Training for CYCLISTS

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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From the editor

Over the years I have stumbled across countless resources for cyclists that are based on anecdotal (rather than scientific) evidence. This report is different. Within these pages you will find not only a comprehensive critique of the latest scientific research but a variety of carefully selected, practical techniques which will take your cycling performance to the next level.

Whether gearing up for a race or looking for new ways to improve workouts, cyclists – from amateur to pro – will find the practical, scientifically proven tips contained in this special report priceless.

The report covers a wide range of subjects, determining methodologies for testing your performance with or without a laboratory and telling you how to make the most of your fat stores to help you avoid bonking or hitting the wall!

We also take a look at the amount of fluid you need for long or short rides and reveal exactly what you should be putting into your drinks bottle. Another invaluable article will teach you how you can train your mind to develop emotional control – a skill which is needed to cope with the stress of competition. We even provide cycling workouts that will boost the performance of any athlete – from marathon runner to 100m sprinter.

From 'ride to into work on a sunny day' cyclists to professionals at the very peak of their sport, Training for Cyclists has something to offer everyone and we hope you enjoy this special report.

John Shepherd
Editor

Contributors

Joe Beer is a multi-sport coach providing coaching and coaching software with online companies www.JBST.com, www.ismarttrain.com and www.smarttrain.com He continues to race competitively for Giant Bikes, focusing on time trials and at the time of writing, the 116 mile stage of the L'Etape du Tour on 10 July 2006.

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Professor Greg Whyte is the director of science and research at the English Institute of Sport

Fundamental concepts in physiology relevant to cycling

Study the definitions of these physiological concepts as they appear often throughout this cycling special.

VO_2max

VO_2max refers to the maximum amount of oxygen you can take in, transport and use when working flat out and is an important measure in both sport and health. In endurance sports, such as cycling, VO_2max is often referred to as a 'prerequisite' for good performance – *ie* it does not determine good performance but is necessary for good performance. VO_2max is expressed in millilitres of oxygen absorbed per kilo of body weight per minute (mls.kg-1.min-1). In body-weight supported sports such as cycling or rowing VO_2max is expressed in litres per minute (l.min-1).

Lactate threshold (LT)

LT used to be known as 'anaerobic threshold', but this term fell out of favour because it implies that with increasing exercise intensity there is a sudden switch from aerobic to anaerobic metabolism resulting in the production of lactic acid where there was none before. In reality though, this doesn't happen because lactate is produced in low levels even during low intensity exercise. LT is therefore often taken to be the exercise intensity at which lactate begins to significantly accumulate in the blood.

Relationship between VO_2max and lactate threshold

Having a good VO_2max means an endurance athlete has the potential to perform well. Being able to sustain a high percentage of that capacity with a relatively low blood lactate concentration usually suggests that good performance will be a reality because there's little accumulation of muscle fatiguing lactate even at high oxygen uptakes. When athletes are tested in the laboratory and information on both current VO_2max and LT is gathered, scientists can express the exercise intensity at LT in terms of a percentage of intensity at VO_2max. The fitter an athlete becomes, the harder they can work (*ie* the greater percentage of their VO_2max they can use) before they reach LT point.

Fractional utilisation

The percentage of VO_2max that can be sustained whilst exercising at race pace, dependent upon both training status and exercise duration.

Maximal lactate steady state (MLSS)

The maximum steady state exercise intensity that can be sustained without a significant increase in blood lactate. Moving beyond this point would gradually take the athlete into significantly anaerobic training territory.

Greg Whyte

Are you sitting comfortably? The biomechanics of safe and effective cycling performance

A key objective of sports biomechanics is to improve performance while reducing the incidence of injury. Knowledge of the biomechanics of cycling can benefit recreational, competitive and rehabilitating cyclists alike.

The study of cycling biomechanics has provided some understanding of how the body applies power to the bicycle and the way external forces are combined in opposition to the cyclist. Some understanding of these mechanisms allows recreational cyclists to position themselves for optimal comfort and efficiency and competitive cyclists to improve their performance in competition. It also helps people undergoing injury rehabilitation or physical therapy to derive maximum benefits from the use of stationary cycling ergometers, and reassures therapists that the demands placed on their patients will improve their condition rather than induce further trauma.

Power output is important for both recreational and competitive cyclists, since the varying power needed to move the bicycle under different environmental conditions is something every cyclist must contend with, regardless of experience. The ability to apply pedalling forces effectively in training and competition is a major concern, while correct positioning is critical for successful performance and injury prevention.

Saddle height

Alteration of the saddle height changes joint angles and muscle lengths, thereby changing the kinematics of cycling and the force output of muscles. In a number of studies relating power output to saddle height adjustments, the optimal saddle height, using a seated upright position, has been reported to be 109% of leg length[1,2] *(figure 1)*. This height is considered most efficient for tasks requiring anaerobic work of high intensity for short durations, and approximately 1% less power is delivered for every 1% that the saddle height deviates – in either direction – from 109% of leg length. This is obviously of particular importance to track sprint cyclists, who are required to produce extremely high power outputs for very short periods. Studies looking into the effects of saddle height adjustments on oxygen consumption and lower limb kinematics have shown that, under steady state conditions against a moderate workload, a saddle height of between 105% and 107% of leg length requires the lowest oxygen consumption [3,4]. Lower oxygen consumption for the same power output denotes increased efficiency, which is of particular importance to both touring cyclists and endurance stage racers, who have to ride for long periods.

As saddle height increases, ankle plantar flexion (toe down position) increases near bottom dead centre (BDC) to prevent the knee from becoming fully extended, while at top dead centre (TDC) the knee is within its normal flexion range and the ankle angle does not change. When the seat height is greater than 107% of leg length, ankle plantar flexion can no longer compensate for the required l*eg* extension at BDC. To avoid further knee extension, the pelvis tilts to provide the extra effective leg length – a manoeuvre which could result in injury.

Adjusting saddle height for greater power or endurance

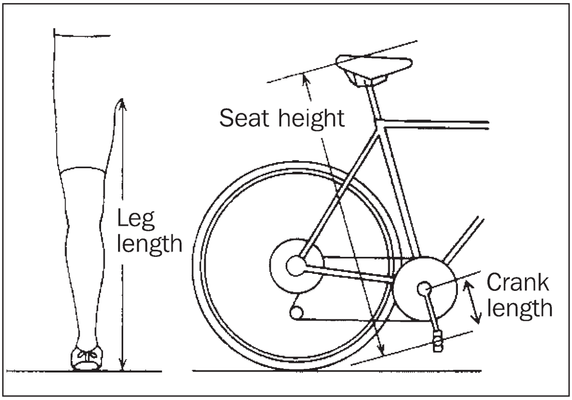
In terms of performance, a saddle height of 109% of leg length is often referred to as the 'maximum saddle height' and is recommended for short-term power output, whereas a saddle height of 105-107% is known as the 'optimum saddle height', and is regarded as most efficient for events of lower intensity and longer duration.

Studies have shown that saddle height also affects muscle activity patterns in the legs [5]. As saddle height decreases, the magnitude of muscle activation in the quadriceps (hip flexors and knee extensors) and hamstring (hip extensors and knee flexors) muscle groups increases. A greater saddle height allows cyclists to pedal with greater ease, particularly at higher workloads.

Crank length

The length of the crank arm *(see figure 1)* is another variable that contributes to the effectiveness of force production.

Figure 1. Methods used to measure leg length, saddle height and crank length



A change in crank length instead of saddle height also alters the distance between the saddle and the pedal, but with somewhat difference consequences. Increasing the length of the crank allows for greater torque production, for example, which does not happen when you merely raise the saddle height. Conversely, decreasing the crank length (rather than lowering the saddle height) would increase the muscular tension involved in force production, which could lead to earlier fatigue. There are limitations on the length of the crank, since the pedal at BDC must clear the ground when cornering and must not interfere with the steering of the front wheel when the foot is furthest forward. The type of terrain and event must also be considered, since longer cranks assist in hill climbing while shorter ones are suited to track events, where fast rotations are required.

Since crank length determines the size of the pedal circle, it affects knee and hip movement and therefore the comfort of the cyclist. If a cyclist uses cranks that are too long, the hips and knees may be encouraged into extreme flexion at TDC (i.e. by being 'pushed' further away), causing great discomfort even if the saddle is at the correct height. When changing crank length, the saddle-to pedal distance must be altered correspondingly to maintain the same effective saddle height. Some researchers have suggested that a 5cm deviation in crank length from the optimum would produce a 1% decrement in power output, whereas a similar deviation from optimal saddle height would result in a 5-8% decrease in efficiency or power in both aerobic and anaerobic cycling (6). Since joint and connective tissue injuries have been associated with over-long cranks, especially when combined with large gears, caution is needed when experimenting with crank lengths.

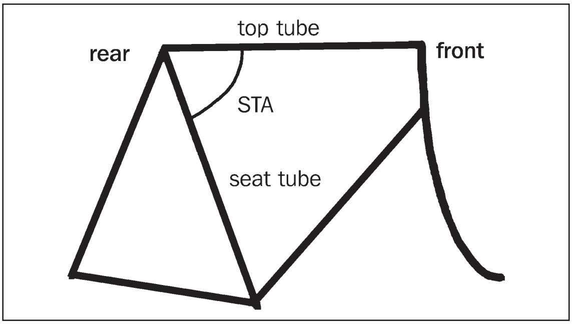
Seat tube angle

The positive interaction between cyclist and bicycle required to maximise cycling performance is dependent on the geometric design of the bicycle. The seat tube angle (STA) between the top tube and the seat tube *(see figure 2)* is important since it determines the rider's comfort level.

Competitive road cyclists claim that STAs between 72° and 76° are most effective for optimal performance, while competitive triathletes often ride with steeper STAs of 76- 78°, and some have experimented with STAs as high as 80-90°. Steeper STAs allow the rider's body weight to be positioned further forward over the crank, and triathletes believe this allows for greater comfort, efficiency and power production when using aerodynamic handlebars.

Since cyclists tend to move to the front of the saddle when cycling at speed on flat or downhill terrain and backwards in the saddle on climbs, there are probably advantages to be gained from selecting a bicycle with an STA best suited to the chosen terrain. Researchers examining the effects of STA on cardiorespiratory variables during steady state cycling have reported that oxygen consumption is higher at shallower STAs (<76°), and significantly lower at steeper STAs (>76°)[7,8]. Road cyclists tend to favour STAs of less than 76° despite the fact that oxygen consumption may be increased. This may be related to the fact that at the shallower STA angles tested there was a systematic decrease in the hip angle, which could contribute to improved performance by changing working muscle lengths and recruitment patterns. The standard recommendation for cyclists on STA has been to select an angle that will result in the patella (kneecap) of the forward leg being directly over the pedal axle when the cranks are horizontal. The rationale for this recommendation does not appear to be reported in the scientific literature, but it may be that this position provides for even weight distribution. If this recommendation is followed, STA becomes dependent on the length of the femur (thigh bone), with a shorter femur requiring a steeper STA.

Figure 2. Convention used to define seat tube angle



Saddle fore-aft position

Fore-aft position refers to the location of the rear of the saddle behind a vertical line drawn to the centre of the crank axle (point of crank attachment). The saddle is positioned to allow a plumb-line dropped from the patella to bisect the pedal axle when the crank is in the horizontal forward position. This reduces potential strain on the knee joint and maximises power generation potential; any change in the fore-aft position of the saddle will change the joint angles. The position of the knee over the pedal axle should be regarded as the starting point from which minor adjustments can be made. A saddle positioned too far forward will decrease the knee angle at TDC; increased quadriceps activity will thus be required to extend the knee, raising the risk of patellofemoral injuries. Conversely, a saddle positioned too far backward reduces the effective working of the hip extensor (hamstrings and gluteus maximus) and knee flexor (gastrocnemius) muscles.

Triathletes and time trialists have experimented with the longitudinal position of the saddle, with many adopting an extreme forward posture combined with 'maximum saddle height' with the aim of reducing air resistance while maximising power output. For safety reasons, such extreme positions are confined to time trial and track events only.

Shoe-pedal interface

It is generally accepted that the use of cleated cycling shoes on pedals with toe clips or clipless pedal system, permits propulsive torque generation over a greater portion of the pedalling cycle than regular sports shoes.

It has been demonstrated that toe clips, independent of shoe type, enhance efficiency early in the pedalling cycle because of improved normal (vertical) pedal load utilisation, and that cleated cycling shoes give a further boost to efficiency by permitting effective shear (horizontal) force utilisation near BDC and throughout recovery. The use of pedals with toe clips (seen on many exercise cycles) or clipless pedals (based on the ski binding system) increases the muscular activity in the rectus femoris (hip flexor), biceps femoris (hip extensor) and tibialis anterior (ankle dorsiflexor) muscles, with a corresponding decrease in activity in the vastus medialis, vastus lateralis (knee extensors) and soleus (calf plantar flexor) muscles.

Dorsi flexion in the example provided refers to a toe up position, plantar flexion a toe down position.

With the introduction of clipless pedals, injuries associated with incorrect positioning and alignment of the cleats (or plates) on the cycling shoe became evident and it was generally agreed by biomechanists that rigidly fixing the cyclist's foot to the pedal places undesirable stresses on the knee during pedalling. As a result, a pedal system was designed to provide 'float' – a rotational allowance of the shoe in relation to the pedal. Placing the ball of the foot directly over the pedal helps to decrease stresses across the knee ligaments and is the most efficient cycling position, since it provides a maximum mechanical advantage to the powerful ankle plantar flexor muscles (gastrocnemius and soleus) in turning the crank. A more posterior foot position, with the pedal either in the arch of the foot or under the heel, increases hip extensor and flexor activity but does not allow the full range of ankle motion needed for effective force production as the pedal passes through BDC.

Some cyclists prefer to mount the cleats on their cycling shoes in such a way that the ball of the foot is slightly in front of or behind the pedal axle. When the ball of the foot is ahead of the axle, the effective lever arm from the ankle to the pedal axle is shortened, requiring less force to stabilise the foot on the pedal and putting less strain on the Achilles tendon and gastrocnemius. Triathletes and time trial specialists favour this position as it allows them to produce more force when using large gears, even though it limits their ability to pedal at high cadences. Positioning the ball of the foot behind the pedal axle effectively lengthens the lever arm from the ankle to the pedal axle, making it more difficult for the foot to act as a rigid lever, and the Achilles tendon and gastrocnemius have to work harder to stabilise the foot on the pedal. Track cyclists favour this position since it allows them to pedal at higher cadences during fixed gear events.

Cleat position should allow for anatomical variations from the normal observed during a biomechanical assessment. For example, a cyclist with external tibial rotation should position the cleat to a slightly externally-rotated or toed-out position. This is especially critical for cyclists using the fixed cleat system rather than the floating system, because the former does not allow movement of the foot to compensate for such variation.

Upper body position

The handlebar design popular in triathlons and time trials was developed to improve the aerodynamics of cyclists by allowing them to adopt a 'tuck' position similar to that used in downhill skiing. An aero handlebar with elbow rests allows the rider to adopt a position with a flatter back and reduced frontal area. Ultimately, the flexibility of the cyclist may determine the most comfortable position on the bicycle; some riders have difficulty achieving the flat-back position since it involves forward rotation of the pelvis, which places the hip in greater flexion at TDC. Increased hip flexion effectively lengthens the hip extensor muscles, while shortening the flexor muscles, which could compromise the rider's ability to pedal effectively.

For all cyclists, correct positioning and equipment set-up are vital to achieving optimum power output and avoiding overuse injuries.

Sarah Phillips

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Ultra-endurance psychology – training the mind to take control

Lance Armstrong not only had a great cycling body, he also had incredible mental strength to beat caner and when in the saddle his fellow Tour de France riders, year after year after year. He remained psychologically positive when racing. This doesn't happen by chance; endurance cyclists, like all other endurance athletes can train their mind to develop emotional control.

Emotional control is a skill needed to cope with the stress of competition but the good news is that you can work to improve it. Focusing on emotional control can and will lead to improved performance. And while it can't transform the proverbial carthorse into a racehorse, it can make both go quicker. I will outline the concept of mood profile and suggest ways in which athletes can use this knowledge to improve performance.

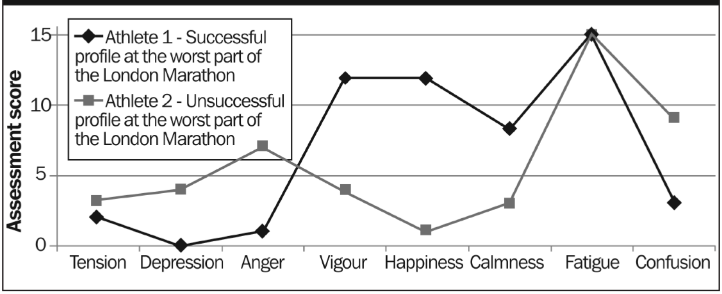
What research has been carried out?

At the University of Wolverhampton, we have done a great deal of research on psychological states in relation to endurance performance. We've studied anxiety and self-confidence in duathletes (1) and triathletes (2) and also studied emotional states before and after marathon races (3, 4). Our recent work has looked at emotional states before, during and after competition. We have looked at changes in emotions during four-hour and two-hour bouts of intense cycling (5,6). We also looked at emotions before and at the worst point of the race during the London Marathon (7). Our latest work has looked at changes in moods and emotions during the course of the Marathon of Britain, a foot race covering a route of approximately 175 miles held in set stages over six days [8]. We have also looked at mood state changes during a 44-day solo expedition to the South Pole [8]. These studies provide a large data set on which to draw and make recommendations for endurance athletes.

Trends

An analysis of the results of these studies shows several trends. First, it is normal to experience intense emotions before competition. Many athletes feel very anxious and most feel some degree of anxiety. Anxiety can be related to inadequate race preparation, setting a goal that is beyond your ability or perceiving the course to be overly difficult. Rarely do athletes get all of these things right and they should expect to feel anxious before each competition/stage. However, they should try to interpret these feelings to mean that they are excited; sport performance is by its very nature uncertain, and even the most confident athletes still have a degree of anticipation regarding how things will turn out. It is possible to feel anxious but to interpret these feelings in a motivational way as being ready to perform. Anxiety can be a good thing.

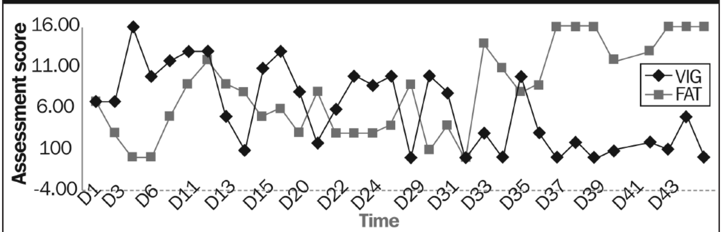
Fig 1: mood profiles of successful and unsuccessful runners at the 2004 London Marathon



The second trend is that athletes experience a mixture of emotional states during bouts of long, intense exercise. Cyclists should expect to feel fatigued. Athletes who cope successfully with endurance performance tend to feel fatigue and happiness simultaneously, whereas athletes who do not cope very well tend to feel fatigued, depressed and angry at the same time.

To illustrate these profiles, data from the 2004 London Marathon is depicted in Figure 1 *(left)*. It is noteworthy that there are no differences in fatigue between the two runners but that the successful runner reports feeling fatigued, vigorous and happy. Figure 2 *(below)* is a graph of a female explorer completing an expedition to the South Pole. This shows that vigour and fatigue fluctuate during repeated bouts of hard exercise; the key message is that endurance athletes should expect to feel intense fatigue and learn strategies to cope.

Fig 2: vigour and fatigue of female explorer during an expedition to the South Pole



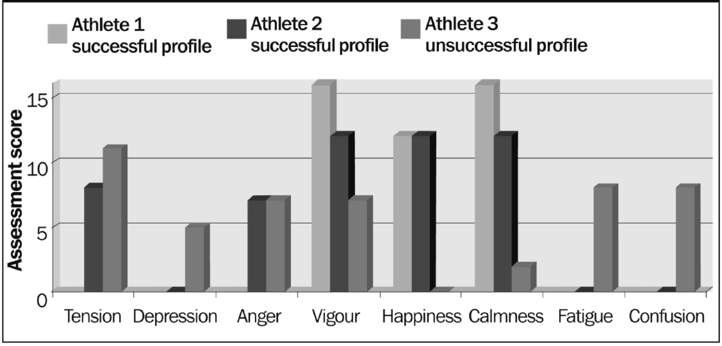
The third trend is that psychological toughness is built on a firm platform of physical fitness. To enjoy repeated bouts of hard exercise during competition you need to have experienced repeated bouts of fatigue that follow long-duration exercise in training. In the same way you train your body to cope with the demands of training, you also train your mind to think positively about the experience.

Developing emotional control

Task 1: learning to recognise your emotional profile associated with success

We all have experienced intense emotions before important events. Some athletes can channel these feelings to enhance performance; some can regulate these feelings and reduce anxiety, while others become debilitated by anxiety. We also know that we rarely experience one emotion on its own but

Fig 3: mood profiles of runners



rather groups of different emotions together. I have depicted these profiles graphically in Figure 3 *(above)*. Using this example, the first athlete feels excited and calm, the second feels anxious and excited, and the third feels anxious and downhearted. Athletes 1 and 2 should perform successfully whereas athlete 3 will probably perform poorly.

- Athlete 1 has an emotional profile typified by feeling vigorous, lively and alert, and in control. This athlete has regulated negative and unpleasant emotions. It is a profile often associated with supreme self-confidence and the perception that all challenges can be attained.
- Athlete 2 shows a different emotional profile associated with success. In contrast to athlete 1, athlete 2 has a profile depicted by feeling vigorous, tense and angry. Athlete 2 will use feelings of tension and anger to aid motivation. For athlete 2, feeling tense can be like a warning signal – 'I am about to try to achieve an important goal, and unless I work really hard, I will not achieve my goal'.
- Athlete 3 is a different story. This athlete feels anxious, angry, downhearted and depressed. These emotions are likely to interfere with performance. Feeling tense might make you want to try harder but when it is combined with feeling depressed, it can make you feel like giving up.
  Our research has found that feeling downhearted and depressed is possibly the most damaging emotion to

experience before and during competition. When athletes feel depressed, angry and fatigued at the same time they tend to turn anger inwards to self-blame and implode; poor performance is likely.

Task 2: assessing your emotional profile

I ask athletes to complete self-report scales before training sessions and before competition. I also ask them to rate whether they achieved their goals. Emotional responses occur in all of these situations and knowing how emotions change can be extremely useful in understanding how behaviour can change. You should assess your emotional profile before a number of different performances; something that can be done by completing an emotion scale shortly before competition or a training session [4]. After competing, you should rate whether you performed to expectation or under-performed. Performance should be rated in relation to your own expectations and your own goals. You will need around five successful and five unsuccessful performances before you can gather trends. Obviously, this is not always possible to do as you might be having a run of good form where most sessions/races are successful. One way to get started is to think back to some of your recent performances and rate how you felt before a few races where you performed well (in relation to your own expectations) and a few races where you performed poorly (again in relation to your own expectations). Once you have a profile associated with successful and unsuccessful performance, a psychological skills programme can be tailored for your specific needs.

‘Performance should be rated in relation to your own expectations and your own goals.’

Assessment questionnaire

We assess emotions using self-report methods, typically a questionnaire. Of course, there are limitations with such an approach, as accuracy requires honesty. However, I would argue that there is not a better method available. A valid assessment of emotion necessarily requires access into thoughts and feelings. It's true that we can make hormonal measurements (*eg* adrenaline) to infer emotions, and also that these hormones are detectable in emotions such as anxiety, anger and excitement. However, a limitation with this approach is that the physiology of emotional states, such as vigour or excitement is similar to other high activation states such as, anxiety and anger.

The only way to validate a physiological measure of anxiety or vigour is to compare it against a self report measure; that is, to ask someone whether they were angry, anxious or excited. It's important to know your emotional states associated with success and failure. Once you've identified the factors linked with poor performance, you can begin to develop a strategy to combat these factors.

Task 3: visualising success

One strategy for developing emotional control is to use imagery. Imagery is effective because it can be used to replay situations. The emotions experienced during those situations can be changed from dysfunctional to functional. Imagery is a good way to do this as the situation can be replayed and aspects of it can be changed. A good way of starting to learn imagery is to find a quiet place on your own. Sit down in a chair and make yourself comfortable, close your eyes, breathe deeply and evenly until you feel calm and relaxed. Picture yourself standing in your competitive environment and look around you taking care to notice as many details as possible. What can you hear? What does your competitive environment smell like? How are you feeling?

Immerse yourself in your competitive environment using all of your senses. Using 30-second blocks, you should relive the experience through your own eyes in real time. We encourage athletes to visualise in the first person and recall the emotional experiences before and during performance. We also use imagery to help athletes cope with difficult situations. You should try to anticipate a difficult situation and see yourself coping with it successfully. An important part of this process is to imagine successfully tackling a number of the factors that make the task difficult; never underestimate the difficulty of the task as this can create a false sense of self-confidence. For example, imagine yourself coping through the toughest part of the race, when your body feels exhausted. Imagine yourself coping successfully with this fatigue, feeling anger and depression starting to build up as you sense your physical fitness not being able to match the standard of performance you have set as a goal.

During imagery sessions you should rehearse the psyche-up strategies that would be used to raise vigour. For ultra-endurance events such as the Tour de France, you should imagine how you will feel at the start of a difficult stage. Imagine how you talk yourself into feeling ready, downplaying feelings of soreness. Imagine yourself as a cyclist of the course; focus on each pedal revolution, on the small details, and go through how attainable each part is when broken down in to simple steps. This will develop effective coping strategies for successfully dealing with unpleasant emotions experienced in competition.

Task 4: use self-talk

Controlling emotions during an event is also about controlling that inner voice in your head. When you are feeling tired, this inner voice can be very negative. It can question what you are doing, and try to 'talk' you out of keeping going, and become a general nuisance. Positive self-talk is needed when feeling tired. Endurance cycling involves coping with fatigue, which can be learned; you can turn the voice off and you can turn from negative to positive. First, think back to those rides when you felt tired. Think of what you said to yourself. Write it down. The next step is to change the negative self-statements into positive self-statements. For example, consider the negative self-statement, 'My legs have gone. I will have to stop'. This relationship between feeling tired and what to do about these feelings is clearly terminal for performance. We need to change both parts of this self-statement. Rather than saying 'my legs have gone' we need to change this to a transient statement such

‘Tiredness tends to come in waves during endurance activity and intense feelings of physical tiredness can pass.’

as, ‘my legs are tired’. This is more likely to be true in any case. Tiredness tends to come in waves during endurance activity and intense feelings of physical tiredness can pass. It is also important to change the strategy for dealing with fatigue. I suggest that cyclists should focus on their technique when feeling tired. Focusing on technique is a good strategy as it is largely under the control of the athlete. If the cyclist focuses all of their attention on technique, this can detract attention from sensations of fatigue. The outcome is a much more positive self-statement: ‘My legs are feeling tired, so I will concentrate on my technique to make it more efficient.’

A good way of using self-talk is to try to anticipate difficult moments in competition or in training. Develop self-talk scripts to change negative scenarios to positive ones. Use a combination of imagery and self-talk to create situations in which you experience unpleasant emotions, and see yourself deal successfully with these situations, using positive self-talk to control the inner voice in your head that can be negative.

In conclusion

Let’s draw together the main points outlined here. What should an ultra-endurance athlete, such as a cyclist, know and expect before an event? They should expect to feel fatigue and develop strategies to cope with this. They should also expect to feel anxious before each ride but should try to interpret these feelings as excitement; sport performance is by its very nature uncertain, and even the most confident athletes still have a degree of anticipation regarding how things will turn out. Remember that psychological toughness is built on a firm platform of physical fitness. To ‘enjoy’ endurance events athletes need to have experienced repeated bouts of fatigue that follows long-duration exercise. In the same way you train your body to cope with the demands of training, you should also train your mind to think positively about the experience. Finally, prepare thoroughly for the specific demands of the event.

Andy Lane

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Physiological and nutritional mechanisms that can influence cycling performance

As any cyclist should know nutrition is crucial to cycling performance. Specific data is not widely available from Tour de France riders and if it was, would it be entirely relevant to more 'ordinary' cycling mortals? In this article we take real data from the 2006 Etape route, ridden at a pace more in line with an Etape rider, and compare this with laboratory data in order to understand the physiological and nutritional mechanisms that can influence cycling performance.

Let's start by taking a look at the course and then the actual data we gathered while riding it. This will make it possible to work out what energy sources were used, their contributions and how pace judgement can be crucial:

The Etape du Tour provides members of the general public with an opportunity to ride a stage of the Tour de France on closed roads. It is run by the French magazine Verb, for further information go to www.letapedutour.com

Calculating power out put and energy levels

The SRM system *(see box overleaf)* measures the mechanical work input into the bicycle cranks, but the human body is only about 25% efficient in producing energy on a bicycle. Therefore, the energy used by the body to produce 5,450kJ is 21,347kJ, or about 5,083kcal. However, to this we need to add around 100kcals per hour to cover basal metabolism (energy used just

Turning a bicycle into a mobile ergometer – the SRM and other systems

By locating strain gauges at different parts of a bicycle, several systems have been developed to accurately measure the power output of a rider on their own bicycle. Increasingly the weight of these systems has been reduced such that they are now often used in competition; they have also become much more affordable in recent years. The SRM power crank system (www.srm.de), measures the power delivered to the cranks. This was the first system to be used widely by scientists and professional riders and is still regarded as the gold standard today. The Powertap system (www.cycle-ops.com) measures the power delivered to the rear hub. The Ergomo Power Booster measures power via an optical system, which measures the twist in the bottom bracket axle (www.ergomo.net). Since all these systems measure power at different points they have different strengths and weaknesses.

to keep body processes ticking over) making the energy cost just over 6,000kcal.

(*NB* 1kcal = 4.2kJ and 1kcal is equivalent to the commonly used food calorie, *ie* to replace the energy expended in this ride would require the consumption of around 5,000 calories worth of food.).

Exercise intensity and substrate (fat and carbohydrate) utilisation

The field-based data we obtained en route provides useful information about the power requirements necessary to complete the Etape route, but has wider significance if we can compare this information with laboratory data. The graph opposite shows laboratory data of heart rate and carbohydrate and fat utilisation derived from indirect calorimetry[1].

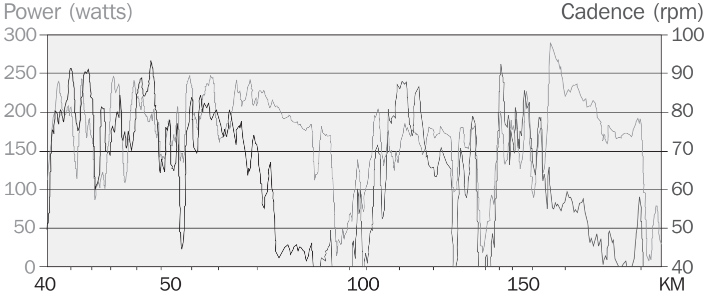
Relationship between power requirements and nutrition

Many people are familiar with the concept of the 'fat burning zone' as illustrated in charts showing percentage energy contribution and typical heart rates that commonly feature on gym walls. Charts showing absolute substrate utilisation are less common since it is harder to make broad generalisations. However, the data from this graph is probably typical for an endurance-trained non-elite cyclist, showing a maximum rate of fat burning of about 35g per hour. Success in many endurance events is dependent on a large fat-burning capacity, and often the key to success is not to deviate too far from the fatmax intensity[2]. Fatmax references the exercise intensity that results in the highest fat oxidation rates.

You can see from the substrate utilisation graph that intensities above fatmax are very costly in terms of carbohydrate usage. The extent of the carbohydrate cost of working at these intensities is often lost in the typical fat-burning zone charts that simply display the relative fuel contribution. At intensities above fatmax, actual fat usage is less than at lower intensities, so carbohydrate has not only to carry the burden of the increased work rate, but also make up the calorie contribution supplied by fat at the lower work rates. Since carbohydrate has less than half the amount of calories per gram than fat, more than 2g of carbohydrate is lost for every gram of fat that would have been used at lower work rates, and this is obviously very costly in terms of carbohydrate usage. It is also evident from the fat utilisation graph that all

'Success in many endurance events is dependent on a large fat-burning capacity, and often the key to success is not to deviate too far from the fatmax intensity.'

SRM power trace of 2006 L'Etape du Tour route Gap-Alpe d'Huez



The graph shows the power output and pedalling cadence as we progressed from Gap (far left) to Alpe d'Huez (far right). Total time was 9 hours 23 minutes including some short stops. The actual riding time (determined by the SRM system) was 8 hours 44 minutes to cover the 189km, with an energy expenditure of 5,450kJ for bike and rider weight of approximately 88kg.

Route summary table: Gap to Alpe d'Huez, November 2005

Hour	Distance covered (km)	Cumulative distance (km)	Average watts	Ascent metres	Descent metres	Approximate altitude
1	31	31	174	280	186	832
2	27	58	180	347	218	964
3	19	77	209	505	43	1,420
4	10	87	203	766	6	2,186
5	22	109	98	221	981	1,435
6	19	128	158	363	208	1,582
7	10	138	154	504	0	2,046
8	39	177	136	94	1,399	778
9	10	187	222	787	0	1,567
+23minutes	3	190	174	297	21	1,843
				∑4,100		

Ascent, descent and altitude figures were gathered from a Polar 720i heart rate monitor, distance and power from SRM professional system. There were only three riders so limited drafting; weather – sunny (for November) with light winds.

significant work intensities require at least some carbohydrate contribution, so when carbohydrate supply is limited, work rates are significantly reduced. This is particularly important in an event such as the Etape because it's quite possible that the work rate required to keep moving could be higher than that attainable in a carbohydrate depleted state. The steeper parts of the Col d'Izoard that occur in the last 6km of the 30km climb have altitudes greater than 2,000m, which will also have an adverse effect on exercise capacity. The following example demonstrates how inappropriate pacing could result in carbohydrate depletion before its summit.

- Our rider worked at approximately 190W for the first four hours. Using the data from the substrate utilisation graph, he would have used approximately 35g of fat and 100g of carbohydrate per hour.
- Assuming our rider started with a relatively full carbohydrate store (muscle and liver glycogen) of 500g and replaced 60g every hour (by taking an energy drink or bar), he would still have 340g left to tackle the rest of the course.
- Look at the route and you can see that for the first four hours there was significantly more climbing (ascending)

than descending, and it was well into hour five before there was any chance to 'catch up' on carbohydrate replenishment without actually stopping.

After the first climb, however, there's a long descent where it's possible that the required work rate could be sufficiently low to allow some glycogen replenishment (from carbohydrate feeding).

But suppose our rider worked at 240W for the first few hours; he would be using 200g of carbohydrate per hour and only 10g of fat. The rider would then run out of carbohydrate before four hours and would be unlikely to make it to the top of the first major climb. So if carbohydrate is so important, why not just take more than 60g per hour? It seems that the body has a limited capacity to process carbohydrate during exercise and much research into the science of energy drinks has focused on ways to deliver carbohydrate energy more rapidly to the working muscles.

'For cyclists, any reduction in weight (eg lighter bicycle, clothing or carrying less drink up the steeper parts of the course) will result in energy savings.'

The highest carbohydrate oxidation rates reported in the scientific literature (in laboratory conditions) appear to be about 102g per hour when carbohydrate was provided as a mixture of different types of sugars in the same drink (3). Oxidation rates using less sophisticated carbohydrate mixtures such as glucose or sucrose solutions show little support for supplying carbohydrate at rates greater than 60-80g per hour. There is obviously scope for improving carbohydrate delivery if competitors take advantage of modern energy drinks but this requires more thought than simply taking vast amounts of any carbohydrate. Taking too much carbohydrate, in whatever form, is more likely to compromise hydration and result in gastrointestinal distress than improve performance. While cases of riders consuming much more than 80g per hour are not unheard of, usually the challenge is to remember to deliver more than 60g per hour, especially during the first few hours where there is also a great temptation to work at levels much higher than fatmax.

Body mass and composition

The substrate utilisation graph also provides a useful perspective for looking at body mass and body composition. For cyclists, any reduction in weight (*eg* lighter bicycle, clothing or carrying less drink up the steeper parts of the course) will result in energy savings. A reduction in body mass seems attractive since it reduces not only weight, but also the body volume, which will result in a reduction in wind drag (the main impedance to level and downhill cycling). But while there is an argument for reducing any non-specific muscle mass, it is the muscle that provides the power and where the significant carbohydrate is stored. Body fat on the other hand does not provide any force, adds drag and may hinder thermoregulation (control of body temperature, through, for example, sweating). But how much do we need to complete an endurance event like the Etape?

An 80kg male with a body fat percentage of 14% (just less than the national average) who rides continually for 194 hours (eight days and nights) at a fatmax of 40g per hour would still finish the ride with 5% body fat and weighing 72.24kg. So, on a one-day event like the Etape, even if a good fatmax of 40g per hour is attained for eight hours, the cumulative fat usage is only 320g. This explains why elite competitors in the Tour de France are able to limit their body fat percentage to 5% or lower without compromising performance. It can also give an idea of the volume of training needed to achieve a body fat goal. A basic work model can illustrate the huge energy savings possible with a low body fat percentage (*eg* Tour rider at 5%) compared with a 'normal' person at 14%. The extra work done by our normal person in lifting the extra 7.76kg of body fat over the cumulative vertical climbing distance of 4,100 metres is:

Work (joules) = mass x gravity x vertical distance

In this case, the extra work = 7.76kg x 9.81m/s x 4,100m = 309,720 joules (nearly 300kcals).

Our 5% body fat Tour rider would expend 6% less energy over the route, and while there would be some loss of acceleration on the descents (less gravitational force to overcome wind resistance), the overall benefits would still be much greater because of the reduction in drag caused by the smaller body mass. If you'd like to explore the effect of different variables on the energy cost of cycling in more detail, take a look at the website www.analyticcycling.com, which uses many of these models in a web interface making it easy for riders to apply personal data to performance variables.

Other ways to reduce cycling energy requirements

At speeds over 16km/h on level roads most of the energy cost of cycling comes from overcoming wind drag. Riding immediately behind another rider can reduce the energy cost of cycling on a flat road at 40km/h by over 25%; riding in the middle of a tightly packed bunch can produce energy savings of up to 40%. Drafting has been described as a very important skill for a competitive cyclist since it can have a huge impact on energy requirements. Scientists analysing data from Tour de France competitors have remarked not only on the exceptionally high power outputs, but also on how riders are able to use drafting skills to complete stages with surprisingly low average powers. One rider was able to complete a six-hour stage of the Tour with an average power of 98W despite a 40km/h average speed(4). In our case, the data was from one rider in a group of just three, so there was limited potential for drafting. However, since many thousands of riders take part in the Etape, drafting is one of the most effective ways of reducing the energy cost. The downside for riders using these skills in the Etape is that fast moving bunches tend to keep moving quickly on the climbs. One of the first things people notice when riding a cycle equipped with a power meter is how even small gradients have a huge impact on power requirements. Recently, scientists modelling cycling time trial performance have debated the merits of using more power on climbs than on flat and downhill sections(5). The reasoning is that wind drag increases as a cube of the speed, so, for example, much less effort is needed to go from 16 to 17km/h than from 30 to 31km/h. This means that going harder on climbs will theoretically result in faster times than an 'even power' strategy because the energy losses through wind drag would be lower. However, the power increase on climbs that have been proposed are much lower (~5-10%) than those that typically occur in uncontrolled bunches. Riders must be aware that trying to keep up with a bunch that continually pushes them to power outputs above their fatmax will have a huge detrimental impact on their carbohydrate stores.

Pedalling cadence and energy

Failing to change down gears when pedalling cadence falls can also increase the rate of carbohydrate usage. Low pedalling frequencies increase the torque on the muscle and so increase the recruitment of fast-twitch, more strength and power orientated muscle fibres [6]. These fibres prefer to use carbohydrate as a fuel since they lack the enzymes necessary to process high quantities of fat. The SRM trace shows that in our example cadence dropped to less than 50rpm for significant time periods (especially towards the top of the first climb) with a gear of 39x27. Most competitors in the real Etape would do well to have gears at least this low. Although gradients may not look so great on course profiles, competitors need to take account of the length of the climbs and also the effect of altitude. Aerobic power declines by about 5% when compared to sea level at elevations of as little as 500m. Much of the route is over 1,500m and steep sections occur at elevations of over 2,000m. Competitors should account for power losses of 10% or more when choosing gear ratios and pacing strategies.

Tim Lawson

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The road to success – training secrets of the pros

Although professional cyclists have much more time and far greater resources to train than amateurs, we can still profit considerably by knowing how they train.

Grand Tour winners who race day after day for two to three weeks are some of the fittest athletes on the planet. Lance Armstrong, seven-time Tour de France winner has been tested in the lab and shown to have an incredibly high maximum oxygen uptake (VO_2max) of around 80-85mls/ kg/min [1].

In interviews after his recent hour record of 49.700km *(see PP 220)* Czech rider Ondrej Sosenka said of his preparation 'lots of medium intensity work, supplemented by strength training. I tried not to go beyond my anaerobic threshold too much' [2]. How nice it would be to have seen exactly what he did. The training required to ride as a professional, making your living on two wheels, is no big secret. It's an awful lot – somewhere between 20,000 and 40,000km of riding per annum. But if we trawl the scientific journals, only a few papers actually report on elite riders' data; even the Lance Armstrong data above only spanned 1992-1999. Recent data may be hinted at, but nothing appears in black and white based on scientific analysis.

Smoke and mirrors

Most elite data reports come from interviews, team or rider websites or general cycling folklore passed around clubs through hearsay. Often this is released for maximum psychological impact – perhaps a hint on how many watts a rider is producing uphill, how much faster a new bike has been shown to be in the wind tunnel, or how many hours per day they are riding consistently. Did someone say smoke and mirrors?

However, there's much less of a hush-hush culture among the UK's elite level time-trialling fraternity. Top riders often give out information about what they do, probably because few have ever relied totally on their riding to pay the mortgage, so the secrecy level is lower. In defence of professional cyclists, many sports don't tell their secrets to success – after all, why would you? Granted, it still takes the right genetic make-up and a lot of hard work to get to the top, but why tell your competitors what you are up to? It's true that there's some passing around of information as riders move teams and independent trainers/coaches work with riders across various teams and countries. But wouldn't it be nice for you, the budding amateur, to get hold of some of the insider knowledge? Tips from the top can help amateurs to improve and reach their own genetic limits. However, we need to bear in mind that just because we know what the pros do won't make the rest of us (with our humble genetics) into tour winners, hour record holders or elite level time triallists. Sadly, we didn't get the cream of the genetic handout. That said, the challenge for athletes across sports is to maximise their genetic potential – to get 99.99% out of what they have. So, what little golden nuggets have trickled down from elite riders and the top sports science labs to help us maximise performance?

'Tips from the top can help amateurs to improve and reach their own genetic limits.'

The dragon's den

There's a well-known quote about the best performers in a sport: 'Winners do what losers are not prepared to do.' Turn that around and you get something along the lines of: 'Copy what winners do and you won't be a loser.' The rub, however, is that you have to take the whole package, believe in all aspects and not pick and choose what you want to believe. Although amateur riders can't commit the same amount of time as the pros, the bottom line is that the training proportions and principles must still be held to rigidly. The pros will most likely be riding four to six hours per day, most days of the week – in other words they have a 25- to 35-hour week in the saddle. Pro team websites give you instant information (albeit uncorroborated) about what riders are up to. For example, Matthias Kessler on the www.t-mobileteam.com spoke of 'a solid five hours each day on the bike' in December 2005 [3]. Your time, on the other hand, is taken up with your day job. However, there's no short cut to getting your best. You can't skirt around the need for time in the saddle and just hammer intervals three or four days a week. Read that sentence again. There are no quick fixes, no short cut secrets, no miracle riding intensities allowing you to get by with hardly any 'in-the-saddle hours' being banked into your 'riding fitness bank account' – period.

Three big differences between the amateurs and the pros

Here are the three big differences between elite riding and amateur riding, backed by science and rider data:

Controlled base riding

The biggest difference in elites versus amateurs is discipline. Pro teams ride at controlled levels for their base training, which is checked using after session data analysis of heart rate monitors and/or power measuring systems. The amateur, meanwhile, usually uses an emotional assessment of the session such as the degree of fatigue, or whether he or she has managed to ride faster or slower than the normal speed. Sports scientists have devised a way to break the training into three 'zones', each with a separate intensity and physiological training effect. Yes, there have been zones or percentages previously written into training folklore, such as the Karvonen heart rate method, but these are often theoretical models, and there's little actual proof that pro riders use these methods themselves.

Karvonen heart rate method

A method where resting heart rate is subtracted from maximum heart rate to give heart rate range. This is then multiplied by a given percentage and resting HR added back on (*eg* 200max – 50rest = 150 range; 150range x 75% = 112; 112 + 50rest = 162 (*ie* 75% of heart rate reserve is 162)

Ramp test
A progressive effort of cycling holding 2- to 3- minute workloads and assessing heart rate at the end of each stage (eg 100, 125, 150, 200 watts). For full protocol see www.JBST.com click on 'Training tools' and look for 'Do your own RAMP test'

The new training impulse (TRIMP) method works by studying elite heart rate (HR) data to find out what works best and therefore how amateurs should train. The TRIMP zones 1, 2 and 3 are calculated by pinpointing two cardio-respiratory markers as a rider performs a RAMP test.

Zone 1 can be thought of as a low intensity zone, zone 2 as a modest intensity or 'threshold' zone and zone 3 as a 'lactate accumulation' or high intensity zone. By hooking up a rider to a mouthpiece and very expensive oxygen and carbon dioxide measurement equipment, a breath-by-breath analysis is possible. From this rider 'input and output' breathing data, critical metabolic thresholds can then define where zones 1, 2 and 3 occur. This kind of testing is obviously not possible for amateur riders to do at home. Fortunately however, analysis of data across several sports shows similar points where the zones are likely to occur[4,5,6]. Specifically, tour riders have been shown to have top of zone 1 and top of zone 2 at 79 and 89% maximum heart rate respectively[5]. Even those who race just 4,000m (at >60km/h) on the track still build an annual base of 30,000km or more 'mostly low-intensity, high mileage'[7]. This paper by Schumacher and Mueller is actually a rare insight into just what the riders did to establish the world record 4km pursuit in the Sydney Olympics.

The TRIMP analysis derived from pro athletes suggests that amateurs need to ensure that more than two thirds of their weekly training volume is in zone 1. That means the heart rate is kept below 80%HRmax for typically 70 to 80% of weekly volume. This is, in fact, what some amateurs already adhere to during some winter months (ironically called 'recovery' by amateurs) but it's actually what professionals do all year round. Even the big tour races, such as the Tour de France, are ridden in zone 1 for more than three quarters of the time [5]. If there's one thing that we see time and time again in amateur time triallists, road racers, triathletes, runners and duathletes, it's doing the base training too hard.

Specific intervals

Part two of the pro riders' jigsaw puzzle of training is specific interval training. Get the first principle right by building a solid base and keeping rides between interval sessions or races in zone 1 and you will be balancing stress and recovery just right. Remember the quoted percentage above; 'more than two thirds' will feel easy, so at the most you will be doing no more than 20-30% of total weekly time as intervals.

This quantity of interval training may sound a lot but many amateurs are unwittingly including extra anaerobic training (above 80%maxHR) sprinkled in their so-called 'steady' or 'endurance' training rides, which bumps up total time spent interval training beyond the 20-30% threshold. This is why subjective comments and feelings are no substitute for actual HR data downloading after training sessions.

I download data from clients to see what actually goes on – hence I call HR downloads lie detectors, because you can see if someone is in the right zone or not. If you stay in zone 1 when you are meant to, it's possible to hit zone 2 or 3 when you need to. The key to interval training is that you do the right intensity for the right amount of time and then rest accordingly. Some much loved intervals have no proof to back them up, such as 'minute-on, minute-off', where a rider goes hard for 60 seconds then easy for 60 seconds. This also raises the question of what is hard and easy if you are not using heart rate or power to gauge your effort. Many cyclists now have heart rate monitors and (increasingly) power measuring indoor trainers or on-the-bike systems (see page 33 nutrition article). This means amateurs can interval train using either heart rate or power output as a measure of intensity. However, you need to get the duration, intensity and rest right.

Look at the table overleaf; it gives you some proven pro

Name	Benefit	Reps (#)	Duration (m:ss)	Intensity (%)	Recovery (m:ss)	Total Work (m:ss)	Reference
Boardman Specials	Able to have better power over a one-hour time trial effort	20-60	00:10	1 hour average power	00:20	10:00-30:00	(9)
Swimmers' Specials	High aerobic load with little anaerobic over-stressing	40	00:15	Race speed	00:15	10:00	(10)(14)
All-out sprints	Increased acceleration and better time trial tolerance of **acidosis**	8-12	00:30	175% PP or maximal 30% effort, ideally seated	04:30	4:00-6:00	(11)
Sustained endurance intervals	Improved tolerance to efforts around threshold intensity (~85%HRmax)	5-8	04:00	85% PP or around 88%HRmax	01:30	20:00-32:00	(11)
High intensity intervals	Improved tolerance to efforts around threshold intensity (~85%HRmax)	6-9	05:00	80% PP or around 85-88% HRmax	01:00	30:00-45:00	(12)
Doctor Dangermouse Distances	Improved time trial ability	4	4km	85% PP or around 88%HRmax	As long as the work interval takes	16km (~20-30 mins)	(13)
Telekom Forties	Improved power	10	00:40	Big gear effort approx 85% PP	00:20	06:00	(15)
UCI Eights	Sprint power and maintenance of leg strength in winter	sets of 8	00:08	Maximal sprint	01:52	1:20-4:00	(16)

PP denotes the maximum sustainable effort for 2.5 minutes during a RAMP test.
HRmax denotes the maximum heart rate in supervised indoor exercise test

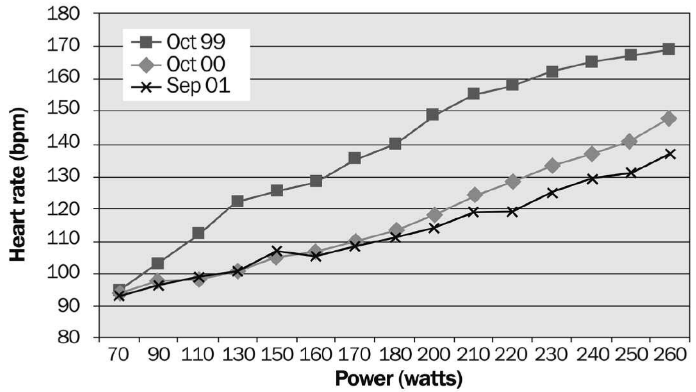
cyclist originated sessions. Yes, they're hard – but that's OK because the rest of your riding's been easy, right? Interval training is a very potent form of training [8] and as such should not be used by those short on time to 'get fit quick'. It has a downside of suppressing the immune system and bringing form on too early if entered into too aggressively in what should be a fitness-building period (*eg* October to January).

Monitoring fitness and form

How do you assess how your fitness is going when asked by another rider? Many times it's a totally subjective stab in the dark based on recent riding feel or a 'scalp count' taken from recent group training rides.

Pro teams cannot guess; they have to use hard and fast numbers to work out who is on form, if the training is working and who needs to rest. Data have shown that sub maximal RAMP testing is a sensitive indicator of the progress in the training state of elite male cyclists during a training or competition season [17]. This can be achieved using one of the many indoor cycling trainers that measure power. Voilà – your

Figure 1: over time the rider's heart rate drops for the same power output



own lab that tells you how well you are progressing. If you get a drop in heart rate for the same power output, you're getting fitter. Conversely, bad form, illness or tiredness is revealed by a raised heart rate for the same power *(see Figure 1, above)*. This is a clinical, 'at home' test and it predicts performances because you know when you are coming into form. As a warm-up the day before a race, a RAMP test gives you a good idea of how things are going for the next day. Granted, your head plays a big part in the outcome of your races (as Andy Lane's article on

Dragon's den secret one – discipline:
You must ensure the majority of weekly time is spent in zone 1, even during the height of your season. It takes time to build and maintain fitness. It should feel easy doing so.

Dragon's den secret two – focus:
You must do interval training with a clear objective, no more than 20-30% of weekly volume and look to progress over a 6- to 12-week period up to an important goal event.

Dragon's den secret three – monitor:
You must have a way to assess your fitness, and indoor testing is a great way to get this data. It also serves as a warm-up prior to indoor or outside riding.

pages 23-31 indicates), but you need to have the engine in place to hope to get a PB or a place on the podium.

So, three lessons then from the dragon's den. None are quick fixes but they combine to build, monitor and peak form at the time that you want it. It's no surprise when elite athletes hit form just as they hit their key race – it was planned for. As the old saying goes: 'Planning prevents poor performances, possibly!'

Joe Beer

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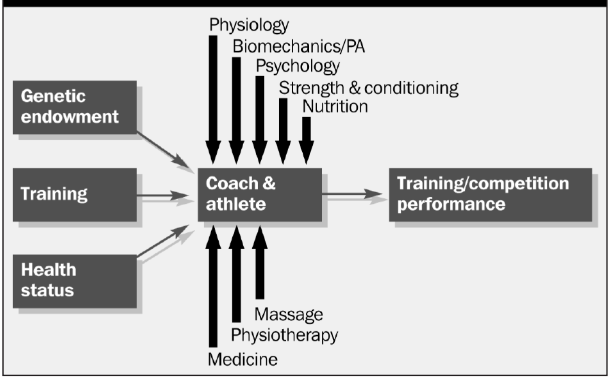
Physiological assessment in cycling

We've already seen that elite cyclists can't afford to guess at their form – they need hard and fast numbers from tests to work out how hard to train, or whether to rest. But how are these tests carried out and how can the results help physiologists and coaches to plan better training programmes?

The sport science support team represents a multidisciplinary group of subject-specific experts from a wide range of disciplines whose role is to work in an interdisciplinary fashion with other science (and medicine) specialties to enhance cycling performance. The core support team include specialists from the fields of biomechanics, physiology, psychology, nutrition, performance analysis and strength and conditioning. This team interacts directly at the coach-athlete interface to offer expert solutions and knowledge, leading to an enhancement of training and competition performance *(see figure 1, below)*.

Figure 1: the interdisciplinary sport science and medicine support team



The role of the physiologist as part of the interdisciplinary team is to provide expert solutions and knowledge to a wide range of issues related to training and competition performance as well as cyclist health [1]. One of the key areas of intervention is the identification of the physiological determinants of performance and the assessment of those determinants.

While coaches and cyclists are able to identify overall variations in performance, the physiologist is able to dissect overall performance into its component parts through physiological assessment, allowing a more detailed interrogation of performance.

Physiological assessment is used as an intimate part of the 'training triad' consisting of three elements:

1. **Profiling –** profiling various determinants of performance allows comparison with 'gold standard' values;
2. **Prescription –** prescription of training through identification of strengths and weaknesses from profiling and identification of training intensity zones, often using heart rate or power output, can optimise the training stimulus;
3. **Monitoring –** monitoring subsequent training adaptations allows continuous evaluation and optimisation of the training stimulus.

'While coaches and cyclists are able to identify overall variations in performance, the physiologist is able to dissect overall performance into its component parts through physiological assessment, allowing a more detailed interrogation of performance.'

Recent debate regarding physiological assessment has focused on the role of laboratory- versus field-based testing. The limitations of laboratory-based testing and the benefits of field-based testing can be largely encapsulated in the concept of specificity – *ie* it can be very difficult, when using laboratory-based ergometers, to replicate the exact movement patterns and limb velocities that actually occur when cycling on the road or to utilise exactly the same muscle groups. However, laboratory-based testing also has its advantages. While field-based testing provides information and data that is more ecologically valid, the downside is that it may lack control and therefore often lacks reliability. Unlike laboratory-based testing, field-based testing is subject far more to the vagaries of the weather and to the idiosyncrasies of location and topography and the presence or absence of others. Laboratory-based testing might reduce ecological validity, but it enhances reliability and allows measurements to be taken that would otherwise be impossible in field settings.

In an appropriately equipped exercise physiology laboratory, temperature and airflow can be standardised, and the flow of people controlled to limit the Hawthorne (audience) effect. These controls improve confidence in the interpretation of results, reflecting changes in physiology rather than the environment. The optimum physiological assessment programme will, of course, utilise laboratory- and field-based testing [2].

Physiological assessment of a cyclist must take place on a bike or cycle ergometer that very closely replicates that cyclist's individual cycling position, and any assessments must target the principal energy systems associated with his or her performance – *eg* to properly test the performance of a sprint cyclist would require tests that target the same type of energy systems (anaerobic) used in sprinting [3,4]. Cycling represents a wide range of disciplines that require the full spectrum of energy systems from track sprinting through to multi-day tour events. It is beyond the scope of this article to examine the physiological assessment of all cycling events, therefore we'll examine appropriate testing for single episode endurance races, ranging from the 10-mile time trial through to single-stage racing (circa six hours).

Key determinants of endurance cycling performance

Understanding the key determinants of endurance cycling performance is fundamental to the physiological assessment of a cyclist [5]. The key determinants of endurance cycling performance include the following [6]:

- Maximum oxygen consumption – usually abbreviated as VO_2max – *see page 11*
- Lactate threshold – *see page 11*

- Fractional utilisation – oxygen consumption at lactate threshold – *see page 12*
- Maximal lactate steady state – (often termed critical velocity). The point when exercise continues within aerobic energy creation parameters. Lactate is created but crucially is cleared and re-used to create energy within the working muscles. Lactate does not accumulate to the extent that it significantly impairs performance, this occurs during progressively intense anaerobic training
- Peak power output – (power at VO_2max).

‘When it’s not possible to measure oxygen consumption, physiologists can also use heart rate or blood lactate concentration at a given power output to derive an indication of efficiency.’

Any testing programme used to assess an endurance cyclist needs to reliably measure these determinants.

Measuring each of these physiological factors one by one is impractical, both in terms of time and cost, so tests have been devised that assess a number of them simultaneously:

Incremental protocol

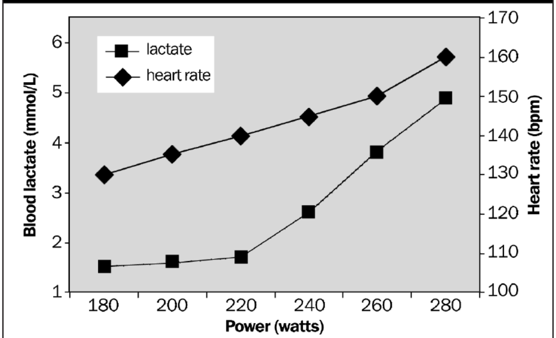
This test consists of six, four-minute stages with each stage performed at 20 watts higher power output than the previous stage. An ear lobe blood sample for subsequent lactate analysis is collected in the final 30s of each stage. Heart rates (using commercially available telemetry systems) and oxygen consumption (using indirect calorimetry) are measured throughout the test.

Establishing the target power for each stage begins with the conversion of a recent best time for a 25-mile time trial to an average power. For example, a cyclist with a best time of 60 minutes for a 25-mile time trial would be set 240 watts as the reference power. The fourth stage is then allocated the 240-watt level and the velocities for stages 1, 2, 3, 5 and 6 are calculated by subtracting or adding 20 watts – *ie* stage 1 at 180W, stage 2 at 200W, stage 3 at 220W, stage 4 at 240W, stage 5 at 260W and stage 6 at 280W. Following the completion of stage 6, power output is increased by 20W every minute until the cyclist can no longer continue (volitional exhaustion).

Derivation of VO_2max and fractional utilisation

VO_2max is established from a test lasting between nine and 16 minutes. This type of test described above will take around 25 minutes and hence in this instance maximal oxygen uptake is referred to as 'VO_2peak'. VO_2peak has been demonstrated to be within 3% of VO_2max. Fractional utilisation is the volume of

Figure 2: heart rate and blood lactate concentration during cycle-ergometer protocol



Note that lactate threshold occurs at 220W

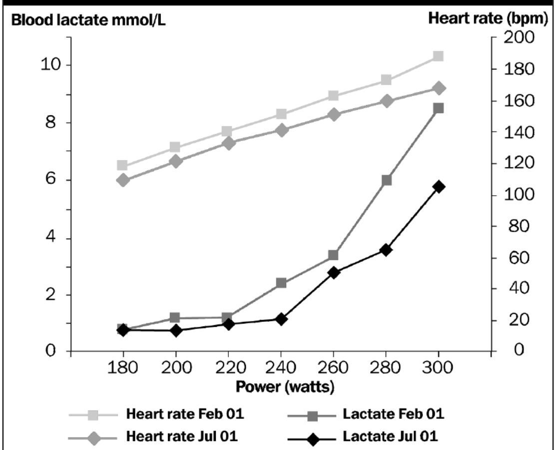
oxygen consumed at lactate threshold expressed as a percentage of VO_2max. It is also sometimes used, however, to describe VO_2 as a percentage of VO_2max (or VO_2peak) at a specified intensity – *eg* the percentage of VO_2max being used at 25 mile time trial pace, or at 280W power output.

Derivation of oxygen economy

Oxygen economy refers to the volume of oxygen taken up by active muscles at a given sub-maximal exercise intensity. During cycling on the ergometer, a standard power output may be used for comparison. Reduced volume of oxygen consumed at this sub-maximal power output is interpreted as an improved oxygen economy and improved efficiency and performance. When it's not possible to measure oxygen consumption, physiologists can also use heart rate or blood lactate concentration at a given power output to derive an indication of efficiency. Figure 2 *(above)* illustrates the blood lactate (LT) and heart rate profile for our mythical endurance cyclist. From the graph, you can see that the lactate threshold occurs at 220W and the heart rate corresponding to this speed is 140 beats per minute. However, giving a single target heart rate value to a cyclist wouldn't really provide useful training information because he or she would need a range of training intensities to properly target the physiological mechanisms underpinning performance. Instead, giving a heart rate range based on the test information is far more practical. For training outdoors, we would advise the cyclist to use a 10-beat range – *ie* 135-145 beats per minute. For training on the rollers or cycle ergometer (where weather and terrain do not change), a 5-beat range of 137-142 beats per minute would be given.

Knowing the heart rate at LT allows the heart rates for other training zones to be calculated. For example, base endurance training (long slow distance, LSD) is calculated at 120-130 beats per minute (*ie* staying five beats below the LT range). Care is needed when estimating maximum heart rate using the common '220 – age' formula, as this method rarely reflects the cyclist's true maximum heat rate and can lead to inappropriate training prescription.

Figure 3: the impact of 26 weeks of training on the work rate-blood lactate/heart rate profile in an endurance cyclist



Note the downward and rightward shift of both the heart rate and blood lactate curves following training.

However, an incremental test also provides a measured maximal heart rate – very valuable for prescribing precise training intensities. The prescription of training using individual heart rate zones allows specific, targeted training prescription that can have a profoundly beneficial effect on training adaptation.

Retesting

Following a number of weeks of training, retesting our mythical cyclist would reveal changes in VO_2peak, fractional utilisation, oxygen economy and lactate threshold. Improved endurance is characterised by a rightward shift in the work rate blood lactate/heart rate curve *(see figure 3 opposite)*. If training goes particularly well and the prescribed heart-rate zone proves to be ideal for the cyclist, it may also be possible to simultaneously observe an increase in the intensity at which LT occurs. If you look at figure 3, in the first test LT occurred at 220W, but in the second test (after a number of weeks of LT-specific training) the entire curve has shifted to the right and the power at LT has increased to 240W, demonstrating a training induced physiological adaptation and that the training programme has worked.

RAMP testing

The RAMP test represents a gradual and continual increase in workload to maximal volitional exhaustion. RAMP tests are commonly used to establish three main physiological markers: VO_2max, maximum heart rate and maximum minute power (MMP). MMP is defined as the average power output sustained for the final minute of exercise, and is closely correlated with shorter time trial performances. Using breath-by breath gas analysis throughout the test, it is possible to identify anaerobic threshold, a point closely reflecting LT, which can be used to prescribe exercise as detailed above[(7)].

Field-based testing

Field-based testing (*ie* on the road) is more sports specific than laboratory-based testing.However, because it is very difficult to standardise the test environment from one occasion to the next, it can lack reliability. In short, it tends to be less objective and far more subjective. The tests outlined above can be adapted for use in a field setting with some degree of success, but the best field-based method of physiological assessment is the time trial. Time trialling over a variety of distances can offer a great deal of useful information regarding the full range of energy systems and technical requirements of an endurance cyclist's performance [8].

Summary

Identifying and testing the determinants of performance is fundamental to the physiological assessment of cyclists. The bad news is that these assessments often require significant expertise and experience, and expensive equipment and facilities.The good news, however, is that a number of these tests can be replicated without fully equipped laboratories, for example RAMP testing and time trialling, from which important information, specific to an individual cyclist, can be gleaned and used in the profiling, prescription and monitoring triad. Ideally, a combination of laboratory- and field-based testing should be employed in the physiological assessment of the endurance cyclist.

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Sports drinks or water: what is the best choice for your bike's drink bottle?

What does the term sports nutrition conjure up in your mind? Carbohydrate and protein? Vitamins and minerals? Or maybe the more exotic ergogenic aids like creatine? Whatever springs to mind, I bet it isn't water. Yet water is of supreme, overriding importance to both your health and performance.

Your body might appear solid, but it's actually much more like a bag of salty water, containing a few bones to maintain its shape. Water accounts for around 70% of your body weight – that's eight stone of water in an 11-stone adult! However, the loss of even a tiny fraction of this water can significantly reduce your performance, which is why maintaining good hydration is vital for all serious athletes.

Water is the medium in which the biochemistry of the body takes place. Every one of our trillions of cells both contains and is bathed in a watery medium. It's hardly surprising, therefore, that we have developed mechanisms for keeping the water content of the body pretty constant. Because some water is continually being lost in urine (in the process of excreting waste products), a constant throughput of water is required to maintain fluid balance. This balance is controlled principally by the kidneys and the thirst mechanism. When total body water drops, hormonal messages are sent to the brain to create thirst. Excessive water intake, on the other hand, stimulates an increase in urine production. As well as providing the perfect chemical environment for our bodies, water has another extraordinary property – the ability to stop our bodies overheating by evaporating via the skin in the form of sweat. This is particularly important during exercise, when heat output rises dramatically. At rest, the average 70kg adult consumes around 0.25 litres of oxygen per minute, which equates to about 70 watts of heat output. But when running at six-minute-mile pace, oxygen consumption rises 16-fold to over four litres per minute and heat output rises to over 1,100 watts! Unless the ambient temperature is sufficiently low, this extra heat cannot be radiated or carried away through convection quickly enough to prevent heat build-up, so heat loss via evaporative cooling (*ie* sweating) has to occur. For a 70kg runner running at this pace, the approximate energy burn rate is around 1,000kcal per hour. In warm conditions it would take over 1.5 litres per hour of sweat evaporation to remove the extra heat generated. When you take into account the fact that some sweat will drip off the skin without contributing to evaporative cooling, it is easy to see how runners can lose two litres of fluid per hour or more in hot conditions. And since fluid losses of just 2% of body weight (that's 1.5 litres from our 70kg runner) can cause a significant drop in

Hyponatraemia – the dangers of fluid overload

Hyponatraemia is a disorder in fluid-electrolyte balance that results in an abnormally low plasma sodium concentration (less than 135mmol per litre compared with a normal range of 138-142mmol/L). A sustained decrease in plasma sodium concentration disrupts the dynamics of water exchange (osmotic balance) across the blood-brain barrier, resulting in a rapid influx of water into the brain. This can cause swelling in the brain, leading to a series of increasingly severe neurological responses, such as confusion, seizure, coma – even death.

The lower the blood sodium and the faster it falls, the greater the risk of life-threatening consequences. A drop in plasma sodium concentration to 125-135mmol/L often results in little more than gastrointestinal symptoms, such as bloating and nausea. Below 125mmol/L, the symptoms become more severe and can include confusion, throbbing headache, wheezy breathing, swollen hands and feet, unusual fatigue and reduced coordination. Below 120mmol/L, the risk of seizure, coma and death is increased. Hyponatraemia in athletes is often, although not always, caused by excessive drinking. During exercise, urine production is decreased, reducing the body's ability to excrete excess water, while at the same time sodium losses are increased through sweating. The combined effect makes it much more likely that the body's sodium content will be significantly diluted.

performance, our mythical runner could be in trouble in less than an hour without taking extra fluid on board!

Because even small losses of water can cause a drop in performance, optimum hydration is extremely important to athletes. However, replacing fluid lost in sweat and urine is not the only justification for boosting fluid intake. Glycogen (stored muscle carbohydrate) is the body's principle fuel for high intensity activities, and replenishing glycogen stores with dietary carbohydrate is vital to continuing high performance.

But the process of 'fixing' carbohydrate into muscles in the form of glycogen also requires water; each gram of glycogen fixed into muscle fibres requires around 3g of water, which is why you often feel thirsty after a high-carbohydrate post-training meal. If you don't drink to aid this process, water is simply drawn out of the bloodstream, leading to dehydration. Fluid, then, is vital for adequate recovery – not just to replace water lost through sweating, but also to help replenish lost glycogen.

'Because even small losses of water can cause a drop in performance, optimum hydration is extremely important to athletes.'

A comprehensive hydration strategy involves ensuring good hydration before training/ competition, maintaining it during exercise and then replacing any shortfall as soon as possible afterwards. However, hydration isn't just about water, fluid loss via urine and, especially, sweating involves the loss of electrolyte minerals – calcium, magnesium, sodium, potassium and chloride. Although the composition varies from person to person (partly as a function of acclimatisation) a litre of sweat typically contains the following[1,2]:

- Calcium – 0.02g
- Magnesium – 0.05g
- Sodium – 1.15g
- Potassium – 0.23g
- Chloride – 1.48g

There are three reasons why replacing these minerals by means of an electrolyte mineral containing drink may be better then drinking pure water alone:

1. Although the amounts lost in sweat are generally small in proportion to total body stores, prolonged heavy sweating

can lead to significant mineral losses (particularly of sodium). Drinking pure water effectively dilutes the concentration of electrolyte minerals in the blood, which can impair a number of normal physiological processes. An extreme example of such an impairment is 'hyponatraemia', when low plasma sodium levels can be literally life threatening *(see box on page 64)*.

2. Drinks containing electrolyte minerals – particularly sodium – are known to promote thirst, thereby stimulating a greater voluntary intake of fluid[3]. There is also evidence that drinks containing sodium enhance the rate and completeness of rehydration after a bout of exercise[4].
3. When the electrolyte minerals – again particularly sodium – are present in appropriate concentrations, the rate of fluid absorption from the small intestine into the rest of the body appears to be enhanced, especially in conjunction with small amounts of glucose[5]. This is particularly important when rapid uptake of fluid is required, such as during strenuous exercise in the heat.

Pre-exercise hydration is principally a function of your fluid intake patterns and diet. The use of glycerol to induce a state of hyper-hydration before long events in very hot conditions is summarised in the box opposite, so we won't dwell on it here.

Suffice it to say that if the fundamental dietary and normal fluid intake patterns are right, good pretraining/ competition hydration will be the norm – not something that requires special attention a few hours before the event! As for post training/competition rehydration, the most reliable indicator is body weight, and your fluid replacement needs are considered in detail on page 77 of this special. Research evidence suggests that fluids containing significant amounts of electrolytes (especially sodium) have a slightly greater impact in restoring hydration than fluids with little or no electrolytes/ sodium[6]. However, the amount of sodium in the drink is critical. American scientists compared rehydration efficiency using each of the following[7]:

- a 6% carbohydrate solution with no added sodium;
- a 6% carbohydrate solution with 25mEq(0.58g) of sodium per litre;
- a 6% carbohydrate solution with 50mEq (1.16g) of sodium/L.

The subjects dehydrated by 3% of body weight during 90 minutes of exercise and drank as much as they wanted of one of the above beverages during a three-hour recovery period. The researchers found that the beverage with 25mEq of sodium per litre stimulated the greatest fluid intake, while the high sodium drink either suppressed thirst or diminished the palatability of the fluid.

Glycerol myths and reality

For most people, taking a glycerol/water solution before an event produces an increase in total body water (hyper-hydration). The question, however, is whether this extra water in the body actually enhances performance, and to date there is no clear-cut evidence to suggest that it does. It is true that after ingestion glycerol stays in the body and holds water with it, but the unanswered question is whether this extra water increases hydration within the cells or simply increases the amount of water swilling around in general circulation? Overall, the current weight of evidence is tilted slightly in favour of a glycerol hyper-hydration protocol, but only in events where substantial dehydration is likely to be a problem, such as Tour cycling. Moreover, there is still no agreement about the best way to take glycerol solution, or about whether certain kinds of plain water hyper-hydration protocols might offer similar benefits. Unless your event is long and taking place in hot/humid conditions, resulting in unavoidable dehydration, there is probably little point in using glycerol. Not only are there unlikely to be any performance benefits, but glycerol ingestion can cause stomach upsets, together with headaches and blurred vision at higher doses. If you are tempted to try glycerol, make sure you've tried other hydration methods first. Glycerol should be considered only as a last resort.

Although many athletes fail to get it right, maintaining optimum hydration before and after exercise is a relatively straightforward process. Staying hydrated on the move, when cycling for example, however, is a different story. When fluid losses are rapid (*ie* in hot, humid conditions), large amounts of fluids need to be absorbed quickly to maintain hydration status. But hydrating an exercising human body is not as simple as topping up a leaking bucket! The rate of fluid absorption in the body is determined by a two-stage process:

- **Gastric emptying –** how quickly ingested fluid leaves the stomach. In more dilute solutions, this is often the key step that determines the overall rate of fluid absorption;
- **Intestinal absorption –** the rate of absorption across the intestinal wall.

Optimal fluid absorption requires rapid gastric emptying and efficient uptake in the intestine. Contrary to what you might expect, fluid absorption tends to take place in the small intestine rather than the stomach. Studies have shown that the larger the volume of fluid in the stomach, the more rapid the emptying into the small intestine, which means that maintaining a large fluid volume in the stomach by repeated drinking will maximise the rate of fluid (and nutrient) delivery to the small intestine(8,9). Gastric emptying rate is also influenced by fluid composition. Early studies showed that, regardless of their electrolyte or glucose content, solutions with a lower overall concentration (or osmolality) than body fluids were emptied as rapidly as plain water(10,11). With glucose solutions, for example, this would allow for a concentration of up to 2.5% (2.5g per litre of water) At the time it seemed that concentrations above this threshold would slow gastric emptying. But more recent work has established that drinks containing glucose concentrations of up to around 4-5% are emptied as rapidly as water(12). Beyond a concentration of 5%, glucose solutions are emptied more slowly from the stomach, but they can nevertheless result in a faster delivery of glucose overall(13). This is because the increase in glucose per unit volume delivered by these more concentrated drinks more than makes up for the reduced volume absorbed; where fluid\ replacement is of a lesser importance than energy replacement, more concentrated drinks may be preferable.

In recent years, there has been a growing trend towards the use of short chain glucose polymers, such as maltodextrins, in fluid/energy replacement drinks. The theory is that glucose polymers are emptied more rapidly from the stomach than pure glucose. However, the evidence is far from conclusive and the various studies that have been carried out have reached conflicting conclusions[14-17]. This may be because concentrated beverages are known to increase the volume of gastric and intestinal secretions. It's possible, therefore, that the total volume of stomach contents may have been greater when solutions containing glucose rather than polymers were drunk, even though the amount of the ingested drink remaining in the stomach was the same. This would affect gastric emptying rates (remembering that gastric emptying is more rapid with high volumes of fluid in the stomach). However, while the evidence that glucose polymers can offer a significant advantage over pure glucose is thin on the ground, there's almost no evidence to suggest that the emptying rate of polymer solutions is slower than that of free glucose solutions with the same energy content. Indeed, most studies have reported that polymer solutions are generally emptied faster, if not significantly so.

After gastric emptying, ingested fluids are absorbed in the small intestine. Pure water, or very dilute solutions, diffuse readily across the intestine. However, research has shown that dilute glucose/electrolyte solutions with a concentration that is slightly less than that of plasma maximise the rate of water absorption[18]. The researchers found that optimum hydration from the intestine was obtained with a solution containing 60mEq (1.38g) of sodium and 111mmols (20.0g) glucose per litre of water. Where energy (*ie* glucose) replacement is the main goal, studies have shown that uptake from the small intestine into the body rises as the concentration of glucose rises in the intestine. This is simply because there is more glucose available per unit volume for absorption. However, very concentrated solutions of glucose (more than 6%) can have an adverse effect on fluid balance. This is due to the process known as osmosis, whereby water separated by a permeable membrane (in this case the intestinal wall) passes from a more dilute to a more concentrated solution. When you ingest a drink with a very high concentration of glucose, the fluid in the bloodstream (on the other side of the intestinal wall) will be relatively dilute by comparison. And the osmotic pressure exerted by the very concentrated glucose solution will actually draw water out of the bloodstream and into the intestine. This results in a loss of available body water, effectively increasing dehydration.

Although it has a chemical structure similar to glucose, the fruit sugar fructose diffuses passively across the intestinal wall. Studies have shown that fructose is absorbed more slowly than glucose and that it promotes less water uptake[19]. Moreover, fructose is known to exert a greater osmotic pressure, which means that, for a given concentration, it is more likely to draw water into the intestine, which can cause abdominal distress. These properties make fructose much less desirable as an energy component in sports drinks than glucose.

A study on cyclists compared the effects of glucose and fructose in a 6% solution during a 1hr 45min bout of cycling[20]. By comparison with glucose, fructose was associated with more gastrointestinal distress, a greater loss of plasma volume, higher levels of stress hormone and substantially poorer exercise performance! Properly formulated carbohydrate/electrolyte drinks can and do increase hydration (and, as a bonus, supply extra carbohydrate to working muscles), so it's hardly surprising that they really do enhance performance when fluid loss is an issue[21-29]. But what's the best strategy for individual athletes? And how do you decide on the best drinks for you? Here are some simple guidelines derived from the evidence referred to in this article:

Pre, post and mid exercise hydration strategies

Pre-exercise

- Make sure your normal diet contains plenty of water and a minimum of other substances known to impair hydration;
- Drink ample (but not excessive) water in the run-up to a training session or event;
- Consider using glycerol for hyper-hydration only if you are an elite athletes undertaking long endurance events in extremely hot conditions. Even then it has its drawbacks.

Post-exercise

- Follow the advice on replacing (and calculating) lost fluid in terms of volume *(see page77)*;
- Drinks containing electrolytes (especially sodium) stimulate the desire to drink and may therefore be preferable to plain water. There's also evidence that these drinks are absorbed more efficiently from the small intestine, especially when carbohydrate is present;
- Remember that you'll need to absorb extra fluid for glycogen replenishment – about 300ml for every 100g of carbohydrate consumed.

Mid-exercise

- For events lasting less than 30 minutes, mid exercise fluid replacement isn't necessary, since it's not possible to lose enough fluid to affect performance in such a short space of time;

Understanding sports drinks

With so many sports drinks on the market, it's easy to become confused about which type is best suited to your needs. Isotonic, energy and recovery drinks can all be used to promote hydration, but tend to have slightly differing effects, which are explained below. It's important to understand, though, that these categories can overlap – *eg* energy drinks containing relatively small amounts of carbohydrate can be almost isotonic – so the distinctions here should serve as a guide only.

Never experiment with a new drink during competition. Try it in training first to see how your body tolerates it! Choose a drink you find palatable. If it doesn't taste nice, you won't drink it, no matter how advanced the formula!

Isotonic drinks provide the body with water, energy and electrolytes in a form enabling the water to be absorbed as rapidly as possible. Studies have shown that fluid is rapidly emptied from the stomach when it contains roughly the same concentration of dissolved substances as that of blood serum – a value of 280 milli-osmoles/kg for you technophiles out there! At this concentration, a drink is said to be 'isotonic' or at the

'During exercise, energy in the form of carbohydrate, and electrolyte minerals, such as sodium, potassium, calcium and magnesium, are lost along with water.'

same concentration as your body fluids. During exercise, energy in the form of carbohydrate, and electrolyte minerals, such as sodium, potassium, calcium and magnesium, are lost along with water. When these substances are dissolved in water at an isotonic concentration they not only help replace lost fluid more rapidly than even plain water but also help replace some of the lost energy and minerals. However, research has demonstrated that drinks containing dissolved glucose at higher than isotonic concentrations (up to 5%) can be emptied from the stomach just as rapidly, and can therefore replace lost energy more rapidly. Although not strictly isotonic, these drinks offer all the fluid replacement benefits of isotonic drinks and are often marketed as such.

Energy drinks are less about replacing lost fluid and more about keeping the working muscles supplied with energy during very long and sustained workouts. Energy drinks need to contain much higher concentrations of soluble carbohydrates than isotonic drinks, because an isotonic solution of carbohydrate struggles to provide energy at a sufficient rate to replace what is lost during intense exercise. The disadvantage of energy drinks is that their high carbohydrate concentrations tend to slow down the rate of water absorption, particularly during hard exercise. They are therefore best reserved for longer endurance events performed in more temperate conditions, where a very high rate of fluid replacement is not quite so critical.

Recovery drinks, as the name suggests, are taken after training to supply the muscles with everything they need for recovery, including water, carbohydrate and amino acids. These drinks often contain such additional nutrients as electrolyte minerals, vitamins needed to aid metabolism of the ingested carbohydrate, and protein and more exotic co-factors designed to accelerate recovery. Because they're taken after training, rapid gastric emptying and absorption is not a priority.

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How to calculate how much fluid you need

As a guide you should drink just enough to ensure that you lose no more than about 1-3% of pre-race weight. This can be achieved in the following way:

1. You should record your naked body weight immediately before and after a number of training sessions, along with details of distance/duration, clothing and weather conditions;
2. Add drink taken during the session to weight loss, ideally working in kilograms and litres, since 1kg of weight is roughly equivalent to 1L of fluid;
3. After a few weeks you and your coach should begin to see some patterns emerging and will be able to calculate sweat rate per hour. This may be as little as 200-300ml or as much as 2-3L, depending on your physiology, exercise intensity, clothing and conditions;
4. Once you know your sweat loss rates applicable to particular conditions, you can plan your drinking strategy for any given event.

John Shepherd and Ron Maughan

Cycle training – can it improve the performance of non-cycling athletes?

Can cycling improve the performance of the non-cyclist? After all we are continually being told that the greatest performance gains will derive from the most sport specific training; surely therefore cycling cannot be of benefit to the runner, let alone the sprinter, or a footballer, whose sport specific movement patterns and skills are far removed from pedal pushing.

X-Training
Combining two or more training modes into a training programme is known as X-Training. In the sports world X-Training tends to reference two (or more) activities that would not normally be associated with working in harmony to bring about a desired sport specific outcome. For example, cycling and running, or cycling and cricket.

Cycling to boost endurance – for non-cyclists

It's seems a pretty feasible theory that long distance cycling should benefit endurance athletes such as rowers and distance runners. After all, these activities also place a heavy reliance on the aerobic energy system. And research has backed this theory up.

A team from the University of Texas reviewed existing studies on the transfer of training effects on VO_2max, between cycling, running and swimming[1] *(see jargon buster, page 11)*.

They discovered that there is indeed some transfer of training effects in terms of VO_2max from one training method to another, and that running had the greatest positive transference and swimming the least, with cycling ranked in the middle.

The greater VO_2max transference of running may be attributed to the fact that it places greater stress on the body (than either of the two other exercise types), due to the impact forces involved and the larger amount of musculature recruited. Consequentially, it is more likely to improve measures of aerobic fitness, more quickly than other endurance training options.

However, the group also discovered that the X-Training effects never exceed those induced by the sport specific training mode *ie* the best way to train for running is to run, swimming is to swim *etc*. However, while excessive X-Training can negatively affect performance (by effectively displacing the sport specific training), there is evidence that for both endurance and (perhaps more surprisingly) for speed activities cycling can, if performed under certain conditions, contribute to improved or at least maintained non-cycling sports performance.

Cycling during the 'recovery' phase of training

Runners (and other athletes) usually take some form of rest at the end of the training period season, before recommencing their build up to the next. There has been considerable debate about how much fitness is lost during this period and whether the recovery should be active or passive. Researchers from California looked into the effectiveness of cycling as a X-Training means between competitive seasons, in female distance runners [2].

Active recovery
A recovery period characterised by activity, designed to help the recovery process by speeding up the removal of metabolites, keeping joints and muscles mobilised *etc*.

Passive recovery
Recovery period with no activity

In particular, the researchers wanted to find out whether substituting 50% of running training volume with cycling would maintain 3000m track race performance and VO_2max measurements during a 5-week recuperative phase at the end of the X-country season.

Eleven college runners were assigned to either:

- A run only training group;
- A cycle and run only training group, which performed the two different activities on different days.

Both groups trained at 75-80% of maximum heart rate. Training volumes were similar to the competitive season, except that cycling made up 50% of the volume for the 'cycle and run' group.

At the end of the 5-week period, the team discovered that 3000m race times were on average slower by 1.4% (9 seconds) in the run-only training group, while the running and cycling group subjects were only slightly lagging behind (3.4% or 22 seconds slower). Equally, important was the discovery that no significant change was found in VO_2 max between either group.

The implications of this research go far beyond recommending the use of cycling for endurance athletes moving from one 'season' into another, as there is a real possibility that cycling has a role to play in all year round endurance training for non-cyclists. This is because:

- Cycling may enable the endurance athlete's body greater time to recover from tough training/competitive training phases and improve future injury resilience (more about this later);
- From a mental perspective, the involvement of a different training method (cycling) may help to 'rejuvenate' the mental approach of endurance athletes, and ultimately boost performance.

Prolonging a running career by cycling

Running guru Tim Noakes [3] believes that cycling can be of further benefit to endurance runners, particularly masters runners and those involved in the marathon and ultra-distance events. This he argues is because of cycling's role in injury prevention, and in particular the ability of the legs to withstand prolonged eccentric muscular damage, resulting from years of distance running. Noakes believes that this damage will slow down even the most circumspect trainers with age.

'Cycling may enable the endurance athlete's body greater time to recover from tough training/ competitive training phases and improve future injury resilience'

An eccentric contraction occurs when a muscle lengthens as it contracts. This occurs in the quadriceps muscles every time they absorb the impact on each and every foot-strike when running. The quadriceps are placed under even greater eccentric strain during downhill running (a condition likely to induce considerable muscle soreness when performed for the first time or after a prolonged break). Noakes believes that cycling can offer respite from eccentric muscular damage, potentially prolonging endurance and master athletes' running careers. This is because it will reduce the amount of eccentric impact damage and can maintain and even improve endurance performance.

Noakes cites triathlon as a case in point, where some of the very best triathletes in the world have achieved prodigious endurance running performances despite relatively modest running training. He provides the following explanations:

- Cycling can produce the same metabolic stress on the body without the same loading stresses on the muscles and the skeleton (particularly, eccentric muscle damage, as noted previously);
- Cycling may also help to 'programme' the brain to withstand the mental aspect of completing an activity*, such as an Ironman triathlon, that could last 10 hours or more. To bolster his belief he cites the thoughts of one of the world's greatest triathletes Mark Allen, who observed that he only gained Hawaiian Ironman success after he performed workouts that matched his winning race times.

**Noakes is a huge advocate of the role of the brain in optimising endurance performance; this is the premise of his*

Central Governor Theory, which argues that perceptions of fatigue and subsequent performance are regulated by the brain in an effort to conserve energy for emergencies. According to the theory, the brain will always terminate endurance activity at a level specific to the athlete's fitness; a level that can positively be adjusted with the 'right' training

On the face of the available evidence, using cycling as a means to improving/maintaining the endurance of non-cyclists seems worth experimenting with. Introducing the activity in a way similar to that used in the 3000m running study quoted above could be a useful starting point – *ie* at a transition in training (eg at beginning of a recovery period) and with a 1:1 ratio of cycling and running. Intensities (in terms of heart rate, for example) should be kept to a level similar to a running-only program. As a rough guide, cycle distances should be increased threefold in comparison to running distances in order to achieve a similar cardio-vascular training effect.

Cycling to improve speed

George Dintiman [4] is one of the world's foremost speed training exerts and he advocates the use of cycling to develop over-speed. Over-speed refers to a training condition that allows the athlete to perform his or her sport skill(s) above the speeds achievable under normal conditions. Examples of over-speed methods include, downhill sprinting and towing using elasticised harnesses *(see PP 221 for a detailed consideration of the merits of over-speed training)*.

Dintiman believes that high-speed cycling can potentially increase sprinting leg speed. He has devised an over-speed cycling protocol, which progresses the athlete through a 'high-quality' interval training program. Quality in this case refers to the fact that the program does not elicit a significant level of fatigue and lactate build up.

The design allows the athlete to complete the given number of repetitions at very high speeds. Each repetition consists of incredibly short over-speed cycling efforts which last no more than 2.5 seconds, sandwiched between 2-minute recovery periods. After each flat out effort, pedalling speed is gradually decreased over a period of 5-10 seconds, before the 25-30rpm 2-minute recovery period is performed. At the end of the 8-week program, 9 such repetitions are completed.

It should be noted that the use of high-speed cycling in a speed athlete's training program serves a supportive/peripheral role, and should not be seen in anyway as a 'cornerstone' workout, to be used regularly in, for example, a sprinter's training program. The reason is that the cycling motion has limited transference to the sprinting action – *ie* cycling unlike sprinting requires no speed assisting arm action. Nevertheless, in terms of eliciting an enhanced neuromuscular response, which may transfer into out and out leg speed, high-speed cycling should not be discounted.

Neuromuscular response
The ability of the body to send and respond to electrical impulses sent through the spinal chord to the muscles from the brain and *vice-versa*.

However, for out and out speed development, very intense cycling interval workouts, performed regularly over 2-4 minute intervals, with similar recoveries should be avoided. That's because these workouts are primarily designed to improve a muscle's ability to produce and mop up lactate when producing energy. They are not designed to develop leg speed and may well 'dull' the speed and power responsiveness of fast twitch muscle fibres.

Lactate
A metabolic product of vigorous exercise, which when it accumulates (ie its rate of production exceeds its rate of clearance), hampers muscular activity and produces feelings of extreme fatigue

To improve creatine phosphate energy supply for high speed short duration explosive efforts

Speed and power athletes need to perform repeated high powered efforts, for example, short sprints or high loading weight lifts. Creatine phosphate is stored in muscles and is the key 'fuel' for these short term alactic anaerobic energy system energy system activities. At longest this energy system produces muscular power for no more than 10 seconds.

Alactic anaerobic energy system
This energy system relies on the release of high energy phosphates to provide energy for exercise, notably creatine phosphate. It has no oxygen requirement and provides energy for no more than 10 seconds.

Cycle interval training similar to that described for enhancing leg speed, can improve the ability of muscles to produce and replenish creatine phosphate stores, although the exact mechanisms for this are not known. This could be useful for a speed athlete who has sustained a minor injury, that prevents them from completing their normal alactic anaerobic energy system training activities, or for the masters sprinter, who has adopted a more circumspect approach to training and avoids performing too many, potentially injury inducing track sprinting workouts. A suggested workout is as follows:

- Warm-up
- 20 seconds flat out effort on a medium/high resistance on a stationary bike
- 2 minutes 'easy' pedalling recovery
- Repeat six times
- Warm-down.

Cycling and Growth Hormone Release

Cycling can have a significant effect on stimulating growth hormone (GH) release, particularly if workouts are performed intensely. GH is often described as the 'sport hormone' because it is involved in numerous anabolic (growth) functions, relating to cell proliferation and division throughout the body. Specifically, GH stimulates bone, cartilage and muscle growth, and can play a very significant role in lean muscle mass development and fat reduction. The key to increased GH response is exercise intensity; as a rule of thumb, the more intense the exercise, the greater the response [(5)].

A team from Loughborough University in the UK studied the effect of maximal cycle sprinting on GH production [(6)]. Ten male cyclists completed two 30-second sprints separated by 1 hour's passive recovery on two occasions. The first effort was completed against a resistance equivalent to 7.5% of body mass and the second effort against a higher resistance equivalent to 10% of body mass. Blood samples were taken at rest, between the two sprints and one hour post-exercise. Although both sprints resulted in the same peak and mean power outputs, the measurements of GH levels showed that the first (lower intensity) effort elicited a significantly higher GH response than the second (higher intensity) effort. Athletes must therefore be mindful of not performing too many tough, high intensity workouts, in one day or over a number of days, in order to avoid compromising GH release. The body needs adequate rest and recovery between tough workouts, as it is during this time that the body adapts and develops increased levels of fitness (this does not occur during training). The body will also profit optimally from the release of training induced GH during recovery, in terms of increased anabolic function (see below for GH's contribution to recovery from injury).

For athletes who are injured and cannot perform their normal high intensity activities, cycling using quality interval training methods to promote GH stimulation may be of real value. To reiterate, cycling places little strain on the body, yet can elicit high GH responses, which could significantly contribute to the maintenance of condition (and potentially speed up the healing process due to an increased 'assisting' hormonal response).

It is also possible to cycle with care using one leg only on a stationary bike and this is a possibility worthwhile considering, (with relevant medical/expert approval), for an athlete who has injured one limb yet wants to maintain as much hormonal (and creatine phosphate/short term anaerobic energy system) condition as possible. Although beyond the scope of this article, arm cycling using an arm crank machine, could also provide a further training option, dependent on injury.

In conclusion

Cycling can offer the endurance and speed athlete great potential *ie* by contributing to injury reduction and rehabilitation. In terms of performance it can at worst contribute to maintaining existing levels of non-cycling athletes' endurance (given appropriate application). In terms of speed, cycling also throws up some very interesting potential benefits. However, whatever the type of activity being trained for, it is crucial that cycling is seen as an adjunct to the core, specific training completed by the athlete, and must never supplant it.

.John Shepherd

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WHAT THE PAPERS SAY

Reports on recent endurance-related studies by Isabel Walker and Nick Grantham

A low antioxidant intake may harm athletes

Cyclists as endurance athletes are probably aware of the antioxidant debate that's currently raging in sport science circles. In a nutshell, there is some confusion over whether athletes require antioxidant supplements (vitamins C and E, the carotenoids and selenium) to help protect them from the increased damage to cells that inevitably occurs when the body has to process large amounts of oxygen – *ie* during vigorous exercise. Some studies have indicated that antioxidant supplementation can indeed afford protection,while others have found not only that they offer no protection but that high levels of certain antioxidants can actually increase oxidative damage and even impair performance! A new study has examined this issue from a completely different perspective by looking at what happens to athletes when they switch from a healthy, antioxidant-rich diet to a more processed antioxidant-poor diet. Seventeen trained athletes underwent two identical exercise tests (a period of submaximal exercise followed by exercise to exhaustion) under two different conditions:

- while consuming their normal healthy diet, which was analysed by the researchers and found (as expected) to be rich in naturally occurring antioxidants;
- after two weeks on a low-antioxidant diet, containing only about a third of the antioxidants present in their normal diet.

After each test, blood samples were taken to see how the diets affected the efficiency of the athletes' antioxidant defence systems and the amount of circulating isoprostane (a biochemical marker produced in the body as a result of oxidative damage).

The researchers found that on the low antioxidant diet isoprostane concentrations were 38% higher after submaximal exercise, 45% higher after exhaustive exercise and 31% higher one hour post-exercise than they were on the high antioxidant diet. Furthermore, although exercise time to exhaustion was not affected by the diets, the athletes' rate of perceived exertion was increased on the low antioxidant diet at all exercise intensities. Although measurements of athletes' antioxidant defence capacities on the two diets weren't significantly different, they tended to be lower on the low-antioxidant diet.

The researchers concluded that, while there appeared to be no reason to recommend antioxidant supplements to athletes participating in acute high intensity exercise while consuming naturally antioxidant-rich diets, supplementation might be beneficial for those consuming low-antioxidant diets for prolonged periods of time.

Med Sci Sports Exerc 2005; 37(1): 63-71

Andrew Hamilton

Getting a little too hot under the saddle – cycling and sperm count

Male endurance cyclists may be at risk of significant changes in the structure if not the quality of their sperm, according to a new study from South Africa. Previous studies have suggested that regular endurance training may compromise testicular function. And this may be a particular risk for cyclists, who are exposed, additionally, to mechanical compression and irritation of the testes while performing their sport. The researchers compared semen samples from 10 long-distance competitive cyclists with those of 10 sedentary controls. The cyclists, who were non-professional, had trained for more than 40 minutes a day on at least three days per week for at least three months before the study began, and none of the subjects had any history of reproductive disorders or were using medication that could have altered sperm production in any way. No significant difference in volume of samples, or sperm count were observed between the two groups. However, the cyclists had a significantly lower proportion of spermatozoa with a normal morphology (structure) than the controls and produced a high percentage of tapered forms of abnormal spermatozoa. This is contrary to the findings of a previous study of cyclists, which reported no significant alterations in normal morphology. The researchers provide two possible explanations for this apparent contradiction:

1. The cyclists in the previous study were professionals, whose superior cycling techniques may have minimised the mechanical stress associated with the cycling action (see article 1 page 13 to optimise your cycling technique);
2. The previous study was carried out in the lower ambient temperatures of Europe. The hotter climes of Africa probably resulted in higher scrotal temperatures, which might have had a negative impact on sperm production.

The researchers comment: 'During training, cyclists are exposed to periodic increases in body temperature and reduction in testosterone levels due to prolonged bouts of exercise. In addition, cyclists are exposed to mechanical compression to the testis, because of the mode of exercise. 'These mechanisms could act synergistically in some endurance-trained cyclists and may diminish reproductive function and result in potential problems with fertility.' Nevertheless, as they point out, although alterations in semen morphology occurred in the cyclists, these remained within the normal range for adults. 'The morphological alterations may therefore not warrant fertility concerns at this stage,' they conclude. 'However, our subjects were still young and as they grow older the alterations may become clinically significant, particularly if the exercise is continued.'
Int J Sports Med 2004;25:247-251

Isabel Walker

Torso stabilisation increases cycling efficiency

In cycling exercise studies that have been used to evaluate muscle metabolism and energy output, it has always been assumed that any metabolic changes are due to the muscles actually involved in cycling. But new research conducted by US scientists at the University of Utah has thrown this assumption into doubt. The goal of this study was to determine whether a torso stabilisation device would reduce the metabolic cost of producing cycling power – *ie* increase cycling efficiency and lower energy expenditure for the same cycling power output. Nine male cyclists cycled on a Velotron cycle ergometer at

power outputs that produced 50, 75, and 100% of their ventilatory thresholds (the exercise intensity that produces a sudden jump in breathing rate). Three different pedal cadences were used: 40rpm, 60rpm and 80rpm. Each cyclist was tested with and without torso stabilisation (a device to limit movement in the torso when pedalling). The metabolic costs of these different intensities and pedalling cadences measured with and without the stabilisation device showed that not only did torso stabilisation reduce the metabolic cost of producing sub-maximal cycling power (*ie* increase cycling efficiency) but that this reduction was also related to pedalling cadence. The overall reduction in metabolic cost was around 1%, with the greatest reductions at lower pedalling rates where pedalling force was greatest (-1.6% at 40rpm, -1.2% at 60rpm, -0.2% at 80rpm). The researchers concluded that 'muscular contractions associated with torso stabilisation elicit significant metabolic costs, which tend to be greatest at low pedalling rates'. The implications of this study are potentially significant for cyclists. Not only does high cadence pedalling appear to increase efficiency by reducing the amount of energy required to stabilise the upper body when cycling, but there's also the possibility that cyclists with efficient torso stabilising muscles (*ie* greater core stability) may have an energetic advantage over those with weak stabilising muscles.
Can J Appl Physiol Aug 2005; 30(4):433-41

Dehydration affects lactate accumulation in cyclists

Research carried out by Belgian scientists suggests that exercise induced dehydration can significantly affect the rate of fatigue-inducing lactate accumulation during cycling. Nine triathletes completed two test sessions in random order. These sessions consisted of:

- **Hydration condition –** two graded cycling tests to exhaustion (pre-test and post-test) interspersed by a two-hour endurance exercise bout during which 1.35 litres of fluid per hour was administered to keep the subjects hydrated, plus carbohydrates to supply energy;
- **Dehydration condition –** exactly as above, but with no fluid administered during the endurance bout.

The researchers were particularly interested to see how dehydration affected the power/lactate curve – *ie* whether the dehydration would produce lactate accumulation at lower power outputs or heart rates. Unsurprisingly, the dehydration condition produced a loss of around 2kg of body weight compared to the hydration condition; however, this did not appear to affect the heart rates at which lactate threshold was reached. The relationship between power outputs and lactate threshold told a different story, with a drop of around 12% in power output for the same level of blood lactate – or to put it another way, a higher blood lactate level for the same power output. So what does this mean for cyclists? According to the scientists, when dehydration is a potential problem, cyclists who are carrying out structured training based on blood lactate levels should use heart rates to monitor exercise intensity and not power outputs. This is because while dehydration doesn't appear to affect the relationship between heart rate and blood lactate it does affect the blood lactate/power output relationship.
Int J Sports Med Dec 2005; 26(10):854-8

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