

A reduction in training combined with nutritional advice can then result in a significant improvement in the lactate curve after a period of time.

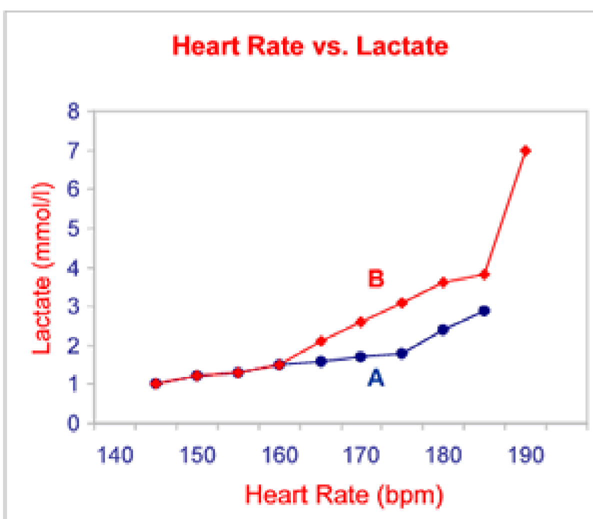


Figure 10
Curve A reflects an athlete who shows symptoms of overtraining and who is unable to raise his lactate. 6 weeks of aerobic training combined with dietary advice shows a much more satisfactory response in an athlete who also felt much better.

Linear Curve

The lactate increases in linear fashion with the heart rate and no obvious curve can be distinguished (Figure 9 curve A). This is a curve that represents an unfit endurance athlete who produces a significant lactate level even at lower training intensities. This curve is often seen in junior athletes and beginners.
This athlete needs to be advised to train mainly in the lower intensity zones e.g. easy, steady and moderately hard, to improve the oxygen processing capacity for the working muscles. This usually shows a significant response within a short period (Figure 9 curve B).
Please note: This type of curve is also common in sprint athletes who have a higher ratio of fast twitch fibres.

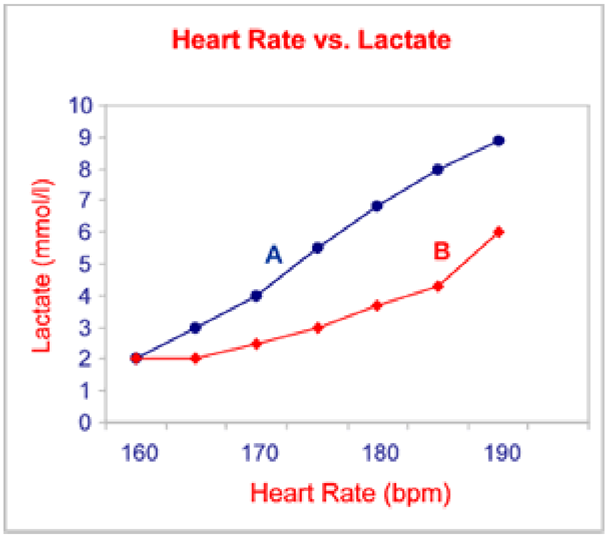


Figure 9
Curve A represents an unfit athlete. When re-tested after 6 weeks of aerobic training a dramatic improvement in metabolic fitness is evident (curve B)

Interpretation of Results

Every athlete has their own unique lactate curve, which depends, not only on their current fitness level but also on unique individual characteristics s of the athlete in relation to all factors responsible for lactate metabolism. This includes genetic endowment (e.g. ratio between fast twitch and slow twitch fibres).

Normal Curve

The normal curve represents the endurance athletes who have some background in training and who have a reasonable aerobic base. Lactate is processed efficiently at the lower training intensities. A clear lactate threshold is clearly identifiable at an increased training intensity. (Fig 7 curve A)

To improve this athlete will need to spend a certain amount of training at intensities around the lactate threshold. This means doing repetitions and time trails just below (moderately hard) at (hard) and just above (very hard) the lactate threshold. Emphasis on high intensity combined with the ratio of the different intensities used during training is dependent on the athlete's training phase. The aim is to shift the curve to the right with as a result a shift of the lactate threshold to a higher threshold (and racing) intensity

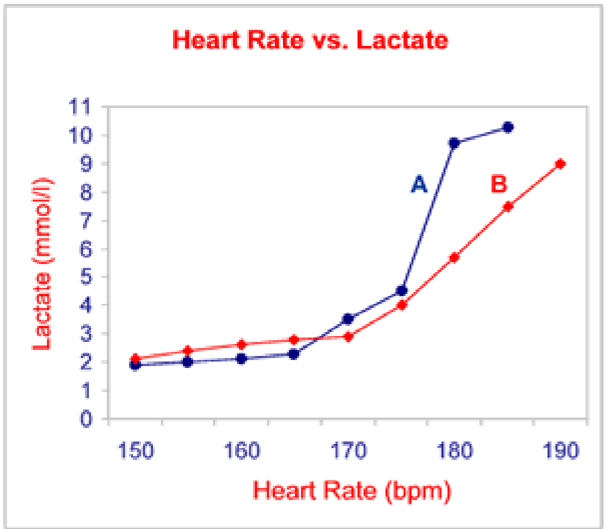


Figure 7

Curve A represents the lactate curve of an athlete for running early in the season, following a period of base training. Curve B was done 6 months late towards the end of the competitive season, and reflects the benefits of high intensity training and racing

Steep Curve

This is a curve of a very fit, well-trained athlete (Fig 8). This athlete has been training properly for many years and has a curve close to maximum potential. Little improvement of the curve can be achieved by training intensity.
Intensity training will result in a maintenance effect. This athlete will need to experiment with additional methods to improve endurance performance including looking at strength, technique, efficiency, nutrition, ergogenic aids and mental factors.

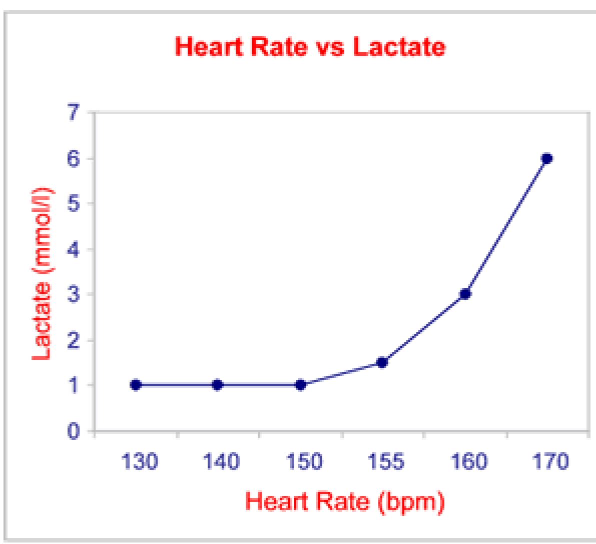


Figure 8
This is the curve of a very fit and experienced athlete. High intensity racing and training will maintain fitness and further improvement will need to be achieved by exploring other factors relating to performance

The Lactate Index

The three zones have been identified corresponding with specific measurable metabolic changes in the body, consisting of the aerobic zone, the uneven aerobic zone and the anaerobic zone.

The aerobic and uneven aerobic zone pertain to exercise for health for the general population and to the aerobic conditioning zone for performance athletes. The anaerobic zone pertains to specific performance improvement for competitive endurance athletes. It can also be used for sprint and power athletes.

For practical purposes five training intensity zones will be identified, based on the metabolic, heart rate and psychological response to increased workloads. They are illustrated in Fig.5.

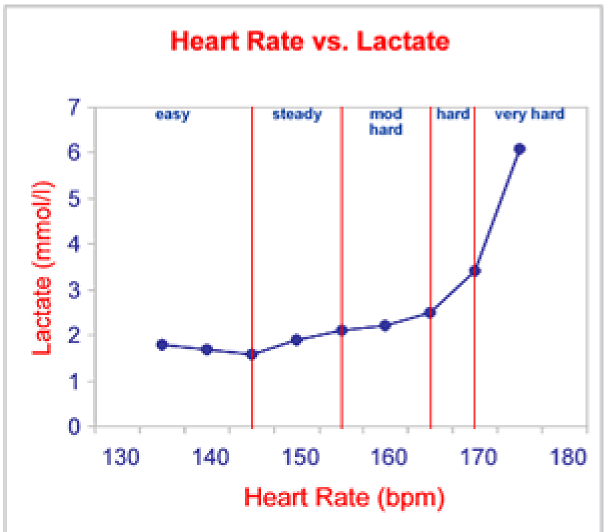


Figure 5
The five training intensity zones based on the lactate curve

Easy Zone

The easy zone corresponds with the even aerobic zone where all working muscle fibres are in an aerobic state. This level is perceived as easy or the pace at which a conversation can be held.
Except at the immediate onset of exercise at this level, little or no additional lactate is produced compared to resting levels. The heart rate is usually more than 40-50 beats below maximum and effects relate to increased circulation and temperature of working muscles.
This zone is appropriate for exercise for health and warm-up, cool down, recovery and technique training for competitive athletes.

Lactate (Anaerobic) Threshold

When intensity increases further there will be a point where anaerobic fibres prevail and not all lactate produced can be processed. At this point the oxygen consumption is unable to account for the overall energy turnover. This point can be regarded as the true, whole body, lactate threshold. This is also the time that the anaerobic fibres start to deplete their glycogen stores at a much faster rate, eventually contributing to the limitation of exercise duration at this intensity. The lactate or anaerobic threshold is identified by the second, much more rapid increase in lactate.

The meaning of the lactate threshold and its exact point is still under scientific scrutiny. However the concept of the uneven zone, flanked by the two thresholds is a practical and attractive way to explain the theory behind the use of lactate measurements to assess work performance and to establish training intensity zones. The aerobic and anaerobic thresholds are illustrated in Figure 4.

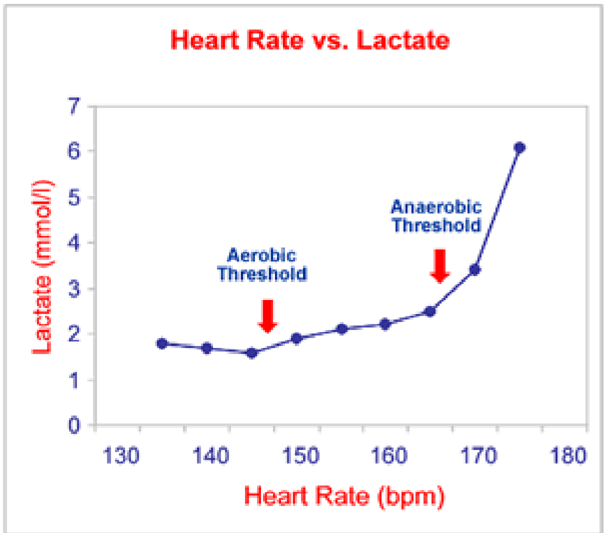


Figure 4
The aerobic threshold is identified by the first small rise in lactate and the anaerobic threshold by the second more obvious and rapid rise in lactate. This is an example based on an athlete with a maximum heart rate of 175-180 beats per minute

Moderately Hard Zone

This zone identifies the transition from the uneven aerobic zone to the anaerobic zone. Lactate levels in the blood are starting to rise when the lactate turnover reaches close to maximum capacity. This is the zone where exercise becomes less comfortable and conversation is difficult.
As rapidly accelerated lactate accumulation is still avoided, this zone can be considered as a "safe" higher intensity training zone resulting in specific performance improvement without unduly stressing the metabolic system by rapidly accumulating lactate. Corresponding heart rates are usually between approximately 20-40 beats below maximum heart rate. In well-trained athletes this pace can be maintained for 30-120 minutes.

Lactate Testing Protocols

Choose one of the protocols specified below, according to the needs of the athlete. Where possible, test the athlete in the discipline closest to his/her chosen sports e.g. test a cyclist on a cycle ergometer/ velodrome, a water polo player in a swimming pool.

(A) Lactate Profile Protocol (Cycle Ergometer)	(B) Lactate Profile Protocol (Treadmill)
Equipment • Kingcycle interfaced to computer • Road bike • Lactate analyser • Heart rate monitor • Fan	**Equipment** • Treadmill • Lactate analyser • Heart rate monitor • Fan
• Pre-exercise lactate sample • 5 minute warm-up @ 50 watts < stage 1 • 1st stage @ 125-200 watts (depending on ability) • Increase power 25 watts per stage • Duration of stages = 5 minutes • Collect blood samples during last 30 seconds of each stage	• Stretching and walking, but no running warm up • Constant 1.5% grade to simulate over ground running • 1st stage velocity is set so 5th stage coincides (within 0.5 km/hr) with 10,000 metre race pace • Increase speed 1km/hr per stage • Duration of stages =5 minutes

• 5 min active recovery on bike	• Athlete straddles treadmill belt while blood sample collected (30 sec to 1 min)
Criteria for ending test • Continue until 2 consecutive stages with >1 mmol increase and lactate concentration > 4.0 mmol	**Criteria for ending test** • Continue until 2 consecutive stages with >1 mmol increase and lactate concentration > 4.0 mmol
Data Analysis • Lactate threshold power-cycle • Lactate threshold heart rate-cycle	**Data Analysis** • Lactate threshold speed-run • Lactate threshold heart rate-run
(C) Lactate Profile Protocol Cycle Ergometer and Treadmill	
The 2 protocols can be combined with a 15-minute rest in between for triathletes and duathletes to establish lactate response when running after biking.	

Lactate Profile Protocol (Field Testing)	**Notes**
Equipment • Lactate analyzer • Heart rate monitor • Fan	**Field Locations** • Swimming pool • Cycling velodrome or road circuit • Running track or road circuit
Swimming • Pre-exercise lactate sample • 5 minutes easy warm-up • 5 x 400 metres with following intensities • Easy (Max heart rate (MHR) minus 40-50 beats) • Moderate (Max heart rate minus 30-40 beats) • Solid (Max heart rate (MHR) minus 20-30 beats) • Hard (Max heart rate minus 10-20 beats) • Very hard (Max heart rate (MHR) minus 10 beats) • 1 minute rest between repetitions for blood sampling1 minute rest between repetitions for blood sampling.	Time, heart rate and lactate concentration are recorded immediately after each repetition. It is critical for the validity of the results that athletes utilise even pacing while blood sample collected (30 sec to 1 min) **Data Analysis** • Lactate threshold speed • Lactate threshold heart rate • Stroke rate (swimming only)
Cycling • Pre-exercise lactate sample • 5 minutes easy warm-up • Length of stages 4km • 5 repetitions with progressive intensities as per swimming protocol • 1 minute rest between repetitions for blood sampling	Time, heart rate and lactate concentration are recorded immediately after each repetition. Environmental conditions should be recorded to contribute to interpretation of subsequent tests **Data Analysis** • Lactate threshold speed • Lactate threshold heart rate
Running • Pre-exercise lactate sample • 5 minutes easy warm-up • Length of stages 1600 metres • 5 repetitions with progressive intensities as per swimming protocol • 1 minute rest between repetitions for blood sampling	Time, heart rate and lactate concentration are recorded immediately after each repetition. Environmental conditions should be recorded to contribute to interpretation of subsequent tests **Data Analysis** • Lactate threshold speed • Lactate threshold heart rate

Response to Progressive Training Intensities

Progressive training intensity results in accompanying changes in metabolic, cardiovascular, psychological, muscular and hormonal and neural factors.
For the purpose of this guide, the focus will be on the psychological (measured by RPE), cardiovascular (measured by heart rate) and metabolic (measured by lactate) response.
An understanding by sports scientists and coaches of the physiological response at different levels of intensity and the accompanying subjective mental perception will assist greatly in the use of appropriate and uniformly accepted terminology.
The following observations have been made in relation to the responses of the metabolic, cardiovascular and psychological systems during progressive exercise intensities.

Cardiovascular Response

The main aim of our cardiovascular system during progressive exercise intensity is to meet the increasing demands of the working muscle. This is achieved by an increase in circulation to the working muscle, followed by an increased stroke volume of the heart and a rise in heart rate.
There is a linear relationship between heart rate response and intensity of exercise as measured by oxygen uptake. The main adaptation of the heart to increased fitness is an increase in stroke volume, thereby contributing to a reduction of heart rate response to a given level of sub-maximal exercise.
Dynamic muscle training over time results in an improved efficiency of the metabolic process. It also results in an improvement in technique (intra-muscular and inter-muscular coordination). These adaptations will result in an reduction of oxygen requirements at a given workload and therefore a further lowering of the heart rate at a given sub maximal workload.

Metabolic (Lactate) response

When energy requirements increase during progressive exercise intensity, more pyruvate will be produced through increased anaerobic glycolysis.
There will be a point that there is not enough oxygen to process all the pyruvate through the Krebs cycle.
The excessive pyruvate is transferred into lactic acid, which immediately dissociates into lactate and H+.
Based on current evidence regarding the production and processing pathways of lactate the following three steps can be distinguished during progressive exercise intensity.

Steady Zone

The steady zone corresponds with the uneven aerobic phase. Its onset can generally be measured by a first raise in lactate, which subsequently stabilises or rises slightly over time.
Compared to the easy zone, more effort is required to sustain this pace although conversation is still possible. This zone usually corresponds with a heart rate that is 30-50 beats below maximum.
This zone relates to exercise for health and is also a large component of aerobic training for endurance athletes, to improve oxygen dependent metabolic efficiency (See Figure 5).

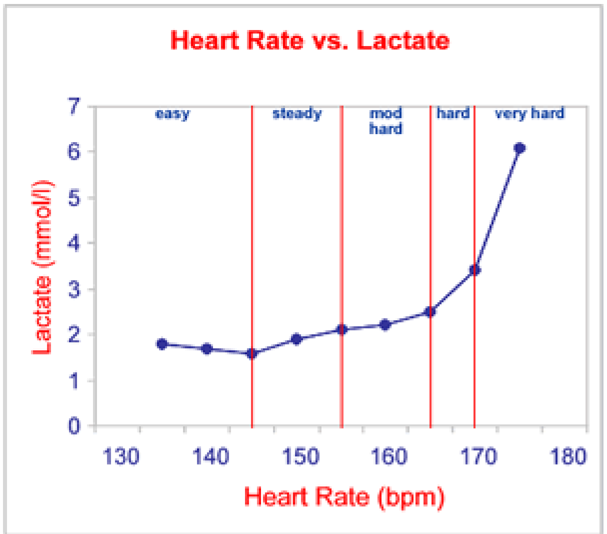


Figure 5
The five training intensity zones based on the lactate curve

Uneven Aerobic Response

When the training intensity increases there will be a point whereby some muscle fibres form more pyruvate than can be oxidised in the Krebs cycle. These muscle fibres become anaerobic. The anaerobic component results in an increased ATP (energy) production and an excess of pyruvate, which the Krebs cycle is unable to fully oxidise. This residual pyruvate is quickly transformed to lactate.

Other muscle fibres however, either within the same muscle or muscle group, or elsewhere, as well as other organs (heart, liver) have the ability to oxidise substantial amounts of lactate. They can come to the rescue and process the excess lactate by directly oxidising it through the Krebs cycle thereby sparing its own glycogen stores.

The coupling of the anaerobic fibres and the aerobic fibres will still lead to an overall aerobic system as the oxygen consumption is sufficient to cover the overall energy turnover.

During the uneven aerobic response the anaerobic fibres can be identified as the white or fast twitch fibres and the aerobic fibres as the red or slow twitch fibres. It can be argued that during the uneven aerobic phase the exercising body functions at a maximum aerobic efficiency. At this intensity, the maximum amount of ATP molecules, and therefore energy, is produced aerobically but the anaerobic effects of rapid glycogen depletion and lactate accumulations are avoided.

When training at this intensity the capacity of the working muscle to process oxygen will be improved through effects on oxygen transport, delivery and intracellular processing.
Of note is that during the uneven response, the anaerobic fibres use relatively less, and the coupled aerobic fibres relatively more oxygen to produce the same amount of ATP, resulting in an overall aerobic state with maximum energy production and efficient use of glycogen stores.

Very Hard Zone

Close to maximum pace (maximum pace is sprinting) can only be maintained for short periods of time (1-4 minutes in well trained athletes) before lactate accumulation and accompanying protons interfere with metabolic processes to such an extent that side effects in relation to cardiovascular, respiratory, metabolic and muscular (contractile) performance quickly results in a drop off in pace.
This pace exceeds race pace for endurance sports and therefore less specific for the endurance athlete. However it is recognised that benefits can be expected from training at this pace through the effects on the neural (neuromuscular) system (technique), lactate tolerance and VO2 max.

Simple Lactate Testing for Swimming

Step 1

Test protocol: The test protocol used is a standardised test devised by Australian swimming which is 7 x 200 on a 5.00 min interval. The objective of this set is the last 200 (# 7) to be your MAX effort. For the athlete to set their goal times for each 200 you add 5 sec to each 200 which would make the first 200 the slowest (easiest). For example if the MAX effort of the athlete is 2:30 than the goal time for repeat #7 would be 2:30, #6 would be 2:35, #5 would be 2:40, #4 would be 2.45, # 3 would be 2.50, #2 would be 2.55 and the first 200 would be 3.00 min (see table below). It is extremely important for the athlete to know these goal times before they start the test set. The test requires the coach to take a lactate, heart rate, and a time reading after each 200. That's the tricky part, its OK if you only test 1 or 2 athletes, but when it involves 20 to 30 it's another kettle of fish all together.

200 repeat #	Target time calculation	Target Time
1st 200m	MAX - 30 sec	3:00
2nd 200m	MAX - 25 sec	2:55
3rd 200m	MAX - 20 sec	2:50
4th 200m	MAX - 15 sec	2:45
5th 200m	MAX - 10 sec	2:40
6th 200m	MAX - 5 sec	2:35
7th 200m	MAX effort	2:30

Step 2

Prepare your Lactate Tester. There are 2 main models, the Accusport monitor, which is about $1000, and the analyser that we use at www.trainingsmartonline.com - the Lactate Pro that retails for about $800.

Each test requires a test strip that the blood is swabbed onto, a lancet to prick the finger, rubber gloves and an alcohol swab to clean the area. All up the cost of each test is between 4 and 5 dollars per test per athlete x 30 athletes = 210 tests. At $5.00 each it is costs just over $1000.

Also needed for this testing is an accurate heart rate monitor. Most athletes have HR monitors so this is a relatively easy requirement. A hand full of volunteers to help record and run the show is essential also. Also plenty of pool time.

Step 3 -- If you test more than a few athletes you need quite a bit of help: We once had 18 athletes to test so the way we set it up was to have 3 testing stations: each station had one blood analyser, one person recording (taking time, HR, Lactate) and 3 athletes (with about the same goal times) assigned to them.

Each athlete leaves 1min 30sec after the other because you can only do 1 test (it takes at least 1 min to do a test) at a time. This is where the athlete plays a big part of the process – they need to be able to swim to their pre assigned goal times, take their HR and get ready to have a blood sample taken all whilst keeping an eye on the 5 min interval. We practiced this three times at training before the real test in order to determine the goals and ensure we could swim at the correct pace.

Step 4 -- The Big Session: We standardised our test workout to: 400 easy swim, 8 x 50 choice on 50 sec, 4 x 200 pull buoy only on 2:40/2:50/3:00, 7 x 200 test set on 5:00, 500 easy swim cool-down. This session takes about 1 hour (we did two groups back to back).

Step 5 -- What to do with the data: Use Microsoft Excel to create a simple template to plot goal time, actual time, velocity, HR, and lactate. This sort of set up is essential to make sense of the data collected during the testing.

Now it is a simple process of entering all the data in to the template. The template provided us with beautiful looking graphs following the rising lactate, HR and velocity. BUT what does it all mean?

Step 6 -- Interpreting all these numbers is the hardest part. Sports scientists will talk about break points in the graph for HR and lactate, lactates in the 4 to 5 mmol range, and HR jumps in order to find the elusive AT. This is where a bit of the black art of coaching comes into it. As a coach you will have spent countless hours with your athletes under all sorts of training conditions, which will give you a clue to their particular traits and habits. Sports science and coaching come together now in an assessment of all the data and graphs to determine an individuals AT - HR, time and lactate. We simply looked for some key indicators like lactate values between 4/5 mmol, break points in the graph of HR and lactate (or a deflection in the curve) and the velocity.

With this we also added the old swim coaches trick of taking 10 sec off the 7th 200 time and looked at the time of the 5th 200. All these where factors which steered us towards determining each athletes own AT in HR and pace.

Conclusion: After contemplating the question of whether this form of testing is worthwhile, we can only come up with a yes vote. The testing is expensive, its hard to organise, its hard to set up on the day, it does take up a lot of time BUT it does achieve some very positive results. It does enable the coach to set individual HR and times for each athlete (then you as a coach needs to have the ability to write sessions to suit). It does confirm the session you are doing achieve the desired training response. It also gives your squad a moral boost and a secret weapon in their training. Finally, it makes you step outside your comfort zone and experiment with different methods and search for a new response (Gathercole, 2001).

Training at the Anaerobic Threshold

For elite athletes, anaerobic threshold occurs around 85-90% of their Maximum HR. How will you benefit from training? Training won't slow down the rate at which blood lactate accumulates but what it will do is delay it's onset until a higher exercise intensity. In short... You will tap more of your 'aerobic potential'.

Anaerobic threshold training is relatively straight-forward once you have established your target heart rate zone. The intensity of training sessions should be at or just below your anaerobic threshold. Anaerobic threshold training sessions can take the form of either interval or continuous training. Interval training should consist of three to five, 6-12 minute intervals. The rest period between intervals should be 2-3 minutes. Ideally you would reach your target heart rate as quickly as possible -- inside a minute. The aim is to saturate the muscles in lactic acid, which will educate the body's buffering mechanism (alkaline) to deal with it more effectively.

A typical anaerobic threshold training session for a cyclist might be...

Interval Training Session. Frequency 2x per week. Intensity 95-100% IAT Heart Rate. No. intervals – 5. Interval time - 10mins. Rest interval - 3mins.

A continuous training session to improve anaerobic threshold should last for 20-45 minutes. This is more demanding than the interval session so build up to it gradually.

Interval Training Session. Frequency 2x per week. Intensity 95-100% IAT Heart Rate. Time 20-45mins.

Removing Lactic Acid

The process of lactic acid removal takes approx. one hour, but this can be accelerated by undertaking an appropriate warm down which ensures a rapid and continuous supply of oxygen to the muscles. Alternating hot/cold showers also aids this process by creating a 'pumping' action in the blood vessels as they contract/dilate.
Remember, acidosis destroys mitochondria. The fastest way to clear the lactate buildup is with "active recovery". Don't stop too long at the finish line; instead go for a nice slow jog for about 15 minutes. This should clear your lactate level back to resting levels by re-using the lactate as fuel. The nice thing is that you can check it with your lactate tester. Take your lactate after the 15 minute recovery jog. It should be back down to around 2mmol/l. If it is still high run for a little longer and then check again. Scientific studies have shown very clearly that active recovery is the quickest way to clear lactate, much quicker than just resting. The 15-30 minutes you take to do active recovery after a race can speed up your race recovery by a full day.

Re-Testing

Depending on the goal of the athlete, and the training phase they are in, it may be necessary to repeat the lactate test every 4 to 8 weeks. The IAT Heart Rate may change with training. It usually will increase as the athlete becomes more fit, however, fatigue can produce a drop in the IAT heart rate. The IAT heart rate is depressed by a high intensity effort such as a race. After a hard race the IAT heart rate will be significantly lower and takes 2-3 days to recover to the pre-race level. Training should be at 20-30 beats below the pre-race IAT heart rate for at least two days following a race to promote recovery.

Sodium Bicarbonate

If there was some way to reduce the lactic acid within the muscle cells, one could theoretically delay fatigue and thus continue exercising at a very high intensity for longer.

Sodium bicarbonate is an alkalising agent and therefore reduces the acidity of the blood (known as a buffering action). By buffering acidity in the blood, bicarbonate may be able to draw more of the acid produced within the muscle cells out into the blood and thus reduce the level of acidity within the muscle cells themselves. This could delay the onset of fatigue.

Research indicates that sodium bicarbonate ingestion can improve your lactate threshold. Richard Kreider (University of Memphis) conducted a six day trial with a Sodium bicarbonate supplement where 4 grams/day were consumed. At the end of this period VO2max was improved by 9%, LT raised by 12% and blood-haemoglobin levels by 5%.

Who Might Benefit?

The specific athletes who might stand to benefit from bicarbonate supplementation will typically compete in events that last between one and seven minutes, i.e. 400m to 1500m running, 100m to 400m swimming, most rowing competitions, and many team sports with their repeated nature of high intensity exercise which stresses the anaerobic glycolysis system significantly and produces a lot of acidity.

A Practical Approach

Before using either bicarbonate, it is wise to check with the governing body of your sport that the substance is not contrary to doping regulations. The most important practical point is the need to experiment with the supplement during training. Typically, an 800m runner, may perform a time trial on a particular day after a couple of days of light training. A further couple of days later, after only more light training, he/she can repeat the time trial in a similar environment after bicarbonate supplementation. The exact protocol would be to ingest 0.3g of sodium bicarbonate per kg of body weight approximately one to two hours before the time trial. That is, for a 66kg runner, consume 20g of sodium bicarbonate (about four teaspoons) and, yes, the commonly found bicarbonate of soda is exactly the substance needed. This experimenting, if repeated several times, should reveal whether bicarbonate supplementation is likely to produce any benefit and whether the athlete concerned is susceptible to any side effects.

It is likely that large individual differences do exist as far as response to supplementation is concerned. It has been suggested that the more highly trained athletes are less likely to benefit from it because their body's natural buffering systems are already so well developed, but so far this is just speculation. It has also been shown that sprinters build up more acidity within their muscles than endurance runners in response to the same exercise, and so may be more likely to benefit from the buffering effect. From the scientific research, it appears that the size of the dose is quite important, and that taking only 0.2g per kg is less likely to be beneficial than 0.3g per kg, although no evidence exists suggesting that an even greater dose is better still.

Side Effects

As for the side-effects, these may take the form of pain, cramping, diarrhoea or a feeling of being bloated, the athlete who suffers must try to eliminate them. Drinking up to a litre of water with the dose is often effective and should be carried out as standard. Breaking up the bicarbonate dose into, say, four equal portions taken over the course of an hour may also help.

Application to Triathlon

Racing at the anaerobic threshold (AT) produces high lactate levels and is therefore only sustainable for much shorter periods, like in Sprint and Olympic distance triathlon.
A short-distance triathlete needs a more diverse profile that blends aerobic and anaerobic power, so that they can sprint up a hill to stay with the pack and work at a very high power output for short periods of time. For them, the development of anaerobic threshold is key, and they will produce a much wider range of lactate levels across their test.

Triathletes racing half-ironman and ironman events will need to race slightly below their IAT to preserve their muscle glycogen stores and delay fatigue.

Once you have found your thresholds, you can start to train very specifically and develop your physiology in the manner most appropriate to your event. Then on race day, you'll know exactly what effort to race at to achieve your optimal performance.

So in reality, if you are looking to qualify for the Hawaii Ironman or to achieve your Ironman personal best, the way forward is simple. Get a test to find your thresholds, train smart using this data, re-test during your taper to find your new & improved AT — and then race just below your AT and go faster than you ever have before.

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