BOOSTING ENERGY FOR ENHANCED PERFORMANCE

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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FOR ENHANCED PERFORMANCE

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From the editor

With modern day's array of supplements and sports drinks, it may seem like there is an abundance of energy out there to be utilised by athletes. However, as this report illustrates, these fuels count for little compared to enhancing your energy metabolism. It may sound like alternative therapy, but there is a great deal of science to advocate training in tune with your body's natural needs.

The opening chapter begins by introducing chronobiology (your body clock in Layman's terms) and goes on to explain how you can train and perform in tune with your body's rhythms. Next the importance of sleep is explained, and the problems athletes will encounter if they neglect good sleeping patterns are divulged. Misconceptions are put right in the following article as the role of lactic acid is queried, with surprising conclusions. The fourth chapter investigates how your body recovers during rest, and how different methods of training produce different results. The final chapter sees one man put himself through a gruelling cycling experience in order to understand how Tour-de-France cyclists maintain their extraordinary energy levels day after day.

This report should, naturally, improve both your well-being and performance.

Sam Bordiss
Editor

Chronobiology – how timing could give you the edge

We may live in a high-technology 24/7 world, but the daily or circadian rhythm remains deeply ingrained in our physiological make-up. There's consequently plenty of research to suggest that athletes ignore this rhythm at their peril.

Introduction

Humans have evolved in, and are surrounded by, a world full of rhythms, and it would be incredible if these rhythms didn't exert a significant effect on our physiological function and performance potential. In recent years, the field of chronobiology has confirmed that this is indeed the case.

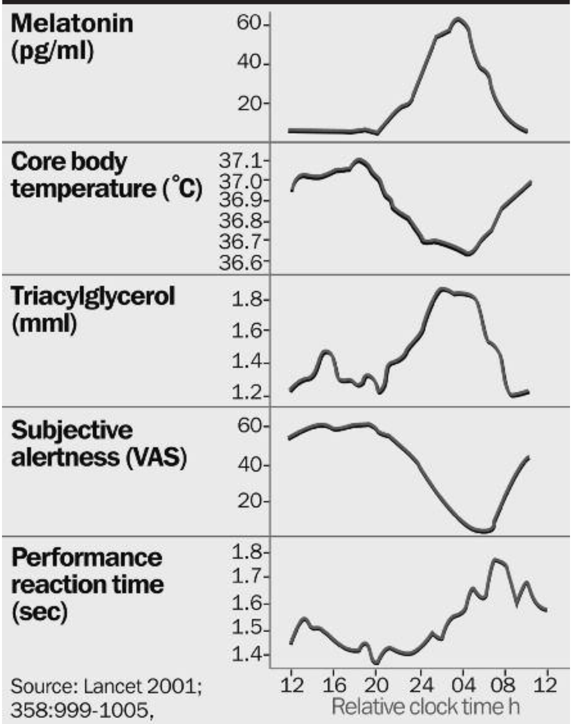
Everybody is aware of the powerful circadian (daily) rhythm; it is after all what regulates your sleeping and waking patterns. However, other rhythms can also affect physiological function, although the magnitudes of their effects tend to be somewhat weaker, which can make some of them rather difficult to detect against the background of environmentally induced physiological variations.

Circadian rhythm

The circadian rhythm is the most powerful rhythm affecting humans; as well as the sleep/waking cycle, it affects hormone secretions, body temperature, mental alertness and (as we'll see) physical performance capacity. The graphs overleaf show the typical daily variations of melatonin, core temperature, triacylglycerol, alertness and reaction time as a result of the circadian rhythm.

Due to these rhythmic fluctuations, many people experience maximum mental alertness, fastest reaction times and highest

Typical circadian rhythm induced fluctuations in the body



Source: Lancet 2001; 358:999-1005,

core temperature in the late afternoon/early evening period, while the peak in melatonin concentrations in the middle of the night period leads to maximum fatigue/sleepiness and lowest alertness.

It's important to understand that while the circadian rhythm is modulated by environmental stimuli, it's essentially a 'free-running' rhythm; put someone in an isolated, darkened room for a week, where they have no idea what time of day it is, and these rhythmic fluctuations will persist. However, in these free-running conditions, the circadian rhythm is not exactly 24 hours, but a little over[1, 2]. Hence the need for external stimuli such as light to keep the rhythm synchronised with the 24-hour clock. It's also true that within the basic circadian rhythm, different people may exhibit slightly differing physiological and behavioural responses.

Circadian rhythm and performance

A growing body of evidence suggests that manipulating the timing of training and/or your circadian rhythm can produce significant benefits. However, one of the problems that has beset researchers studying the effects of circadian rhythm on physical performance is that the magnitude of these effects tends to be small relative to the continual background 'noise' of other factors impacting on performance such as nutrition or psychological factors.

Moreover, studies of this type necessarily examine physical performance at different points in the rhythm and on different days; unless the sleep patterns remain constant between tests, significant errors can arise. There's also evidence that the amplitude of these rhythms may be altered by varying exercise intensity, and that other rhythms can interfere with the circadian rhythm (especially the monthly menstrual rhythm in women[3]).

For example, a UK study published just over a year ago looked at blood lactate concentrations (a marker of physiological fatigue during endurance exercise) in 11 trained female endurance athletes at rest and during the final stage of an incremental multi-stage test on a Concept II rowing ergometer[4]. Researchers were keen to discover what exercise intensity was required to produce a blood lactate concentration of 4mmol/l at different times of day (06.00h and 18.00 h), at two phases of the menstrual cycle (the midfollicular phase and the midluteal phase). The results showed that at the midluteal phase of the menstrual cycle, the 4mmol/l threshold occurred at a significantly higher exercise intensity, heart rate and oxygen consumption than it did in the midfollicular phase. But when researchers looked for a time of day interaction effect, none was evident.

Benefits of afternoon/evening training

However, the results above contrast sharply with a study by the same group of researchers on circadian rhythms and lactate

'Compared to the morning, the total work performed was greater in the afternoon, both aerobically and anaerobically'

threshold in male rowers the previous year[5]. Eleven male athletes followed the same incremental protocol described above, but this time rowing at 02.00, 06.00, 10.00, 14.00, 18.00 and 22.00 hours (on separate days with full recovery between tests). The researchers gathered the data and, using statistical analysis, found that the oxygen consumption needed to produce a blood lactate concentration of 4mmol/l peaked at 21.39h while the highest heart rate needed to reach this threshold occurred at 20.32h. In plain English, the rowers were able to work most intensely for a given build-up of lactate around about 9pm in the evening, which also coincided with their peak core temperature. It also suggested that there was an interaction between menstrual and circadian rhythms in the female rowers previously mentioned.

More evidence for the link between circadian rhythm and aerobic/anaerobic performance came from a US study that evaluated the effect of the time of day on high intensity, constant-power cycle ergometry performance by both men and women[6]. Fourteen subjects performed the tests both in the morning and the afternoon in randomised order. The load was set at 5 watts per kilo of body for the women and 6 watts per kilo for men (intense – a 75kg male would be working at 450 watts!). Compared to the morning, the total work performed was 9.6% greater in the afternoon and this afternoon work was associated with a 5.1% higher aerobic power and a 5.6% larger anaerobic contribution. Moreover, the trend was equally strong in both the men and the women.

A much more recent study looked at anaerobic power developed in 30-second cycling tests carried out at different times of the day[7]. In this study, French researchers looked at the force and velocity of muscular contractions during cycle ergometry of 19 subjects tested at 02.00h, 06.00h, 10.00h, 14.00h, 18.00h and 22.00h on separate days, and how closely correlated to core temperature any performance changes were. The results were as follows:

- Peak core temperatures occurred at just before 18.30h;
- Maximum peak power tended to occur just before 17.30h (7.6% higher than average peak power);

- Maximum mean power occurred at 18.00h (11.3% higher);
- The changes in power output and core temperature were strongly associated (indicating that this was a circadian rhythm effect).

The researchers concluded that athletes could benefit by recording their temperature and timing their bouts of subsequent anaerobic training to coincide with peaks in their circadian rhythm.

Strength and circadian rhythm

Research into how circadian rhythms affect performance is not limited to anaerobic power/lactate studies. A 2002 UK study on the effects of circadian rhythm on strength found that the time of day affected maximal lifting strength in young female subjects with an 8% increase in maximal strength at 18.00h compared to 06.00h[9]. However, this effect was only observed in the luteal phase of the cycle; in the follicular phase, there was no discernible effect.

A more recent Iranian study, published 16 months ago, looked at isometric and isokinetic leg strength in eight women

Circadian rhythm and sleep loss interaction

Given that circadian rhythms are involved in regulating sleep patterns, it's natural to ask whether the afternoon/evening performance advantages persist after a disturbance of the sleep pattern. The same French group examined the effect of one night's sleep deprivation on muscular strength using force/velocity analysis in the morning and afternoon of the following day[8]. In the sleep deprivation condition, the subjects remained awake overnight, while in the control condition, the same subjects slept at home, retiring at about 23.00h and rising at 05.00h. Testing was carried out at 06.00h and 18.00h in both conditions. The researchers (as expected) found that the normal circadian rhythm of temperature fluctuation was not affected by the sleep deprivation, and that even after sleep deprivation, maximal and peak power was still significantly higher at 18.00h. However, they also found that the expected improvement in power outputs in the evening was not as great after sleep deprivation – *ie* after 36 hours without sleep, the expected anaerobic performance due to circadian rhythm was diminished.

during the follicular phase only of the menstrual cycle (to prevent any masking effect), under conditions of both adequate sleep and partial sleep loss[10]. The researchers also assessed the strength of involuntary contractions in the quadriceps produced by electrical stimulation (this technique is used to help screen out any effects of varying levels of motivation at different testing times). The results showed that the peak torque generated by the leg muscles was 4.5-5.9% higher at 18.00h compared with 06.00h and that the performance rhythms were synchronised with rectal temperature (*ie* circadian rhythm). Furthermore, partial sleep loss did not alter the magnitude or variations in muscle strength with changing time of day.

These results were supported by a French study on circadian variations in strength in men and women published at the same time and in the same journal[11]. Twelve men and eight women were tested for maximal isometric voluntary contraction force of quadriceps and hamstrings at six different times of the day (02.00h, 06.00h, 10.00h, 14.00h, 18.00h and 22.00h), the order of which was assigned randomly. At each of these times, three trials were performed separated by three minutes' recovery, and the highest value recorded. Rectal temperatures to track the circadian rhythm were recorded and involuntary force values were also recorded when an electric stimulus was applied (to control for motivation effects). The results were as follows:

- Circadian peaks (highest core temperatures) occurred at 17.29h and 16.40h for males and females respectively;
- Maximum voluntary leg strength occurred at 17.06h in males (increase of just over 2.5%) and 15.35h in females (increase of just under 3%);
- The increase in voluntary leg strength in the men was not large enough to be considered statistically significant; however, when the involuntary contractions (via electrical stimulation) were considered, there was a very significant increase in strength. This suggests that in the men, there was a strong circadian effect, but they were somehow able to compensate for it by increasing the strength of voluntary

contractions when they were not near their circadian peak. There is also evidence from earlier studies that circadian rhythm affects strength. For example, a study conducted 10 years ago by researchers from the University of Dijon on the variation of maximum isometric elbow torque in PE students at different times of day found that peak torque tended to occur at 17.58h, and was nearly 7% higher than the averaged peak torque figure over the whole day. Moreover, when the experiment was repeated and spread out over a period of six days, the peak torque figure was calculated to occur at 17.55h – just three minutes earlier. This led the researchers to conclude that the circadian rhythms affecting muscular activity are remarkably constant[12].

Why does circadian rhythm affect performance?

There are a number of possible explanations as to why performance may be enhanced during the hours around the peak of the circadian rhythm, but increased core temperature almost certainly plays a major role. Higher body temperatures result in less viscous blood flow and muscles that are more supple, with less energy loss from internal friction. However, there is evidence that increased core temperatures in the afternoon/evening as a result of the circadian rhythm may also help because the body is in more of a 'heat loss' mode than compared with early morning 'heat gain' mode when core temperatures are low.

British researchers looked at heart rate, core temperature, sternum skin temperature and forearm skin blood flow during exercise, and throughout a subsequent 30-minute recovery period in 12 males exercising at 70% VO_2max at both 08.00h and 18.00h[13]. Comparisons were made of the changes of heart rate, temperature, and skin blood flow produced by the exercise at the two times of day. What the researchers found was that the increases in core and sternum temperatures during the afternoon exercise were significantly less than the morning, even though the workloads were not significantly different. Also, resting forearm skin blood flow (a measure of the ability of the

Resetting your circadian clock using light

Although the circadian rhythm is free-running, it can be 'reset' with the help of appropriate environmental stimuli. The most powerful of these stimuli is light, which strikes receptors in the retina containing a photo pigment called melanopsin. This causes stimulation of the suprachiasmatic nucleus (SCN), a distinct group of cells located in the hypothalamus region of the brain, and these cells help interpret information on day length and pass it on to the pineal gland (a pea-like structure found near the base of the brain), which then secretes the hormone melatonin in response.

Recent research into Seasonal affective depression (SAD) indicates that the SCN is particularly responsive to blue light with wavelengths of around 468nm(16). During winter months at high latitudes, these wavelengths are dramatically reduced even in bright sunlight, which is why SAD (now thought to be a severe manifestation of circadian rhythm disruption) develops in sensitive individuals.

This research has important implications for athletes wishing to reset circadian rhythm. During mid-summer months, simply going to bed and getting up at earlier or later times(see below) will provide a sufficient stimulus because there's plenty of bright sunlight (containing blue wavelengths) around to stimulate the SCN.

However, at other times, light therapy may be useful. Devices such as the 'Apollo GoLite' provide a powerful and portable source of 468nm blue light, thereby mimicking the effect that exposure to bright midday summer sunshine has. To advance circadian rhythm (*ie* move it earlier, needed for example when travelling east), exposure to blue light first thing in the morning is recommended; to delay circadian rhythm (make the peak occur later – useful when travelling west), evening exposure to blue light is recommended.

Other tips for adjusting circadian rhythm

- Allow approximately one day per time zone (hour) for adjustment when travelling across zones;
- Adaptation when travelling west (delaying rhythm) tends to be easier (because the free-running circadian rhythm is slightly longer than 24 hours) and may require less adaptation;
- As well as evening light exposure, research suggests that late evening exercise can also help delay circadian rhythm (useful for travelling west)[17];
- Research suggests that when travelling east or preparing yourself for a daytime competition, resetting circadian rhythm is best performed in advance using several smaller steps of 30 minutes over a longer period, rather than fewer but larger steps[18]. This strategy can be combined with bright light therapy for maximum benefits.

body to lose excess heat) was higher in the afternoon exercise bout and the rate of change of blood flow as exercise was commenced was also higher.

Summary – manipulating circadian rhythm for performance gains

Although some early studies have reported little effect of circadian rhythm on athletic performance(14), the weight of more recent research suggests that for high intensity aerobic/anaerobic and strength training, circadian rhythm significantly affects performance potential. The obvious question for athletes and coaches therefore is how they can they can train in harmony with this rhythm to maximise performance. Here are some suggestions:

- Measure your own circadian rhythm; this is best done by taking your temperature every two hours during a rest day following several days of a normal, regular sleep pattern. Plot the figures and observe when the peak occurs (normally late afternoon/early evening);
- Try where possible to schedule important and/or strenuous workouts within an hour or so of circadian peak; you will almost certainly gain quality over attempting the same workout earlier in the day;
- Early morning workouts should be performed at a gentle pace and a more thorough warm-up performed to reduce the risk of injury;
- Getting up much earlier than usual (*ie* when your circadian rhythm is in a trough) to 'squeeze' in a workout may be counterproductive; the quality of the workout is likely to be reduced, the risk of injury is increased and you will of course be losing sleep into the bargain!
- Adaptation to hot conditions during a workout seems to be more efficient during circadian peak; ensure plenty of fluid/hydration during hot morning workouts;
- Athletes trying to build strength should time workouts to coincide with their circadian peak; research suggests that late afternoon weight training produces a more favourable post-exercise anabolic hormone profile, with higher levels

of testosterone and lower levels of cortisol (a hormone associated with physiological stress and muscle tissue breakdown)[15];

- For competition (where the time of the event is usually fixed), you may wish to experiment with manipulating your circadian rhythm so that you're nearer your peak at the time of the event (see box above). The same applies when competing abroad in different time zones;
- Unless you're trying to manipulate your circadian rhythm, try to maintain regular bedtime and waking hours; irregular hours can disrupt circadian rhythm, leading to a generalised drop in performance.

Andrew Hamilton

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Sport performance – waking up to the importance of sleep

We spend around a third of our lives in bed, yet many of us pay little attention to either the duration or quality of sleep. As this chapter illustrates, athletes seeking maximum performance neglect sleep at their peril

Introduction

In our modern caffeine-fuelled, 'sleep when you're dead' society, it's easy to form the impression that sleep is not important. The high use of caffeinated sports drinks and pre-workout pick-up formulas by athletes and sports people suggests that it is not just overworked office workers and late night clubbers who are falling into the trap of believing that sleep is not entirely beneficial or useful.

In fact, recent surveys and scientific studies suggest that chronic sleep loss due to the combination of voluntary bed time restriction and poor quality of sleep is an endemic condition in modern society[1,2,3]. The trend to push sleep aside to make room for busier lives shows no sign of abating and most people are now carrying some degree of sleep debt.

In a recent British national sleep survey, 18% of people reported that their sleep was insufficient on the majority of nights, and nearly 60% of people reported insufficient sleep on one or more nights of the previous week[1]. It is not just the amount of time in bed that's important; difficulty getting off to sleep or disturbed, restless sleep can also create a significant sleep debt.

In sportsmen and women, the issue of the sleep deprivation problem is not confined to amateur athletes trying to fit training and competition around busy work schedules. Professional sportsmen and women are also vulnerable.

A recent high-profile example of sleep disturbance in professional sport occurred in the 2006 Tour of California. Top American cyclist Levi Leipheimer looked set for an important victory, having won the opening prologue time trial and ridden strongly in the mountains. He was upbeat about the possibility of taking the overall lead in the next important trial stage, and was the firm favourite for a home win. However, a poor night's sleep meant he was far from fresh in the time trial and a mediocre performance by his standards put him out of contention for overall victory.

Although scientific studies and health bulletins have been talking about restricted and poor quality sleep as a potential health problem for many years, until recently it was still largely thought that sleep was needed purely for the mind. However, sleep deprivation became an increasing health concern with the rising occurrence of traffic and work-related accidents resulting from poor concentration, or people falling asleep whilst in charge of vehicles or machinery. Sleep deprivation is also thought to have played a large role in many large-scale public disasters such as the 1989 Exxon Valdez oil tanker accident[4].

Mind and body

If sleep was needed purely for the mind, athletes could almost have been forgiven for thinking that it was more important just to 'get the workouts done' no matter how tired they felt. If they felt they had not had sufficient sleep then exercising a little mind over matter, helped perhaps by a few strong coffees, would merely make them stronger.

However, this approach is changing, as there is now a considerable body of evidence showing that sleep has a huge role in regulating many physiological functions. According to a recent issue of Nature we are 'Waking up to the importance of sleep' and 'A growing chasm separates the growing scientific understanding of sleep, and the widespread public assumption that it just doesn't matter'[4].

Health problems

There is mounting evidence that insufficient or poor quality sleep doesn't just compromise short-term physical performance, it is also associated with a host of serious health problems including weight gain, insulin resistance, type-2 diabetes and cardiovascular disease[5,6,7,8,9].

As little as six days with sleep duration restricted to four hours per night has been shown to alter the hormone profiles of healthy young people so dramatically that they effectively replicate those typically found in elderly or depressed individuals[2].

Other researchers have applied sleep research to athletic performance. A recent issue of Psychiatric News suggests that 'Sleep May Be Athletes' Best Performance Booster'[10]. And such has been the interest in sleep and sports performance that an entire issue of Clinics in Sports Medicine has been dedicated to this subject and published in a book format as *Sports Chronobiology*[11].

The New England Journal of Medicine recently described sleep as 'a new cardiovascular frontier', highlighting the cardiovascular implications of normal and disturbed sleep[12], and recent research has shown that sleep deprivation can reduce cardiovascular performance by 11%, slow glucose metabolism by 30-40% and result in other changes that indicate possible accelerated ageing[6, 13, 14].

Effects of sleep debt on sports performance

Physiological

Impaired glucose metabolism and the ability to replenish carbohydrate
Reduced cardiovascular performance
Impaired motor function and reaction times
Increased appetite and associated weight gain
Delayed visual reaction time
Delayed auditory reaction time

Psychological

Increased perceived exertion for a given training load
Impaired mood – may affect motivation to train
Reduced short-term memory capability

Measuring sleep debt

Several tests exist to quantify sleepiness and sleep debt. Tests like the Stamford Sleepiness Scale rate the likelihood of falling asleep while doing activities such as driving through to reading a book or sitting quietly in a dark room, and could be a useful addition to a training diary. By carefully noting sleepiness scores and correlating them with physical performance, athletes may be in a better position to decide whether an extra hour in bed may have a superior training effect than doing an extra training session.

More accurate tests of sleepiness involve sitting in a darkened room while brain wave activity is measured. Using this kind of test, it is possible to accurately measure 'sleep latency', which is the scientific term for the length of time it takes to go from full alertness to the moment of sleep.

For those athletes who have the time, it may be useful to replicate some of the experiments that attempt to quantify sleep debt by having subjects lie in dark soundproofed rooms for 14 hours each night. At the start of these studies many people sleep close to 14 hours, and only level out at a typical 8.5 hours sleep or so once the sleep debt has been repaid.

Hormones and sleep

Sleep deprivation is associated with a series of hormonal changes involving ghrelin and leptin (*see box on page 26*). In particular, restricted sleep has been associated with reduced leptin levels, increased ghrelin levels and elevated body mass index[15].

These hormonal changes can lead to increased hunger and appetite, making it more difficult to achieve the low body fat levels required for success in many sports. In one recent study, two days of restricted sleep resulted in an increased appetite of calorie-dense high carbohydrate foods, including sweets, salty snacks and starchy food, by 33-45%[6].

The quality of sleep is as important as duration. Sleep fragmentation due to fidgeting, restless legs or difficulty getting off to sleep can all combine with reduced sleep duration to contribute to sleep deficiency. Studies have also shown that sleep debt is cumulative, so even small amounts of sleep shortfall on a regular basis can accumulate to levels sufficient to compromise health and performance until that sleep debt is repaid[11].

Sleep and activity

Sports scientists working with coaches are beginning to use high technology actigraph devices to help monitor and improve sleep in athletes[16]. Although it is commonly believed that exercise improves sleep quality, there is little in the way of scientific evidence to support this notion. Whilst some exercise may improve sleep in sedentary populations, sleep disorders are common in elite athletes and sleep disruption becomes more common with increased training volume[17] Athletes often report limbs that 'can't stop running' much in the same way that a racing mind can disturb sleep in stressed executives.

Periodic limb movement or 'restless leg syndrome' is a well known cause of disturbed sleep, and indicates a link between nutrition and sleep quality that goes far deeper than caffeinated beverages, alcohol or large meals at night reducing the quality of sleep.

There are, in fact, many nutrients within food that can help reduce the time taken to fall asleep, while others have a more complex relationship – eg where poor sleep may help create a deficiency, or a nutrient deficiency may result in poor sleep quality.

Poor sleep and suboptimal nutrition can both result in reduced exercise performance and in many cases it is difficult to find the initial cause of an accelerating downward spiral. This is especially important because many studies have suggested that suboptimal nutrition status in important 'sleep' minerals is far from uncommon.

In athletes, these problems can be compounded because the energy demands often place additional strain on these important nutrients. An over-reliance on cow's milk and milk products may also result in mineral and amino acid concentrations that are not conducive to good sleep.

Protein, tryptophan and sleep

Another nutrient that has a major impact on sleep is tryptophan, which is one of the essential amino acid building blocks of protein. Tryptophan is used directly to synthesise the brain

Magnesium – a vital 'sleep material'

Sleep disruption, high training volumes, exercise capacity and magnesium status are all related. A magnesium deficiency can cause periodic limb movement and 'restless leg syndrome', which can lead to poor quality sleep and significant sleep debt, and magnesium supplementation has been shown to be an effective treatment for periodic limb movement during sleep with or without restless leg syndrome[21].

However, this is a two-way process because chronic sleep deprivation or sleep debt has been reported to cause a further drain on magnesium levels, resulting in reduced exercise capacity[22].

It is possible that high training volumes and sleep deprivation may reduce magnesium status by a similar mechanism involving stress hormones. French researchers have described various mechanisms by which the stress caused by physical exercise may contribute to magnesium depletion(23). These include the mobilisation of fatty acids for energy in endurance exercise, urinary losses and sweat losses. The good news, however, is that the reduction in exercise performance due to poor or disturbed sleep can be somewhat ameliorated by magnesium supplementation[23].

neurotransmitter serotonin and the sleep hormone melatonin, and so effective is it at raising the levels of these hormones that it was used as an effective hypnotic for many years.

Tryptophan is well tolerated and without tolerance effects; however, it was banned for many years after an outbreak of eosinophilia myalgia syndrome was linked to the supplement[18, 19, 20]. It was later concluded that this condition was not caused by tryptophan itself, but possibly by a contamination, and tryptophan has been allowed into supplements since November 2005 albeit at very low doses.

However, partly due to the ban, much effort was focused on finding natural proteins high in tryptophan, particularly relative to the other large 'neutral' amino acids. This is because tryptophan competes with other neutral amino acids for entry into the brain, so when trying to increase uptake into the brain (to boost serotonin and melatonin synthesis), it is the ratio of tryptophan that is important.

Much focus has been centred on the milk protein fraction alpha-lactalbumin, which is a natural protein source with the highest tryptophan content relative to other large neutral amino acids. Alpha-lactalbumin is found in human breast milk and cow's milk; however, the principle whey protein in cow's milk is beta-lactoglobulin, a low-tryptophan protein that is not found in human milk.

Efforts have been made over recent years to isolate alpha-lactalbumin for use in the human infant formula and it's now possible to produce alpha-lactalbumin on a commercial scale[24]. Researchers have therefore investigated its effectiveness in raising plasma tryptophan levels to see if it could be used in a similar way to tryptophan supplements[25]. Studies have shown that alpha-lactalbumin taken in an evening beverage reduces the subjective rating of insomnia and time awake during the night, improves sleep, and increases morning alertness and brain measures of attention[26,27].

Contrary to popular belief, milk is not an ideal bedtime drink; not only does it have a relatively low tryptophan content (because cow's milk contains protein fractions not found in human milk), it also contains large amounts of calcium, which can reduce zinc and magnesium uptake – important minerals for sleep and growth/recovery.

Hormones and neurotransmitters linked to sleep

Melatonin – the 'sleep' hormone; levels are often reduced in those with poor sleep patterns;
Serotonin – brain neurotransmitter that contributes to the regulation of sleep, appetite, and mood. People experiencing depression or anxiety often have a serotonin deficiency; poor sleep lowers serotonin levels;
Ghrelin – the 'appetite' hormone; levels increase with sleep debt along with cravings for sweet, fatty foods;
Leptin – the 'anorexic' hormone; reduced levels are associated with weight gain;
Testosterone – 'muscle-building' hormone; levels decrease with poor sleep;
Cortisol – the 'stress' hormone responsible for muscle breakdown; levels are increased during sleep deprivation, particularly in late afternoon and evening;
Prolactin – hormone produced by the pituitary gland that stimulates breast development and milk production; levels elevated with poor sleep.

Low tryptophan levels in athletes

The use of protein powders and amino acid supplements for recovery and weight gain in athletic populations has rocketed in recent years. However, it is possible that the amino acid profile of proteins typically used by athletes and sports people could contribute to sleep disturbance by reducing the availability of tryptophan to the brain. Many of these protein powders are high in branched-chain amino acids and whey proteins high in beta-lactoglobulin. Both of these contain high levels of large neutral amino acids, which compete with tryptophan for absorption[28].

The general trend for low-carbohydrate/high-protein foods may also contribute to high levels of competing amino acids; carbohydrate consumption will typically result in an insulin response that drives branched-chain amino acids into muscle tissue, which effectively increases the plasma levels of tryptophan.

Summary

Sleep deprivation is a growing problem, and one that can significantly impair performance in athletes. It's also an area that's easily overlooked in the rush to fit training schedules around work and family commitments. If you suspect you're not getting all the sleep you need, addressing your sleep shortage may pay far more dividends than an extra training session here and there.

Sleep tips

- Avoid caffeine-containing drinks after 3pm as they can increase the time taken to fall asleep at bedtime;
- Avoid alcohol use in the three-hour period before bedtime. It may help you to fall asleep, but it can lead to disturbed sleep later in the night;
- Don't eat a large meal before retiring for the night. By the same token, don't go to bed hungry, especially if you've trained that evening as you may awaken later in the night with hunger pangs;
- If you're suffering from sleep problems, try to increase your intake of magnesium-rich foods (beans, peas, lentils, nuts,

seeds, wholegrain breads and cereals, and green leafy vegetables); magnesium supplements may be also useful;

- Make sure your bed is comfortable; experiment with mattresses and pillows to increase sleeping comfort;
- Keep your bedroom well ventilated, quiet and cool;
- Go to bed when you're sleepy/tired, not when it's time to go to bed by habit;
- Take the time to wind down before bedtime. Don't get involved in any kind of anxiety-provoking activities or thoughts in the 90 minutes before bedtime;
- Try getting an extra hour's sleep every night for two weeks and see how your performance improves.

Tim Lawson

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Lactate – ‘bad guy’ no longer, but rather one of the body’s most vital fuels

Perhaps it’s time to stop being prejudice, and open up to the facts on one of sport’s most discriminated substances

Introduction

Slumped on my rowing machine, I was in pain. I’d just completed two four-minute intervals with a 5:30-minute recovery at 95% effort. My heart rate was relatively comfortable within a minute or so of completing the second interval, but my legs and, in particular, my quadriceps were on fire.

Physiologically my heart seemed stronger than my legs, its oxygen-processing capability apparently in excess of the energy that my legs were able to produce. It took 15 minutes for the burning to stop, and for the rest of the evening my legs felt like jelly. I cursed lactic acid, the (presumed) cause of my pain.

My experience of intense CV training got me thinking about aerobic and anaerobic energy metabolism, and particularly the role of lactate and lactic acid. Note that these are two different chemicals that are often mistakenly assumed to be one (of which more later).

Like many athletes and coaches I had been raised on the notion that lactate was bad; after all, why should we need to warm down to clear it out of our muscles if it was good? It was a ‘waste product’ that caused muscle damage and was the consequence only of anaerobic training – such as the workout I had just completed. Recently, however, I have begun to question much, if not all, of this received wisdom.

Let me start by quoting the words of the famous exercise physiologist and running doctor, Tim Noakes, on this subject: 'In fact, lactate may be one of the most important energy fuels in the body. Let us banish once and for all the bad publicity that lactic acid has attracted for so long and elevate it to its rightful place as one of the most important of the body's fuels.'[1]

However, before we follow Noakes' train of thought, let us first consider why lactate has been labelled the bad guy for so long. This chemical was one of the first that exercise scientists were able to analyse and it is partly for this reason that it has been mistakenly linked with a myriad of exercise-induced physiological responses, including fatigue, cramp and sprains. At one time, it was even suggested that lactate was the prime cause of muscular contraction!

'Lactate is actually produced within our muscles at very low exercise intensities, as well as much higher ones'

For those of us of a certain age, lactate's bad guy image was also reinforced by the late TV commentator Ron Pickering's immortal reference to 'swimming in a sea of lactic acid', which was usually applied to 400m runners as they tired down the home straight. As we shall see, Ron would have been more accurate (if less dramatic) had he referred to athletes 'bathing in an invigorating pool of lactate' as they headed down the back straight. Indeed, he could have applied this metaphor to virtually any running event or sporting performance lasting more than around seven seconds.

However, old habits die hard and it is perhaps only now that lactate is beginning to shed its bad image.

Lactate is actually produced within our muscles at very low exercise intensities, as well as at much higher ones; in fact, it is argued that it is also present in the body at rest. It is therefore not the consequence of anaerobic exercise.

The importance of glycolysis

Crucially, lactate actually helps to produce energy. It is created during glycolysis, which literally means the breakdown of glucose. Glucose is derived from the carbohydrate we eat, and glycolysis kick-starts chemical processes within our muscles that produce the energy required for sustained muscular contraction.

Without glycolysis we would be unable to sustain exercise for more than a few seconds.

There are two types of glycolysis: oxygen-dependent and oxygen-independent; and these can be equated to the aerobic and anaerobic energy systems. Each type of glycolysis produces lactate, although the oxygen-independent variant produces it as lactic acid.

Glycolysis results in the production of pyruvic acid (PA) through the breakdown of glucose, which involves more than 10 different chemical reactions. PA is then used within the Krebs cycle, a complex chain of reactions leading to energy production.

When PA begins to accumulate in our muscles, as a result of what can be a relatively minimal increase in exercise intensity, the enzyme lactic dehydrogenase converts it into lactate. Under moderate-to-high exercise intensities, lactate is converted back to PA, which is then re-used for continued energy production.

The Krebs cycle provides nearly 90% of the energy required for CV exercise in the form of adenosine triphosphate (ATP), the body's universal energy donor.

Our muscles possess two basic types of muscle fibre, each with a different speed of contraction and potential to contract repeatedly. Both of these fibre types play a crucial role in lactate production, lactate clearance and exercise performance.

Slow-twitch fibres are fatigue resistant and are therefore used for sustained exercise; in terms of lactate they are best suited to clearance. Fast- twitch fibres have a 2-3-fold greater speed of contraction and in their 'pure' form are used for powerful – if relatively short-lived – activity like sprinting; they are better suited to lactate production.

Lactate stacker workouts

Fast-twitch fibres can be subdivided into type IIa and type IIb. The former are considered 'transitional' in that they can, with the right training, improve either their fast-twitch or their slow-twitch capacity.

Lactate stacker workouts are a great way to boost endurance performance. These high-intensity interval workouts generate large volumes of lactate very quickly, while their short recovery periods ensure that lactate levels soar again during the subsequent intervals. Very early into these workouts, an ever-increasing amount of energy needs to be fuelled without oxygen, resulting in oxygen-independent glycolysis.

In terms of improving the use and reuse of lactate in our muscles for boosting endurance performance, lactate stacker workouts encourage fast-twitch fibres to produce more of the muscle cell protein known as monocarboxylate transporter 1 (MCT-1), which is present in slow-twitch fibres in relative abundance.

MCT-1s are important in that they transport lactate into muscle cells, where it is broken down to produce further energy for exercise. Very simply, the more MCT-1s a muscle has, the greater the rate of lactate clearance and the greater your muscular endurance. Note also that lactate stacker sessions increase the number of mitochondria (cellular energy power plants) and capillaries (oxygenated blood highways) in and to your muscles, so also boosting their potential for sustained, powerful muscular contractions.

‘The pain that accompanies lactic acid is thought to result from the irritant effect of acidic muscles on nerve endings’

Despite their benefits, these workouts may have contributed to lactate’s bad guy reputation. In life it is natural to dislike something that hurts – and if you haven’t performed a stacker session yourself, take it from me that it hurts! And you curse the stinging sensations in your muscles, which you believe derive from lactate.

However, when lactate is released into the bloodstream it does not cause pain. If it did, we’d be hurting all over, perhaps all the time, or at least after any form of exercise, even a stroll in the park. Putting this into context, lactate begins to rise, as a consequence of glycolysis, in the untrained at only about 55% of their maximum capacity for aerobic metabolism (VO_2max).

So if lactate is not the painful problem, what is? To answer this question, we need to understand a bit of chemistry. Any substance that ionises in solution and gives off hydrogen ions is an acid. When we exercise at a high intensity (such as those encountered during a lactate stacker workout), we set up the right conditions for acid to develop in our muscles.

Although we are still gulping in oxygen, it becomes insufficient to furnish the required amount of energy. This alters the results of the chemical equations taking place, and lactic acid is produced instead of lactate. Specifically, lactic acid is formed when pyruvic acid temporarily accepts two hydrogens (electrons) due the shortage of oxygen. Note, though, that lactic acid returns to lactate once it enters the blood stream.

Lactic acid can be thought of as lactate's metaphorical cousin. Lactate is the goody-goody, always able to get the energy creation job done (at least up to certain intensities – as high as 80% VO_2max for the endurance-trained athlete). Unfortunately, lactic acid ends up getting the rap, despite trying to emulate its cousin; when trying to contribute to energy production at higher exercise intensities, its rate of production ultimately exceeds its rate of clearance, resulting in a loss of muscle power, pain and eventual exercise cessation.

Not a waste product

The pain that accompanies lactic acid is thought to result from the irritant effect of acidic muscles on nerve endings. Lactic acid is also believed to 'irritate' the central nervous system, leading to feelings of nausea and disorientation.

Lactic acid, like lactate, is not a waste product. During recovery, when there is a much more plentiful supply of oxygen, lactic acid loses its two hydrogens and reverts to pyruvic acid for use as an energy source. In fact, 50% of the lactate produced during a tough workout (remember that lactic acid returns to lactate when it enters the blood stream) is used for replenishing muscle glycogen stores during recovery. Note that glycogen is premium grade muscle fuel derived from carbohydrate, which can be stored in the muscles and liver in limited amounts (up to about 375g).

The contribution lactate makes to glycogen replenishment and post-exercise recovery occurs during what is known as the 'lactate shuttle'. When lactate is released into the blood stream, the liver uses it to produce blood glucose and glycogen, while the heart and other muscles use it for energy production. For energy sustainability during exercise, the ability of the lactate shuffle to redistribute carbohydrate – as potential glycogen, through the metabolism of lactate – from muscles that are fully glycogen- stocked is key.

The lactate shuffle lifts glycogen from muscles that are not being used significantly – eg the arms during marathon running – to areas where glycogen is being drawn significantly – eg the legs – thus helping to sustain energy.

Although we should see lactate as the good guy from now on in terms of its energy contribution, we should not get too carried away with all it promises, particularly when it comes to using it to predict endurance performance through lactate threshold (LT) testing.

Lactate threshold testing

The lactate threshold is the notional point at which lactate levels accumulate within our muscles to the extent that glycolysis proceeds with less and less oxygen and muscular action eventually grinds to a halt. LT can be viewed as the muscular engine's 'red line'; once the 'lactic needle' enters this band, power is gradually lost.

LT tests generally take the form of an incremental increase in effort against a controlled resistance, such as treadmill belt speed. Blood samples are taken, usually from the ear, for analysis of lactate accumulation.

However, Watts and associates have noted that: 'Lactate threshold values will differ with different durations of incremental (test) steps. The criteria used to determine the lactate threshold will affect the threshold value. LT values are largely a matter of the protocol used and the criteria established for declaring a threshold. Without such knowledge the absolute value of a LT is meaningless and unreliable.'(2) When reviewing endurance training research and testing protocols, Berg made similar observations.(3)

Santos took the argument further when he specifically examined the use of LT as a predictor of endurance performance for half-marathon times.(2) Eighteen long-distance runners performed a total of 33 half-marathons, together with an equal number of incremental field tests (4 x 2,000m) to establish the relationship between running speed and blood lactate levels. Basically, the researchers wanted to discover how fast the runners needed to run to be able to stay within comfortable – for achieving fast half-marathon times – lactate levels.

Speeds used in the field test ranged from 4.2 to 5.8 metres per second, with a progression of 0.4m/s each step. Following each loading level, blood samples were taken and analysed. At first it seemed that the step tests were valuable predictors of half-marathon times, with test speeds corresponding to lactate concentrations of between 3.0 and 5.5mmol, reflecting half-marathon speed. Even higher correlations were found at lactate levels of 4.5, 5.0 and 5.5mmol running speeds.

However, when the athletes actually raced, these strong correlations fell apart; 70% of the athletes' final competition times fell outside the level of prediction based on the lactate levels of 4.5-5.5mmol achieved during the supposedly predictive step testing.

Predictive limitations

In an attempt to further explain lactate levels and LT's shortfalls when it comes to endurance event performance, Noakes writes: 'Lactate is a natural product of carbohydrate metabolism during exercise. As the rate of energy production rises, so more carbohydrate is used and as a result, more lactate appears in the bloodstream. Hence a rising blood lactate level only indicates that more carbohydrate is being burned. It does not mean that the muscle's work is becoming more anaerobic.'[(1)]

Thus attempts to correlate event performance with a notional lactate threshold are ultimately doomed to failure. Noakes suggests that better predictors of endurance performance are time trials, race results at shorter distances and self-analysis (for suitably experienced athletes).

By now some of your misconceptions surrounding lactate should have been cleared up. The reality is that lactate (or lactic acid) is neither a bad guy nor a waste product, but a key ingredient in energy production and sustainability.

So now, when you experience the pain of a highly beneficial lactate stacker workout, you should not curse lactic acid but rather pat it on the back for the attempt it has been making at keeping your muscles working and the contribution it will be making to your post-workout recovery.

Lactate only falls short in complete redemption when used to specifically predict endurance performance.

John Shepherd

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The metabolic impact of exercise – or how your body works out while you put your feet up

You finished your workout a couple of hours ago and now you are relaxing, but in fact your body may not be quite as relaxed as you think. There are a number of ways in which exercise can exert lasting physiological effects that persist for long after you have showered and headed home. And knowledge of these processes will help you to optimise your performance and recovery, as well as managing your body weight

Weight is an important issue for sportsmen and women. Rugby or American football players, for example, need powerful lean muscle and body mass to hit their opponents hard and absorb the impacts of the game. A top player can burn 3,000 calories or more on a typical training day – enough to cause a worrying loss in body weight and lean muscle if calories are not replaced consistently and appropriately.

Endurance athletes are less concerned than rugby players with putting weight on, but must also be careful to ingest enough food calories to maintain their body weight, maximise recovery and optimally fuel their activities.

Both types of athlete may be assiduous in calculating the number of calories they need for their respective activities; but the reality is that they may underestimate their true calorific requirements by as much as 20% by failing to take account of the following factors:

- A consistently elevated metabolic rate, resulting from regular endurance training, that can increase calorific expenditure by as much as 17%;
- The energy cost of lean muscle, which can burn up to three times more calories than non-lean body tissue; a 0.45kg gain in muscle can increase weekly calorie burn by 350kcal.

Both of these factors are affected by sex and age, of which more later.

Let's begin by understanding metabolic rate. **Total daily energy expenditure (TDEE)** is just that – the sum total of energy expended over a day. A very significant proportion (60-75%) of TDEE is used to maintain the **resting metabolic rate (RMR)**, which fuels a broad range of invisible essential bodily functions, including heart, lung and mental function. (Calculations of RMR are made over a 24-hour period but do not include the calories burned during sleeping.) You may be surprised to learn that physical activity accounts for no more than 15% of TDEE.

However, numerous scientific studies have demonstrated a training-induced rise in RMR of up to 20%. This response is known as **excess post-exercise oxygen consumption (EPOC)**. EPOC appears to have two phases: a first lasting less than two hours and a second with a more prolonged effect, lasting up to 48 hours. The former is thought to be more significant in terms of calorie burning than the latter.

The mechanisms underlying short-term EPOC created by endurance training are well known, involving the following bodily processes:

- Replenishment of oxygen stores;
- Re-stocking of prime muscle fuels adenosine triphosphate (ATP) and creatine phosphate;
- Removal of excess lactate from the bloodstream;
- Increased body temperature, circulation and ventilation rate.

The mechanisms involved in the longer lasting EPOC are less well understood, although they may include a sustained enhancement of circulation, ventilation rate and body temperature. Interestingly, little is known about the mechanisms underlying EPOC after resistance exercise, of which more later.

If endurance training can affect EPOC significantly, how is this effect mediated by training intensity and frequency?

It appears that a high intensity of training is needed to generate a significant metabolic EPOC. As Pohleman of the University of Vermont in the United States writes: 'An exercise prescription for the general population that consists of exercise of low (less than 50% VO_2max) or moderate intensity (50-75% VO_2max) does not appear to produce a prolonged elevation of post-exercise metabolic rate that would influence body-weight.'[1]

Higher exercise intensities induce greater metabolic responses that take more time to dissipate. Paradoxically, though, athletes (particularly endurance athletes) can actually slow their RMR when training intensely and for prolonged periods. This tends to happen when calories are consumed in

Ronsen's study of high-frequency training

This study was set up to consider:

1. The impact of prior exercise on metabolic responses to a subsequent exercise session;
2. The effect of different recovery periods between two daily exercise sessions on metabolic responses to the second bout.

The athletes each completed four 25-hour trials, as follows[2]:

- One bout of exercise only;
- Two bouts of exercise separated by three hours of rest and one meal;
- Two bouts of exercise separated by six hours of rest and two meals;
- No exercise.

All the exercise bouts consisted of 10 minutes of cycling at 50% of VO_2max, followed by 65 minutes at 75% of VO_2max.

Increased metabolic stress – including a higher mean oxygen uptake, heart rate, rectal (core) temperature and EPOC and a lower respiratory exchange ratio – was observed when strenuous exercise was repeated after only three hours of recovery. But metabolic stress was reduced when a longer recovery period, including an additional meal, was given.

insufficient quantities to fuel energy expenditure plus the additional increase in RMR.

In such situations the body can 'hang on' to this inadequate energy supply, thus slowing RMR. This 'starvation mode' is a legacy from our prehistoric ancestors who often had to go for long periods without food and whose bodies consequently developed the ability to use food sparingly in order to sustain life.

To avoid inducing this paradoxical response, sportsmen and women should ensure they eat enough and, crucially, that they eat regularly, with as many as five meals spread across the day and snacks consumed as needed before, during and after workouts.

It is important to understand that eating itself is a significant booster of metabolism in that the thermic effect of feeding (TEF) can account for up to 10% of TDEE. TEF refers to the energy cost of all the processes involved in the consumption and digestion of food.

If high-intensity workouts boost the body's metabolic rate, what is the impact of high-frequency training, eg twice daily workouts? Ronsen et al from Norway addressed this question in a study of nine elite male athletes, described in the box above.

Athletes seeking to boost their metabolism through frequent exercise should be careful, in the light of Ronsen's findings, not to allow too long a gap between sessions. Essentially, the briefer the interval between sessions, the greater the combined energy expenditure.

Most athletes train with weights to increase their power and injury resistance, but are often unaware of the fact that their increased lean muscle mass needs more feeding. It is said that every 0.45kg increase in muscle needs an extra 50 calories a day just to maintain it, which can obviously have a significant effect on calorific intake.

Within the fitness industry weight training is widely advocated as a way to lose weight on the grounds that the leaner you are, the more efficient you will be at burning fat. In general this is true; however, research by Lemmer et al from the US suggests that weight training has a lesser metabolic impact on women than on men[3].

The research team compared the age and gender effects of a 24-week strength training programme on RMR, energy expenditure of physical activity (EEPA) and body composition.

The following groups were involved in the study:

- 10 men and 9 women aged 20-30;
- 11 men and 10 women aged 65-75.

When results from all the subjects were pooled, absolute RMR increased by a significant margin of 7%. However, when the groups were considered separately some clear gender differences emerged, with only the men showing a significant rise in RMR.

There are two possible explanations for this apparent difference:

1. The relatively brief duration of the trial. Had the women continued with strength training for a longer period they might have been able to increase their lean mass to a more significant level, thus giving a greater kick to RMR;
2. Women are biologically programmed for less significant lean muscle adaptation than men because of their lack of the male growth hormone testosterone.

However, subsequent research by Dionne et al of Canada indicated that younger women might derive a greater boost to RMR from strength training than their older counterparts(4). The researchers found that younger women who weight trained for six weeks managed to increase their RMR, specifically from 1,379 to 1,451 calories a day, while older women did not experience similar benefits.

A round-up of research on EPOC carried out in Norway concluded: 'The relationships between the intensity and duration of resistance exercise and the magnitude and duration of EPOC have not been determined, but a more prolonged and substantial EPOC has been found after hard- versus moderate-resistance exercise. Thus, the intensity of resistance exercise seems to be of importance for EPOC.'(5)

A final factor to note in terms of the effects of training on metabolism is the likelihood that men and women engaged in sport and fitness burn more calories than sedentary people by virtue of increased energy levels that make them more active in general. Again, this additional energy expenditure needs to factored into calorific calculations if adequate body fuelling is to be maintained.

John Shepherd

Summary points

- Training can boost the resting metabolic rate (RMR) by up to 20%;
- High-intensity training has a greater effect on RMR than low-intensity training;
- The briefer the interval between two exercise sessions performed on the same day, the greater the combined energy expenditure;
- Weight training has a lesser metabolic impact on women than on men;
- However, younger women are more likely to benefit than older ones.

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Taking on The Tour

Ever wondered how on earth those Tour de France boys manage to fuel themselves in order to keep the cranks spinning day after day? Well wonder no more, as our man takes you on a virtual journey through one of the toughest stages of the lot – Alpe d'Huez

Introduction

'Everything about the Tour is just about impossible; you can't drink enough to keep hydrated, you can't eat enough carbohydrate to keep fuelled and you can't eat enough protein to keep your muscle mass. You start lean and finish like a P.O.W!' This is professional cyclist Magnus Backstedt's blunt analysis of the unique challenge that is the Tour de France. Magnus is one of the heaviest riders ever to have finished the Tour and, at over 98kg, his estimated calorie expenditure was regularly over 10,000kcal per day during the mountain stages.

The Tour de France is contested over three weeks and usually involves several consecutive mountain stages. The energy requirements of even the lightest riders are huge and only the fittest, most talented professional cyclists get to start. Many do not even finish.

Every year amateur cyclists can get a taste of what it's like to take on the Tour, by competing in L'Etape du Tour; literally 'stage of the tour', usually one of the mountain stages used in the actual race. This year the Etape route starts in Gap and includes the Col d'Izoard and the Col de Lauteret before finishing on top of the legendary Alpe d'Huez.

A multitude of tools are now available that make it easier than ever to produce accurate 'real life' data on the physiological requirements of challenges like the Tour de France. Modern cycle computers can effectively turn a bicycle into a mobile ergometer (*see box on page 57*), and devices such as altimeters are now commonly built into heart rate monitors.

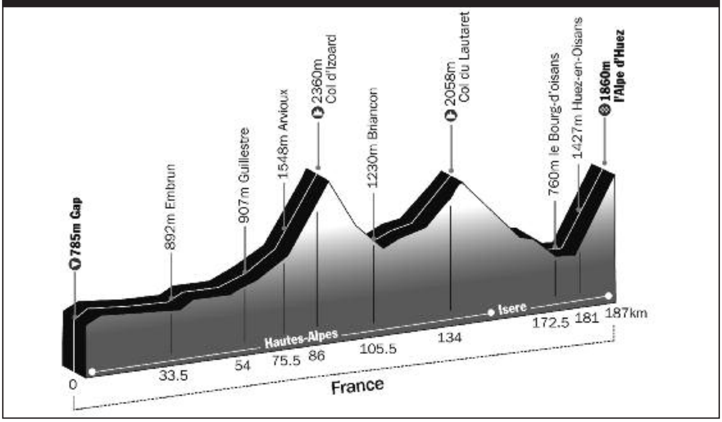
This kind of data is regularly used by teams and professional riders to prepare for races. However, information is seldom published since teams are understandably reluctant to release data that might be used tactically against them. In any case, just how useful data from a tour rider would be to someone preparing for the Etape is questionable. Top professional riders are so much fitter and more skilled than the average Etape rider that they are able to complete a stage in a much shorter time.

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 performance.

In particular, by comparing this information with indirect calorimetry data, it is possible to work out the fuels used and show the importance of pace judgement on subsequent performance. The importance of carbohydrate feeding provision during the ride and training the ability to use fat as a fuel at high work rates is also revealed, something that applies equally well to many other endurance events.

Let's start by taking a look at the course and then the actual data we gathered while riding the course:

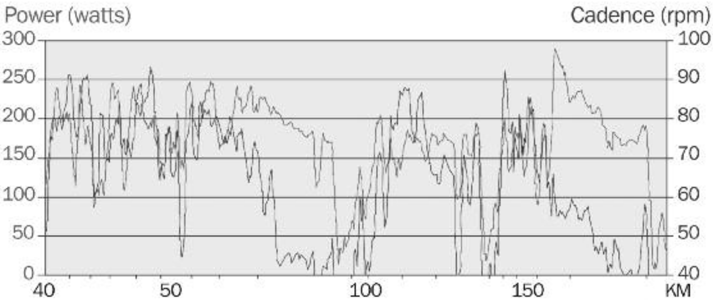
An altitude profile of the 2006 route from Gap to Alpe d'Huez taken from www.letapedutour.com/2006/us/index.htm



Calculating power output and energy requirements

The SRM system (*see box below*) 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 human body to produce 5,450kJ is 21,347kJ, or about 5,083kcal (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.). However, to this we need to add around 100kcals per hour to cover basal metabolism (energy used just to keep body processes ticking over) making the energy cost just over 6,000kcal.

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.

Exercise intensity and substrate 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 on page 4 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].

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 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, 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.

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
				$\sum$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.

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. 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

Turning a bicycle into a mobile ergometer

By locating strain gauges at different parts of a bicycle, several systems have been developed to accurately measure 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.

drag and may hinder thermoregulation. 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%.

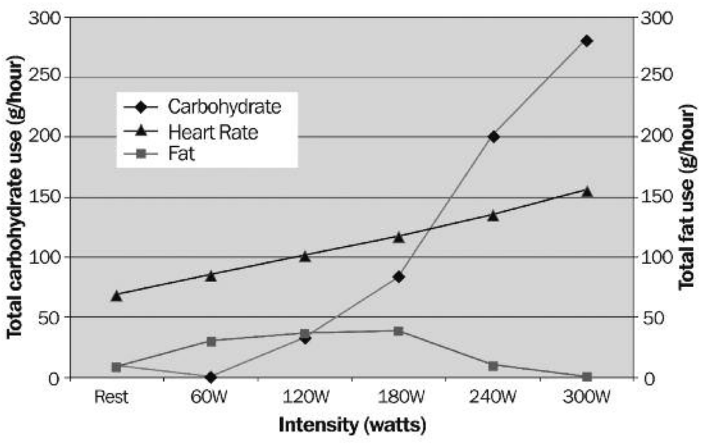
Drafting has been described as a very important skill for a competitive cyclist since it can have a huge impact on energy requirements. Scientists analysing data from Tour de France competitors have remarked not only on the exceptionally high power outputs, but also on how riders are able to use drafting 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

Total metabolic fuel use with increasing exercise intensity



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 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.

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