RECOVERY

the magic ingredient of any training program

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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Recovery – the magic ingredient of any training program

Contrary to popular belief, training does not make you stronger, faster or fitter. Those benefits only come during recovery, when adaptation takes place. No matter how hard you train, without adequate recovery, you'll not only squander your hard training effort – you'll also struggle to recuperate for your next session. And the harder and more frequently you train, the more vital optimum recovery becomes.

As this special report makes clear, recovery is much, much more about simply putting your feet up after a hard training session; correct post-exercise nutrition, together with appropriate training program design and monitoring are absolutely critical if you want to perform consistently well. Other factors are also important such as maximising sleep quantity and quality!

It's not possible to stress just how important recovery is for sports performance. Improving your recovery will produce more performance benefits than any amount of increase in training intensity or volume, and will also reduce your risk of sustaining an injury. So if you want to know what the latest research says about what and when to eat and drink and how to structure your training for optimum recovery and maximum performance, look no further!

Andrew Hamilton BSc Hons MRSC ACSM (editor)

Eating and recovery: should protein replenishment start before exercise?

When it comes to recovery from athletic endeavours, the notion that 'it's not just what you eat but when you eat it' seems intuitively correct. For example, numerous studies have demonstrated that muscles are hungrier for refuelling after exercise than they are before, giving rise to the concept of the 'post-exercise window of opportunity'. However, more recent research has suggested that this window of opportunity may be wider than anyone had imagined, writes **Andrew Hamilton**

At a Glance

- The fundamental requirements of post-exercise feeding are outlined;
- The role of protein in recovery is explained;
- Recent research about protein timing for optimum recovery and muscle growth is presented.

One of the problems with making definitive recommendations about the timing of meals and drinks to enhance post-exercise recovery is the multifaceted nature of the components required for recovery. In broad-brush terms, there are four major nutritional requirements during post-exercise recovery:

- *Water* – to replace fluid lost as sweat and to aid the process of 'glycogen fixation';
- *Electrolytes* – to replenish minerals lost in sweat (*eg* sodium, chloride, calcium, magnesium);
- *Carbohydrate* – to replenish muscle glycogen, the body's

premium grade fuel for strenuous exercise, and also to top up liver glycogen stores, which serve as a reserve to maintain correct blood sugar levels;

- *Protein* – to repair and regenerate muscle fibres damaged during exercise, to promote muscle growth and adaptation, and to replenish the amino acid pool within the body.

"To maximise the rate of glycogen repletion, carbohydrate consumption should be a priority after exercise"

Although even a small degree of water loss can impair performance, the process of rehydration to replace lost water and electrolytes is relatively straightforward. Our bodies always strive to maintain optimum water and electrolyte balance, so as long as we consume plenty of fluids after training and eat a reasonably balanced diet (which will contain electrolyte minerals), full rehydration will occur as a matter of course. Moreover, it's quite easy to tell when we're fully hydrated – a pale straw-coloured urine and frequent urination being the most obvious signs.

Refuelling muscles with carbohydrate is less straightforward. Regular *PP* readers will be aware of the importance of carbohydrate feeding after exercise and also during prolonged endurance events. One of the earliest landmark studies demonstrated that a typical diet (with about 45% of calories derived from carbohydrate) produced a steady depletion in muscle glycogen during three successive days of running training (10 miles per day) [1]. However, when runners were given additional dietary carbohydrate, they achieved near maximal repletion of muscle glycogen within 24 hours.

Subsequent studies showed that, to maximise the rate of glycogen repletion, carbohydrate consumption should be a priority after exercise. In fact, a literature review concluded that the highest muscle glycogen synthesis rates occur when large amounts of carbohydrate (1-1.85g per kg of body weight per hour) are consumed immediately after exercise and at 15- to 60-minute intervals thereafter, for up to five hours [2]. Conversely, delaying carbohydrate ingestion by several hours may slow down muscle glycogen synthesis.

We now know that there is actually a two-phase process of glycogen replenishment. In the first hour after exercise, a muscle transporter protein known as GLUT4 quite literally opens the gates to your muscle cells, allowing glucose to flood in thereby facilitating the rapid synthesis of muscle glycogen. This is supplemented by a slower but longer lasting process, whereby carbohydrate-hungry muscles become much more sensitive to insulin, the anabolic hormone that helps drive glucose into muscle cells.

Although animal studies have shown that this second phase of enhanced glycogen replenishment can last for up to 72 hours post-exercise [3,4], the general consensus is that athletes engaged in frequent training should aim to start glycogen replenishment immediately after each training session. This is because the training schedules of most athletes simply don't allow for up to

Essential and non-essential amino acids

Just as words are constructed from letters of the alphabet, so all proteins are constructed from amino acid building blocks chemically linked together. Our diets typically contain around 20 of these amino acid building blocks in the foods we eat. Once the plant or animal proteins we eat have been digested to release the amino acids, our cells reassemble them to produce human proteins such as hair, skin, muscle *etc*.

Of the 20 amino acid building blocks, some are considered absolutely essential because they can't be manufactured in the body from other molecules. These include:

Arginine	*Histidine*	*Isoleucine*	*Leucine*	*Lysine*
Methionine	*Phenylalanine*	*Tyrosine*	*Tryptophan*	*Valine*

The other amino acids are classed as non-essential because they can be synthesised in the body from fragments of the essential amino acids and carbon residues from glucose metabolism. More recently, scientists have identified a third category of amino acids, known as 'conditionally essential'. Conditionally essential amino acids can be synthesised in the body when demand is low, but when demand rises (*eg* at times of metabolic stress) synthesis can't keep up with demand and dietary sources then become vital. The amino acid glutamine is thought to fall into this category, being non-essential at rest but becoming essential at times of severe metabolic stress.

72 hours of recovery time between sessions, so athletes seeking rapid recovery must take advantage of the rapid phase 1 GLUT4 process and consume carbohydrates immediately after training!

Carbohydrate metabolism is a very well researched area of sports nutrition. This is because dietary carbohydrate and the glucose/glycogen our bodies produce from it are premium grade fuels and absolutely pivotal to sports performance. But another, less obvious, reason is that muscle glycogen stores are relatively easy to test by means of muscle biopsy. Moreover, muscle glycogen levels change rapidly in response to exercise (depletion) or carbohydrate feeding (replenishment). These factors make it much easier to investigate the relationship between the timing of carbohydrate feeding and its effects.

Contrast this with protein metabolism: unlike with carbs, there's no 'protein store' in the body, other than muscle tissue, and observing changes in muscle fibres in response to protein ingestion is difficult for two main reasons:

- It can take many days to detect an increase in muscle fibre mass as the result of protein incorporation into muscle tissue, which makes it very difficult to deduce a link between timing of protein intake and the body's response;
- Proteins in the body are in a constant state of flux; if protein demand suddenly rises, muscle fibres can be broken down to provide the body with extra amino acids for the amino acid pool and then regenerated from recycled amino acids once this demand has subsided. This explains why many studies on protein intake and muscle growth/ recovery are conducted over weeks, not days.

Sampling muscle tissue for protein

Fortunately, however, a chemical imaging technique called radiolabelling has enabled scientists to probe the uptake of ingested protein amino acids into muscle cells. In simple terms, one of the amino acid building blocks of protein is 'labelled' by removing a normal hydrogen atom from the molecule and replacing it with radioactive hydrogen. This means you can see what happens to this molecule using scanners when a subject consumes a protein drink or food containing it. If you take a sample of muscle tissue and detect the presence of radio-active hydrogen, you know that the body has incorporated the amino acid into muscle tissues – *ie* that protein synthesis has taken place.

One of the first findings to arise from using this technique was that the presence of amino acids in the bloodstream and their availability to muscle cells is vital for protein synthesis after exercise. In a study on six untrained men, American scientists infused them intravenously with a mixture of pure amino acids and studied the protein dynamics both at rest then for three hours after a leg resistance exercise routine [5]. They used an infusion rather than oral supplementation because they wanted to be certain that the muscles had an immediately increased supply of amino acids (*ie* without the time delay that digestion would introduce).

The amino acid infusion produced an increase in protein synthesis even at rest. However, after the resistance training there was a further substantial increase in muscle protein synthesis of 30-100%! In other words, amino acid supplementation not only enhanced protein balance and synthesis at rest but also led to an interactive post-exercise effect, which resulted in around a two-fold increase in protein synthesis after exercise.

Although an infusion of amino acids before training is extremely effective at enhancing the body's ability to increase protein synthesis, it is not exactly practicable, so the obvious question to ask is whether amino acids taken orally after exercise can produce a similar effect?

A subsequent study was designed to answer this question [6]. A group of healthy subjects performed a leg resistance routine and were then randomly fed one of three drinks:

- Placebo (no amino acids);
- An essential amino acid drink;
- A mixed amino acid drink containing essential and non-essential amino acids *(see box on page 13)*.

After training, the subjects rested for 45 minutes then began ingesting 4-5oz of drink every 15 minutes. Analysis of the results

“Amino acid supplementation not only enhanced protein balance and synthesis at rest but also led to an interactive post-exercise effect, which resulted in around a two-fold increase in protein synthesis after exercise”

clearly showed that, while protein balance was negative when the placebo drink was consumed (*ie* muscle protein was being broken down overall), it became strongly positive when the amino acid drinks were consumed, and the increase in protein synthesis was almost as great as after infusion. The researchers also found that protein synthesis was not enhanced by the addition of non-essential amino acids.

'So what?', I hear you ask. 'Surely everybody knows that protein is required after training?' Well they probably do, but there's a big difference between amino acids and protein; although amino acid solutions don't reach the muscles instantly, they are absorbed very rapidly by comparison with protein. That's because the process of digesting proteins

Fast and slow proteins

Research suggests that the key to stimulating maximal protein synthesis in exercised muscles is to raise the level of circulating blood amino acids as rapidly as possible after exercise – or, even better, beforehand. Whichever strategy is employed, it is clear that proteins that digest and release their amino acid building blocks rapidly are best suited to raising blood amino acid levels quickly.

There are four commonly used proteins in sports drinks; whey, casein, egg and soy. Of these, whey is digested most rapidly, taking only about two hours to release its amino acids. Soy and egg release their amino acids at a gentler rate – around five hours – while casein is a slow-releasing protein, taking up to seven hours to release its amino acids. All these figures are approximate, as there is a large degree of individual variability in digestion rates.

In many of the studies referred to in this article, pure free-form (unbonded) amino acids were used. No digestion is required to release these amino acids, which means they can cross from the gut into the bloodstream within minutes rather than hours. Free-form amino acids can be purchased and mixed with fruit juice to produce an extremely fast-releasing drink. There are two major drawbacks, however: firstly, gram for gram, pure amino acids are very expensive by comparison with ordinary protein; secondly, they tend to taste like old socks, making any drink potentially unpalatable!

(consisting of long chains of chemically linked amino acids) to release the constituent amino acid building blocks is quite time consuming – even for rapidly digested proteins like whey. A post-workout high-protein drink or meal could take several hours to produce maximum amino acid concentrations around muscle cells, yet we know it is the presence and availability of high levels of amino acids that seems to stimulate growth, especially after exercise.

Other studies support the notion that exercised muscles need protein very rapidly. A 12-week study on elderly males on a progressive resistance exercise programme found that a post-training meal immediately after training produced bigger gains in muscle fibre thickness than when given two hours later [7]. Some researchers have cautioned that this might be because the muscles of elderly people are 'less sensitive' to amino acids after exercise and that immediate post-exercise feeding of protein is of no benefit to younger people. However, another study throws doubt on this argument [8].

"It may be that, for optimum recovery and growth, protein replenishment should begin even before exercise!"

Scientists studied the effects of a fast-digesting protein (whey) and a slow-digesting protein (casein) in two groups of volunteers:

- Nine elderly subjects (average age 72);
- Six young subjects (average age 24).

Protein after exercise

They found that, irrespective of age, whey protein led to a faster rise in blood amino acids than casein, thereby producing a higher rate of muscle protein synthesis. While there was no exercise component in this study, these results mirror those of the infused amino acid study mentioned above [5], suggesting that consuming protein or amino acids as soon as possible after exercise is beneficial for muscle protein synthesis.

The conventional wisdom on recovery nutrition has tended to emphasise the importance of rapid carbohydrate replenishment, with little urgency about protein replenishment. However, the studies to date suggest that we neglect rapid protein replacement at our peril! In fact, it may be that, for

Using essential amino acids before training

If you've never used free-form amino acids before training but would like to try, there are basically two options:

- **Capsules.** These can be purchased over the counter at health stores. The problem is that often only single types of amino acids are available in capsule form, which means purchasing several different bottles then taking a capsule out of each to ensure you've consumed all the essential amino acids (*see box elsewhere in this article*). This will be expensive as well as inconvenient!
- **Powder.** A slightly cheaper and much more convenient option is to purchase a proprietary amino acid blend. These products generally come in a tub containing the premixed powder.

As far as dosage is concerned, there are no precise recommendations. However, for a full body workout, something in excess of the 6g used in the limited leg exercise studies described in this article would seem sensible – perhaps 10-15g. Free-form amino acids are best taken with fruit juice: this not only provides carbohydrate but also helps hide the unpleasant taste!

optimum recovery and growth, protein replenishment should begin even before exercise!

This idea arose from a study on six healthy and active subjects (three men and three women), who participated in two exercise trials in random order. In one trial, they performed an intense 45-minute resistance training routine for the legs, then immediately consumed an amino acid drink containing 6g of essential amino acids (including radiolabelled phenylalanine) and 35g of carbohydrate [9]. (The carbohydrate was added to generate an insulin response – something that is known to help drive amino acids into muscle cells [10].) Blood samples and muscle biopsies were then taken for two hours after training, and muscle protein synthesis measured. The other trial followed exactly the same protocol, but this time the amino acid/carbohydrate drink was consumed immediately before training.

The results were surprising to say the least. In the two hours post-training, almost twice as much phenylalanine was taken up by the leg muscles and incorporated into muscle protein when the protein/carbohydrate drink was consumed before rather than after training. Even more surprisingly, while muscle protein synthesis increased dramatically and then declined after an hour when the drink was consumed after training, the boost in muscle protein synthesis was sustained for longer when the drink was consumed before training.

The researchers went on to conclude that consumption of a relatively small amount of amino acids (combined with carbohydrate) immediately before exercise is a very potent stimulator of muscle protein synthesis.

In summary, there is good evidence for carbohydrate feeding as soon as possible after training; not only does it facilitate the short-term (GLUT4) mechanism of glycogen synthesis, but it also allows for additional glycogen replenishment before the next training session (more often than not the following day). If you're taking a break from training for a few days, however, immediate carbohydrate feeding may not be necessary.

More surprisingly, perhaps, the evidence also suggests that boosting blood levels of amino acids by consuming quick-releasing proteins (or free amino acids) as soon as possible after training is a good idea; indeed, if maximising muscle growth is your goal, it could be an even better idea to raise blood amino acid levels before training.

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Jargonbuster

Glycogen fixation
The process whereby glycogen is manufactured from carbohydrate and locked into muscle cells

Amino acid pool
A collective term for the 'free' amino acids (*ie* not forming proteins) circulating around the body and available for use by the body

Muscle transporter protein
A protein molecule that sits in the cell wall and facilitates the passage of substances in or out of the cell

Anabolic hormone
Any chemical messenger molecule in the body that promotes tissue (and particularly muscle) synthesis

Muscle biopsy
A method of mechanically removing a small slither of tissue from a muscle for analysis

Radiolabelling
A chemical technique of replacing an atom in a molecule with a radioactive atom (usually of the same type) so that the movement of the molecule can be tracked in the body

Milk and recovery – what's the story?

The sports nutrition world is filled with high-tech products designed to make recovery as quick and as efficient as possible, but, according to* Amanda Carlson*, new research on milk suggests that it could be a cheaper and equally effective alternative

At a Glance

- The main nutritional requirements of post-exercise recovery are identified;
- Recent research on the benefits of consuming milk as part of a post-exercise recovery strategy is presented;
- Practical advice is given on using milk-based drinks as an inexpensive alternative to proprietary recovery formulations is given.

The words milk and muscle seem to naturally go together. But does the consumption of milk after a training session really promote muscle growth? Can milk give us what we need to attain maximum performance day in and day out?

Recovery revisited

First, let's investigate the efficacy and importance of a recovery drink when paired with training. When we think about what an ideal recovery drink would look like or be made up of, we have to take a step back and think about what the body goes through during a workout.

After a workout, your body is in a state of stress and it needs nourishment. More often than not, your body will be dehydrated, your blood insulin levels will be low, cortisol and other 'breakdown' hormones will be high, your glycogen (fuel stores) will be low or depleted, and your muscles will be in a state of breakdown. Your recovery nutrition strategy, in simple terms, should reverse all those things and restore your body to a hydrated, fuelled, recovered, and muscle building state *(see box, right)*[1].

The main components of recovery:

Refuelling muscles

When the science of sports started to come into its own, fuel (glycogen) restoration using carbohydrate was the name of the game. Studies have proven that taking in carbohydrate will indeed replenish fuel stores, and that the glycaemic index (GI) of these carbohydrates is important for enhancing glycogen recovery, with higher GI carbohydrates (carbohydrates that are broken down rapidly) producing more glycogen restoration in the post-workout period when compared with their low GI counter parts. In terms of how much carbohydrate is needed in the post-workout period, it is generally accepted that anywhere from 1.0-1.2g/kg body weight is ideal[2]. This research leads to our first rule of recovery nutrition:

For optimal glycogen restoration recovery, use a high glycaemic index carbohydrate source (Ivy *et al*).

"In terms of how much carbohydrate is needed in the post-workout period, it is generally accepted that anywhere from1.0-1.2g/kg bodyweight is ideal"

Rebuilding muscles

There's more to recovery than just refuelling muscles and scientists soon began to wonder how best to rebuild muscles and promote quick and efficient adaptations to training. The quest to find the perfect post-workout cocktail was now the hot research topic – which protein was best, how much was needed and could you just use amino acids? As an example, US scientists found that as little as 6g of essential amino acids combined with 35g of carbohydrate resulted in muscle building[3].

A study in 2004 at University of Texas looked at the effect of two other types of protein on muscle building[4]. The point of this study was to compare the response of muscle protein synthesis after exercise to casein and whey proteins. Casein protein is digested and emptied from the stomach at a slower rate than

Recovery nutrition: Putting the body back into balance *(John Ivy PhD)*	
Post-exercise environment	**Converting post-exercise environment from a catabolic state to an anabolic state**
● Dehydrated ● Blood insulin is low ● Cortisol and other catabolic hormones are elevated ● Immune system suppressed ● Muscle and liver glycogen reduced or depleted ● Muscle is in a catabolic state with increased proteolysis	● Rehydrate ● Increase blood insulin levels ● Lower blood cortisol levels and other catabolic hormones ● Strengthen the immune system ● Restore muscle and liver glycogen ● Stimulate muscle protein synthesis and tissue repair

whey protein; whey protein is therefore deemed the 'fast protein' and casein protein is considered to be its 'slow brother'.

The amino acids from slow protein such as casein appear in the blood more slowly, but the response lasts longer than with fast proteins. In this study the researchers consumed either 20g of casein, 20g of whey, or a placebo one hour after a resistance-training bout. They found that despite the different blood amino acid response, both proteins resulted in net protein balance – *ie* muscle gain.

In 2006, a study by US scientists from Baylor University examined the effects of whey protein supplementation on body composition, muscular strength, muscular endurance, and anaerobic capacity during 10 weeks of resistance training(5). Thirty-six resistance-trained males followed a four-days-per-week split body part resistance training programme for 10 weeks. Three groups of supplements were randomly assigned, prior to the beginning of the exercise programme, to all subjects:

1. 48g carbohydrate placebo;
2. 40g whey protein + 8g casein;

3. 40g of whey protein + 3g branched-chain amino acids + 5g of the amino acid L-glutamine.

The whey/casein group experienced the greatest increases in lean mass. Significant increases in one rep-max (1RM) bench press and leg press were observed in all groups after 10 weeks. In this study, the combination of whey and casein protein promoted the greatest increases in fat-free mass after 10 weeks of heavy resistance training. Athletes, coaches, and nutritionists can use these findings to increase fat-free mass and to improve body composition during resistance training. From this, we can formulate our second rule of recovery nutrition:

For the most complete muscular adaptation, make sure to have a combination of whey and casein protein in your post-workout cocktail.

“The whey/casein group experienced the greatest increases in lean mass”

Timing and ratio

In 1988 John Ivy stirred up the world of sports nutrition with his ideas on muscle glycogen recovery and the importance of the timing of carbohydrate. The highest rates of muscle glycogen storage occur during the first hour after exercise due to activation of glycogen synthase (a glycogen building enzyme)(6). The activation of glycogen synthase is actually stimulated by the degree of glycogen depletion(7). Exercise-induced increases in insulin sensitivity and the permeability of the muscle cell membrane to glucose also account for the physiological mechanisms behind post-workout carbohydrate timing(8).

Carbohydrate feeding immediately after exercise appears to take advantage of these effects, as shown by higher rates of glycogen storage during the first two hours of recovery, slowing thereafter to the more typical rates of storage. The most important finding of this study, however, is that failure to consume carbohydrate in the immediate phase of post-exercise recovery leads to very low rates of glycogen restoration until feeding occurs(6). Therefore the intake of carbohydrate in the first two hours after exercise allows a somewhat faster rate of glycogen synthesis than normal. This is the period where you need to take in the recommended amount of carbohydrate, which ranges from approx. 1.0-1.5g per kilo of body weight. Athletes should ingest sufficient carbohydrate as soon after exercise as is practical to start recovery as soon as possible and maximise the time for glycogen synthesis[9] *(see figures 1 and 2)*.

If less carbohydrate is consumed, the addition of protein to equal the caloric content of a supplement between 1.2 and 1.5g carbohydrate per kg of body weight can be ingested. It has been found that the isocaloric content of the combined protein and carbohydrate supplement promotes glycogen storage. The addition of protein to a carbohydrate supplement and its benefits to glycogen synthesis are not conclusive; you should therefore, make sure that carbohydrate is ingested at the level recommended above. However, a combination of carbohydrate and protein still promotes glycogen storage. The addition of protein additionally benefits muscle repair[10].

Figure 1: Bullseye countdown to optimal recovery

This bullseye picture represents how with every passing minute, your refuelling 'window of opportunity' becomes smaller and smaller. The largest window is in the first 30 minutes or so; after that the window gets smaller and smaller making recovery less efficient.

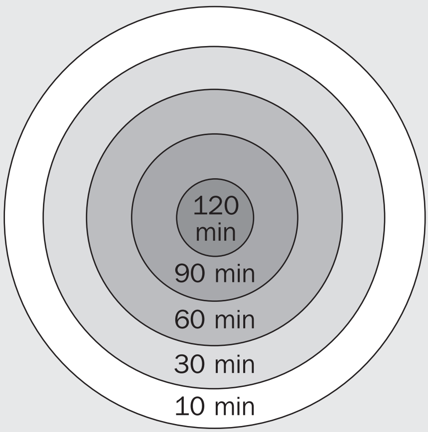
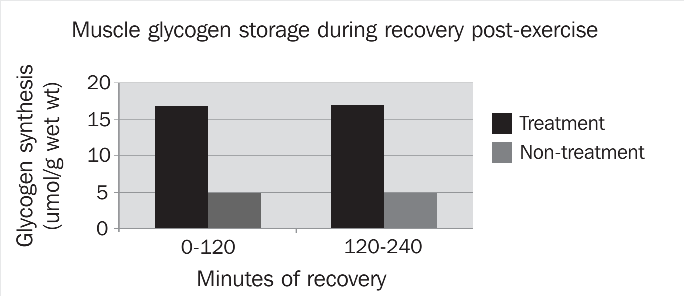


Figure 2: Timing and glycogen synthesis

The treatment group received a carbohydrate drink and the non-treatment group received a placebo drink. The first group received their drink within two hours of training, while the second group received their treatment after two hours. The first group who received the carbohydrate recovered significantly more glycogen then the group who waited two hours for their post-workout recovery, indicating the importance of nutrient timing on recovery.



The best sources of carbohydrate and protein, as well as the ideal carbohydrate to protein ratio will always be hotly debated. However, the consensus of research suggests that the ideal recovery drink should be liquid and comprised of an easily digested carbohydrate and a whey/casein mixture of protein, with the carbohydrate to protein ratio reflecting your individual weight goals as well as training demands. This ratio should increase with the intensity of your training, leaving it to fall anywhere between 2-4g of carbohydrate for every 1g of protein. As it happens, these guidelines remarkably resemble the components of low-fat milk[1]!

Recovery drinks have long been associated with supplements and therefore much of the research has been focused on the optimal supplements to use after training. However, over the past few years, researchers have investigated the potential of good old-fashioned low-fat milk as a recovery drink. The results may seem surprising, but when looked at objectively they make sense.

Milk research

Several studies have compared the post-training (weight training) effects of milk, soy protein and carbohydrate alone. In each of these studies, the subjects given milk as a post-training recovery drink gained more lean muscle mass than their soy and/or carbohydrate counterparts[11-14].

In 2004, US scientists from Virginia Tech published one of the first studies comparing the effects of a milk and a carbohydrate electrolyte beverage consumed in the immediate post workout period[11]. In this study, 19 men consumed either a milk or carbohydrate electrolyte drink immediately following each workout, during a 10-week resistance training programme. The authors concluded that the milk group tended to increase muscle mass, but the magnitude of the gains weren't large enough to be considered statistically significant. They suggested that more prolonged training and supplementation period would expand the trend for greater muscle mass gains in a milk group.

In 2007, Canadian scientists evaluated the long-term consequences of milk or soy protein, or carbohydrate (as maltodextrin) on muscle mass gains after resistance training[12]. Subjects trained five days a week for 12 weeks and were given isocaloric beverages consisting of either fat-free milk, fat-free soy protein, or maltodextrin within an hour after their training sessions.

“The consistent consumption of milk after resistance training can promote greater hypertrophy when combined with resistance training”

In the study, they found no differences in strength development between the groups. However, the researchers did determine that type II muscle fibre increased in all groups; moreover, it increased the most in the milk group. Muscle mass gains were also significantly greater in the milk group when compared with both the soy and control groups. They concluded that the consistent consumption of milk after resistance training can promote greater hypertrophy when combined with resistance training.

Endurance and hydration

The effects of milk have also been shown to aid recovery from endurance exercise. Scientists from Indiana University suggest that chocolate milk is an effective recovery aid between two exhausting bouts of exercise[15].

Table 1: Examples of milk-based recovery drinks

When choosing a recovery beverage, consider the intensity of workouts. The more intense, the greater the carbohydrate demands to replenish fuel. Low- to moderate-intensity training recovery can be achieved with a 2:1 carbohydrate to protein ratio. Higher-intensity sessions will need a carbohydrate to protein ratio of nearer 3 or 4:1.

For low-moderate-intensity training:	For moderate-high-intensity training
16oz skim milk w/ 1tbs chocolate syrup: 223 calories 17g protein 36g carbohydrate 1g fat ~2:1 carb:Pro	**12oz Starbucks' chocolate milk:** 190 calories 13g protein 35g carbohydrate 1.5g fat ~3:1 carb:Pro
24oz skim milk w/ 1tbs chocolate syrup: 309 calories 25g protein 48g carbohydrate 1.3g fat ~2:1 carb: Pro	**16oz ready-to-drink non-fat Nestle's Nesquik:** 320 calories 16g protein 64g carbohydrate 0g fat 4:1 carb:Pro
24oz Skim milk w/ 2tbs golden syrup*: 360 calories 26g protein 60g carbohydrate 1g fat ~2.3:1 carb:Pro ** eg – Hershey's or Tate and Lyle*	**16oz skim milk w/ 3tbs golden syrup:** 323 calories 17g protein 60g carbohydrate 1g fat ~3.5:1 carb:Pro **24oz skim milk w/ 3tbs golden syrup:** 409 calories 25g protein 72g carbohydrate 1g fat ~3:1 carb:Pro

In their study nine endurance-trained cyclists performed an interval workout followed by four hours of recovery and then another endurance trial to exhaustion. After the first exercise bout, subjects consumed a post-ride recovery beverage consisting of either chocolate milk or carbohydrate and electrolytes. Time to exhaustion and total work were significantly greater for the chocolate milk compared to the carbohydrate electrolyte group. This suggests that in addition to promoting a greater hypertrophy adaptation in a strength training group, a milk recovery drink can also improve performance on a subsequent endurance bout. For athletes performing multiple training sessions a day, the potential of milk enhancing not only recovery and performance is very real.

Another study worth mentioning looked at the effects of chocolate milk, a fluid replacement drink and a carbohydrate replacement drink on recovery between two exhaustive bouts of cycling. Chocolate milk proved to be an effective recovery option between rides. It allowed riders to cycle for a longer period of time on their second ride than with the use of the carbohydrate or fluid replacement options alone(15).

Research has also shown milk to be an effective rehydration drink. Subjects consuming milk (with added sodium) post-training actually remained hydrated longer than when they consumed sports drinks or water(16). These hydration findings are consistent with the improved fluid retention shown with protein enhanced sports drinks(17).

Conclusion

Based on this compelling research, low-fat milk is an effective post-training recovery drink. When used in conjunction with resistance training, it produces gains in muscle mass, aids in hydration and speeds recovery. To some, this is surprising news! How can something as simple as low-fat milk produce such results? The answer lies in the components of milk. They closely resemble the previously mentioned guidelines for an effective recovery drink. In fact the similarities are startling; milk is first and foremost a liquid, contains easily digested carbohydrate and a mixture of whey/casein protein. In addition, the carbohydrate to protein ratio of milk can easily be manipulated to meet your needs by adding something like syrup, a chocolate stir-in or a wholesome piece of fruit *(see table 1)*.

Does this mean that specially engineered recovery supplements are useless? No! But it will allow younger athletes and those who are on a tight budget to effectively recover and make lean body mass gains without breaking the bank.

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Jargonbuster

Insulin
A hormone whose presence informs cells that we are well fed, causing liver and muscle cells to take in glucose and store it in the form of glycogen

Cortisol
A catabolic hormone with physiological opposite effects to insulin. When cortisol is high, the body decreases the formation of glycogen and promotes the breakdown of glycogen, fats, and proteins

Glycogen
An insoluble, highly branched form of carbohydrate stored in muscles and liver

Glucose
A simple sugar that is an important carbohydrate because the cells uses it for their primary source of energy

Half-time recovery – what's best for maximising fulltime performance?

The days of sliced oranges and a cup tea at half-time are long gone. As* Tim Lawson *explains, optimum half-time recovery is a complex science in which a number of factors need to be considered

At a Glance

- The relationship between half-time nutrition and the demands of the sport and players' positions in that sport is explained;
- The importance of replacing sufficient, but not excessive, fluid and carbohydrate for recovery is discussed;
- Strategies for the optimum replacement of carbohydrate and electrolytes are outlined.

The half-time nutritional strategies employed by many sports teams often rely as much on tradition, fashion and even sponsorship deals as they do on sound science. But with sports like football becoming so high profile, nutritional strategies are becoming increasingly sophisticated, with many teams employing full-time nutritionists and sport scientists. Increasingly, top teams are using specialist sports drinks and other products with an emphasis on different priorities for different positions and individuals.

The traditional approach to half-time recovery usually involves a cup of tea and a slice of orange, and like many nutritional practices that have stood the test of time, this almost certainly has some merit. Similarly, other foods such as high-

"There have been very few studies that have looked specifically at a nutritional intervention at half-time and its effect on performance in the second half"

carbohydrate cakes, confectionery and even jelly babies have been advocated because they contain useful energy. Some scientific papers have even recommended snacks like pretzels because they contain high levels of sodium[1].

However, these kinds of products may also contain other ingredients that are not entirely beneficial for sports performance. For instance, it may not be possible to measure the performance detriments of hydrogenated vegetable oils or trans-fats in a single game but their negative effects on health are well documented, which is why they're banned in several countries. Similarly, colourings and other additives are often contained in these kinds of products, which have at least been associated with disruptive behaviour and poor concentration in school children, if not some of the crazy on- and off-ball fouls often seen on TV[2]!

So what are the main factors to consider when planning nutrition in the half-time interval? Since the first World Congress on the Science of Football was held at Liverpool in 1987, there has been much published research on the physical demands of football and other team sports, and the nutritional status of participants. Fluid, electrolyte and carbohydrate needs have been studied during training and in match simulations, as well as the effects of dietary manipulations on sport-specific skills. Fatigue has been observed as a transient phenomenon during matches and general performance declines towards the end of matches. However, the underlying factors responsible for fatigue during football are still not fully understood[3,4].

There have been very few studies that have looked specifically at a nutritional intervention at half-time and its effect on performance in the second half. A study presented at the 2006 American College of Sports Medicine annual meeting, showed that players who had been fed a mixture of protein and carbohydrates at half-time performed worse in the second half than those given a carbohydrate drink. However, the principles for effective nutritional strategies need to be deduced from the research based on the demands of the game and the factors known to limit physical performance. Case studies are therefore important.

Physical demands of team sports

There are significant differences in the physical demands of team sports like soccer, American football and rugby, with soccer being more physically demanding in terms of distance covered per minute than rugby, for instance(5). However, most team sports show activity patterns that would be expected to have a considerable energy cost, with typical values for distance covered per match at around 8-11km.

The energy cost of competing in a match is much higher than an even-paced run of the same distance, as there are numerous changes of pace with many periods of intense activity, which is typically associated with heavy demands on carbohydrate energy supply(4). Within the same sport, different league standards are often associated with different activity levels, with top-class sport clearly differentiated from lower levels by the increased volume of high-intensity play(3).

Outcomes in team sports are highly influenced by skill, so it

Inappropriate and devious strategies…

The most inappropriate nutritional strategy must go to the Sunday league team who were sponsored by a brewery and really did drink a pint of the sponsor's lager at half-time. Apparently they all thought they played better in the second half, but no one had done the match analysis and they were keen for it to stay that way!

The most devious nutritional strategy involved the use of high-tech sports drinks and gels for the home team but sugar-free cordial and sweeteners rather than sugar for the tea that the league rules obliged them to provide for the visiting team. A lesson perhaps for visiting teams and sports people to be self-sufficient, but it was surprising how long the home team were able to get away with this tactic by explaining that 'Sugar is not healthy and you wouldn't want your guys getting fat would you?!'

is also important to consider factors that may influence skill and concentration when considering strategies to optimise performance. Often these factors go hand in hand with carbohydrate depletion, associated with reduced exercise capacity and poor concentration – effects that may be compounded by dehydration. Both dehydration and muscle glycogen depletion have been associated with injury and accidents, so efforts to prevent these affecting performances could have repercussions well beyond the immediate match.

One of the main difficulties in discussing nutritional strategies for the half-time interval in order to optimise performance in the second half is that the factors may vary according to the state that players are in prior to the match. In the early 1990s, scientific publications commenting on nutrition for football tended to suggest that even when players were consuming sufficient calories to meet their energy needs, they should consume more carbohydrate in order to recover between training sessions and to maximise muscle glycogen stores prior to a match[6,7].

"Both dehydration and muscle glycogen depletion have been associated with injury and accidents, so efforts to prevent these affecting performances could have repercussions well beyond the immediate match"

More recent publications, whilst stressing the importance of replenishing muscle glycogen stores between training sessions and the potential benefits of carbohydrate loading for matches, have also warned about the over-consumption of carbohydrate if optimal body composition is to be achieved[8].

However, studies using dietary analysis continue to suggest that many soccer players are failing to consume sufficient carbohydrate to recover and optimise carbohydrate stores[9] and two Spanish studies published in 2005 suggested that the eating habits of young players were so poor that nutritional intervention and education was necessary in order to improve general healthy dietary practices[6,7].

The impact of carbohydrate supplementation during the half-time interval could well depend upon the prior eating habits of the player. Similarly, the rehydration needs, and therefore the efficacy of half-time rehydration strategies, will depend on the pre-game hydration status as much as the playing conditions and player work rates. Researchers from

Pennsylvania State University recently investigated the effect of dehydration and rehydration on basketball skill. Urine tests showed that some subjects taking part in the experiment were already dehydrated when they arrived at the experiment venue, even though they had been encouraged to stay well hydrated the day before each trial[10].

This situation is probably reflected in real game situations, especially where squads are not monitored closely in their build-up to games. Sport nutritionists working with Premier League football clubs have noted that players often turn up to training less optimally hydrated during cold weather than in the hotter months. This may be because players give hydration less priority when the sun is not shining and are unaware of the increased water vapour losses in cold conditions.

The growing use of under-pitch heating also means that more games can be played in very cold air temperatures, where water vapour losses are significant. If well-monitored players at high levels of sport are often sub-optimally hydrated, there's a good chance that players in other leagues are starting matches in a sub-optimal state and will therefore be in a worse state at half-time than necessary.

Just enough and no more

Scientific studies of sub-elite sportsmen and women show there is much to be gained by replacing fatty, energy-dense foods with more carbohydrate[11,12]. However, at the very elite end of sport, nutritionists are fine-tuning energy and hydration provision to provide just enough.

This is to maximise power-to-weight ratio; each gram of carbohydrate stored as muscle glycogen is bound to 3g of water, so if a player starts with 500g of muscle glycogen and this is used during the game it will release 1.5kg of water. This released water is important when considering the fluid and energy requirements at half-time.

While dehydration resulting in a loss of body mass of 2% or greater can result in reduced endurance exercise capacity, and sprinting and sport-specific skills can be adversely affected by

"Assuming that players start a match with reasonable sodium stores, most players are unlikely to be become performance limited due to sodium depletion during one match"

losses of 3% or more[3,10], players are able to tolerate a level of dehydration. There's no merit in encouraging players to consume more fluid than required to maintain performance, because this would be the equivalent of sending players out with a weight vest! However, any change in body mass should not be calculated by the difference between that immediately prior to the match and half-time, but instead baseline body mass should be established by early morning measurements taken before any carbohydrate loading has taken place[13].

Although there are some reports of soccer players losing up to four or five litres per hour of sweat in very hot and humid environments and up to three litres in temperate climates, sweat losses closer to two litres per hour are probably more typical[1,3,13]. In such cases, a half-time fluid consumption of between 500 and 800mls should be sufficient to prevent a decrease in body mass greater than 1% during the second half.

Individual differences

Recent publications studying the sweat response and water and electrolyte needs of footballers have noted that there are wide individual differences amongst the same teams that were not position dependant[1,13]. In an ideal world each individual would have a specific fine-tuned nutritional strategy, but this can be almost impossible in the squad culture that tends to exist in everyday training situations.

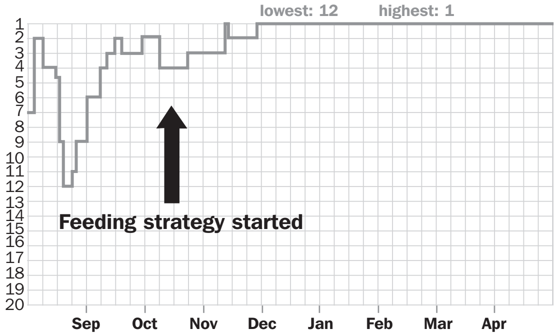
Nutrients, especially electrolytes, may prevent fatigue and reduce muscle cramps in the second half. The most important electrolyte lost in sweat is sodium and research has shown a wide individual variation in sodium losses – as low as the equivalent of 1g of salt to over 6g in 90 minutes. Assuming that players start a match with reasonable sodium stores, most players are unlikely to be become performance limited due to sodium depletion during one match; the main role of sodium in a half-time recovery situation is to encourage fluid uptake in situations where large fluid volumes need to be consumed at half-time (because sodium stimulates thirst).

However, 6g is the suggested total maximum daily salt

CASE STUDY

Accrington Stanley Football Club is most famously associated with nutrition via a long-running milk commercial. However, medical and support staff were keen to use scientific sports drinks in order to improve energy levels in the latter parts of games. The strategy needed to be simple to administer and integrate into a squad, have good acceptability and be cost effective. A simple feeding strategy based upon each player drinking 500mls of a 12% glucose polymer/fructose solution (SIS PSP22) prior to the match and at half-time was initiated in October 2005.

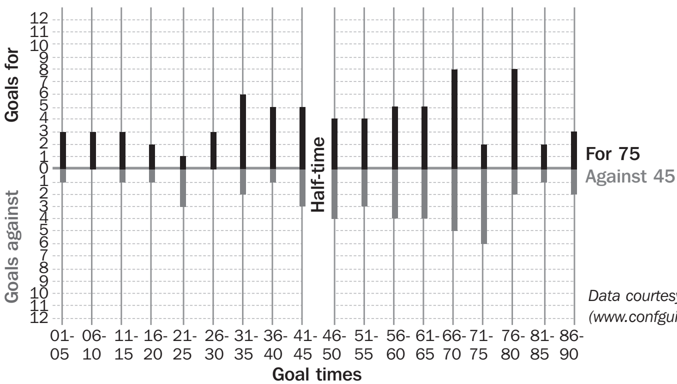
Accrington Stanley 2005/6 league position



Data courtesy of Confguide (www.confguide.com)

The feeding strategy was thought to be a major contributing factor to Accrington's league title success and record-breaking unbeaten run. Medical and support staff point to the timing of 'for' and 'against' goals as evidence; rather than running out of energy, Accrington were scoring more often and conceding less in the latter 15 minutes of each half.

Goal times (minutes) and numbers 2005/06



Data courtesy of Confguide (www.confguide.com) allowance recommended by the UK Food Standards Agency and there has been considerable pressure from the government for food producers to reduce the amount of sodium in food[14]. It is not clear if 'high sodium sweaters' are so because they consume a high-sodium diet or for other reasons. It is clear, however, that sweat losses of 6g in 90 minutes cannot be sustained unless consumption is increased beyond the current recommended daily maximum. Unseasonably hot weather and reduced sodium foods may combine to leave players potentially short of this important electrolyte.

Research on many games players suggests that the status of other nutrients is often poor[9,12,15], and minerals such as zinc, magnesium and calcium (found as electrolytes in sweat) and other minerals such as iron[16] may be sub-optimal prior to matches. Whilst a player suffering from fatigue or cramps due to poor nutrition prior to the match may benefit from carbohydrate/electrolyte supplementation at half-time, it's probably better to improve diet between matches rather than try to patch up poor general nutrition with a half-time fix.

Half-time carbohydrate

In players starting with an adequate nutritional status, fluid or electrolyte losses are not usually a limiting factor in performance towards the end of games. However, carbohydrate shortfalls are almost certainly responsible for fatigue in games, irrespective of player position or standard. Low carbohydrate levels can compromise mental skills as well as physical performance, and there is consensus that carbohydrate supplementation can improve performance. Muscle glycogen stores are generally quite low at the end of games, and even when overall stores are not depleted, carbohydrate may be depleted in specific limiting muscle fibres[3].

Carbohydrate supplementation to replace lost muscle glycogen makes sense and has been shown to help prevent deterioration in the performance of soccer players in simulated matches[15] and to improve performance in soccer- and basketball-specific tests[10,17]. However, gastric-emptying studies have shown that the activity levels in competitive games are such that they are likely to delay gastric emptying and possibly reduce the effectiveness of carbohydrate drinks given immediately prior to or during matches[18].

To counteract slow gastric emptying, glucose polymers (maltodextrins) have been recommended for many years; they have a lower osmolality than simple sugars, can improve gastric emptying and are relatively light on the stomach[19]. Recent research from Birmingham University suggests that energy drinks using multiple energy substrates may result in improved energy delivery to the muscles[20]. Combinations of maltodextrin and fructose would therefore seem to be a sensible combination to form the basis of a half-time nutritional strategy, combining good gastric emptying with the benefits of multiple energy substrate transport across the small intestine.

Half-time is, however, relatively short and care should be taken to maximise the opportunity to refuel and recover when gastric emptying is not limited by intense match activity. Isotonic energy gels can be a practical solution, providing players with a bolus dose of carbohydrate as they leave the field, gaining valuable recovery time over a team waiting until they reach the changing rooms to get drinks. Although this article is about half-time nutritional recovery strategies, it also makes sense to use any natural breaks in the game to take on carbohydrate, and fluid/electrolytes in hot conditions.

It's worth cautioning against a 'one size fits all' policy with regard to player nutrition. A strategy of ensuring that each player consumes at least 400-500mls of 10-12% glucose polymer/fructose solution is a good baseline for half-time refuelling. In hot conditions, and for players with very high sweat rates, more fluid may be needed to prevent dehydration reaching detrimental levels. Fluid requirements can be checked by comparing half-time weights to baseline measures in training matches, and players should be encouraged to fine-tune their thirst perception using this feedback. When 800mls or more of fluid needs to be drunk at half-time, it is possibly useful to consume solutions containing at least some electrolyte, especially sodium.

"It's worth cautioning against a 'one size fits all' policy with regard to player nutrition"

Summary

Do

- Try to take account of individual needs as well as those of the squad more generally;
- Maximise muscle glycogen restoration by getting carbohydrate in as soon as possible;
- Modify hydration according to weather/activity levels;
- Remember that in fast games, sweat rates can be at or close to maximal, even in cold conditions;
- Remember that additional water vapour losses can be significant in extremely cold weather and that the advent of heated pitches means that more games are now played in very low air temperatures;
- Tailor half-time nutrition to individual needs – especially important in hot conditions when there may be large differences in sweat rate and composition;
- Consider caffeinated beverages for players who have not been involved in play for long periods. Some teams have reported positive effects of caffeine, and because of the possible beneficial effects on attention and vigilance it could be particularly useful for goalkeepers in matches when they are not involved in play for long periods in games.

Don't

- Wait until the half-time period to fix dietary problems that should have been fixed before the game or several weeks before the game;
- Drink to maintain pre-match body mass. Baseline body mass should be calculated from morning weigh-ins. This is likely to be considerably lighter than pre-match weight. Try to drink a sufficient amount so that weight does not drop by more than 2% of the morning weight;
- Take more carbohydrate or fluid than is necessary. More is not necessarily better and around 120-150g of carbohydrate is probably ample during a 90-minute game. Any carbohydrate calories consumed above that required increases chances of fat gain and any fluid intake above that required to prevent a performance drop will reduce physical performance by virtue of the increased mass of fluid that has to be carried around;
- Carry out other nutritional strategies at the expense of carbohydrate delivery or hydration.

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Jargonbuster

Osmolality
The concentration of particles of a substance per unit volume in a solution (as opposed to weight of substance per unit volume)

The glycaemic index: how to harness it for optimum recovery

Unless you've been living on Mars for the last 15 years, you'll already be aware that carbohydrate nutrition is just about the most important weapon in your nutritional toolbox for maximising sport performance. In recent years, the 'glycaemic index' – the rate of carbohydrate energy release – has become an important consideration for athletes seeking to consume the 'right' type of carbohydrate for a particular mode of training or recovery. But why is this index important and how can you use it to plan your carbohydrate intake for better recovery? New research has thrown up some interesting findings, according to **Andrew Hamilton**

At a Glance

- The basics of carbohydrate digestion and metabolism and the subsequent effects on insulin and post-exercise muscle recovery are explained;
- The concepts of GI and GL in dietary carbohydrate are introduced and compared;
- Recommendations are made for optimising GI and GL to maximise exercise performance and recovery.

Glucose is your body's premium grade fuel and almost all of it is derived from dietary carbohydrate. But, although all carbohydrates supply glucose to the body, the rate at which they are digested and release that glucose into the bloodstream, where it can be absorbed, varies considerably.

For example, the carbohydrate in oatmeal consists of glucose building blocks chemically bound together in long chains to form starch; and the glucose can't be released into the bloodstream until digestion breaks the chemical bonds in the starch chains to release the individual glucose building blocks, all of which takes time. This process is also slowed down considerably by the presence of gummy fibres, which tend to trap the starch in a gel-like matrix, further delaying the release of glucose. The net result is that the release of glucose into the blood following an oat-based meal is slow, gentle and prolonged.

Now contrast this with the same amount of carbohydrate consumed in the form of a drink sweetened with glucose syrup. Most of the carbohydrate in glucose syrup comes from free, unbound glucose building blocks, so it can pass straight from the intestine into the bloodstream, without digestion, in a rapid sudden surge.

Since glucose is such an important molecule in energy metabolism, it would be surprising if our bodies didn't have precise mechanisms for controlling its flow around the body, as indeed they do. The brain runs almost exclusively on glucose, which it gets from the blood as the end result of breaking down dietary carbohydrate. However, the brain is extremely sensitive to the concentration of glucose in the blood (often referred to as 'blood sugar'); even a mild shortfall can produce such symptoms as weakness, dizziness, fatigue, poor concentration and confusion, while large excesses (as you get with uncontrolled diabetes) can lead to coma and even death.

Blood glucose levels are controlled by hormones, which stimulate hunger pangs and the release of glucose from liver stores when blood glucose drops (*eg* when food hasn't been eaten for a few hours) and which promote the uptake of glucose into the tissues, such as muscle, when blood glucose levels rise too high (as after a meal containing quick releasing carbohydrates). In healthy adults, between meals the body strives to maintain a blood glucose level of around 3.4-6.0 millimoles per litre (60-110mg of glucose per 100ml). When blood glucose rises above the upper limit (*eg* after a meal), the hormone insulin stimulates uptake of glucose into the cells, where it can be stored as glycogen in muscles and the liver or transformed to triglycerides (precursors to fat molecules). The net effect is to lower blood glucose.

After several hours without food, blood glucose levels tend to drift downwards, and when the level drops below the lower limit the hormone glucagon stimulates the conversion of liver glycogen back to glucose and, if liver glycogen stores are low, also provides a route for the production of glucose from fragments of other molecules, such as lactate and amino acids. The net effect is a rise in blood glucose. Together, insulin and glucagon keep blood glucose within the narrow range required by the body and, in particular, the brain.

If blood glucose levels are so carefully controlled, why does the rate of glucose release from dietary carbohydrates matter? The reason is that each time your body acts to bring blood glucose back to within its optimum range, a number of physiological consequences follow.

Eat a meal rich in quick releasing carbohydrates, such as sugar, and your blood glucose rockets upwards, causing a rapid release of insulin. This can be good or bad depending on the circumstances. After training, for example, when your muscles are 'hungry' for glucose to recover and replenish depleted glycogen stores, a rapid rise in insulin stimulates the uptake of glucose and amino acids into those muscles, so aiding growth and repair.

“Eat a meal rich in quick releasing carbohydrates, such as sugar, and your blood glucose rockets upwards, causing a rapid release of insulin. This can be good or bad depending on the circumstances”

However, eat that same meal when there's no particular demand for glucose and, once your liver glycogen stores are topped up, there's only one possible destiny for the excess glucose removed from the blood by insulin – storage as fat!

Insulin control is not perfect, particularly when the rise in blood sugar from eating dietary carbohydrates is large and rapid, such as after a sugary meal. A rapid rise in blood sugar stimulates a larger-than-normal insulin response with the result that blood sugar levels can eventually end up below the optimum range, leading to both mental and physical fatigue. This explains why some people find that quick releasing carbohydrates give an initial energy boost, giving rise to a subsequent dip 30-60 minutes later.

There is considerable individual variability in insulin response, though, and some people can eat quick releasing carbohydrates with impunity, while others find they play havoc with energy levels!

On the other hand, slow releasing carbohydrates, such as oats, pasta, lentils and beans, produce only a gentle rise in blood sugar and a correspondingly small insulin response, making it easier for the body to maintain optimum blood glucose levels.

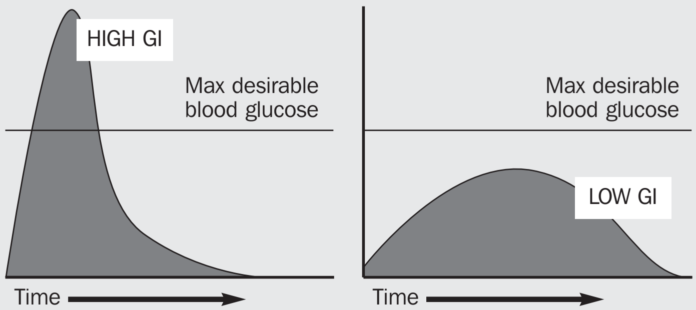
Another benefit of slow releasing carbohydrates is that, for a given calorie intake, blood glucose levels are sustained in the desired range for longer than when quick release carbohydrates are consumed. This delays the onset of hunger (useful when weight control is a priority) and also reduces the risk that stored proteins will need to be broken down for energy, thus depleting muscle mass!

Because the varying energy release rates of different carbohydrates impact on a range of physiological functions, including sport performance, scientists have devised a way of measuring their effect on blood glucose levels. The result is the 'glycaemic index', whereby carbs are ranked on a scale from 0 to 100 according to the extent to which they raise blood sugar levels. Foods with a high GI are those which are rapidly digested and absorbed and result in marked fluctuations in blood sugar levels, while low GI foods are digested and absorbed slowly, producing gradual rises in blood sugar and insulin levels.

To determine the GI rating of a given carbohydrate, measured portions are fed to healthy people after an overnight fast, with blood samples collected at 15-30 minute intervals over the next two hours. These blood samples are used to construct a blood sugar response curve, as illustrated in figure 1,opposite, which determines the GI rating in relation to pure glucose. Pure glucose (one of the very quickest releasing carbohydrates) is assigned a value of 100 and all other foods are ranked by comparison.

The GI rating table, overleaf, contains a few surprises. For example, a baked potato releases glucose into the bloodstream

Figure 1: blood sugar response curves for high GI and low GI foods



50% faster than chocolate, which contains plenty of sugar! Similarly, that wholesome Shredded Wheat breakfast cereal causes a faster rise in blood sugar than apricot jam! That is because the GI rating of a carbohydrate is not determined purely by how 'refined' or sugary it is but also by the following factors:

- *The type of sugar present* – Fructose (the main sugar in fruit) has to be converted to glucose in the liver before it can appear in the blood, thereby reducing the rate at which blood glucose rises and attracting a relatively low GI rating. Sucrose (table sugar) consists of one unit of glucose and one of fructose bonded together; this bond has to be broken before free glucose is released and then fructose has to be converted to glucose. This explains why the GI of table sugar is much lower than that of pure glucose;
- *Amount and type of fibre present* – Fibre delays breakdown of carbohydrate in a number of ways. Sometimes it acts as a physical barrier, slowing down the digestive process of breaking down carbohydrate; this is why whole apples have a lower GI than apple juice. Sometimes, as with porridge, gummy fibres bind the carbohydrate into a gel-like structure, slowing down the rate of digestion;
- *Carbohydrate microstructure* – The structure of the food can also play a role. For example, with pasta the physical entrapment of starch granules in a sponge-like network of

Table 1: GI rating for some common carbohydrates

(Approximate values, varying according to brand/variety/ripeness/preparation *etc*)[2]

Glucose	100	Kiwi fruit	53
Rice Crispies	83	Carrots	51
Cornflakes	81	Oat bran	50
Puffed Wheat	80	Mixed grain	49
Jelly beans	80	Chocolate	49
Dark rye bread	76	Peas	48
Doughnut	76	Grapes	48
Potato (boiled or mashed)	74	Baked beans (tinned)	46
Dates (dried)	72	Porridge	46
Swede	72	Pineapple juice	46
Potato (jacket baked)	72	Fructose	46
White bread	70	Orange	44
Shredded Wheat	70	Apple juice (clear)	44
Wholemeal bread	69	All Bran	43
Croissant	69	Spaghetti (white)	43
French baguette	68	Peach	42
Parsnips	68	Pinto beans	40
Pineapple	66	Spaghetti (wholemeal)	39
Rye bread	65	Tomato juice	38
Mars bar	65	Apple	37
Table sugar	65	Pear	36
Apricot (tinned)	64	Chickpeas	33
Raisins	64	Hazelnuts	33
Beetroot	64	Yoghurt (low-fat, sweetened)	33
Potato: new	62	Split peas	32
Ice cream	61	Strawberry	32
Digestive biscuit	60	Milk (skimmed)	32
Pitta bread	58	Plums	32
Muesli	58	Butter beans	31
Banana (ripe)	58	Apricot (dried)	30
Sourdough	57	Banana (unripe)	30
Sultanas	57	Peanut butter	29
Rich Tea biscuits	57	Kidney beans	28
Mango	56	Lentils	28
Sweet corn	55	Milk (full fat)	27
Apricot (jam)	55	Grapefruit	25
Popcorn	55	Cherries	22
Orange juice	55	Cashews	22
Special K	54	Peanuts	22
Potato crisps	54	Soya beans	20
Sweet potato	54	Yoghurt (low-fat, unsweetened)	14

protein molecules in the pasta dough slows digestion, leading to a low GI rating;

- *Amount of fat present* – Fat in foods tends to slow the rate of stomach emptying and therefore the rate at which foods are digested. For any given carbohydrate, the presence of fat will produce a lower GI, which explains why crisps have a lower GI than boiled or baked potatoes and ice cream a lower GI than sorbet!

While GI is a very useful concept, it can't be taken as the sole predictor of the effects of eating a particular type of carbohydrate. That is because blood glucose response is also determined by the amount of food eaten. A more reliable rating system is the 'glycaemic load' (GL), which takes account of both the quality (GI value) of a given carbohydrate and the amount consumed, so more accurately predicting its effects on blood sugar.

The glycaemic load, in units, of a portion of carbohydrate is expressed as: GI rating x grams of carbohydrate in portion size/100. Note that each unit of GL produces the same effect on blood sugar as eating 1g of pure glucose.

The glycaemic load rating makes sense of some of the surprising GI rankings. For example, a banana may have a GI rating of 58 compared with just 49 for chocolate, but comparing GL values paints the true picture. A typical 120g banana contains around 24g of carbohydrate, which has a GI value of 58. The GL is therefore 58 x 24/100, *ie* approximately 14 units. But 120g of chocolate provides 75g of carbohydrate, which has a GI value of 49, and so has a GL value of 75 x 49/100 = 32 units. In other words, gram for gram, chocolate has more than twice the impact on your blood sugar of bananas, despite its lower GI ranking.

By totalling up the GL units for foods you eat throughout the day, you can arrive at an overall GL for the day. The average (processed) Western diet contains around 120 GL units per day, which is on the high side *(see table 2, overleaf)*.

The glycaemic index and load of foods have important implications for training and recovery. The early research focused largely on the role of high GI carbohydrates and post-exercise recovery, and it soon became apparent that high GI foods accelerate and maximise glycogen resynthesis and recovery after training. One of the landmark studies looked at cyclists who undertook two exercise trials to deplete muscle glycogen and then consumed either high GI or low GI carbs[(1)].

Table 2: GI and GL classified

	Glycaemic index (GI)	Glycaemic load (GL) Individual serving	Glycaemic load Total daily intake
Low	55 or below	10 or below	Below 80
Medium	56-69	11-19	80-120
High	70-plus	20-plus	120-plus

The high GI trial resulted in a bigger measured insulin response and increase in muscle glycogen during the 24-hour period after training. These findings were subsequently confirmed by other studies, which explains why high GI carbs are recommended for optimum recovery for 24 hours after training.

Pre-training GI values

Attention then turned to the issue of how different GI carbs affect performance when consumed before training, with Australian researchers noting that a low GI carbohydrate meal (lentils) eaten one hour before exercise increased cyclists' time to exhaustion by comparison with an equal amount of carbohydrate eaten in the form of a high GI carbohydrate food (potatoes)[3]. Their explanation was that the lower glucose and insulin responses produced more stable levels of blood glucose throughout the cycling bout which, combined with a slower rate of muscle glycogen usage, would have enhanced endurance.

This study lent credibility to the notion that consuming high GI carbs before training was probably not a good idea because they could impair performance by destabilising blood sugar levels. And it probably explains why endurance athletes are now advised to choose low glycaemic carbohydrate foods for their pre-event or pre-training meals.

The problem is that much of the subsequent research has failed to support these findings. In a follow-up study, the same researchers fed cyclists either low GI or high GI meals one hour before cycling to exhaustion[4]. They found that, although the low GI meals were associated with higher blood glucose levels after 90 minutes of exercise than their high GI counterparts, there were no differences in time to exhaustion.

Another study compared the effects of low GI food (lentils) and high GI food (potatoes) in cyclists before 50 minutes of submaximal cycling followed by a 15-minute performance trial[5]. As expected, the high GI meal led to an increase in blood glucose before exercise and a decline in blood glucose at the onset of exercise by comparison with the low GI meal. But again this made no difference to performance.

However, not all the subsequent research has been negative. In a similar trial on cyclists, plasma insulin levels were lower for the low GI meal through the first 20 minutes of cycling, and the exercise time to exhaustion was longer[6]. The low GI meal also maintained higher blood glucose levels at the end of two hours of exercise.

There's still some degree of uncertainty about the advantages of low GI carbs over high GI carbs as pre-race snacks/meals. And the fact that some individuals are known to be particularly sensitive to insulin-induced blood sugar falls may account for the somewhat mixed research results.

"Some research has also suggested that the GI of pre-exercise carbohydrate may affect the ratio of fat to carbohydrate used as fuel"

Some research has also suggested that the GI of pre-exercise carbohydrate may affect the ratio of fat to carbohydrate used as fuel. In a study on runners, fed either low or high GI carbohydrate three hours before a treadmill run, researchers were intrigued to discover that, although performance times did not differ significantly, during the first 80 minutes of exercise, carbohydrate oxidation was 12% lower and fat oxidation 118% higher in the low GI trial than the high GI trial[7]!

This finding is supported by more recent research on runners, who took part in three treadmill runs three hours after being fed either high GI food, low GI food or no food at all[8]. As expected, the researchers found that the fasting state produced the highest rate of fat oxidation during exercise. However, total fat oxidation was also significantly higher in the low GI trial than in the high GI trial, while the high GI meal caused a significant drop in blood glucose to below the fasting level – not a desirable effect!

An increased rate of fat oxidation following a low GI meal could be important because it would conserve muscle glycogen, so prolonging endurance in longer events, while maintaining or reducing body fat.

There is also some evidence that low GI pre-exercise meals may help endurance athletes by reducing blood lactate. Another study on trained cyclists involved an incremental exercise test to exhaustion 65 minutes after consuming either high GI, low GI or non-carbohydrate food(9). Although time to fatigue did not differ significantly between the groups, during exercise blood glucose levels were significantly lower in cyclists who'd eaten the high GI meal. Interestingly, blood lactate was also higher in the high GI group in the early part of the test (at submaximal intensities), suggesting that athletes engaging in prolonged low intensity exercise might benefit from a low GI pre-exercise meal.

However, it may be that athletes who routinely use carbohydrate drinks during training have little to gain by manipulating the GI of pre-exercise meals. One study looked at trained cyclists who drank a carbohydrate solution during a two-hour submaximal workout followed by a high intensity ride two hours after consuming either a high GI food (potato), a low GI food (pasta) or a low energy jelly (control)(10).

Despite between-groups differences in blood glucose, insulin and fatty acids, the researchers found that the amount and proportion of carbohydrate used for energy was the same, regardless of the pre-exercise meal, with no differences in time taken to complete the high- intensity ride. The researchers concluded that when carbohydrate drinks are ingested in recommended amounts during exercise, the type of pre-exercise carbohydrate consumed has little effect on metabolism or subsequent performance.

Making GI work for you

How can this knowledge about GI and GL help you enhance your own training and nutrition? The following advice should help:

- For maximum recovery, be sure to include some moderate/high GI carbohydrates in your post-training snacks/meals to maximise glycogen repletion;

- Despite the generally accepted advice, there is little evidence to suggest that higher GI pre-race snacks and meals adversely affect exercise performance during shorter events;
- There is evidence to suggest that low GI carbs may be preferable before longer, lower intensity events (two hours-plus). However…
- If you are susceptible to blood sugar swings (*ie* you often experience an energy dip 30-60 minutes after eating a carbohydrate-rich meal/snack), stick to low GI carbs for three hours before training, whatever the duration/intensity of your event, as these are less likely to disturb your blood sugar and adversely affect training;
- If weight control is a priority, avoid high GI pre-exercise snacks, which reduce the proportion of energy derived from fat burning during subsequent training;
- Away from training, try to emphasise low GI carbs in your diet, as these are less likely than high GI carbs to over-stimulate your insulin system and for continuing the process of recovery;
- Remember that the specific effect of a carbohydrate on your blood sugar results from both the quality (GI) and the quantity (GL) of that carbohydrate. Stick to low/medium GL food servings away from training and medium/high GL servings after training;
- The GI and GL of carbohydrates will both be reduced by fat consumed with your meal. For optimum glycogen replenishment, consume your moderate/high GI carbs with only small amounts of fatty foods!

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Jargonbuster

Hormones
Compounds made in the body that act as chemical messengers, telling cells what to do

Glycogen
A 'giant' molecule used for carbohydrate storage in the muscle and liver, consisting of large numbers of glucose units linked together to form an insoluble matrix of readily available carbohydrate

Triglycerides
A fat storage and transport molecule, consisting of glycerol bonded to three fatty acids

Blood lactate
A by-product of intense exercise, indicating that insufficient oxygen is available to fuel that exercise and leading to muscular fatigue

Is GABA the 'next creatine' for strength athletes?

The naturally occurring amino acid known as GABA has long been know to function as an inhibitory neurotransmitter in the brain, and as such, is popular as an 'anti-anxiety' supplement. However, exciting new research suggests that it may also stimulate the natural release of growth hormone, which could yield benefits such as enhanced muscle recovery and strength gains.* Andrew Hamilton *explains

At a Glance

- The role and different types of growth hormone in the body are explained;
- The nutritional link between GABA and growth hormone is outlined;
- New research on the potential benefits of GABA supplementation is presented and recommendations are made.

Back in the 90s, the use of creatine as a strength-building supplement revolutionised sports nutrition, because unlike most other supplements out there, it actually did what it claimed on the tin! Since then, a number of would-be pretenders to the throne have appeared on the market, but none has matched creatine for its sheer efficacy.

Creatine is able to produce short-term recovery and strength gains because it enhances the short-term, high-intensity energy pathway in muscles known as the 'phospho-creatine (PC) system'. An enhanced PC energy pathway allows muscle fibres to contract vigorously for longer, thus producing more intense loading and fatigue. This in turn produces a greater repair and growth stimulus, and in the longer term, with adequate rest and nutrition, greater strength gains.

The role of growth hormone

One of the key players in muscle recovery following exercise is a substance called 'growth hormone' or GH for short. GH is a large protein molecule that is synthesised, stored, and secreted by specialised cells within anterior pituitary gland in the brain *(see box 1 belowf)*.

In the body, GH has a number of biological functions, but of particular interest to athletes is the fact that it increases protein synthesis and promotes fat burning[1], increases calcium retention and therefore strengthens and increases bone mineralisation, and it also stimulates the immune system.

In adults, GH is not secreted steadily, but instead in discrete bursts resulting in about five large pulses or peaks of GH release each day. These peaks last from about 10-30 minutes and the most predictable of these peaks occurs roughly an hour after the onset of sleep[2]. However, another extremely powerful GH release stimulus is exercise, particularly high-intensity exercise such as resistance training or high-intensity anaerobic training[3-6].

Box 1: GH in the body – irGH and ifGH

GH exists in several forms in the body, only some of which are biologically active. To produce its biological effects, GH must bind to GH receptors on cell surfaces in a kind of 'lock and key' reaction.

There are two specific regions of the GH molecule that can bind to these receptors and thus switch on the chain of biological reactions that follow; if a GH molecule contains both of these regions, it is assumed to be biologically active. This 'active' form of GH is sometimes referred to as 'immunofunctional GH' or ifGH. By contrast, 'immunoreactive GH' refers to a measure of total GH present (ie all of the forms of GH, both biologically active and inactive).

Although rises and falls in irGH levels are normally mirrored by similar changes in ifGH levels, the ideal measurement of GH levels in research studies is ifGH, because this is guaranteed to be the fraction of GH that is active in the body.

Given that GH promotes muscular growth and repair, and also stimulates fat burning, it's not surprising that some athletes have been tempted to resort to GH abuse in order to accelerate recovery from training, increase strength and maintain low body fat levels. However, not only is this illegal, GH abuse is a potentially risky business, leading to potential health complications such as high blood pressure and heart damage[7].

The GABA-GH connection

If you want to maximise natural GH release and create an anabolic environment, intense exercise and adequate sleep are vital. But are there any nutritional tricks you can use to further enhance GH secretion? Given that GH is secreted from the brain, the obvious question to then ask is whether there are any nutrients that could in some way influence brain function.

As it happens, there are a large number of biologically active compounds that are involved in regulating brain chemistry and the central nervous system (CNS), and which are synthesised from simple constituents of foods. These compounds are collectively known as neurotransmitters, which control and regulate brain and CNS activity by acting on specific receptors within those regions.

The role of GABA in brain chemistry

Gamma amino butyric acid (more commonly known as GABA) is a naturally occurring AA present in small amounts in the body. Although it's not present in muscle tissue or in food (unlike most other AAs), it can be synthesised in the body from the AA L-glutamine[8] and is found in the CNS, pancreatic islet cells and kidney.

In the CNS, GABA is the chief inhibitory neurotransmitter, tending to decrease the electrochemical activity and therefore excitability of nerve cells. This explains why the administration of GABA can produce anti-anxiety and anti-convulsant effects and why much research into anxiolytic and anticonvulsant medication has focused around slowing down the breakdown of GABA in the CNS.

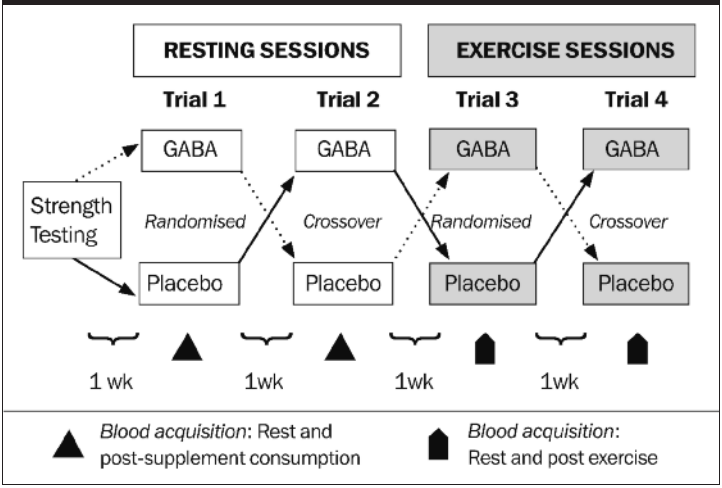
All well and good, but what can GABA offer to athletes seeking optimum recovery? Well, it just so happens that GABA supplementation while at rest seems to directly stimulate GH secretion in the brain via centrally mediated mechanisms[9,10]. However, until recently, there was no research available to show whether this effect is significant; *ie* does supplementation boost ifGH (the active form) and how relevant is this compared to the effect of GH release as a result of exercise?

More importantly, what is the effect of combining both resistance exercise and supplemented GABA on irGH and ifGH?

GABA and resistance training for GH release

Until recently the answers to the questions above were unknown, but a fascinating recent study carried out by US scientists at the University of Florida makes for truly intriguing reading[11]. The researchers hypothesised that GABA ingestion would increase circulating irGH and ifGH concentrations at rest, and that oral GABA administration would augment the irGH/ifGH response to resistance exercise (*ie* result in a larger release of GH) – ideal for athletes for all the reasons given earlier.

Figure 1: Experimental design of GABA/ resistance training study



The study was designed as a randomised, double-blind, placebo-controlled, crossover study – *ie* to be as rigorous and as accurate as possible. In the study, 11 healthy, resistance-trained males (average age 23.6yrs, average weight 87.5kgs) were investigated to see what effects 3 grams of GABA supplementation had on subsequent irGH and ifGH release followed by either a period of rest, or a session of resistance training.

The study consisted of four trials, each separated by a week; in trial 1, the subjects were given either 3 grams of GABA or capsules containing inert sucrose (table sugar) of the same calorific value. After taking GABA or placebo they then rested and measurements were made. In trial 2, exactly the same protocol was followed but those who had taken placebo now took GABA and vice-versa. Trials 3 and 4 mirrored trials 1 and 2, except that now, after taking the GABA/placebo supplements, the subjects performed an intense 15-minute resistance routine, which included the following exercises: chest press, lat pulldown, chest fly, seated row, shoulder press, biceps curl, triceps extension, leg press, leg curl, leg extension, and calf raise. Figure 1 shows a schematic representation of the overall experimental design.

Before each trial, blood was collected and then again afterwards at 15, 30, 45, 60, 75, and 90 minutes in the ‘rest’ trials and after 1, 15, 30, 45, 60, 75 minutes in the ‘exercise’ trials. These blood samples were analysed for subsequent irGH and ifGH concentrations. The researchers also timed the trials and blood collections so that they all took place between 07.00h and 09.00h in order to minimise any circadian variability (GH secretion tends to rise and fall naturally at different times of the day).

Results of GABA supplementation

The results obtained by the team were as follows:

- *Exercise performance* – there was no difference in exercise performance between those subjects taking GABA and those taking placebo (as expected – GABA would not be expected to exert a direct effect at the muscular level);
- *irGH and ifGH secretion* – as might be expected, compared to the equivalent resting trials, those with resistance training

resulted in significantly higher levels (up to 18-fold) of irGH and ifGH (we already know that exercise is a powerful stimulator of GH release);

- *GH release at rest* – GABA ingestion produced significantly elevated levels of both irGH and ifGH regardless of whether exercise was performed – up to 15-fold!
- *Effects of GABA plus exercis*e – the fact that GABA can enhance GH release is encouraging enough, but even more impressive was that GABA plus exercise produced significantly higher levels of irGH and ifGH than exercise plus placebo, both at various time points after administration and in terms of total amounts secreted (area under curve – AUC). For example, the irGH response after exercise-GABA was approximately 200% greater than exercise-placebo at 30 minutes after exercise cessation. Likewise, the ifGH response after exercise-GABA was 175% greater than exercise-placebo at 30 minutes after exercise. The same trends were noted for peak concentrations of both irGH and ifGH. Figures 2, 3 and 4 *(opposite)* illustrate these results.

“The irGH response after exercise-GABA was approximately 200% greater than exercise-placebo at 30 minutes after exercise”

What does this mean for athletes?

The two key findings from this study are that, firstly, GABA supplementation at rest dramatically enhances the release of ifGH. This is important because it’s the first study that shows GABA supplementation at rest increases ifGH – the portion of GH that’s known to be biologically active. This increase is significant; compared to rest-placebo, ingestion of GABA produced three to four times as much total secretion. Similarly, GABA ingestion combined with rest produced peak concentrations of ifGH that were over four times higher than without GABA.

However, even more interesting is the combined GABA-exercise effects on GH; looking at the figures given above, you can see how, compared to exercise alone (*ie* plus placebo), taking GABA boosted the GH response significantly: 200% more irGH and 175% more of the biologically active ifGH at 30 minutes after exercise following GABA ingestion is not to be

Results of the GABA/resistance training study

Figure 2: Changes in irGH and ifGH blood concentrations over time

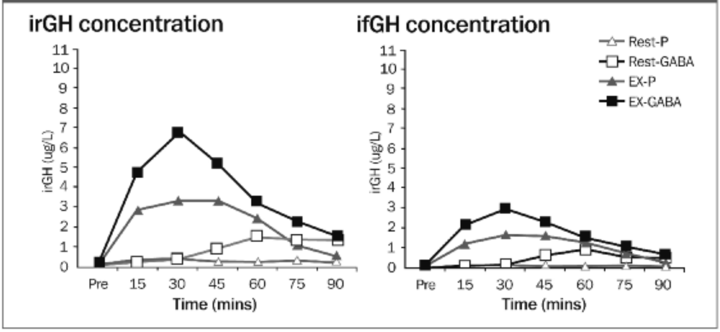


Figure 3: irGH and ifGH AUC secretions

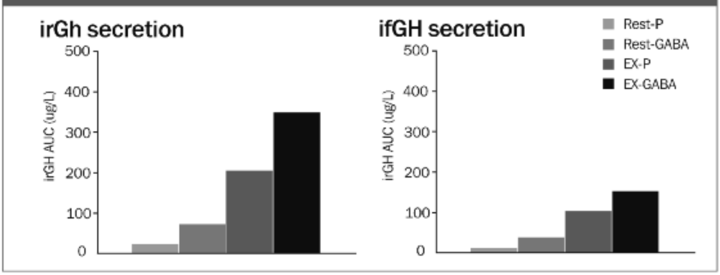
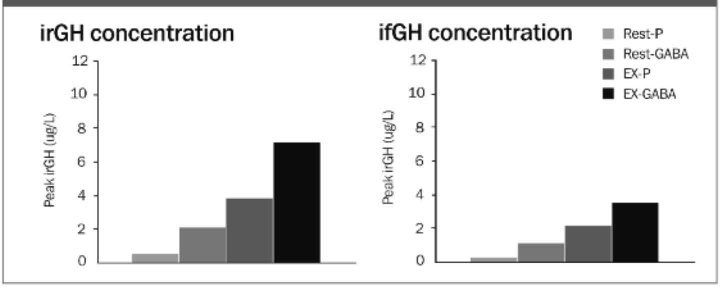


Figure 4: Peak irGH and ifGH blood concentrations



sneezed at! Moreover, compared to placebo-GABA, the same trends were observed for total units of irGH and ifGH released (AUC) when GABA and exercise were combined.

For athletes seeking to recover rapidly and gain maximum strength, this seems like a win-win situation; for the same degree of exercise intensity (remember the GABA in itself does not directly improve exercise performance), the magnitude of the subsequent GH release is nearly doubled. Even GABA taken on its own raised levels of both irGH and ifGH, which opens up the intriguing possibility that it could also be used to augment the natural peak of GH production that occurs during the early hours of sleep, thus aiding recovery.

However, before we get too excited, there are important caveats to add. The first is that there's still little understanding of how ingested GABA is able to produce this GH-boosting effect. As any exercise biochemist will tell you, when mechanisms are poorly understood, caution is the by-word.

The second is that despite everything we know about GH, exactly how the administration of GABA to boost exercise-induced GH might affect subsequent growth and recovery in athletes has yet to be determined. Until long-term studies have been conducted to investigate this, we can't be sure if these theoretical benefits will actually translate into improved performance. As the researchers themselves put it, 'Although GABA-induced irGH/ifGH secretion may alter substrate metabolism and/or enhance the skeletal muscle responses to resistance training, this still remains to be determined.'

Despite these caveats, GABA is considered a safe supplement with low toxicity and is relatively cheap: for example, 200g (66 servings) typically costs around \$20-30 in the US and £15-20 in the UK. Those who wish to experiment with it as an adjunct to resistance training therefore, may have little to lose. However, this of course presupposes that the emphasis on recovery remains firmly on intelligent training and good general nutrition – no supplement can ever be a magic bullet. That said, while the jury's still out, the research on GABA to date is promising and it remains an area to watch.

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Jargonbuster

Metabolite
A molecule that results from a subsequent biochemical transformation of the target molecule

Blood-brain barrier
A membranic structure that acts primarily to protect the brain from chemicals in the blood, while still allowing essential metabolic function

Anxiolytic
A substance (usually medication) that reduces anxiety

Precursor
A molecule used in the synthesis of the target molecule

Circadian variability
Rhythmic fluctuations that occur naturally as a result of the body's internal 24-hour clock

Recovery – how to measure it and prescribe a recovery program

***The simple physiological equation employed by most coaches is this: training-plus-recovery-equals-adaptation. But while there are literally hundreds of ways of measuring training (*eg *sets, reps, load, volume, time and intensity) and a similar number for measuring adaptation (game performance, lactate threshold, heart rate, speed, power *etc*), how many coaches measure or prescribe a recovery programme, asks* James Marshall**

At a Glance

- The requirements for optimum physiological recovery are outlined;
- The importance of adequate emotional and cognitive recovery are explained;
- Strategies to optimise all these aspects of recovery are given.

The evidence is that recovery is hugely important for athletes. Of 298 US athletes who participated in a survey after competing in the 1996 Atlanta Olympic Games, 35 (12%) said that the number one coaching decision that affected their performance was 'overtraining/ not getting enough rest'[1]. In fact, it has been reported that athletes are often fitter on the plane home than en route to a competition, simply because of the rest days they have enjoyed after the event!

Recovery is not just the absence of activity; it can also mean an enhancement of activity, such as stretching, or a change of activity, such as swimming instead of running. A coach may assume that if an athlete is not training he or she is recovering, but this may not be the case, and athletes may need a specific programme to help accelerate the recovery process.

The problem is that athletes prefer to focus on what they do best – training – and getting them to focus on recovery can be difficult. Indeed, if recovery sessions are not supervised, athletes may try to slip in extra sessions in order to 'gain an edge'. Thus, coaches need to monitor as well as prescribe their athletes' recovery programmes.

Prevention is better than the cure

Careful planning of the training programme is a key factor in preventing overtraining. External factors may have an adverse influence on an athlete's well-being, leading to under-performance, but at least the coach should be aware of some simple precepts that have been shown to work. Table 1, below, offers a succinct summary of what not to do.

Monotony of training can be a real challenge for an athlete, especially if he/she is in a full time squad or team and has to see the same faces at the same place every day. In such situations, a coach can maintain intensity and quality by ensuring a small change in the routine every week. This could be a change in environment – *eg* taking the team onto a track or beach for runs instead of a pitch; it could be a change of personnel – *eg* getting one of the players or assistant coaches to take a session once a week; or it could be a change of drills – basketball or five-a-side soccer being good alternative conditioning games for rugby players, for example. This sort of variation depends on advance planning and should be maintained even during a losing streak.

Table 1: how to overtrain

1. No rest days
2. No regeneration week every 2-3 weeks
3. Monotonous training programmes
4. More than 3 hours' training a day
5. More than 30% training load increase in a week
6. No alternation of hard/easy days (2,3)

If the training environment is a cause of stress, the athlete needs to take a break from this environment. Coaches like to talk about 'team building' and 'team players', which is great on the pitch, but not every player wants to spend 24 hours a day with his team mates. A good coach will recognise the individual needs of players in terms of both training and recovery. Some players need the team environment and don't like to be left on their own, but allowing some discretionary time in training camps allows players some space to 'do their own thing' to suit their own needs.

A break away from a coach, however inspiring, is also a good thing since it allows athletes to recover emotionally and mentally from the stress of training. However, the coach needs to have confidence that his athletes are responsible and will not engage in silly activities like bungee jumping on the day before a competition!

A complete break from sport is a necessity every year, although this is not always easy in sports with long seasons, such as football and rugby, which impose high physical demands on their players and operate within competitive league structures, with the added problems of cup matches and representative matches.

This break can take the form of an annual vacation, but should not involve an additional source of stress. Having two weeks away from the sport to sit university exams, for example, will not allow for effective recovery. And if your holiday includes long-haul travel, with the additional complication of overcoming jet lag, two weeks may not be enough.

"An athlete experiences stress in physical,menta l and emotional forms, and different recovery strategies are needed to address each of these areas"

Becoming self-aware

An athlete experiences stress in physical, mental and emotional forms, and different recovery strategies are needed to address each of these areas. However, you must be sufficiently self-aware to pinpoint the real source of stress[4].

For example, on returning home after a day at the office, you may feel tired and lacking in the energy you need for your planned training session. But the likelihood is that you are emotionally and mentally rather than physically tired, so a quick

"If you get caught in the negative loop of self -doubt and self blame, recovery cannot begin"

mental and emotional break – *eg* walking the dog, playing with the kids or doing some housework – before training is what you need. Without this break, your mind may not be on the job during training and your performance will suffer in consequence. Conversely, a low intensity, low skill training session is often seen as a great stress reliever for a lot of athletes after a hard day at work.

Self-awareness is an attribute that allows you to recognise how you are feeling physically and mentally and how that affects your reactions to others. Are you getting irate with other people over apparently trivial matters? Is your neck stiff? Do you have trouble concentrating on simple tasks? By identifying your current relaxation status you can determine and implement the appropriate recovery strategy.

Cognitive recovery

A period of adjustment is needed between the experience of a stressful situation and the start of emotional or mental recovery. How many of us can simply 'switch off' after a hard day at work? Everyone has some sort of coping mechanism that allows relaxation to occur, but unfortunately the popular coping mechanism of sinking a couple of pints or glasses of wine may not prove an aid to effective training! This period of adjustment has been described as 'deactivation', and it is necessary to prevent the stressor from one situation (such as work, coach, family) impacting on another situation (*eg* competition, family dinner, school exams)[6].

Sleep, for example, is an aid to mental as well as physical recovery. But without an intervening period of deactivation, sleep can be disturbed, leading to further mental and physical fatigue.

How then can we deactivate? The first point to make is that it takes time and has to be an active, positive process[7]. Simply trying to switch your thoughts away from the stressor without addressing it will simply defer rather than banish those thoughts.

How do you react after a bad performance or training session? Do you analyse what went wrong and what you can do next time to put things right? Or do you concentrate on the

Table 2: the cognitive recovery process
1. Deactivate – list what went wrong, and why, as well as what went right
2. Plan how to change the things that went wrong
3. Review all the things that went right and throw away the list of things that went wrong
4. Start another activity of your choice – *eg* social activity, low level physical activity, reading, listening to music, movies *etc*, relaxation tape or script
5. Sleep

consequences of what went wrong and blame yourself for your lack of ability? Guess which method allows you to deactivate? If you get caught in the negative loop of self-doubt and self-blame, recovery cannot begin.

Deactivation is particularly important when you are at a training camp or in a situation that involves travelling home with the rest of the team. Often there will be a team meal and a rush from warm-down to shower to give people time to eat before getting on the coach. The physical recovery is taken care of to a certain extent, but an individual deactivation and cognitive recovery strategy is still necessary *(see table 2, above)*.

Having relaxing music or a relaxation script on hand (see example below) can help to create a sense of personal space, which allows for deactivation without isolating you from your team mates. Using a script takes practice, however, and you need to get used to relaxing on your own in a quiet familiar environment, such as your bedroom, before you try to do it in more stimulating and stressful situations.

Physical recovery

Physical recovery should start as soon as the session ends, with warm-down, refuelling and showering taking priority. The other methods in the toolbox, listed in table 3, can be used as desired before the start of the next training session. Note, though, that while sleep is listed as a physical recovery strategy, it is not strictly necessary for physical recovery. The absence of movement is sufficient to allow the body to heal physically; sleep

Table 3: physical recovery strategies

- Light aerobic activity – less than 50% of $V0^2max$
- Stretching
- Massage
- Contrast showers – alternating 30 secs hot with 30 secs cold for 4 minutes
- Sleeping or lying down still
- Cold/ice baths – up to 5 mins
- Food
- Hydration
- Whirlpool baths

is more essential for mental and emotional recovery. An athlete who is tired from lack of sleep can still train physically; it is just that the motivation to train is reduced by sleep loss!

Emotional recovery

Some stressful situations are primarily emotional, but the inability to cope with these stressors can lead to a greater perception of stress and a consequent reduction in physical health and performance[8]. The stressors that affect athletes in this way can arise either outside the sporting environment – *eg* relationship problems – or within it – *eg* selection issues. Wrisberg and Johnson have defined these respectively as primary and secondary social functioning[9]. If social functioning is going well, an athlete is better equipped to deal with the physical and mental stress of sporting life. If it isn't, the ability to cope with stress is inhibited, leading to inadequate recovery and consequent performance decline.

Let's consider the hypothetical example of two university football players who go home for a much-needed Christmas break after playing twice a week for the last 13 weeks. Both have to prepare for exams in January, which they have to pass to stay on at university.

The first player is looking forward to the break because he enjoys Christmas with his family and catching up with old friends. He enjoys his time at home and is able to study for his exams.

The second player dreads Christmas because his parents are divorced and he has to try to balance time with both of them, as well as working to pay off some debt. He ends up driving for most of Christmas Eve and Boxing Day and is too tired after work to revise. When soccer training resumes in January, the first player is refreshed and looking forward to training, the second player is tired and can't concentrate during training because of exam worries.

The primary social functioning, involving close family members and friends, is a support system. This support can be expressed in emotional, financial or practical terms.

Think of a young tennis player who is trying to make her way up the junior county rankings. She has to play lots of matches to gain points and will win some and lose some. Her parents have to provide emotional support when she loses a match, financial support by paying for the entry fees, equipment and coaching, and practical support by making sandwiches, driving to the venue, washing kit *etc*.

At the opposite end of the spectrum, at a very high level of sport, some athletes have an entourage to help with practical matters (*eg* the touring party of the British and Irish Lions) and may also be paid. Nevertheless, they will still need the emotional support.

Secondary social functioning is about the athlete's ability to deal with team mates, coaches and the media. This comes down to individual preferences, with some athletes liking a social atmosphere and others needing some personal time. If an

Table 4: emotional recovery strategies

- Spend quality time with close friends and family
- Make sure you have a support network in place to provide financial, emotional and practical help
- Spend time away from the sporting environment – *eg* pursuing another hobby
- Spend some time with team mates outside the sporting environment
- Spend some time on your own for reflection

Sample relaxation script

Let your mind wander to the scene of a beautiful country garden. Look how it is laid out – the lawns, the trees and the flowers. It is a summer's day, just after a light rain shower. Smell the fresh air, feel the damp and moist atmosphere on your skin. Can you smell the flowers, imagine the scent of lavender, or honeysuckle? The grass has just been cut – can you smell it? Now walk down the path into the shade of the trees, look at the texture of their bark and feel how cool it is. Now walk back into the sunlight, feel its warmth on your face, see the butterflies on the shrubs and hear the distant sound of a lawnmower…

Similar scripts can be found in most self-help sport psychology books, but it is best to write your own script based on a very relaxing environment that you have experienced personally. You can then record this onto a tape or CD and listen to it when travelling.

athlete experiences conflict in this area, his ability to recover will again be hampered.

The demands on an athlete's time are huge at most levels. These demands are both internal (striving for perfection, the desire to succeed) and external (*eg* exams, expectations of coach and team mates). To allow for balance and full emotional recovery, time must be spent on enjoyable activities outside the sporting arena. This needn't – and probably shouldn't – involve staying out all night drinking with your non-athlete friends. Instead, activities like going out to dinner, watching a movie, going for a walk or listening to music will all allow you to relax and recover emotionally without having a detrimental effect on your health and performance.

In summary...

This article has identified some recovery strategies that may help athletes deal with physical, emotional and mental stress. The important thing to remember is that, as with physical training, an effective recovery strategy must be customised to an individual. While certain requirements are common to all athletes and can be offered in a team situation – *eg* food, water and physical rest – most recovery activities are a matter of personal preference and depend on individual circumstances, including home and work life.

Athletes should be aware of what works best for them, and also of their current recovery status – *ie* whether they need a complete break or just a bit of time to do something enjoyable. Coaches, for their part, should give the members of their teams some discretionary time every day to allow for individual recovery needs to be expressed.

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Jargonbuster

Recovery
A well-planned activity that matches the situational needs of an athlete in rest and results in regaining an optimal performance state [5]

Cognitive
Relating to intellectual faculties of knowing, thinking or perceiving.

Want to know the key to injury prevention? Plenty of R&R

All work and no recovery makes for an injury-prone and weakened athlete. Read top conditioning coach* Nick Grantham*'s rules for recovery and reap the benefits

At a Glance

- The relationship between recovery and injury risk is explained;
- The concept of a heirarchy of recovery priorities is introduced;
- Strategies for optimising recovery at all levels, both physically and psychologically, are given.

Talent alone is no longer enough to guarantee victory in the sporting arena. Athletes striving for high level success must push their bodies and minds to the limit(1). If you cannot adapt to and cope with the physical and mental demands of training, you will quickly become exhausted. So how can we reach the limits of human performance without tipping over the edge? The key lies in one of the simplest yet most neglected training principles: recovery. In the words of one who should know, the seven-times Tour de France champion Lance Armstrong: 'Recovery… that's the name of the game… Whoever recovers the fastest does the best.'

There is very little rigorous scientific research to help us decide which recovery strategies work – we still rely heavily on the accumulated experience of athletes and coaches. Even so,

Principles of progressive overload

- Training is designed progressively to overload body systems and fuel stores;
- If the training stress is insufficient to overload the body's capabilities, no adaptations will occur;
- If the workload is too great (progressed too quickly, performed too often without adequate rest), then fatigue follows and subsequent performance will be reduced;
- Work alone is not enough to produce the best results; you need time to adapt to training stress;
- To encourage adaptation to training, it is important to plan recovery activities that reduce residual fatigue;
- The sooner you recover from fatigue, and the fresher you are when you undertake a training session, the better the chance of improving.

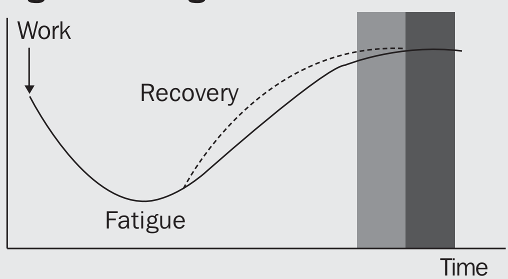
it is possible to set some ground rules and parameters that will enable athletes to tread the fine line between maximising performance and sustaining injury.

Progressive overload

Athletes love to train. But in order for the body to adapt it must have a period of recovery. This is not a new concept; it is a cornerstone of everything coaches and athletes should be trying to achieve. To understand the significance of recovery, you need to understand the fundamental principles of progressive overload.

Figure 1 illustrates the principle of progressive overload. If we introduce a recovery method at the point of fatigue we can expect to reduce the length of time it will take to recover from training (the broken line represents the gain in recovery time and the mid grey shaded area represents the increased window of opportunity to

Figure 1: Progressive overload



move on to the next training effort). So you can move ahead with your programme more rapidly.

One of cycling's best coaches, Peter Keen, explains it thus: 'Nature has given the human body a wonderful engine management system. It actually responds to stress by adapting to cope with it better… the bottom line is the body does not get fitter through exercise; it gets fitter through recovering from exercise.'

"The body does not get fitter through exercise; it gets fitter through recovering from exercise"

Before we can introduce a recovery strategy we need to know which type of fatigue we are dealing with. The type of training effort will determine which of a number of forms of fatigue an athlete will experience[1]. Table 1 below summarises the main forms.

Table 1: Types of fatigue and how they occur

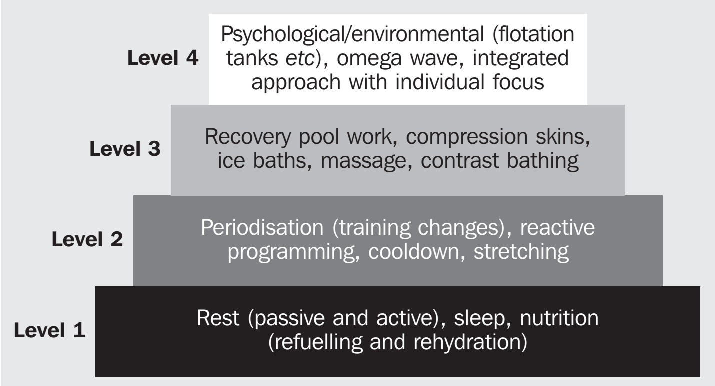
Type of fatigue	Occurs as a result of...
Metabolic (energy stores)	● high volume training ● repeated workloads ● aerobic/anaerobic conditioning ● multiple training sessions throughout day
Tissue damage	● plyometrics ● eccentric loading ● contact sports
Neurological (peripheral nervous system)	● high intensity work ● resistance training (strength and power development) ● speed work ● skill sessions and introduction of new training techniques
Psychological (central nervous system and emotional fatigue)	● training monotony ● lifestyle issues ● heavy game/competition/training period ● pressure plays (training simulating match conditions) ● new training techniques
Environmental	● hot and cold environments ● travel (local, national, international) ● time differences ● competitions

Recovery strategies

It's easy to get carried away with all the new 'toys' such as compression clothing, ice baths *etc*, and forget about the basics such as sleep and nutrition. Figure 2 *(below)* presents an overview of some of the recovery strategies that are available and suggests the order in which coaches and athletes should consider them. This list is not exhaustive.

Strategies at Levels 3 and 4 should not form part of the equation until and unless you already have an established regime at Levels 1 and 2. Put simply, if you are not looking after the basics (sleep, nutrition and training), you are not going to get any additional benefit from more gimmicky recovery tools such as compression skins or contrast bathing.

Figure 2: The recovery pyramid



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Level 1 strategies

Sleep/rest (passive and active)

Sleep is one of the most important forms of rest and provides time for the athlete to adapt to the physical and mental demands of training. Other forms of passive rest include reading, listening to music and flotation (see Level 4 activities). Active rest activities include walking, cross-training and stretching[2].

Nutrition (refuelling and rehydration)

The most important components for nutritional recovery are fluid and fuel replacement. You should avoid drinks containing caffeine and drink enough fluid (water, cordials or sports drinks) before, during and after training to replace sweat loss. There is a relativelu brief window of opportunity for optimal refuelling following a training session. The ideal recovery nutrition strategy (non-sport-specific) is a meal or liquid supplement containing high glycaemic index carbohydrates and quality proteins in approximately a 4:1 ratio that includes 10-20% of your total daily caloric intake of these two macronutrients[3].

“It is crucial that both coach and athlete can react flexibly and appropriately to situations that arise during the training programme”

Level 2 strategies

Periodisation

Periodisation is the cycling of the various training elements (strength, speed, endurance, flexibility *etc*) and variables (intensity, frequency, volume, load) over a period of time in order to ensure you peak for a particular competition or event. A well planned programme will incorporate not just periodised training but appropriate recovery planning[2].

Reactive programming

Once you have a periodised training plan, accept that there will be times when you need to deviate from it – usually because your need to recover will turn out to be different from what was anticipated. It is crucial that both coach and athlete can react flexibly and appropriately to situations that arise during the training programme. If you are tired, there is little point in training for the sake of sticking to the schedule.

Cooldown and stretch

The cooldown is a group of exercises performed immediately after training to provide a period of adjustment between exercise and rest. Its purpose is to improve muscular relaxation, remove waste products, reduce muscular soreness and bring the cardiovascular system back to rest. Stretching is often combined with the cooldown. It is common for athletes to lack sufficient flexibility to perform their sport's movements with the greatest efficiency, so this period immediately after the main workout, in which the body temperature is still elevated, provides a good opportunity to improve your range of movement and reduce your risk of injuries[1].

Level 3 strategies

Recovery pool work

Angela Calder[1] recommends completing a 20-minute pool-based recovery session the day after a heavy training session or competition. Water is an excellent environment in which to conduct a recovery session, providing buoyancy and resistance properties that allow you to train with minimal impact on the body.

Guidelines[2]

Water temperature	20° to 28°C
Duration	10 to 20 mins
Intensity	Light to moderate
Content	Walking (forward/backward), side steps, basic swimming strokes and aqua jogging, stretching (static and dynamic).

Compression skins

Heavy training can cause muscle damage resulting in soreness, swelling, pain and impaired athletic performance[4]. Recent scientific research has indicated that compression clothing can be an effective treatment that minimises swelling, improves the alignment and mobility of scar tissue and improves proprioception (sense of body position in space) in an injured joint after eccentric damage and delayed onset muscle soreness (DOMS)[4].

Ice baths/contrast bathing (hydrotherapies)

Contrast bathing: Alternating hot and cold showers/baths provides an increase in blood flow[2] to the working muscles and speeds the removal of lactic acid[1]. Contrast bathing also stimulates the nervous system and helps to increase arousal, because the brain has to receive and recognise two different types of information (hot and cold).

Guidelines[1,2]

Complete within 30 minutes of training/competition
Begin and end with cold
Repeat the alternations 3 to 4 times

Temperature, cold	10° to 16°C
Temperature, hot	35° to 37°C
Shower, cold	30 to 60 secs
Shower, hot	1 to 2 mins
Bath/spa, cold	30 to 60 secs
Bath/spa, hot	3 to 4 mins

Cold baths (cryotherapy): Cold baths have primarily been used for their pain-relieving properties[2]. But more recently the thinking is that when you plunge your body into a bath full of icy cold water, the blood vessels constrict and the blood will be drained away from the muscles that have been working (removing lactic acid). Once you get out of the bath the capillaries dilate and 'new' blood flows back to the muscles, bringing with it oxygen that will help the functioning of the cells. Research by Sam Erith at Loughborough University, UK, has shown that treatment with cryotherapy improves muscle function, reduces muscle damage and decreases soreness associated with DOMS.

Guidelines[5,6]

Keep body parts moving to prevent a 'barrier' of warm water forming around the limbs.

Cold temperature	5° to 15°C
Duration	7 to 10 minutes to cool the muscles (shorter for short-term pain relief).

Massage

While research results vary wildly, the reported physiological benefits include:

- increased blood flow, enhanced oxygen and nutrient delivery to fatigued muscles, increased removal of lactic acid;

- warming and stretching of soft tissues, increasing flexibility, removal of microtrauma, knots and adhesions.

Reported psychological benefits include:
- Improved mood state;
- Increased relaxation and feeling less fatigued.

Massage also improves your body awareness of which muscles have been stressed[1]. Calder advises athletes to spend 10 minutes at the end of a training day performing some self-massage (particularly legs and shoulders)[1,2,7].

Level 4 strategies

Flotation tanks

These provide an environment with minimal stimulation (reproducing weightlessness and eliminating sound and sight). Reducing the level of stimulation to the brain allows us to focus more effectively on relaxing and becoming emotionally calm[1].

Omega wave

Analyses electrical activity in the heart and slow brain waves to provide an 'inside look' at how your body is functioning. You sit or lie down comfortably. Electrodes are placed on the body and the system collects data on electrical activity in the heart and on brain-wave activity, particularly very slow 'omega' waves. It analyses this and produces a report for the coach or athlete.

The system looks at:
- Heart regulation. Is the heart ready to support high intensity loads, low intensity loads, or is it over-stressed, sluggish, or maladapting to previous training?
- Which energy systems (aerobic, anaerobic) need development, which are ready for work and which are in need of further recovery?
- The functional systems that strive for homeostasis (central nervous system, gas exchange and cardiopulmonary system, detoxification and hormonal systems).

Table 2: Matching recovery strategies to type of fatigue

Type of fatigue	Recovery strategy
Metabolic (energy stores)	● Sleep, rest (passive and active) ● Nutrition ● Hydrotherapies (contrast bathing) ● Massage ● Recovery pool work ● Compression clothing ● Omega wave
Tissue damage	● Sleep, rest (passive and active) ● Nutrition ● Hydrotherapies (cold baths) ● Massage ● Compression clothing ● Recovery pool work
Neurological (peripheral nervous system)	● Sleep, rest (passive and active) ● Hydrotherapies (cold baths) ● Massage
Psychological (CNS and emotional fatigue)	● Sleep, rest (passive and active) ● Flotation tanks ● Omega wave
Environmental	● Sleep, rest (passive and active) ● Hydrotherapies (contrast bathing, cold baths) ● Recovery pool work

Manufacturers claim that, armed with the relevant information, you can work out whether you have recovered from the previous day's competition or training, which energy systems need work, which energy systems are ready to be worked, and the appropriate heart rates – for that particular day – between which you should be working your various energy systems.

It's not an exact science, but Table 2 will give you a head start on which recovery strategy may be the most appropriate for any given type of fatigue. Remember: get the basics established before you try to get too clever.

Conclusion

Recovery cannot be a one-size-fits-all approach. It is a process that should form the cornerstone of a structured training programme, so that athletes can attain maximal physiological adaptations while reducing the risk of residual fatigue that might result in illness or injury[8].

Coaches and athletes are well advised to think about the fundamental principles relating to training and recovery in order to make an informed decision on which recovery method is the most suitable.

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Heart rate variability – what is it and how can it be used to enhance recovery and performance?

Heart rate monitors provide important feedback about the intensity of exercise, but can't measure the cumulative fatigue of workouts or the subsequent training effects. However, new innovations using heart rate variability data mean that's about to change.* Eddie Fletcher *explains

At a Glance

- An explanation is given of beat-to-beat heart rate variability (HRV) andhow it is linked to fatigue;
- The concept of excess post-exercise oxygen consumption (EPOC), andhow it can be used to monitor cardiovascular recovery, is discussed;
- Examples of HRV and EPOC data collected from athletes, and how thesedata can be interpreted to enhance training and recovery, are given.

In practice, it's difficult to assess accurately the effect of training on the body. How do you fix your training load? How well is your body adapting to the training? Is there any accumulated fatigue and how much rest do you need for recovery? Other questions that you need to ask are – how do I know I am getting the right training effect? Have I improved? Am I over- or undertraining?

At rest your body system is in balance. To achieve a training effect, you need to disturb this balance by putting the body under an adaptive stress to which it can react. This stress is known as training and your body's reaction to training is called a training effect.

Traditionally, training zones have been established from fixed formulae. You may be familiar with some of them: using percentage of maximum heart rate or heart rate reserve, percentage of estimated maximum oxygen uptake (VO_2max) or estimated VO_2max reserve, lactate thresholds or a combination of these variables. Heart rate during training gives information on the momentary intensity of exercise but does not take into account the cumulative effect of exercise duration.

Recent research has focused on the use of heart rate variability (HRV) to assess training load, training adaptation and cumulated fatigue(1) and there are now some commercially available products to assist the serious trainer in using HRV to improve athletic performance.

Polar's OwnIndex fitness test monitors resting heart rate (RHR) plus HRV to provide an indication of oxygen uptake. The use of HRV measurement by Polar has been further developed with the introduction of the OwnOptimizer feature. This is an overtraining test, which evaluates individual heart rate response to exercise using HRV and enables the user to optimise their training loads and recovery times. Suunto has products that use HRV to assess training load and accumulated fatigue (for a scientifically balanced view of HRV the reader is referred to an excellent review paper 'Heart Rate Variability in Athletes'(2)).

Whilst innumerable studies have been published concerning training in general, relatively few studies are available on HRV and its application to athletes. Most studies involve small numbers of participants, which diminishes the power of the statistics, although since the review paper, significant progress has been made in the practical use of HRV to monitor fatigue accumulation during exercise.

What is heart rate variability?

Measurement of the beat-to-beat interval of the heart clearly shows that heart rate is not constant but alters from beat to beat. This is known as heart rate variability (HRV). At rest this beat-to-beat interval fluctuates with the breathing cycle – it speeds up during inhalation and slows down during exhalation.

This variation is due to the attenuation of the parasympathetic activity to the heart during inhalation. Heart rate is regulated predominately by the autonomic nervous system (ANS). The ANS describes the nerves that are concerned with regulation of bodily functions and these nerves function without consciousness or volition; the autonomic nerves comprise sympathetic and parasympathetic nerves – sympathetic nerves excite the heart, increasing heart rate, and parasympathetic nerves reduce heart rate.

During exercise, heart rate is regulated by increased sympathetic activity and reduced parasympathetic activity, causing the heart rate to rise. The relative roles of the two activities depend on the exercise intensity. A 1989 study was the first to test this hypothesis, with the data supporting a progressive withdrawal of parasympathetic activity during exercise[3]. A number of subsequent studies have concluded that HRV is a valid technique for non-invasive measurement of parasympathetic activity during exercise.

Measurement of HRV involves analysis of the R-R (beat-to-beat) intervals, with the simplest approach calculating the mean R-R interval. By accurately measuring the time interval between heartbeats, the detected variation can be used to measure the psychological and physiological stress and fatigue on the body during training. Generally speaking, the more relaxed and unloaded (free from fatigue) the body is, the more variable the time between heartbeats.

HRV is measured in milliseconds. During exercise HRV is reduced as heart rate rises. When the body is under a training load, HRV becomes more uniform. This data can be used to calculate information about the body during exercise to a high degree of accuracy.

HRV data can indicate the impact of fatigue due to prior exercise sessions, hydration levels, stress and even the degree of performance anxiety, nervousness or other external stressful influences. Studies have shown that it varies within individuals

“HRV data can indicate the impact of fatigue due to prior exercise sessions, hydration levels, stress and even the degree of performance anxiety, nervousness or other external stressful influences”

> *'You can only train as hard as you can rest'* Tom Kay three-times World Rowing Champion

according to size of left ventricle (inherited trait), fitness level, exercise mode (endurance or static training) and skill (economy of exercise)[2]. Body position, temperature, humidity, altitude, state of mood, hormonal status, drugs and stimulants all have an effect on heart rate and HRV[2], as do gender and age. The general conclusion is that all of the HRV parameters are higher in men but that this gender difference is confined to men and women below 40-50. There's also an age-related decrease in HRV, although for elderly athletes with a lifelong training history, this decline is reduced.

How can HRV be used to enhance athletic performance?

Well-timed rest is one of the most important factors of any training programme. The effect of training sessions can be negligible or even detrimental if insufficient rest and recovery is built in. HRV measurements demonstrate a significant and progressive decrease in parasympathetic activity during long-term heavy training, which is followed by an equally significant increase during rest. Sympathetic activity shows the opposite trend[4].

This cardiac autonomic imbalance suggests that HRV is a useful parameter to detect overtraining (a state of overstress caused by an imbalance between training/competition and recovery) and under-recovery in athletes. Immediately after training, performance potential temporarily decreases, but it begins to rise during recovery. After a certain amount of time, performance rises above the pre-training level because the body is preparing to handle the next training load better than before.

If the body does not receive the next training load within a certain period of time any performance gain begins to slowly decrease. However, if the next high-intensity session is held before the body has recovered from the previous one, performance will remain lower than it would have been after full recovery. Continuous hard training with insufficient recovery will slowly lead to lower performance and a long-term state of overtraining. When overtrained, even a long period of recovery may not be enough to return performance to the original level.

The body needs time for recovery after a single high-intensity session, or a hard training period of several days, or even after a low-intensity but long training session. Without rest, adaptation to the training load will not occur. In the worst case, training will lead to exhaustion and overtraining or under-recovery. Additional non-training stress factors and monotony of training may also contribute to overtraining syndrome.

"Scientists have demonstrated that excess post-exercise oxygen consumption can be predicted from HRV data during exercise. Consequently, EPOC prediction may serve as a tool for monitoring fatigue accumulation during exercise"

EPOC

Until recently there were no useful methods of monitoring fatigue accumulation during training. Scientists have now demonstrated that excess post-exercise oxygen consumption (EPOC) can be predicted from HRV data recorded during exercise. Consequently, EPOC prediction may serve as a tool for monitoring fatigue accumulation during exercise[6].

EPOC, simply defined, is the amount of oxygen your body needs to recover after a training session and is measured in millilitres of oxygen per kilogram of body weight (ml/kg). EPOC calculated from HRV data is therefore a measure of physiological training load and the accumulated cardiovascular fatigue.

EPOC is most useful to describe the stress caused to the body, especially to the respiratory and cardiovascular system, from endurance activities such as running, cycling, swimming and rowing. During exercise the body consumes more oxygen than at rest. The higher the intensity of training, the greater the fatigue and the more oxygen is consumed during and immediately after the training session. Simply put, a higher EPOC value means that the body is more physiologically tired.

An important reality that all athletes and coaches should recognise is that incomplete recovery times will produce significant fatigue. In short, there is a cardiovascular (sympathetic and parasympathetic) form of fatigue that HRV can detect[5].

There is also evidence to suggest that, when recorded overnight, HRV seems to be a better tool than resting heart rate to assess accumulated fatigue and that HRV may be a valuable tool for optimising individual training profiles[4]

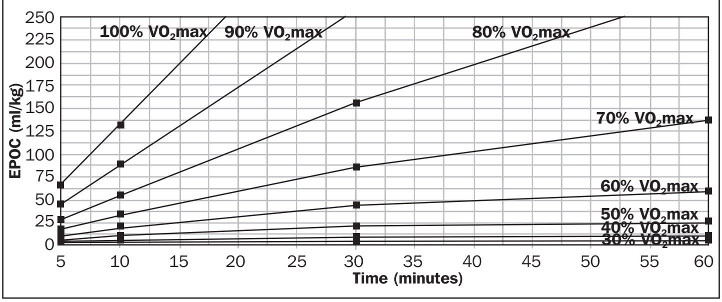
EPOC accumulates faster as training intensity increases but not necessarily when duration is increased, so low-intensity training may not result in a high EPOC value, even if the duration of the training is exceptionally long. With high-intensity training, high EPOC values can be reached even in a short period of time.

Without EPOC as a measure, the wrong conclusions may be drawn from a training session. You may believe that no improvement has occurred or performance has gone backwards, when in reality the difference is fatigue, and actual performance has improved.

At this point it is reasonable to ask the following question: if you can use heart rate as a measure of exercise intensity, why do you need HRV? The simple answer is that during two separate training sessions of equal status one may be harder on the body than the other, even when the heart rate is the same for both sessions. The difference is accumulated fatigue, which HRV can detect and convert into an EPOC value.

The body may appear to recover rapidly from a training session (short-term fatigue) but carry accumulated (long-term) fatigue from training session to training session. This long-term

Figure 1: The effect of training duration and intensity (%VO2max) on EPOC accumulation



fatigue builds up over time and is one reason why periodised training programmes, which build in easier recovery weeks, are needed. So when comparing sessions using HRV and EPOC, the amount of accumulated fatigue affecting each session can be seen by the difference in EPOC value *(see figure 1, opposite)*.

Is there a tool to help athletes to use HRV and EPOC to optimise their training and recovery?

Suunto has developed a heart rate monitor (Suunto t6), which uses an athlete's unique physiological fingerprint to measure training effect. It looks like a conventional heart rate monitor and uses HRV and EPOC to monitor the amount of stress that the body is experiencing to measure the cumulative fatigue (training effect) of each training session.

Based on accurate measurement of the time interval between heartbeats and the detected variation, the t6 software (run on a PC) calculates information about the performance of the body during training and displays the data in a user-friendly format for analysis. As the data is updated, the Suunto t6 becomes an increasingly precise tool for measuring training performance.

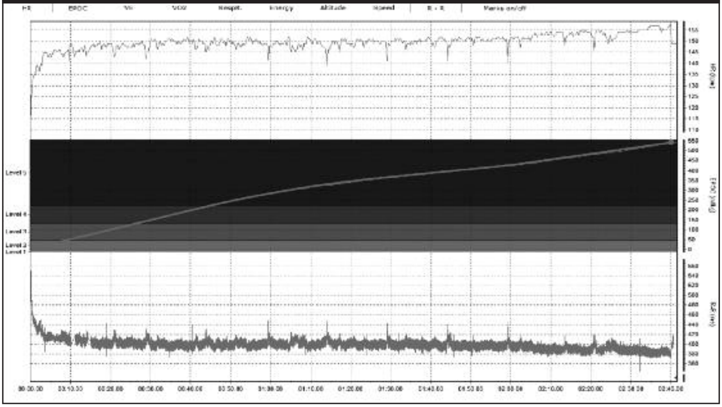
HRV and EPOC in action

HRV and EPOC work well with continuous (rather than interval) type training. At low intensity exercise (40-70% of VO_2max) there is a significant correlation between EPOC and blood lactate concentration. At maximal exercise the correlation is low, signifying that other factors such as body temperature and hormonal changes may influence EPOC, fatigue accumulation and recovery during high-intensity exercise[6].

In figure 2, overleaf, a graph of EPOC data collected for a British record rowing marathon on the Concept 2 ergometer is shown:

- The top trace is heart rate, which was kept below 90% of maximum with an even rowing pace;
- The middle trace is the EPOC (note that despite a level heart rate the graph continued to increase as fatigue accumulated);

Figure 2: A graph of EPOC data collected during British record rowing marathon



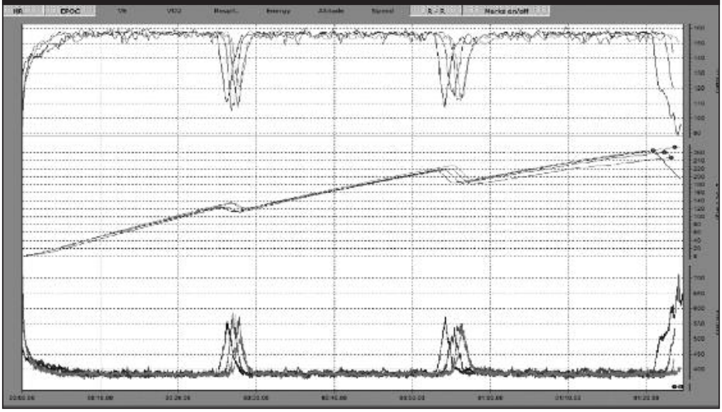
- The bottom trace is the HRV, the R-R intervals (note the slow narrowing of the time interval between beats).

In this particular model there are five levels of EPOC. Recovery from each level is as follows:
- Levels 1 and 2 – 3 hours to 1 day
- Level 3 – 1-2 days
- Level 4 – 1-4 days
- Level 5 – 2-7 days

The exact amount of recovery required would depend on how long the training remained in a particular EPOC level. With this marathon the rower was into level 5 EPOC after 45 minutes and spent just under two hours at that level – recovery from this extended bout of exercise can be measured in weeks rather than days.

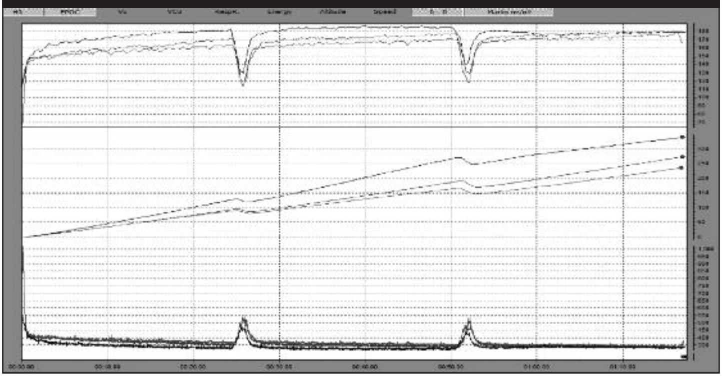
Figure 3 is an overlay graph of a rower doing an 18,000m row (split into 3 x 6,000m) on four separate occasions; two in week 1 of a periodised programme and two in week 4. Note the tight correlation of heart rate, EPOC and R-R interval, indicating that this athlete recovered well between sessions and that the training programme had the right balance of exercise intensity and rest.

Figure 3: EPOC data acquired during 18,000m row (3 x 6,000m) on four separate occasions



Now let's look at figure 4 – an example of the same session (different athlete) giving different EPOC values each session and therefore requiring varying recovery periods. Here the periodisation wasn't right and the athlete was under-recovering and accumulating fatigue.

Figure 4: An example of different EPOC values, each session requiring varying recovery periods



Summary

The way in which the cardiovascular system responds to the stress of exercise continues to intrigue physiologists. Although some understanding of HRV and its application to athletes is becoming clearer, it is still almost an unexplored domain. The significant change is that there is now a commercial product available that athletes can begin to use to monitor this 'cardiovascular fatigue' to ensure that their training programmes include the right mix of duration, frequency, intensity, rest and recovery. HRV and EPOC can be used to monitor individual sessions, allowing the athlete and coach to react immediately to the output data by either amending subsequent training to deal with accumulated fatigue or ensuring that the athlete has sufficient rest to make an adequate recovery.

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Don’t stress! – using HRV data to optimise rest and recovery

Following on from his previous article, **Eddie Fletcher** *expands the debate by looking at the use of heart rate variability to analyse and assess whether athletes are achieving adequate rest and recovery to avoid injury, illness or risk of over training so that endurance performance is optimised*

At a Glance

- The physiological and physical effects of fatigue and evidence for rest and recovery are presented and explained;
- The use of daily stress and recovery analysis to enhance endurance performance is outlined and examples given.

Why is it important to recover?

Overtraining is an imbalance between training/competition and recovery. Additional non-training stress factors and monotony of training may also contribute to overtraining syndrome. While short-term overtraining can be seen as a normal part of athletic training (HRV does not seem to be affected[1]) long-term overtraining can lead to a state described as burnout or overtraining syndrome[2].

Well-timed rest is one of the most important factors of any training programme. The effects of training sessions can be negligible or even detrimental if insufficient rest and recovery is built in. HRV measurements demonstrate a significant and progressive decrease in parasympathetic activity during long-term

Cardiovascular fatigue

- Physical training with incomplete recovery can produce significant fatigue. Studies of cardiovascular responses show that there is a sympathetic and a parasympathetic form of fatigue;
- In short there is a cardiovascular form of fatigue which HRV can detect;
- There is also evidence to suggest that when recorded overnight, HRV seems to be a better tool than resting heart rate to assess accumulated fatigue and that HRV may be a valuable tool for optimising individual training plans.

heavy training, which is followed by an equally significant increase during rest. Sympathetic activity shows the opposite trend.

This cardiac autonomic imbalance suggests that HRV is a useful parameter to detect overtraining and under recovery in athletes. During training, performance temporarily decreases but begins to rise during recovery. After a certain amount of time, performance rises above the pre-training level because the body is preparing to handle the next training load better than before.

If the body does not receive the next training load within a certain period of time any performance gain begins to slowly decrease. However, if the next high-intensity session is held before the body has recovered from the previous one performance will remain lower than it would have been after full recovery. Continuous hard training with insufficient recovery will slowly lead to lower performance and a long-term state of overtraining. When overtrained, even a long period of recovery may not be enough to return performance to the original level.

The body needs time for recovery after a single high-intensity session, or a hard training period of several days, or even after a low-intensity but long training session. Without rest, adaptation to the training load will not occur.

The 'overload' principle is an important aspect of training and can be quantified by training load, duration, frequency and rest. However, application of excessive training stress or too many training sessions can result in exhaustion of the body's physiological system. Numerous studies have demonstrated that overtraining from long-term stress or exhaustion is caused by a prolonged imbalance between training and other internal and external stressors and recovery.

How does HRV stress/recovery analysis work?

The ANS reacts quickly to changing conditions. Many changes in physiological functions and especially in the autonomic nervous system function are reflected in our heart. Heartbeat measurement and analysis of heart rate reactions and HRV can provide significant information on body processes.

Beat-by-beat heart rate data contains much more information than just actual heart rate. Different types of reactions and changes in the heart rate contain embedded physiological information. By analysing HRV it is possible to verify that athletes are able to recover during the working day, between training sessions and especially during the night. In this context, stress can be defined as a physiological state of a heightened level of ANS function that is not caused by immediate physical demands. Accordingly, the HRV method is not able to specifically identify individual stressors but rather indicates the cumulative effect of different sources of ANS stress (*eg* lack of sleep, poor recovery from physical training, medication *etc*).

Some heart rate monitors (*eg* models from Polar and Suunto) use HRV measurement as a feature to assess training load and overtraining based on individual heart rate response enabling the user to optimise their training load and recovery time (for a scientifically balanced view of HRV the reader is referred to an excellent review paper 'Heart Rate Variability in Athletes').

"HRV data can indicate the impact of fatigue due to prior exercise sessions, hydration levels, stress and even the degree of performance anxiety, nervousness or other external stressful influences"

What are the benefits of measuring recovery?

There are a number of benefits of measuring how much recovery has taken place. These include:

- Detecting early signs of overtraining or illness;
- Optimising training load by finding the balance between training load and recovery;
- Providing evidence-based support for critical coaching decisions;

- Recording individual baseline values *eg* during off-season when the body is fully recovered;
- Checking the recovery status during hard training periods;
- Checking recovery status when subjective feelings and fitness levels indicates poor recovery;
- Making sure that the body is recovered sufficiently before a new hard training period.

Using software such as that from Firstbeat Technologies, a recovery test is usually done as an overnight measurement so that the effect of external stressors can be minimised. It is also advisable to do some daily stress measurements to look at overall lifestyle stress. The selected time interval should also be standardised so that the results of different measurements can be compared individually. The first sleeping hours are often the most sensitive for recovery analysis (*eg* if you go to bed at 10-11pm, analyse from midnight to 4.00am).

Stress and recovery index – some examples

Stress and recovery in the Firstbeat Technologies software are represented on a scale from -100 to +100 *(see figure 1)*. The stress and recovery index is the balance between stress and recovery. In the following diagrams 'dark' represents stress reactions whereas 'light' represents recovery reactions.

The intensities of the stress and recovery reactions are influenced by heart rate, heart rate variability and respiration rate, and can be considered as sensitive markers for detecting under-recovery and overtraining in sports.

Figure 3 shows when stress is present only during the first

Figure 1: Stress/recovery index showing relative recovery (+20)

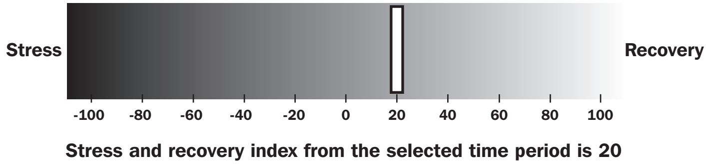


Figure 2: Interpretation of stress and recovery during the night (1)

No stress reactions detected during the night; athlete is well recovered

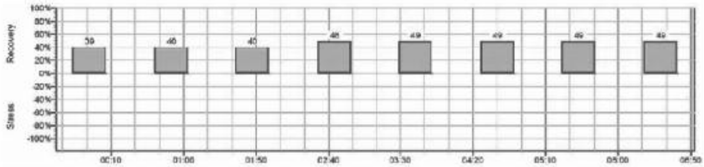


Figure 3: Interpretation of stress and recovery during the night (2)

Stress only present during first sleeping hours, after which good recovery

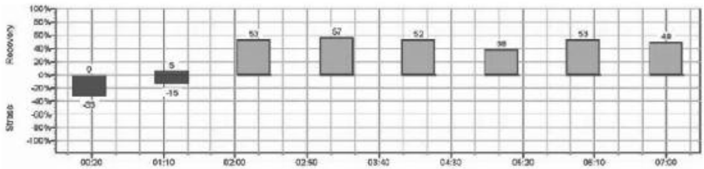


Figure 4: Interpretation of stress and recovery during the night (3)

Stress is present during whole night; an increased risk of overtraining – more rest needed

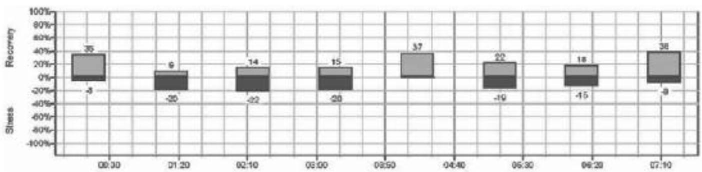
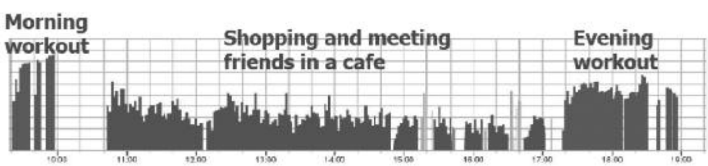


Figure 5: Shopping during the day – poor recovery



sleeping hours before the recovery reactions start to occur (therefore no risk for overtraining). Figure 4 shows stress reactions present during the whole night, indicating an increased risk of overtraining and that more rest is needed.

What are the benefits of measuring daily stress?

As with recovery, there are several benefits of measuring daily stress. In particular, daily stress monitoring can help athletes to:

- Maximise recovery between training sessions;
- Learn how different daily routines enable and limit recovery;
- Observe the effects of training at high altitude;
- Assess how travelling and jetlag affects recovery after competition/training;
- Repeat the daily stress recordings and observe how changes in daily routines affect stress and recovery;
- Check for social and psychological stressors that influence recovery and manipulate daily routines for arrangements to minimise stress during the day.

Practical applications of daily stress measurement

Figures 5 and 6 show the balance between stress and recovery during the daytime period after a morning workout and before an evening workout. Figure 5 shows that shopping did not enhance recovery between two training sessions because stress reactions were detected during the whole time period between training sessions! However, taking a nap and relaxing at home enhanced the recovery reactions, preparing the body for the next workout *(figure 6)*.

Working routines and daily stress index

Having carried out a large number of these tests, it is very clear that the largest influence on daily stress and recovery are work, family and emotional stressors with some individuals rarely recovering from normal daily activities. For example, figure 7 shows the full working day stress index for James, a busy

Figure 6: Napping and reading during the day – good recovery

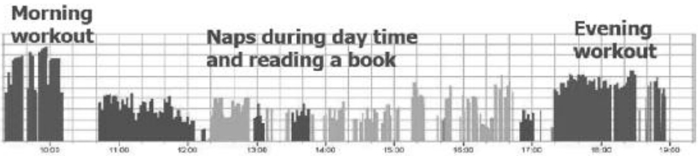


Figure 7: Full working day stress index for James

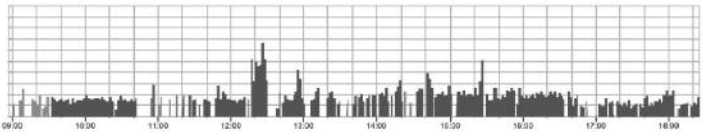


Figure 8: Overnight log of the recovery for James stress index showing poor recovery

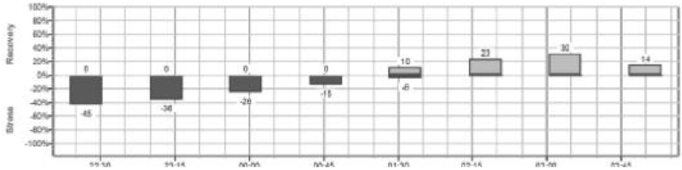
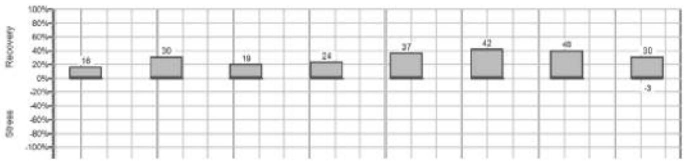


Figure 9: Overnight recovery log after a week away from work – 100% recovery



professional, while figure 8 is the overnight log of the recovery stress index showing very little recovery.

Now compare this with figure 9, which shows James' overnight recovery log after a week away from work, but having climbed Mount Kilimanjaro just three days previously! His recovery stress index scored +100, which meant he was fully recovered.

Conclusion

HRV is a relatively simple, but effective, tool for regular checks of progress during endurance training programmes. Overtraining or under recovery are real issues that athletes and coaches alike need to consider. It is also evident that the stress of normal everyday activities exerts a larger influence on training and race performance. Seemingly relaxing activities such as shopping may impose more stress rather than help recovery. Taking a nap, reading a book or listening to music appear to be excellent de-stressors. Overload periods need to be used with caution and additional rest periods or reduced intensity training sessions introduced to ensure athletes are optimising their training and recovery time. Close to a competition, monitoring of taper activities can be undertaken to ensure that the athlete competes in a fully recovered state. Heart rate variability monitors and associated software are powerful tools for athletes and coaches, providing useful information which can be used to adjust training programmes to best effect.

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Sport recovery and 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. But as* Tim Lawson *explains, athletes seeking maximum performance and recovery neglect sleep at their peril

At a Glance

- Sleep deprivation is widespread and produces a number of detrimental effects for athletes;
- The physiological effects of sleep deprivation on hormone balance are explained;
- The complex relationship between nutrition (especially magnesium andprotein nutrition) and sleep is explained;
- Suggestions are made on how to improve sleep patterns.

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[1-3]. 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 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 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.

"There is now a considerable body of evidence showing that sleep has a huge role in regulating many physiological functions"

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

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

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 2005 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(5-9).

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. In 2005, Psychiatric News suggested 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

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.

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 also 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).

Hormones and sleep

Sleep deprivation is associated with a series of hormonal changes involving ghrelin and leptin *(see box)*. 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 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].

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.

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

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].

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 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[18-20]. 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.

“Another nutrient that has amajor impact on sleep is tryptophan, which is one of the essential amino acid building blocks of protein”

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.

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.

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Jargonbuster

Body mass index
A measure of 'fatness', defined as weight in kilos divided by height squared in meters

Actigraph
A small electronic device, worn by an individual, that records and reports levels of activity as well as calories burned, limb movements and sleep levels

Eosinophilia myalgia syndrome
A blood condition characterised by tenderness and muscle aches, fatigue, cough, rashes, joint aches and shortness of breath

Neutral amino acids
Building-blocks of protein that carry no electrical charge

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