CARBOHYDRATE REVOLUTION

new findings for maximum sports performance

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Carbohydrate – still the king of sports nutrition

If there's one nutrient that's revolutionised sports nutrition, it's carbohydrate. Ever since the 1980s, study after study has proved beyond doubt that ample carbohydrate is absolutely vital for sportsmen and women who take their performance seriously. In 2010, there can be few athletes who are unaware of the importance of this key dietary nutrient; carbohydrate nutrition is now just part and parcel of most athletes' training plans.

What's less well known however is that research into carbohydrate and sport performance has been continuing apace and the last few years have seen some exciting breakthroughs in our understanding of how to optimise carbohydrate nutrition for peak performance. The type of carbohydrate you consume, when and how you consume it, and what you combine it with can all be manipulated to further boost performance. What's even more exciting is that these extra gains are not just incremental – they can be very significant indeed.

In this special report, we look at the latest research on carbohydrate and performance, which is redefining how athletes should use carbohydrate nutrition to boost performance and accelerate recovery. Indeed, it's no exaggeration to say that some of these findings are truly revolutionary, and if reaching your true sporting potential is important to you, they cannot be ignored. They also serve to remind us that over a quarter of a century on since its importance was first established, carbohydrate is still the undisputed king of sports nutrients!

Andrew Hamilton BSc Hons MRSC

The glycaemic index: how athletes can make it work for them

At a Glance

- Looks at the fundamentals of carbohydrate metabolism and energy;
- Explains the concepts of glycaemic index and load;
- Make recommendations on how athletes can adapt their carbohydrate intake for maximum performance.

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? New research has thrown up some interesting findings, according to **Andrew Hamilton**

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

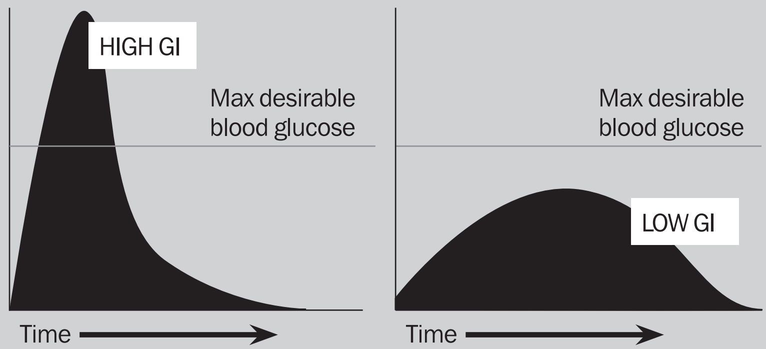
Jargonbuster

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

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



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 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.

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, below, 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, opposite, contains a few surprises. For example, a baked potato releases glucose into the bloodstream 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 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

Table 1: GI rating for some common carbohydrates

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

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

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]. 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.

Jargonbuster

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

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

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. 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:

- 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;

● 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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What's the best carbohydrate refuelling strategy formaximising fulltime performance?

At a Glance

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

The days of sliced oranges and a cup tea at half-time are long gone. As **Tim Lawson** *explains, optimum half-time nutrition is a complex science in which a number of factors need to be considered. The half-time nutritional strategies employed bymany 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 nutritionusually 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-carbohydrate cakes, confectionery and even jellybabies have

'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'

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 thecrazy on- and off-ball fouls often seen on TV [2]!

So what are the main factors to consider whenplanning nutrition in the half-time interval? Sincethe first World Congress on the Science of Footballwas 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 duringtraining 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, presentedat 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 thosegiven a carbohydrate drink. However, the principlesfor 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 matchat 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 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 inorder 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 early1990s, 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 consumemore carbohydrate in order to recover between training sessions and to maximise muscle glycogenstores prior to a match[6,7].

More recent publications, whilst stressing theimportance 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 beachieved[8].

However, studies using dietary analysis continueto suggest that many soccer players are failing to consume sufficient carbohydrate to 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 dependupon the prior eating habits of the player. Similarly,the rehydration needs, and therefore the efficacy of half-time rehydration strategies, will depend on thepre-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].

Inappropriate and devious strategies…

The most inappropriate nutritional strategy must go to the Sunday leagueteam who were sponsored by a brewery and really did drink a pint of thesponsor's lager at half-time. Apparently they all thought they played betterin the second half, but no one had done the match analysis and they werekeen for it to stay that way! The most devious nutritional strategy involved the use of high-tech sportsdrinks and gels for the home team but sugar-free cordial and sweetenersrather than sugar for the tea that the league rules obliged them to providefor the visiting team. A lesson perhaps for visiting teams and sports peopleto be self-sufficient, but it was surprising how long the home team wereable to get away with this tactic by explaining that 'Sugar is not healthy andyou wouldn't want your guys getting fat would you?!'

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 bebecause 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 andwomen show there is much to be gained byreplacing fatty, energy-dense foods with more carbohydrate[11,12]. However, at the very elite end ofsport, nutritionists are fine-tuning energy andhydration provision to provide just enough.This is to maximise power-to-weight ratio; each gram of carbohydrate stored as muscle glycogen isbound to 3g of water, so if a player starts with 500g of muscle glycogen and this is used during thegame 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 bodymass of 2% or greater can result in reduced endurance exercise capacity, and sprinting and sport-specific skills can be adversely affected by losses of 3% or more[3,10], players are able to tolerate a level of dehydration. There's no merit inencouraging players to consume more fluid than required to maintain performance, because this would be the equivalent of sending players out witha 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 ofsweat in very hot and humid environments and upto three litres in temperate climates, sweat lossescloser to two litres per hour are probably moretypical[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 andwater 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 individualvariation in sodium losses – as low as the equivalent of 1g of salt to over 6g in 90 minutes. Assuming tha tplayers 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 situation is toencourage 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 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 theyconsume a high-sodium diet or for other reasons. It is clear, however, that sweat losses of 6g in 90minutes cannot be sustained unless consumption is increased beyond the current

Case study

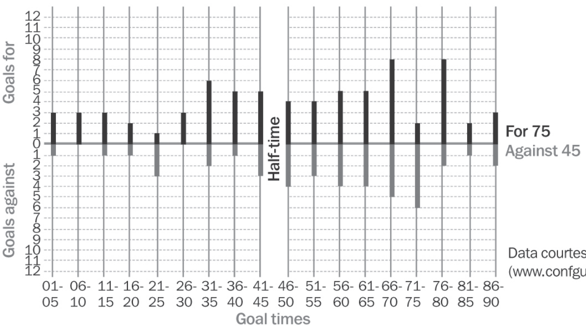
Accrington Stanley Football Club is most famously associated with nutritionvia a long-running milk commercial. However, medical and support staffwere keen to use scientific sports drinks in order to improve energy levels inthe latter parts of games. The strategy needed to be simple to administerand integrate into a squad, have good acceptability and be cost effective. Asimple feeding strategy based upon each player drinking 500mls of a 12%glucose polymer/fructose solution (SIS PSP22) prior to the match and athalf-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 toAccrington's league title success and record-breaking unbeaten run.Medical and support staff point to the timing of 'for' and 'against' goals asevidence; rather than running out of energy, Accrington were scoring moreoften 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) 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 mineralssuch as iron[16] may be sub-optimal prior tomatches. 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 isconsensus that carbohydrate supplementation canimprove performance. Muscle glycogen stores aregenerally quite low at the end of games, and evenwhen overall stores are not depleted, carbohydratemay 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 performanceof 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 incompetitive 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 low erosmolality 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 gastricemptying with the benefits of multiple energy substrate transport across the small intestine.

Half-time is, however, relatively short and careshould be taken to maximise the opportunity to refuel when gastric emptying is not limited by intense match activity. Isotonic energy gels can bea practical solution, providing players with a bonus 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 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 ispossibly useful to consume solutions containing atleast some electrolyte, especially sodium.

Jargonbuster

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

Summary

Do

Try to take account of individual needs as well as those of the squad moregenerally;

- Maximise muscle glycogen restoration by getting carbohydrate in as soon aspossible;

Modify hydration according to weather/activity levels;

- Remember that in fast games, sweat rates can be at or close to maximal, evenin cold conditions;
- Remember that additional water vapour losses can be significant in extremelycold weather and that the advent of heated pitches means that more games arenow played in very low air temperatures;
- Tailor half-time nutrition to individual needs – especially important in hotconditions when there may be large differences in sweat rate and composition;
- Consider caffeinated beverages for players who have not been involved in playfor long periods. Some teams have reported positive effects of caffeine, andbecause of the possible beneficial effects on attention and vigilance it could beparticularly useful for goalkeepers in matches when they are not involved in playfor long periods in games.

Don't

- Wait until the half-time period to fix dietary problems that should have been fixedbefore the game or several weeks before the game;
- Drink to maintain pre-match body mass. Baseline body mass should becalculated from morning weigh-ins. This is likely to be considerably lighter thanpre-match weight. Try to drink a sufficient amount so that weight does not drop bymore 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 aperformance 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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Sports drink use – optimising muscle mass for endurance

At a Glance

- The importance of muscle mass and strength for endurance athletes isexplained;
- The role of post-exercise carbohydrate and protein for maintainingmuscle mass in endurance athletes is outlined;
- Other factors such as the timing of protein-carbohydrate ingestion andsupplements such creatine are discussed and recommendations made.

Endurance athletes face an interesting paradox when it comes to muscle mass. Bigger, stronger muscles generate more forceful contractions,resulting in higher power and greater speed. However, the weight of bulky muscles imposes greater demands on our limited energy stores,especially in weight-bearing sports. But as **Professor Mike Saunders** *explains, maintaining adequate sport-specific muscle mass is criticalfor optimal performance in endurance athletes*

Let's begin by clarifying why muscle mass is important for endurance athletes:

- *Higher peak power output* – Some endurance sports, such as marathon running, are performed at relatively constant, moderate intensities. As a result, peak power is of secondary importance in these events. However, shorter high-intensity bursts are often needed to power over hills, successfully execute breakaways and win sprints. If you have higher peak power, you will be more successful in these endeavours;
- *Lower relative muscular effort* – Every sport movement (ie a running stride at a certain speed)produces a given amount of

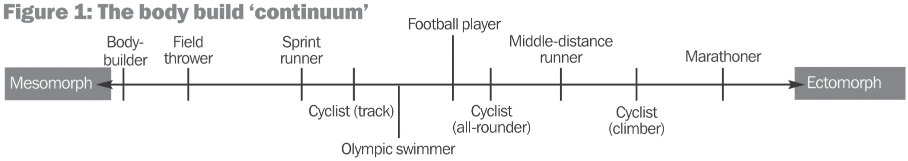
force on your muscles.By increasing muscular strength, this same force becomes a lower percentage of your maximum effort, prolonging your muscular endurance. This effect is largest in individuals who are the weakest.For example, strength training alone, without any cardiovascular training, can increase the tread mill endurance of the elderly;

● *Reduced injury risk*– Stronger muscles are morecapable of withstanding the potentially injury-producing forces that inevitably occur in sport. It iswidely believed that increasing muscular strengthcan reduce the risk for sport-related injuries.

How much muscle does an endurance athlete need?

Scientists use the terms **mesomorph** and **ectomorph** to describe the extremes of muscularity in athletes. Pure mesomorphs, such as body builders, are heavy athletes with lots of muscle mass,while pure ectomorphs are light athletes with low levels of fat and muscle. Endurance athletes tend to be quite ectomorphic compared to other athletes. However, this should not be misinterpreted to assume that skinnier is always better! The optimal amount of muscularity for an endurance athlete will depend on a variety offactors, including the length and intensity of the event, the mode of locomotion in the sport, and numerous other factors. In general, higher muscularity is more beneficial in events that are shorter in duration, events requiring high-intensity bursts of power, and in sports where body weight is supported, minimising the effects of gravity. Thus, we usually observe greater muscularity in swimmers, sprint/track cyclists, and team-sport endurance athletes such as football players. By comparison, distance runners and ‘climbing-specialist’ cyclists tend to be among the most ectomorphic athletes *(see figure 1)*.

Figure 1: The body build ‘continuum’



A good comparative example is provided in professional cycling, where time-trial specialists tend to have weight/height ratios of approximately 2.5lbs per inch of height (ie former Tour de France prologue winners Fabian Cancellara and Thor Hushovd have reported ratios of 2.4-2.5) while climbing specialists tend to be closer to about 2.0lbs per inch (the three top climbers in the 2007 Tour; Michael Rasmussen, Mauricio Soler, and Alberto Contador had ratios of approximately 1.9-2.0). The greater muscle mass of the time trialists allows them to generate more power (and thus speed) than the lighter climbers during flat time trials, but their added muscle mass becomes a disadvantage in the mountains, where the forces of gravity encountered during long climbs slows the heavier riders. In summary, muscle mass is critical for the performance of all endurance athletes, but its importance, and thus the amount of time you should devote to training to develop muscle mass is related to the specific demands of your event. However, even for the featherweight athlete, maintenance of adequate sport-specific muscle mass is crucial for performance. Adequate muscle mass allows you to generate higher power outputs, produce lower muscular efforts during sub-maximal workloads, and may enhance injury resistance.

Dietary strategies forbuilding/maintaining muscle mass

Don't neglect the carbohydrates – When you think about building muscle, protein is the ingredient that immediately comes to mind. However, be careful not to neglect carbohydrate intake in your quest for adequate protein.Endurance sports create a very high demand for energy, and the process of muscle building also requires considerable energy. Our bodies use carbohydrate as their primary fuel during most endurance activities, and it is known that inadequate consumption of dietary carbohydrate can lead to depletion of your valuable muscle glycogen stores.

The 'low-carb' diet craze of the past decade mayhave some of you second-guessing your needs for dietary carbohydrates.

Jargonbuster

Mesomorph
An individual with high muscularity; the opposite of anectomorph

Ectomorph
A person with low levelsof muscle mass. Endurance athletes, especially in weight-bearing sports, tend to be among the most ectomorphic competitive athletes.

Protein balance
The balance between protein synthesis (building new protein structures, such a muscle) and protein degradation (breakdown of protein structures in the body)

Jargonbuster

Catabolic
Negative protein balance, where proteind egradation is greater than protein synthesis

Essential aminoacids
Amino acids that cannot be produced by the body, and thus must be obtained from the diet. Eight of the 20 amino acids areconsidered 'essential'amino acids for adults.

Branched chainamino acids
A group of specific essential amino acids, including leucine,isoleucine, and valine

In case you need another reason to consume your carbs, a study fromresearchers at the University of Birmingham(England) examined distance runners who were performing 11 days of intensified training on low(40%) and high (70%) carbohydrate diets[1]. When consuming the higher carbohydrate diet, the runners maintained much better endurance performance and fewer symptoms of overtraining, even though the calories were matched betweenthe two diets. The bottom line: if you are performing intensive endurance training, don't skimp on the carbohydrates!

Importance of consuming protein – Protein is in a constant state of turnover in the body, with protein synthesis (building of new protein structures, including muscle) occurring in tandem with protein degradation (the breakdown of body proteins). If your goal is to maintain your existing muscle mass, you must strive for a state of **protein balance**, where the daily losses of protein through degradation are offset by equal gains in protein synthesis. If muscle building is desired, you must sustain a period where protein synthesis outweighs protein breakdown. Scientists are beginning to study how protein intake can influence protein balance in endurance athletes. In addition, the roles of dietary protein on muscle damage, muscle glycogen replenishment and subsequent exercise performance have been recently studied.

Improved protein balance

Exercise stimulates protein synthesis but it alsoincreases the rate of protein breakdown.Researchers at Maastricht University (TheNetherlands) examined protein balance inendurance athletes during six hours ofcycling/running[2]. When carbohydrate was consumed at 30-minute intervals throughoutexercise, protein balance remained in a negativestate throughout exercise and during four hours ofpost-exercise recovery. However, when a **mix** of carbohydrate and protein was consumed duringthe exercise, protein synthesis was increased andprotein breakdown was decreased, resulting in a positive protein balance during and following exercise *(see*

Figure 2: Protein turnover during/ following exercise

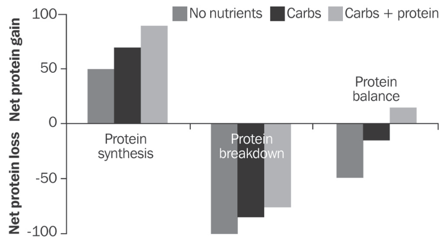


Figure 3: Post-exercise responses in muscle

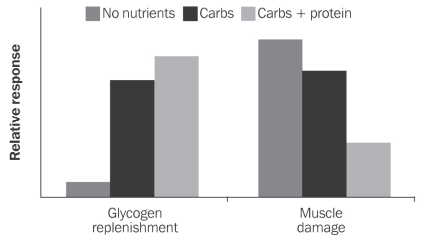


figure 2). This study suggests that evenwith adequate carbohydrate consumption, endurance training can create a catabolicstate for the muscles if protein intake is not adequate. So, consuming some protein along with your carbohydrates during/following long endurance events can improve your protein balance. Muscle damage A number of recent studies from our laboratory at James Madison University (USA) have shown that consuming mixes of carbohydrate and protein during or following exercise can reduce markers ofmuscle damage and muscle soreness following heavy endurance exercise. These findings have been observed when carbohydrate-protein drinks were consumed following exhaustive bouts of cycling[3,4], as well as following the daily training sessions of cross-country runners[5]. Interestingly, we also observed an association between the mileage the runners were performing, and the amount of benefit they received from the protein. In other words, the harder you train, themore potential you create for muscle damage and the more important it is that you consume a mix of carbohydrate-protein immediately following training sessions.

Figure 3 : notice how the mix of carbohydrate and protein produces suprior glycogen replenishment and the least amount of muscle damage"

Muscle glycogen replenishment

Investigators from the University of Texas have reported that consumption of carbohydrate-protein following exercise speeds the rate of muscle glycogen replenishment after exercise compared to carbs alone[6]. However, other researchers have suggested that these effects could also be obtained with frequently repeated doses of carbohydrate throughout recovery. While this may be possible, high-frequency carbohydrate dosing may be impractical, and could lead to high levels of calorie consumption, which may have implications forweight management and other dietary issues. While scientists will continue to investigate this issue, it appears that when moderate doses of calories are consumed following exercise, acombination of carbohydrate and protein ingestion provides equal or superior rates of glycogen replenishment versus carbohydrates alone. When you consider the added benefits of improved protein balance and reductions in muscle damage, a post-exercise mix of carbohydrate and protein seems a desirable choice for athletes performing endurance training *(see figure 3)*.

Carbohydrate-protein and subsequent performance

A few studies have reported that carbohydrate-protein consumption during recovery from exercise can improve your performance in subsequent exercise(4,7,8). Although other researchers have not reported benefits in subsequent performance with carbohydrate-protein ingestion(9,10), the variation in these findings may be related to differing effects ofthe initial exercise bout. For example, if the initial exercise session does not produce a significan tamount of muscle damage or glycogen depletion, then it is unlikely that any supplement will improve subsequent performance because you can recover adequately without it. This concept is supported by a previously mentioned study, in which we observed that high-mileage runners had greater potential for reduced muscle damage and improved performance insubsequent exercise than low-mileage runners(5).In short, if you are training hard, consuming some carbohydrate-protein immediately following your exercise session could help your muscles recover faster, and allow you to perform better the next day. If you never train hard enough to really tax your muscles, then the potential recovery benefits are less significant, and will not likely influence performance in the short term.

It should be clear that carbohydrates andprotein are important nutrients for enduranceathletes, but how much should you eat, and when?

Window of opportunity

While it is impossible to provide complete nutritional advice so briefly, perhaps the most important advice is to take advantage of your 'post-exercise recovery window'. Your muscles act like a sponge for nutrients during exercise and immediately afterwards, bypassing insulin-dependent mechanisms for nutrient uptake and speeding the rate of glycogen replenishment and muscle recovery after exercise. This window of opportunity slowly closes over a period of a few hours after exercise. As a result, consuming a carbohydrate feeding a few hours after exercise is less effective for muscle recovery than consuming the same amount within 30 minutes. Therefore, athletes who require rapid recovery from exercise should consume their carbohydrates immediately after their training sessions. As previously discussed, the addition of protein to this post-exercise feeding may produce further benefits, such as increased rates of glycogen replenishment, improved protein balance, and reduced muscle damage. Specific guidelines regarding amounts of carbohydrate and protein are more difficult to provide, as the ideal dose is influenced by many factors. In laboratory studies(11), relatively large amounts of post-exercise carbohydrate and protein (1.2-1.4g carbohydrate and 0.3-0.5g protein per kg body weight) fed every two hours after heavy exercise have been shown to maximise muscle glycogen replenishment and augmen tmuscle recovery. However, before you begin consuming such large amounts of nutrients after each training session, remember that these values are typically obtained from studies examining recovery following exhaustive exercise. In general, the longer and harder you've exercised, and the shorter time period you have to recover, the moreimportant it is to consume large doses of carbohydrate and protein. Conversely, these large doses are not necessary if you're performings horter, easier workouts, or

'Athletes who require rapid recovery from exercise should consume their carbohydrates immediately after their training sessions; the addition of protein to this post-exercise feeding may produce further benefits'

if a primary goal of the exercise session is weight management.A simple approach to your nutrient timing is to move some of your daily caloric intake to the post-exercise time frame. For example, if you are currently in energy balance (not gaining or losing weight), you could consume a 200-500kcal'recovery' feeding immediately after your training sessions, and then reduce your dinner amount by the same number of calories. This should allow you the benefits of the post-exercise recovery window, without altering other important aspects of your diet and training.

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Carbohydrate drinks – can fructose enhance endurance?

At a Glance

- The importance of consuming carbohydrate during endurance events is explained;
- The background to modern carbohydrate drink formulation is outlined;
- Recent research on the potential benefits of mixed carbohydrate drinks containingfructose is presented;
- Recommendations for endurance athletes are made.

Despite the numerous claims to the contrary bythe sports nutrition industry, real advances insports nutrition are comparatively rare. But recent research into carbohydrate absorption and utilisation could herald a new breed of carbohydrate drink, which promises genuinelyenhanced endurance performance. **Andrew Hamilton** *explains.*

Before we go on to discuss carbohydrate formulations, it's worth recapping just why carbohydrate nutrition is so vital for athletes. Although the human body can use fat and carbohydrate as the principle fuels to provide energy, it's carbohydrate that is the preferred or 'premium grade' fuel for sporting activity.There are two main reasons for this. Firstly, carbohydrate is more oxygen-efficient than fat; each molecule of oxygen yields six molecules of ATP (adenosine triphosphate – the energy liberating molecule used in muscle contraction) compared with only 5.7 ATPs per oxygen molecule when fat isoxidised. That's important because the amount ofoxygen available to working muscles isn't unlimited– it's determined by your maximum oxygen uptake (VO2max).Secondly and more importantly, unlike fat (andprotein), carbohydrate can be broken down very rapidly without oxygen to provide large amounts of extra ATP via a process known as glycolysis during intense (anaerobic) exercise. And since all but ultra-endurance athletes tend to work at or near their anaerobic threshold, this additional energy route provided by carbohydrate is vital for maximal performance. This explains why, when your muscle carbohydrate supplies (glycogen) run low, you sometimes feel as though you've hit a 'wall' and have to drop your pace significantly from that sustained when glycogen stores were higher.

Carbohydrate storage

Endurance training coupled with the rightcarbohydrate loading strategy can maximiseglycogen concentrations, which can extend theduration of exercise by up to 20%before fatiguesets in(1). Studies have shown that the onset offatigue coincides closely with the depletion ofglycogen in exercising muscles(2,3). However, valuable as these glycogen stores are,and even though some extra carbohydrate (in the form of circulating blood glucose) can be made available to working muscles courtesy of glycogen stored in the liver, they are often insufficient to supply the energy needs during longer events. For example, a trained marathon runner canoxidise carbohydrate at around 200-250g per hour at racing pace; even if he or she begins the race with fully loaded stores, muscle glycogen stores would become depleted long before the end of the race. Premature depletion can be an even bigger problem in longer events such as triathlon or endurance cycling and can even be a problem for athletes whose events last 90 minutes or less and who have not been able to fully load glycogenstores beforehand. Given that stores of precious muscle glycogenare limited, can ingesting carbohydrate drink sduring exercise help offset the effects of glycogen depletion by providing working muscles with another source of glucose? Back in the early 1980s,the prevailing consensus was that it made littlepositive contribution. This was because of the concern that carbohydrate drinks could impair fluid uptake, which might increase the risk of dehydration. It was also mistakenly believed thatingested carbohydrate in such drinks actually contributed little to energy production in the working muscles[4].Later that decade, however, it became clear thatcarbohydrate ingested during exercise can indeedbe oxidised at a rate of roughly 1g per minute[5,7](supplying approximately 250kcals per hour) and a number of studies subsequently showed that this could be supplied and absorbed well by drinking 600-1,200mls of a solution of 4-8% (40-80g per litreof water) carbohydrate solution per hour[8,11]. Mor eimportantly, it was also demonstrated both that this ingested carbohydrate becomes the predominant source of carbohydrate energy late in a bout of prolonged exercise[10], and that it candelay the onset of fatigue during prolonged cycling and running as well as improving the power output that can be maintained[12,13]. Drink formulation

The research findings above have helped to shapethe formulation of most of today's popular carbohydrate drinks. Most of these supply energy in the form of glucose or glucose polymers *(see box for explanation)* at a concentration of around6%, to be consumed at the rate of around 1,000mlsper hour, so that around 60g per hour of carbohydrate is ingested. Higher concentrationsor volumes than this are not recommended because not only does gastric distress become aproblem, but also the extra carbohydrate ingested is simply not absorbed or utilised. But as we've already mentioned, 60g per hour actually amounts to around 250kcals per hour, which provides only a modest replenishment of energy compared to that being expended during training or competition. Elite endurance athletes can burn over1,200kcals per hour, of which perhaps 1,000kcals or more will be derived from carbohydrate, leaving a shortfall of at least 750kcals per hour. It's hardly surprising, therefore, that one of the goals of sports nutrition has been to see whether it's possible to increase the rate of carbohydrate replenishment and a series of studies carried out by scientists at the University of Birmingham in the UK indicates that this may indeed be possible.

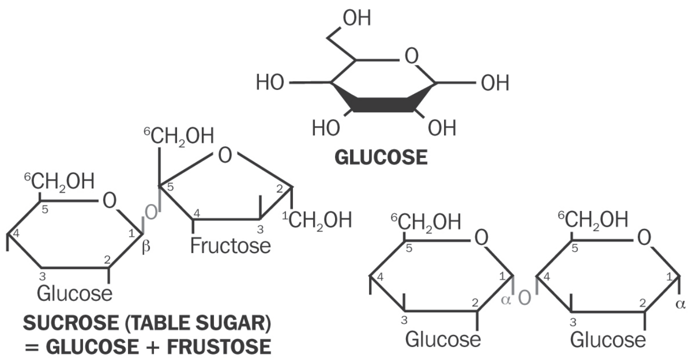
Carbohydrate type and performance

Many of the early studies on carbohydrate feeding during exercise used solutions of glucose, which produced demonstrable improvements in performance as discussed. In the mid-1990s, some researchers experimented by varying the type of carbohydrate used in drinks, for example by using glucose polymers or sucrose (table sugar). However,it seemed that there was little evidence that these other types of carbohydrate offered anyadvantage(3).But, at about the same

CARBOHYDRATE BUILDING BLOCKS

The fundamental building blocks of carbohydrates are molecules known as sugars. Although there are a number of sugars, the most important is glucose, which can be built into very long chains to form starch (found in bread, pasta, potatoes, rice *etc*). Fructose is also important, accounting for a significant proportion of the carbohydrate found in fruits. The disaccharide (*ie* two sugar unit) sucrose is composed of glucose and fructose linked together and is more commonly known as table sugar.

Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is required, which tends to slow the rate of absorption, resulting in a smoother, more sustained uptake into the bloodstream.



SUCROSE (TABLE SUGAR) = GLUCOSE + FRUSTOSE

MALTOSE ('BREWERS SUGAR') = GLUCOSE + GLUCOSE

time, a Canadian research team were experimenting with giving mixtures oftwo different sugars (glucose and fructose) tocyclists. In one experiment cyclists pedalled for twohours at 60% of VO2max while ingesting 500mls ofone of five different drink mixtures[(14)] :

- 50g glucose;
- 100g glucose;
- 50g fructose;
- 100g fructose;
- 100g of 50g glucose + 50g fructose.

These sugars were radio-labelled with carbon-13so the researchers could see how well they were absorbed and oxidised for energy by measuring theamount of carbon dioxide containing carbon-13exhaled by the cyclists (as opposed to unlabelled carbon dioxide, which would indicate oxidation of stored carbohydrate). The key finding was that100g of the 50/50 glucose fructose mix produced a21% larger rate of oxidation than 100g of pure glucose alone and a 62% larger rate than 100g of pure fructose alone.

Although these findings provided experimental support for using mixtures of carbohydrates in the energy supplements for endurance athletes, it wasn't until 2003 that researchers from the University of Birmingham in the UK began looking more closely at the issue. In particular, they wanted to see whether combinations of different sugars could be absorbed and utilised more rapidly than the 1.0g per minute peak values that had been recorded with pure glucose drinks.

One of their early experiments compared the oxidation rates of ingested carbohydrate in nine cyclists during three-hour cycling sessions at 60%of VO2max(15). During the rides, the cyclists drank1, 950mls of radio-labelled carbohydrate solution, which supplied one of the following:

- 1.8g per min of pure glucose;
- 1.2g of glucose + 0.6g per minute of sucrose;
- 1.2g of glucose + 0.6g per minute of maltose;
- Water (control condition).

Jargonbuster

Glycolysis
The partial but rapid breakdown of carbohydrate without oxygen

Anaerobic threshold
The exercise intensity at which the proportion of energy produced without oxygen rises significantly, resulting in an accumulation oflactate

Jargonbuster

Radio-labelled
Where a normal atomin a compound (egglucose) is replaced by a chemically identicalatom, but one carrying a different number of neutrons (isotope)making it possible to track the fate of that compound using a technique known as spectrometry

Carbon-13
A carbon atom with anextra neutron in the nucleus

The results showed that while the pure glucose andglucose/ maltose drinks produced an oxidation rateof 1.06g of carbohydrate per minute, the glucose/sucrose combination drink produced a significantly higher rate of 1.25g per minute. This was an important finding because while both maltose and sucrose are disaccharides *(see box)*, maltose is composed of just two chemically bonded glucose molecules, whereas sucrose combines a glucose with a fructose molecule. This suggested that it was the glucose/fructose combination that wasbeing absorbed more rapidly and therefore producing higher rates of carbohydrate oxidation.

Fructose connection

The same team had also performed another carbohydrate ingestion study on eight cyclists pedalling at 63% of VO2max for two hours(16). In this study the cyclists performed four exercise trials in random order while drinking a radio-labelled solution supplying of one of the following:

- 1.2g per min of glucose (medium glucose);
- 1.8g per min of glucose (high glucose);
- 1.2g of glucose + 0.6g of fructose per minute (glucose/ fructose blend);
- Water (control).

There were two key findings; firstly, the carbohydrate oxidation rate when drinking high glucose drink was no higher than when medium glucose was consumed; secondly, the peak and average oxidation rates of ingested glucose/fructose solution were around 50% higher than both of the glucose-only drinks. These findings point strongly to the fact that the maximum rate of glucose absorption into the body is around 1.2g per minute because feeding more produces no more glucose oxidation – probably because the absorption mechanism is already saturated. But because giving extra fructose does increase overall carbohydrate oxidation rates, they also indicate that fructose in the glucose/fructose drink was absorbed from the intestine via a different mechanism than glucose *(see box)*.The

Intestinal absorption of glucose and fructose

Like many nutrients, sugars aren't absorbed passively – *ie* they don't just 'leak' across the intestinal wall into the bloodstream. They have to be actively transported across by special proteins called '**transporter proteins**'.

We now know that the intestinal transport of glucose occurs via a glucose transporter called SGLT1, which is located in the **brush-border membrane** of the intestine. It is likely that the SGLT1-transporters become saturated at a glucose ingestion rate of around 1g per minute (*ie* all the transport sites are occupied), which means at ingestion rates above 1g per minute, the surplus glucose molecules have to 'queue up' to await transportation.

In contrast to glucose, fructose is absorbed from the intestine by a completely different transporter called GLUT-5. So when carbohydrate is given at 1.8g per minute as 1.2g per min of glucose and 0.6g per min of fructose rather than 1.8g per min of pure glucose, the extra fructose molecules don't have to 'queue up' as they have their own route across the intestine independent of glucose transporters. The net effect is that more carbohydrate in total finds its way into the bloodstream, which means that more is available for oxidation to produce energy.

studies above and others(17) had shown that glucose/fructose mixtures do result in higher oxidation rates of ingested carbohydrate, especially in the later stages of exercise. But what the team wanted to find out was whether this extra carbohydrate uptake could help with water uptake from the intestine, and also whether the increased oxidation of ingested carbohydrate had a sparing effect on muscle glycogen, or other sources of stored carbohydrate (egin the liver).To do this, they set up another study using a similar protocol to that above (eight trained cyclists pedalling at around 60% VO2max on three separate occasions, ingesting one of three drinks on each occasion(18). However, in this study, the duration of the trial was extended to five hours during which the subjects drank one of the following:

- 1.5g per minute of glucose;
- 1.5g per minute of glucose/fructose mix (1.0gglucose/0.5g fructose);
- Water (control).The water used in the drinks was also radio-labelled(to help determine uptake into the bloodstream)and the cycling trials were conducted in warmconditions (32oC) to

Jargonbuster

Transporter proteins
Large molecules that sit in cell walls and assistin the transport of substances in and outof the cell

Brush-border membrane
Densely packed protrusions (microvilli) on the intestinal wall,which help maximise nutrient absorption

add heat stress. Exercise in theheat results in a greater reliance on carbohydratemetabolism, which is thought to be due to increased muscle glycogen utilisation, and is associated withhigher levels of fatiguing lactate concentrations.There were a number of important findingsfrom this study:

- During the last hour of exercise, the oxidationrate of ingested carbohydrate was 36% higher with glucose/fructose than with pure glucose (figure 1);
- During the same time period, the oxidation rate of endogenous (iestored) carbohydrate was significantly less with glucose/fructose than with pure glucose (figure 1);
- The rate of water uptake from the gut into the bloodstream was significantly higher with glucose/fructose than with pure glucose (figure 2);
- The perception of stomach fullness was reduced with the glucose/fructose drink compared to pure glucose;
- Perceived rates of exertion in the later stages of the trial were lower with glucose/fructose than withpure glucose.

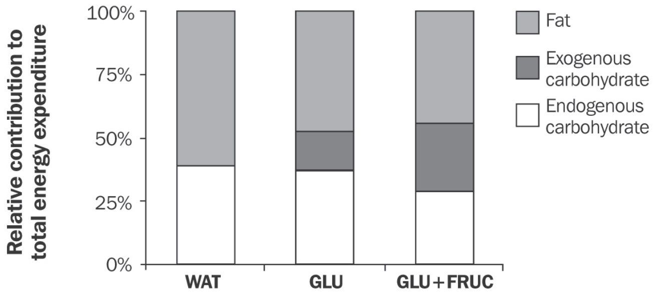
Implications for athletes

These research findings are very encouraging; higher rates of energy production from ingested carbohydrate, lower rates from stored carbohydrate and increased water uptake sounds like a dream combination for endurance athletes. But can a glucose/fructose drink actually enhance endurance performance in real athletes under real race conditions?

Well, the same team of researchers carried out further research published in 2008, which showed that the benefits outlined above of a glucose/fructose combination drink do translate into better performance(19). In the study, eight trained male cyclists were recruited (average age 32 years, average VO2max 64.7mls/kg/min) and cycled for 2 hours at 55% of VO2max followed by a 1-hour time trial in which subjects had to complete a set amount of work as quickly as possible. During these trials, the subjects ingested one of 3 drinks per trial:

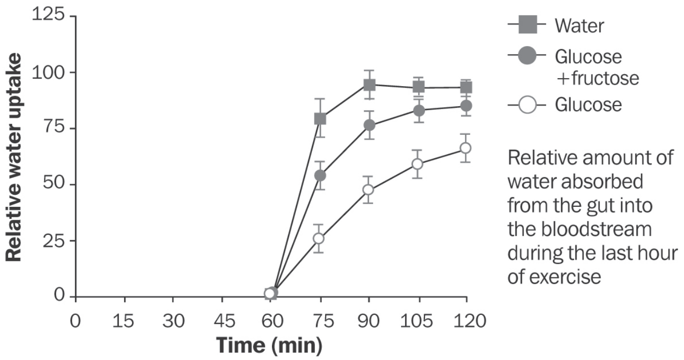
- A glucose-only drink formulated to deliver 1.8g of carbohydrate per minute when consumed as directed;

Figure 1: Drink type and fuel usage



Relative contribution of fat, exogenous (ingested) and endogenous (stored) carbohydrate to energy expenditure during last hour of exercise

Figure 2: Drink type and water uptake



Relative amount of water absorbed from the gut into the bloodstream during the last hour of exercise

- A 2:1 glucose/fructose drink (trade name High5 Supercarbs) delivering an identical total of 1.8g carbohydrate per minute when consumed as directed;
- A placebo drink containing only water and no carbohydrate, disguised to look and taste identical to the other drinks.

The results showed that ingestion of the glucose/fructose drink resulted in an 8% quicker time to completion of the 1-hour time trial compared with the glucose-only drink and a 19% improvement compared with the water placebo drink. Moreover, the total carbohydrate oxidised when consuming either of the two carbohydrate drinks was not different, suggesting that the glucose/fructose drink led to a sparing of endogenous carbohydrate stores (liver and muscle glycogen).

These research findings are very encouraging; higher rates of energy production from ingested carbohydrate, lower rates from stored carbohydrate and increased water uptake is physiologically ideal for endurance athletes. Even better, it seems that glucose/fructose drinks actually enhance performance under real race conditions. The icing on the cake is that these drinks are no more expensive than conventional glucose/glucose polymer drinks, so it seems that future for glucose/fructose carbohydrate drinks looks bright.

However, it's important to emphasise that 2:1 fructose drinks in themselves will not in themselves make you faster; it's the ability to absorb greater amount of carbohydrate from these drinks does. To benefit from these drinks you have to take a larger amount of carbohydrate on-board, which may mean rethinking your nutrition strategy. If you're thinking of trying this new breed of drink, look for a formulation that supplies 2 parts of glucose to 1 part of fructose (as used in the research studies) and be sure to mix and use it according to the manufacturer's recommendations.

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Carbohydrate drinks: should you be adding protein to the mix?

At a Glance

- The theoretical advantages of adding protein to carbohydrate/energy drinks are explained;
- The latest research for and against the addition of protein to carbohydrate drinks is presented;
- Recommendations for athletes are made on the balance of the current evidence.

Sports drink manufacturers are now adding protein to their products, with claims of enhanced performance and recovery for endurance athletes. But do these claims stand up to scientific scrutiny? **Mike Saunders** *investigates…*

During long exercise sessions, especially in the heat, you can lose large amounts of fluid and salts from sweat. In addition, your body's stores of muscle carbohydrate are depleted by prolonged exercise. The water and electrolytes present in most commercial sports beverages therefore can reduce the effects of dehydration and risks of **hyponatremia** when consumed during prolonged exercise. In addition, the carbohydrate they contain provides additional fuel for exercise, allowing you to exercise longer.

Numerous studies have shown that you can improve your endurance performance by consuming sports beverages during exercise, especially in prolonged activities (ie more than two hours) at race-intensity. Most guidelines recommend consuming sports beverages with 4-8% carbohydrate at regular intervals during exercise and under laboratory conditions, 600-1400ml of fluid and 30-60+ grams of carbohydrate per hour appear to maximise the performance benefits.

Sports drinks also promote recovery from heavy exercise, in particular by improving the rates of carbohydrate replenishment in the muscles following heavy training. A study carried out at the University of Birmingham, UK, examined cyclists who were performing eight days of intensified training while consuming low or high-carbohydrate intake during and immediately following exercise[1]. When consuming the sports beverages with adequate carbohydrate content (6% during exercise, 20% post-exercise), the cyclists maintained better endurance performance, had lower perceptions of effort during training, and experienced fewer symptoms of overtraining. The bottom line appears tobethis:whenyouareperformingheavyendurance trainingor competitions, carbohydrate sports drinks canbehelpfulforpromotingimprovedperformance and recovery.

Why add protein to your beverage mix?

The potential advantages of carbohydrate-protein sports drinks have centred on two primary claims:

- Enhanced endurance performance;
- Better recovery following training.

Compared to the extensive research on carbohydrate beverages, there are relatively few studies examining the effects of adding protein to sports beverages. However, there is growing evidence that protein may be a worthwhile ingredient in the carbohydrate drinks of endurance athletes.

At least three studies have been published in the past few years reporting that the consumption of carbohydrate-protein sports drinks improves cycling endurance. Researchers from the University of Texas examined cycling performance during three hours of varied-intensity cycling, intended to simulate competitive cycling conditions[2]. Following this period, the athletes rode to exhaustion at a standardised intensity. The study participants rode significantly longer (26.9min) when receiving a carbohydrate-protein beverage, than when receiving carbohydrate-only (19.7min), with both sports beverages significantly outperforming a placebo beverage.

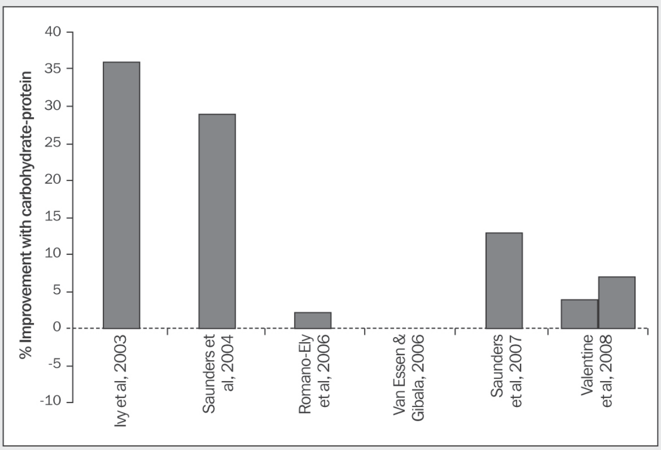
Similarly, our Human Performance Laboratory (James Madison University, US) examined time-to¬exhaustion performance in cyclists while consuming sports beverages[3]. A group of male cyclists rode 29% longer when consuming a carbohydrate-protein beverage compared to a carbohydrate-only drink. In addition, we replicated these findings in a mixed group of male and female cyclists, with athletes riding 13% longer when they drank the carbohydrate-protein drink[4]. Figure 1 shows a summary of results from studies in this area.

Questions

Thestudiesabovehave sparkedconsiderable debate regarding the merit of protein in sports drinks and at least three issues remain to be resolved:

1. Were calorie content differences responsible for performance benefits? – Each of the studies above compared beverages that

Figure 1: Published studies comparing endurance performance between carbohydrate-only and carbohydrate-protein beverages



Jargonbuster

Ergogenic
Producing a positive effect on performance

Hyponatremia
Low blood sodium levels

Statistically significant
An observed effect that is greater than something that could be caused by chance

Central fatigue
A decline in muscular performance related to a decline in central nervous system function, as opposed to impairments in the muscle itself (ie such as depletion of muscle energy stores)

were matched for carbohydrate content. Thus, protein was added to theoretically 'optimal' concentrations of carbohydrate (6-8%) in the drinks. However, this approach resulted in higher caloric content in the carbohydrate-protein beverages. It's possible therefore that the **ergogenic** effects were due to these additional calories.

Our laboratory performed a comparison of calorie-matched beverages, and found no differences in time-to-exhaustion between carbohydrate and carbohydrate-protein drinks(5). However, the carbohydrate-protein beverage contained lower carbohydrate levels than the carbohydrate-only drink, so it is possible that the protein may have provided an ergogenic effect that compensated for the lower carbohydrate content.

In an attempt to clarify this issue, we recently compared in the same study(6):

- A carbohydrate-protein beverage;
- A carbohydrate-matched beverage;
- A calorie-matched carbohydrate beverage.

All beverages were delivered at very high ingestion rates (over 70g of carbohydrate per hour), to be sure that none of the beverages would be penalised by inadequate carbohydrate levels. The carbohydrate-protein beverage still produced an 18% longer timeto-fatigue than a placebo, and 4 and 7% longer than the carbohydrate-and calorie-matched beverages respectively. However, the differences between carbohydrate-protein and carbohydrate-only beverages were not **statistically significant**, so these findings were somewhat inconclusive.

These results mean there is still no current consensus regarding whether extra calories in the carbohydrate-protein drinks explains their benefits. However, at a minimum, the studies discussed above suggest that athletes and scientists have underappreciated the impact of protein ingestion on exercise metabolism. By adding small amounts of protein to your carbohydrate drink, it appears that you receive equal or better performance benefits compared to further additions in carbohydrate content.

2. Is time-to-exhaustion the same as 'endurance performance'? – Canadian researchers compared sports drink performance during a simulated 80km cycling time trial[7]. They observed no differences in performance between carbohydrate and carbohydrate-protein beverages, although both outperformed a calorie-free placebo drink. Based on this study, it has been argued that carbohydrate-protein might not produce enhancements in performance over a prescribed race distance, and that the previous reports of benefits with carbohydrate-protein drinks may have been related to the actual type of performance test used by the researchers.

Performance is a notoriously difficult outcome to measure consistently; one of the reasons for using time-to-exhaustion to assess 'performance' is that it can maximise the relative differences between beverages. While carbohydrate-protein ingestion has increased time-to-exhaustion by 13-36% in the studies mentioned above, this might translate to a few minutes of performance enhancement during a long-duration event. This is a relatively small difference to detect with consistency in the laboratory, because it may be less than the typical day-to-dayvar iationbetweenrepeatedperformance trials, and this factor alone may explain some of the varied findings between laboratories.

To address this issue more completely, we have examined performance differences between carbohydrate and carbohydrate-protein drinks during a simulated 60km cycling time-trial[8]. We theorised that the potential benefits of the carbohydrate-protein drink would be most pronounced in the late stages of exercise, when the athletes were fatiguing. We therefore designed the trial to include three loops of a 20km course, each ending with a 5km climb. Overall, the carbohydrate-protein beverage produced a small benefit in average time (around 50 seconds quicker) and although this difference was not big enough to be statistically conclusive, all of the performance benefit occurred in the final 20km and most of the difference occurred in the final 5km. This resulted in a significant (3%) improvement in late-exercise performance time over the final climb.

3. How does protein promote improved performance? – Possible explanations include:

- Although protein is usually a very minor contributor to the total energy demands of endurance exercise, its role as a fuel (or a regulator of other fuels) could become more important when carbohydrate-protein is ingested during exercise, thus sparing stored carbohydrates, which could be utilised late in exercise, extending endurance;
- Some studies have shown that protein ingestion may influence **central fatigue**, allowing maintained focus and mental performance – could this help explain the ergogenic effects of carbohydrate-protein beverages?

Until we have a better understanding of how protein maypr oducebeneficialeffects,ascientificconsensus regarding the efficacy of carbohydrate-protein drinks is unlikely. However, there are a growing number of athletes, coaches and scientists who believe that carbohydrate-protein beverages do produce some benefits for their athletes. To paraphrase an analogy from Joe Friel's popular endurance training manuals, 'just because we can't figure out how a bee can fly doesn't mean that bees can't fly!'

Protein balance

As an endurance athlete, you are probably not striving to build large, bulky muscles but you need

'There are a growing number of athletes, coaches and scientists who believe that carbohydrate-protein beverages do produce some benefits for their athletes' sufficient muscle mass to sustain force production throughout exercise. Researchers from the Netherlands studied protein balance in endurance athletes receiving carbohydrate or carbohydrate-protein beverages(9). When athletes received a carbohydrate beverage during six hours of cycling and running, protein balance remained in a negative state throughout exercise and during four hours of post-exercise recovery. However, when a carbohydrate-protein beverage was consumed during exercise, protein synthesis was increased and protein breakdown was

Box 1: Carbohydrate-protein drinks and exercise recovery

Carbohydrate-protein ingestion may be even more important for recovery from heavy exercise. Although protein intake was once considered the domain of strength/resistance athletes, many top-level endurance athletes now consider carbohydrate-protein beverages an important nutritional strategy for recovery. Scientific studies have reported various potential benefits of carbohydrate-protein ingestion for recovery, including improved protein balance, reduced muscle damage, and improvements in subsequent exercise performance. Although most research has studied post-exercise consumption of carbohydrate-protein, there is some evidence that you may initiate some of these effects by consuming carbohydrate-protein during exercise as well. We've emphasised protein-carbohydrate 'during exercise' studies here, as it is our purpose to explore the realm of protein's inclusion in 'sports drinks', as opposed to 'recovery drinks' which are rapidly becoming their own separate category of beverages for athletes.

'There are a growing number of athletes, coaches and scientists who believe that carbohydrate-protein beverages do produce some benefits for their athletes'

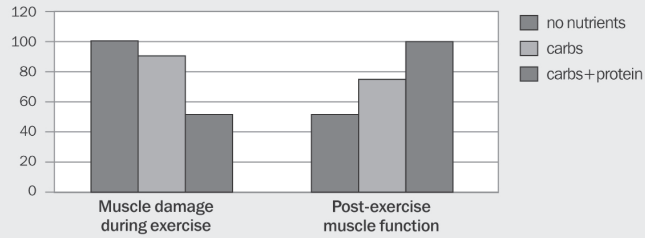
decreased, resulting in a positive protein balance during and following exercise, suggesting that carbohydrate-protein ingestion during exercise can produce some favourable outcomes for your muscular recovery.

Muscle damage

We have examined the effects of carbohydrate-protein on a number of indirect markers of muscle damage. In our initial two studies, we observed that blood-markers of muscle damage[3,5] and muscle soreness[5] were significantly reduced when athletes consumed carbohydrate-protein beverages. However, because carbohydrate-protein beverages were provided both during exercise and immediately post-exercise, it was difficult to determine if these benefits were the result of protein ingested during exercise.

In a more recent study therefore, we examined the effects of a carbohydrate-protein beverage, which was provided at 15-minute intervals during prolonged cycling, but not

Figure 2: Post-exercise responses in muscle recovery with and without protein-carbohydrate during exercise[6]



afterwards[6]. Consumption of the carbohydrate-protein drink resulted in significantly lower markers of muscle damage than a non -caloric placebo, or carbohydrate-only beverages. Even more importantly for performance, the enhanced muscle recovery resulted in significantly better muscle function (measured using a leg-extension test of the quadriceps) than all other beverages 24 hours after the cycling trial *(see figure 2)*!

Subsequent exercise

For most athletes, the most important indicator of muscle recovery is performance in a subsequent exercise session. Few studies have examined the effects of carbohydrate-protein ingestion on subsequent exercise performance and the findings have been mixed; some have reported improvements with carbohydrate-protein intake[3,10,11] while others found no difference between carbohydrate and carbohydrate-protein beverages[12,13].

The study from our laboratory **(figure 2)** suggests that with carbohydrate-protein ingestion, muscle function may be enhanced for at least 24 hours following heavy exercise. However, this may not translate into improved whole-body performance if the initial exercise bout is not appropriately demanding.

This concept is actually true for all reported 'recovery aids' – ie if training sessions are relatively easy, full recovery may occur within 24 hours without any further nutritional supplementation anyway. However, the harder and more frequently you train, the more potential benefit you may receive from optimal nutritional strategies for recovery. In support of this idea, we have observed that runners performing the highest weekly mileages, and cyclists who performed exhaustive exercise when they were relatively unfit, derived the greatest improvements in subsequent performance with carbohydrate-protein consumption.

Optimum protein content

Because there's so little research in the area, it's difficult to recommend optimal levels of protein in sports drinks. In addition, the optimal amount of protein is probably influenced by other factors such as the amount of fluid and carbohydrate you are consuming, your personal stomach tolerance, etc.

Because carbohydrate is the primary fuel during intense endurance exercise, it is logical to assume that the optimal amount of protein should probably be lower than carbohydrate content (about 4-8% by volume (ie 40-80g per litre) in most commercially available sports drinks.

We compared three carbohydrate beverages (6% carbohydrate each) which contained differing amounts of protein and observed that endurance performance was enhanced with small amounts of protein (1-2%), but no further improvements in performance were present with additional protein[14,15]. However, evidence of enhanced muscle recovery was not observed at the lowest levels of protein intake. Though more research is required before specific recommendations can be provided, we generally concluded that protein content should be relatively low (2% or less)in beveragesconsumed during exercise, but should probably be higher (20% or more) in beverages consumed post-exercise, in order to optimise recovery. Some key points regarding sports drink consumption for endurance athletes are provided in box 2.

Box 2: Key points for carbohydrate-protein ingestion during endurance exercise

- Improved endurance performance has been reported with as little as 25 grams/hour of carbohydrate intake. Further benefits have been reported up to 60-75+ gCHO/hr in laboratory studies. Therefore aim to maximise your intake of carbohydrate up to this level during long, intense competitions;
- Consume regular, small doses of sports drinks beginning 10-15 minutes into exercise to maximise intake levels;
- Practice ingesting fluid/carbohydrate during long training sessions;
- Many athletes, especially in weight-bearing sports like running, cannot tolerate such high levels of intake without stomach problems. To maximise performance, consume the highest level you can consistently tolerate without difficulty;
- Consuming carbohydrate drinks containing small amounts of protein (15-20% of total calories) may further improve endurance performance, and initiate improved post-exercise recovery;
- To maximise post-exercise recovery, consume a post-exercise carbohydrate-protein mixture with a somewhat higher concentration of protein (25-35% of total calories).

Summary

Recent studies of carbohydrate-protein ingestion show that endurance athletes and scientists have traditionally underappreciated protein, and no studies have reported impaired performance with carbohydrate-protein drinks. Given that carbohydrate-protein ingestion during exercise may also enhance your recovery from heavy endurance training and reduce muscle damage, it may be particularly helpful to you if you are performing regular, heavy exercise sessions, where rapid recovery is critical.

Practical implications

- Although more research is needed, the balance of evidence is that endurance athletes can benefit from small amounts of added protein;
- Initial findings suggest that protein content should be relatively low (2% or less) in beverages consumed during exercise, but should probably be higher (20% or more) in beverages consumed post-exercise (in order to optimise recovery)

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Recovery nutrition: why carbohydrate is a potent weapon against overtraining

At a Glance

- The condition of overtraining is described and the relationship between overtraining and recovery is outlined;
- The link between overtraining and diet is explained and the new research on the importance of carbohydrate and protein in reducing overtraining risks is presented.

Where should we draw the line between appropriate 'heavy training' and overtraining? And how can carbohydarte nutrition orevent overtraining and accelerate recovery? **Mike Saunders** *explains and shows that these two concepts are intimately linked.*

In simple terms, overtraining is the result of intense training stimuli (and other stressors) combined with inadequate recovery. If appropriate recovery is not provided during hard training, you experience a downward spiral in which continued heavy training creates diminishing returns, and performance levels continue to get worse. However, determining precisely when the 'overtraining line' is crossed is very difficult. This is because the symptoms of overtraining are highly individualised and varied – a laundry list of physical, psychological, immunological and biochemical symptoms.

A consistent end result of overtraining is the impairment of physical performance. When you are overtrained, you can expect to see elevated **perceptions of exertion/fatigue** during exercise, decreased **movement economy**, slower reaction time and impaired performance times. To make things worse, overtraining status is usually only diagnosed with the benefit of hindsight. In other words, by the time you know you are overtrained, it is too late to handle it effectively!

Overtraining terminology

Recently, the terminology around overtraining has been improved. Researchers from the Netherlands and Belgium have described the overtraining process as occurring in three progressive stages *(see box 1 overleaf)*[(1)]:

1. Functional overreaching
2. Non-functional overreaching
3. Overtraining syndrome

Functional overreaching is the normal process of fatigue that occurs with sustained periods of heavy training. Although these periods of hard training cause short-term impairments in performance, this effect is reversed with a relatively short pre-planned recovery period. For example, a 1-week block of hard training may cause moderate levels of fatigue, impairing your peak performance for a few days. However, when you balance this hard training period with a period of adequate recovery, you can quickly return to a level matching and ultimately exceeding your initial level of performance.

Non-functional overreaching is a more severe level of fatigue reached when your performance and energy are not restored after a planned short-term recovery period. This often happens if you work too hard during your recovery days, if you underestimate the impact of the non-training stresses in your life, or if you simply train too long and hard before a recovery period. As a result, you may still feel fatigued following your planned recovery period. This is where flexibility in your training programme becomes very important. If coaches recognise the continued fatigue of an athlete, they can delay the next heavy training phase or competition. This is often enough to reverse the fatigue and restore performance levels.

However, if coaches and athletes ignore fatigue in the non-functional overreaching stage, further heavy training simply results in deeper levels of fatigue. This can become a vicious cycle in which athletes continue heavy training in an attempt to reverse their declining performance, only to exacerbate the problem by further impairing their recovery. True overtraining syndrome is reached only in the most severe cases, and can be quite debilitating. Symptoms of overtraining syndrome overlap with chronic fatigue syndrome and clinical depression, and can only be reversed with several weeks or months of recovery(1).

Balancing training and recovery

The model of overtraining discussed above illustrates the critical balance of well-timed recovery periods within a training program. Your training phases can be specifically designed to cause functional overreaching at strategic times. However, effective trainingprogrammesare createdtoincludeadequate recovery to prevent both non-functional overreaching and overtraining syndrome.

As an example, professional cyclists often perform team training camps that provide a significant early-season training stimulus. The volume of training performed at these camps can induce significant fatigue. However, training camps can produce important improvements in performance if the heavy training is balanced with an appropriate period of short-term recovery.

Recent studies from our Human Performance Laboratory at James Madison University (USA) provide some quantitative evidence to support these concepts. We studied professional cyclists who completed at least three consecutive days of high-volume training, averaging almost 100 miles/day. No tsurprisingly,the heavy training caused significant changes in a number of overreaching/overtraining symptoms. These included increased levels of mental and physical fatigue, increased muscle soreness and elevated markers of muscle damage.

About half of thecyclists then performed an ‘easy’ day of training on the fourth day – about 30 miles at low intensity. For

Jargonbuster

Perceived exertion
Your perception of how hard you are working during exercise, usually assessed at a specific power output or speed

Movement economy
The energy cost necessary to exercise at a specific power output, running speed, etc

Insulin-like effect
An effect which (like that of insulin) allows glucose to be efficiently transported from the blood to the muscle during exercise

Box 1: Model for overtraining terminology			
	Functional overreaching	**Non-functional overreaching**	**Overtraining syndrome**
Level of fatigue	Moderate	Moderate-severe	Severe
Length of recovery	Days to weeks	Weeks to months	Months

these highly trained athletes, this was enough recovery to initiate improvement of all of the symptoms mentioned above.

Overtraining, diet and carbohydrate

Appropriate nutrient intake and timing can play an important role in influencing the overtraining process. It has long been established that adequate carbohydrate intake is required to maintain muscle glycogen levels during heavy training. This is critical to sustaining high training volumes, as muscle glycogen is a primary fuel stored in muscles and used during endurance training and racing. In addition, we know that exercise stimulates enhanced uptake of carbohydrate in the muscles. This so-called **'insulin-like effect'** of exercise remains for a short time following exercise. As a result, the consumption of carbohydrate immediately after training (within 30 minutes) produces faster replenishment of muscle glycogen than if carbohydrate intake is delayed. Thus, it is now common practice for endurance athletes to consume a carbohydrate-rich recovery beverage or snack immediately following demanding training sessions.

More recently, scientists have begun to investigate how carbohydrate intake and timing influence specific aspects of the overtraining process. Researchers from the University of Birmingham examined how dietary carbohydrate intake influenced overreaching symptoms during a period of intensified running training(2). When performing 11 days of intensified training consuming relatively low carbohydrate intake (5.4 grams per kilo of bodyweight per day), the runners experienced significant worsening in mood states, fatigue, muscle soreness, and declines in running performance. These factors were considerably (though not entirely) reversed when the athletes performed the same training demands with higher carbohydrate (8.5g/kg/day) in their diets.

The same research group performed a similar study in cyclists[3]. Athletes consumed sports beverages with low or high carbohydrate content during exercise (low=2%; high=6%) and immediately following exercise (low=2%; high=20%). When consuming the low-carbohydrate drinks over eight days of intensified training, the athletes experienced significant declines in their mood states, increased perceived effort during exercise, and declines in cycling performance. All of these factors improved when the high-carbohydrate beverages were consumed during/following training.

Following the eight-day period of intensified training, the cyclists received fourteen days of reduced volume training to promote recovery. This resulted in significant improvements in cycling performance (exceeding baseline levels) but ***only*** when the athletes drank the high-carbohydrate beverages. By contrast, performance remained suppressed below baseline levels with the low-carbohydrate drinks.

Thus, altering the carbohydrate levels of the cyclists' sports drinks was enough to influence their responses to training. As a result, the intensified training represented a functional overreaching stimulus when appropriate carbohydrate was provided, but a non-functional overreaching stimulus without adequate carbohydrate. This is an excellent illustration of how 'optimal recovery' represents much more than simply lowering the demands of training *(see figure 1)*.

Co-ingestion of carbohydrate and protein

The effects of protein intake on recovery from endurance training have been understudied compared to carbohydrate. As a result, there is no clear consensus among scientists regarding the role that protein plays in the overtraining process. However, recent studies suggest that there may be some additional recovery benefits associated with consuming a mix of carbohydrate and protein following heavy endurance training.

Carbohydrate-protein and glycogen replenishment – Combined intake of carbohydrate-protein may influence a number of factors that are important for recovery in endurance athletes. For example, some studies have shown faster rates of muscle glycogen replenishment when carbohydrate-protein is consumed immediately following endurance exercise (compared to carbohydrate alone).

Other studies have suggested that the additional benefits of added protein are negligible if the carbohydrate doses are very high (over 1.2 g/kg). At a minimum, it appears that carbohydrate-protein ingestion is a highly practical way to ensure high rates of glycogen replenishment following exercise, especially when you are not consuming a high-calorie recovery drink or snack. This is particularly relevant in conjunction with the other potential benefits of carbohydrate-protein ingestion discussed below.

Carbohydrate-protein and protein balance – Combined carbohydrate-protein intake may also have positive effects on **protein balance** for endurance athletes. Researchers at Maastricht University in Holland observed that carbohydrate-protein consumption increased protein synthesis and decreased protein breakdown in endurance athletes, compared to when they consumed carbohydrate alone[4].

Investigators at McMaster University (Canada) made similar observations of enhanced protein balance with carbohydrate-protein ingestion following aerobic exercise[5]. In addition, they reported that the fractional synthetic rate (FSR) within the muscle was improved with carbohydrate-protein intake *(see figure 2, overleaf)*. Collectively, these studies suggest that protein synthesis in the muscle may be improved with carbohydrate-protein intake. Though the long-term effects of improved protein synthesis and protein balance have not been studied in endurance athletes, this evidence suggests that adding protein to carbohydrate drinks may be helpful in stimulating muscle recovery and promoting positive muscle

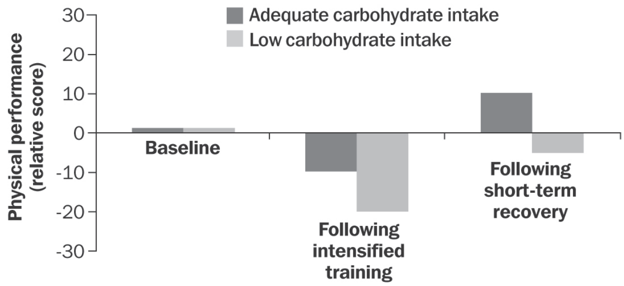
Jargonbuster

Protein balance
The balance between protein synthesis and protein breakdown. 'Positive protein balance' implies more creation than breakdown over a given time period

Fractional synthetic rate (FSR; in muscle)
Protein synthesis actually occurring in the skeletal muscle. By contrast, protein balance/synthesis is usually assessed using whole body measurements

Creatine kinase (CK)
An enzyme which leaks into the blood when muscle cell membranes are damaged, often used as a broad indicator of muscle damage

Figure 1: Effects of carbohydrate intake during intensified training



adaptations following heavy endurance training.

Carbohydrate-protein and muscle recovery – Carbohydrate-protein ingestion has been associated with improvements in various other markers of muscle recovery in endurance athletes. For example,researchersfromourHumanPerformanc e Laboratory at James Madison University have observed that carbohydrate-protein ingestion results in lower blood creatine kinase (CK) levels (an indicator of muscle damage)(6,7), less muscle soreness(7), and improved muscle function(6) following heavy endurance exercise *(see Figure 2)*.

We have observed these benefits in carbohydrate-protein versus carbohydrate-only drinks matched for both carbohydrate content and total calories(6). In addition, we have observed these effects when we studied carbohydrate-protein beverages consumed during endurance exercise(6) or immediately following exercise(7). In one study, we examined carbohydrate and carbohydrate-protein recovery beverages during six days of consecutive training in collegiate distance runners(7). While consuming the drinks containing carbohydrate-protein, the athletes had lower blood CK levels and less muscle soreness, despite performing identical training loads between the two periods.

Carbohydrate-protein and subsequent performance

A critical question for coaches and athletes is whether the improved muscle recovery markers observed when consuming carbohydrate-protein drinks relates to any tangible benefits with respect to sport-specific performance. In other words, if carbohydrate-protein intake improves ‘recovery’, does this lead to enhanced performance during subsequent exercise?

Studies investigating this issue to date have produced mixed findings. For example, in our aforementioned study of runners, we did not observe differences in running performance following the six-day training period between the two beverages. However, this was probably due to the fact that the athletes were reducing their training levels in preparation for a race. Thus, they were probably well recovered prior to the race under both beverage conditions.

This evidence leads to an important observation: *no supplement can be expected to enhance your recovery if you are already fully recovered*. If you only perform light exercise, and take relatively long recovery periods between workouts, then the composition of your post-exercise nutrition regimen is far less critical, and perhaps irrelevant altogether if your regular diet is appropriate. However, if you perform heavy exercise on a regular basis, then it is important that your recovery nutrition includes adequate carbohydrate to maximise your post-exercise recovery. Under these conditions of heavy exercise and short recovery periods, it also seems likely that carbohydrate-protein sustains high performance levels better than carbohydrate alone.

Evidence supporting this concept can be observed in recent studies on this topic, including our study of runners discussed above. As mentioned previously, carbohydrate-protein did not produce performance improvements in runners who were tapering slightly prior to a race. However, the athletes who continued to perform the highest training mileage throughout the six days had the greatest improvements in muscle recovery with the carbohydrate-protein. This same group of ‘harder-training' athletes also had a stronger tendency towards faster race performance with the carbohydrate-protein drink.

More convincingly, US researchers at the University of California-Davis examined the effects of carbohydrate-protein drinks during a short period of heavy cycling training[8]. They assessed changes in blood CK and time to fatigue during three consecutive days of exercise. These variables got significantly worse over the three days of hard training when the cyclists consumed carbohydrate-only drinks. However, these declines were prevented when carbohydrate-protein drinks were consumed.

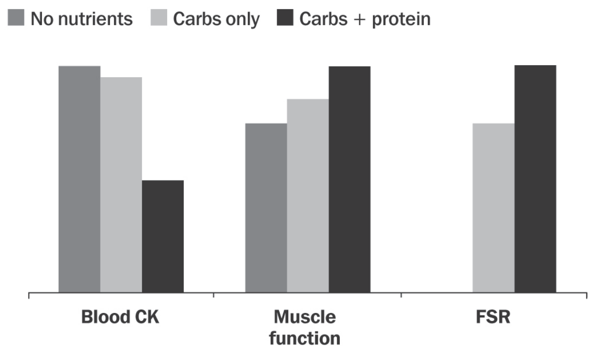
Similarly, researchers from Canada tested recovery and performance during two 60-minute cycling performance tests, separated by six hours[9]. Carbohydrate or carbohydrate-protein recovery drinks were provided immediately after the first exercise trial. The cyclists were able to generate higher power output and better performance in the second exercise session following the carbohydrate-protein beverage, compared to the carbohydrate-only drink.

Not all studies have shown significant improvements in subsequent performance following carbohydrate-protein intake. However, the positive effects of protein seem to appear more regularly in the studies that provide the more demanding training/recovery periods. Thus, the longer and harder you train, the more important the details of your recovery nutrition, including the inclusion of protein, become.

The bottom line

In summary, overtraining is a complex issue, which can have important consequences for endurance athletes. Functional overreaching can be an intended outcome of heavy training periods, provided it is balanced with an appropriate period of recovery. The consumption of adequate nutrients, especially in the period immediately following heavy exercise training, can augment recovery from exercise. Thus, recovery nutrition can assist in the prevention of non-functional overreaching, and allow you to get the most out of your training. In short, this

Figure 2: Effects of carbohydrate-protein on recovery following exercise(6,7)



means making sure that your daily carbohydrate intake (especially immediately post-exercise) is adequately high to maintain your muscle glycogen levels during training. In addition, adding protein to your post exercise recovery drinks and meals appears to have further benefits to promote optimal recovery from heavy exercise.

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Adding protein to carbohydrate drinks: the plot thickens

At a Glance

This article:
- Looks at the criteria for testing nutritional interventions in athletes;
- Questions the strength of the evidence that consuming protein-containing carbohydrate drinks boosts performance;
- Provides updated recommendations on protein supplementation.

In recent years, the addition of protein to carbohydrate to enhance endurance performance has become a popular practice for endurance athletes. However, according to **Kevin Tipton** *and* **Asker Jeukendrup**, *there's less evidence for this practice than many would have us believe…*

Evaluation of nutritional interventions to improve athletic performance such as adding protein to carbohydrate drinks is a notoriously tricky matter. Given that a difference in performance of less than 1% may be the difference between a gold medal and not even making the team, measurement of performance must be very rigid. Unfortunately, that sort of precision is not easy to achieve in a laboratory. There are three factors that must be considered when evaluating a measure of performance: validity, reliability and sensitivity[1]. Let's take a look at what these mean:

Validity – A valid protocol must measure performance as closely as possible to the real thing. The primary methods used to assess endurance performance are the time to exhaustion

Table 1: Critical evaluation of the research design and methods of studies assessing the efficacy of adding protein to carbohydrate to improve endurance capacity or performance. The studies are the same as presented in Figure 1. Note that no study using STT has shown a performance increase with protein ingestion

Ref #	Overall	Subjects		Assessment		Dietary control	Other factors
		Validity	Reliability	Validity	Reliability		
3	**	*** ● Trained male cyclists – VO_2max= ~60mL/min/kg	***	*** ● STT – 60km	****	* ● Ss asked to repeat same food consumption	* ● Feedback given during STT ● Ss asked to refrain from heavy exercise prior to STT ● Ss not highly trained – overall STT time very slow ● No power data reported
4	*	*** ● Trained male cyclists – VO_2max = ~61 mL/min/kg	***	* ● TTE @ 85% VO_2max	*	** ● Diet recorded for 24h prior to TTE ● Ss asked to repeat same food consumption	* ● Variable intensity cycling prior to TTE ● No energy control of drinks – effect could be attributed to additional energy in drinks ● Cho ingestion less than recommended
5	*	* ● Moderately trained male cyclists – VO_2max = ~52 mL/min/kg ● Wide range of abilities	**	* ● TTE @ 75% VO_2max	*	* ● Diet recorded; Ss asked to eat a consistent diet	* ● No energy control of drinks – effect could be attributed to additional energy in drinks ● Cho ingestion less than recommended
6	***	*** ● Trained male cyclists – VO_2max = ~63mL/min/kg	***	*** STT – 80km	****	*** ● Diet recorded ● Strict dietary control for 24h prior to trials – all food provided	*** ● Familiarisation ride ● Exercise recorded and matched prior to trials ● Drinks not matched for energy
7	*	** ● Recreational male athletes – VO_2max = ~60 mL/min/kg ● Wide range of abilities ● Not cyclists	**	* ● TTE @ 70% VO_2max	*	** ● Diet recorded for 24h prior to TTE ● Ss asked to repeat same food consumption	* ● Protein drink included antioxidant – impact of protein cannot be isolated ● Drinks energy matched
8	*	*** ● Trained cyclists – VO_2max = ~58 mL/min/kg ● Males and females	**	* ● TTE @ 75% VO_2max	*	** ● Diet recorded for 24h prior to TTE ● Ss asked to repeat same food consumption	** ● Exercise recorded and matched prior to trials ● Used gels rather than drinks ● Not matched for energy
9	**	*** ● Trained male cyclists – VO_2max = ~56 mL/min/kg	***	*** ● STT – set amount of work (7 kj/kg)	****	** ● Diet recorded for 24h prior to TTE ● Ss asked to repeat same food consumption	*** ● Familiarisation ride ● Exercise recorded and matched prior to trials ● Drinks not matched for energy ● Placebo control group
10	*	** ● Recreational exercisers – VO_2max = ~53 mL/min/kg	**	* ● TTE @ 75% VO_2max	*	** ● Diet recorded for 24h prior to TTE ● Ss asked to repeat same food consumption	** ● Placebo control group ● Drinks energy matched
11	***	*** ● Trained male cyclists – VO_2max = ~63mL/min/kg ● Over 5 years' experience	***	*** ● STT – ~40km ● Front-loaded – 2 h @ 50% maximum power output	****	*** ● Diet recorded ● Strict dietary control for 48h prior to trials – all food provided	*** ● Familiarisation ride ● Exercise recorded and matched prior to trials ● Drinks not matched for energy

Key: TTE – time to exhaustion test; STT – simulated time trial; Ss – subjects; Cho – carbohydrate.
Overall – refers to the applicability of the conclusions for a recommendation to top-level endurance athletes.
Ratings: (based a four star system)
**** Best available – solid conclusions regarding performance possible.
*** Very good – conclusions regarding endurance performance based on these methods may be made with only minimal equivocation.
** Fair – conclusions regarding endurance performance must be tempered and carefully evaluated prior to making recommendations.
*Poor – methodology used is inappropriate for making conclusions regarding endurance performance and should not be used to make recommendations.

protocol (TTE), in which the subject exercises for as long as possible at a set intensity, and simulated time trials (STT). Clearly, the validity of a TTE must be questioned. We are unaware of any events in which a gold medal is awarded for exercising as long as possible at a set intensity! Most endurance events are won by the competitor who finishes the fastest – as in a STT. Furthermore, the physiological responses to STT trials are more similar to those of competition than TTE trials[1]. For these reasons, we consider TTE as an evaluation of endurance capacity, not performance.

Reliability – The ability to reproduce findings across studies. The reliability of TTE has been determined to be somewhere in the range of 25%, whereas STT is closer to 3-4%[2]. These numbers suggest that on a day-to-day basis, with no other factors changing, changes in TTE will be roughly 6 times greater than STT. Certainly, improvements that large with protein ingestion would be remarkable and would revolutionise sport, making champions out of also-rans!

These numbers lead to another important point. Reliability is much better with well trained subjects[1]. It is not much of a stretch to imagine that the responses of highly trained athletes are different than those of less well trained athletes. So, if assessment of the importance of adding protein to carbohydrate for performance of elite athletes is the goal, then for both validity and reliability reasons, STT in well trained athletes should be the test used.

Sensitivity – The signal to noise ratio of a protocol. If there is a lot of noise (poor reliability), the signal will not be detected unless it is very large. If performance changes are small compared to the noise of the measurement, the sensitivity is low. Sensitivity is more difficult to determine than reliability, since few studies report sensitivity or provide the data that make it possible to retrospectively calculate sensitivity.

There is a great deal of interaction among these factors. Taken together, it is clear that when the impact of a nutritional intervention, such as the addition of protein to carbohydrate, is the goal, STT protocols are preferable to TTE. Furthermore, the performance level of the subjects tested should be close to that of the athletes for whom recommendations will be made.

In Table 1, we have summarised our evaluations of nine studies *(see references 3-11)* that have attempted to determine the impact of adding protein to carbohydrate. We have put that table together from the standpoint of using the studies to make recommendations for elite athletes.

Protein plus carbohydrate ingestion during exercise

Hopefully, you can see that if we are to properly evaluate the importance of adding protein to carbohydrate for endurance performance, the design of the studies must be carefully considered. There have now been many studies that have examined the impact of protein ingestion during exercise on endurance capacity and performance *(see figure 1)*. Several have demonstrated a dramatic (13-26%) improvement in endurance capacity, ie TTE, when protein is ingested during exercise.

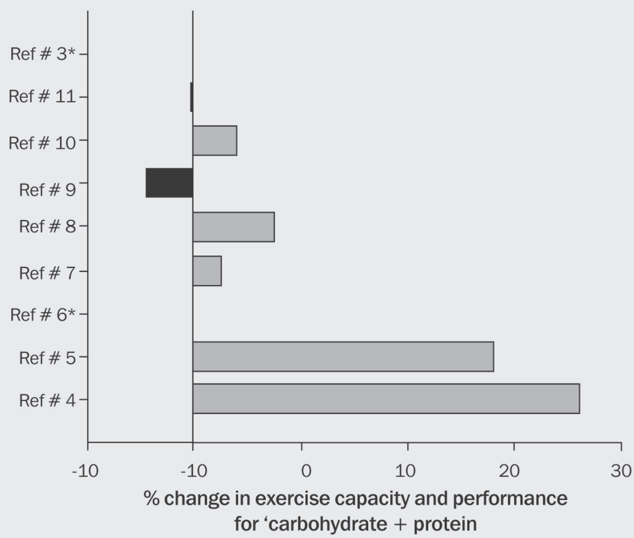
However, before we get too excited about additional protein for endurance performance, it is important to point out that up till now, no study has demonstrated improved STT time, ie endurance performance, with additional protein ingested during exercise. So, a strict interpretation of the research to date would be that if the goal is to ride a bike as long as possible at a fixed intensity, then ingesting protein along with carbohydrate during exercise is advisable. On the other hand, if going faster is the goal then there is no evidence that adding protein to carbohydrate is worthwhile.

Another factor to consider is that the results of many TTE studies are questionable because the time was actually shown to the subjects in those studies. It has been demonstrated quite elegantly that providing feedback about the time will not result in an 'honest' measurement of performance[2] This problem is even more pronounced when carbohydrate and carbohydrate plus protein drinks are provided; it's very difficult to mask the taste of the protein, making trials very difficult to perform in truly a 'double blind' fashion.

A further aspect of performance that has recently been suggested to benefit from protein ingestion during exercise is 'late-exercise performance'. A recent study from a laboratory in Virginia concluded that whereas protein did not impact overall STT time, completion of the latter stages was faster(3). But does this result mean protein should be recommended? If we were to tell an athlete that adding protein allowed them to go faster at the end of a race, they would certainly get very excited. However, the excitement would almost certainly be limited once we explained that overall time was not improved.

'Up till now, no study has demonstrated improved STT time, ie endurance performance, with additional protein ingested during exercise'

Figure 1. Change in exercise capacity (TTE) or performance (STT) with addition of protein to carbohydrate ingestion during endurance exercise in studies to date. Grey bars denote time-to-exhaustion protocols (capacity) and black bars denote time trials (performance)



*No significant changes were observed in studies 3 and 6

Moreover, if an athlete is faster at the end of a race, but not overall, does that not mean the early stages must have been slower? So, the results from this single study cannot be considered conclusive. More research needs to be performed

Protein ingestion for enhanced recovery and adaptation

In addition to enhancing performance during exercise, adding protein to carbohydrate is also recommended for recovery from intense exercise leading to better subsequent performance and adaptations to endurance exercise. Recommendations commonly include ingesting protein/ carbohydrate during exercise, immediately following exercise, for several hours following exercise and even during and following exercise.

Unfortunately, it is not possible to reach a firm conclusion based on the results of these studies at this time; several studies conclude that protein is beneficial for recovery, but some do not. The main problem is that these studies have used varying designs, different types of exercise, different level of subjects and different measurements. Moreover, the term 'recovery' means different things to different people and is assessed in various ways. Finally, control of various factors, in particular dietary control, is often poor to non-existent. Thus, it is very difficult to make any definitive conclusions from the studies so far.

Probably the best way to assess recovery is to measure subsequent performance in intense exercise – from a few hours to a few days afterwards. Using this approach, a number of studies have demonstrated that additional protein results in subsequently improved exercise capacity. Others, however, have not found any improvement with protein. So, at this point, it is not possible to make be 100% certain that additional protein will result in improved recovery from intense endurance exercise.

On the other hand, there's no evidence that adding protein to carbohydrate hurts recovery either. Perhaps a risk/benefit approach is appropriate here; given that extra protein (at least within the energy intake necessary for the athlete), is not harmful to recovery and may even enhance subsequent exercise performance, there's a good rationale for its use. However, it's important to emphasise that any increased protein ingestion should not occur at the expense of reduced carbohydrate intake, because one thing we are certain of is that consuming adequate carbohydrate is essential both for performance and recovery.

to determine if, in fact, protein ingestion helps late-stage exercise performance.

In the light of the above, we have tested that very question in our laboratory. We used a well established STT protocol that has been tested to be very reliable and as sensitive as possible. Moreover, this STT is 'front-loaded' – that is, the cyclists ride for two hours at a submaximal intensity prior to the STT itself. In this way, we can specifically test late-stage exercise performance.

The cyclists participated in two pre-loaded STT protocols in which they consumed carbohydrate alone or carbohydrate plus protein. We found no significant difference in time to complete the time trial. In fact, the average time was slightly faster for the trial without protein. Moreover, there was no difference in average power output during the rides, which is often considered to be a much more sensitive indicator of performance[1]. Finally, power output declined in the last half of the time trial, but there was no difference in power output between carbohydrate-only and protein-carbohydrate at any time during the STT, including the last two stages of the ride. Thus, in a well

'It's worth adding that although many have been suggested, there's no sensible mechanism identified by which protein may improve endurance performance'

controlled assessment of late-stage cycling performance, there was no impact on performance from consuming extra protein. Finally, it's worth adding that although many have been suggested, there's no sensible mechanism identified by which protein may improve endurance performance.

'It's worth adding that although many have been suggested, there's no sensible mechanism identified by which protein may improve endurance performance'

Conclusion

Despite some rationale and even some evidence, we don't feel for racing at least, a solid recommendation for endurance athletes to ingest protein in addition to carbohydrate can be supported by the science. Certainly, the solid and specific recommendations that are often made are not supported by the research mainly because there's simply no evidence that ingesting protein during exercise leads to better performance under race conditions. Although it's a well worn cliché, more studies are needed – specifically with highly trained athletes, using appropriate techniques and controlled for diet before and after exercise (a notoriously difficult task)!

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SPIT OR SWALLOW?

At a Glance

This article:
- Provides an overview of carbohydrate supplementation and performance;
- Looks at new evidence on 'carbohydrate rinsing' for performance enhancement in short endurance events;
- Explains why carbohydrate rinsing works and makes practical recommendations.

Everyone knows that carbohydrate drinks can enhance performance. But as **Asker Jeukendrup** *explains, new research suggests that actually swallowing your favouritesports drink might not be necessary. Bizarre as it sounds, you can rinse your mouth, spit the drink out on the ground and still be faster!*

During the 1980s, carbohydrate supplementation received a lot of attention and a large number of studies demonstrated that fatigue was delayed and performance was improved when exercise lasted two hours or longer. These studies are summarised in recent reviews[1,2]. The reason for the improved performance may be the prevention of hypoglycaemia. However, probably more important is the maintenance of higher rates of carbohydrate oxidation. These high rates of carbohydrate oxidation allow higher work rates to be maintained.

The optimal carbohydrate dose is still open to debate, as dose-response studies have not given clear answers. Some studies have shown a dose response relationship and concluded that more carbohydrate is better. However, a larger number of studies have found no relationship[1,2]. A recent ACSM position statement recommended that athletes take 30-60 grams of carbohydrate per hour[3]. This is partly based on the finding that ingested carbohydrate cannot be oxidised at rates higher than 60 grams per hour[1,2]. But these guidelines may be out of date already, especially for exercise lasting three hours or longer.

Recently it was demonstrated that when a combination of carbohydrates is ingested that use sugars with different intestinal transporters *(ie glucose:fructose)* this can result in very high ingested carbohydrate oxidation rates – as much as high as 105 grams per hour[4] *(Ed – see article #4 elsewhere in this issue)*. When this glucose:fructose drink (2:1) was compared

Carbohydrate supplementation pioneers

It's long been known that carbohydrate feeding can improve endurance performance. One of the earliest reports came from the Boston marathon in 1923 and 1924(5). A group of researchers measured blood glucose in some of the participants of the 1923 Boston Marathon and observed that in most runners, glucose concentrations markedly declined after the race. These investigators suggested that low blood glucose levels were a cause of fatigue.

To test that hypothesis, they encouraged several participants of the same marathon one year later to consume carbohydrates (candy) during the race. This practice, in combination with a high-carbohydrate diet before the race, prevented hypoglycaemia (low blood glucose), and the runners also improved their times. Of course this study had severe methodological issues and would not stand up to the rigour of today's scientific scrutiny. However, it was the first study to suggest that carbohydrate intake during exercise might affect performance.

The importance of carbohydrate for improving exercise capacity was further demonstrated in the 1930s. Investigators let their dogs (Joe and Sally) run without feeding them carbohydrates(6). The dogs became hypoglycemic and fatigued after 4 to 6 hours. When the test was repeated but with carbohydrates during exercise, the dogs ran for 17 hours to 23 hours!

with a glucose drink and performance was measured during a 3-hour cycling trial, it appeared that the glucose:fructose drink improved performance by 8% compared with glucose and 17% compared with a placebo[7].

These data suggest that higher exogenous oxidation rates may result in better performance, at least during very prolonged exercise. These effects are only seen when large amounts of carbohydrate are ingested *(ie 90 grams per hour)*. An overview of up to date recommendations is given in table 1 below.

'The results were remarkable: performance was improved with the carbohydrate mouth rinse compared with a placebo'

Carbohydrate and short duration exercise

Back in 1997, we discovered that carbohydrate feeding can also improve performance during shorter duration exercise of higher intensity[8]. We studied cyclists who performed a 40km time-trial with or without carbohydrate and on average, they were 1 minute faster with carbohydrate. This was a large and unexpected effect for which we did not have an explanation at the time.

'The results were remarkable: performance was improved with the carbohydrate mouth rinse compared with a placebo'

During exercise of one hour or less duration, hypoglycaemia does not develop and blood glucose concentrations may even rise. Also, it takes time before any ingested carbohydrate is absorbed, transported to and used by the muscles, so we calculated that only a small percentage of the carbohydrate ingested during these time trials was actually used as a fuel. This amount was thought to be too small to provide additional fuel and result in a beneficial effect.

In order to further study the potential role of carbohydrate

Table 1: Recommended carbohydrate intake during exercise in order to optimise performance

Exercise duration	CHO needed	CHO intake	Comments
15-45 min	Very small amounts of CHO	*	*
45 min-2h	Small amounts of CHO	Up to 30g/h	Can be achieved with most forms of CHO
1.5-3h	Moderate amounts of CHO	Up to 60g/h	Can be achieved with CHO that are rapidly oxidised (glucose, maltodextrins)
>2.5h	Large amounts of CHO	Up to 90g/h	Can only be achieved by intakes of multiple transportable CHO (glucose:fructose; maltodextrin:fructose)

NB – Some of these time periods overlap because individual tolerance differences need to be taken into account.

as a fuel during this type of exercise, we asked cyclists to perform a 40km time-trial. On one occasion we infused them with a glucose solution, and on another occasion we infused saline (salty water)[9]. The cyclists did not know what they were getting on each occasion.

We observed that when glucose was infused blood glucose concentrations were twice as high and glucose was taken up into the muscle at high rates. However, even though this glucose was going into the muscle and was probably utilised, there was no effect on performance. This tells us that providing fuel during this type of exercise is not that important and other factors determine performance. But if carbohydrate does not exert its effects through being used as additional fuel, how can we explain the performance benefits during a 40km time trial?

Mouth-brain connection

An alternative explanation could be that the carbohydrate somehow influences the brain. For example, there is evidence that taste influences mood and it may also influence the perception of effort. An interesting observation provides support for a central nervous system effect. When you are hypoglycaemic after a long ride or run without food and you are feeling weak and dizzy, all you have to do is bite into a chocolate bar to feel better. Almost instantly the feelings of weakness and dizziness are reduced, and you feel better long before the carbohydrate has reached the blood circulation and the brain. This means that there must be connections from the mouth directly to the brain.

This may also explain why we found improved performance during a 40km time trial. In the following study, we asked cyclists to repeat the 40km time trial but only rinse their mouth with a carbohydrate solution without swallowing any of it[10]. The carbohydrate used in this study was a non-sweet maltodextrin solution, containing carbohydrate, but tasteless. The rinsing protocol was standardised. Subjects would rinse their mouth for 5 seconds with the drink and then spit the drink out into a bowl. They were not allowed to swallow any of the drink.

The results were remarkable: performance was improved with the carbohydrate mouth rinse compared with placebo and the magnitude of the effect was the same as the effect we had seen in the early study with carbohydrate ingestion! They were about 1 minute faster, even though none of the carbohydrate had actually entered the body (no carbohydrate is absorbed in the mouth). Perhaps the carbohydrate in the mouth rinse had connected with a receptor in the mouth that subsequently sent a signal to the brain. This signal probably informed the brain that food was on its way and this reduced the perception of effort, making the exercise task easier. These results were reproduced in studies that followed, although not all studies have found these effects *(see discussion below)*.

Brain imaging

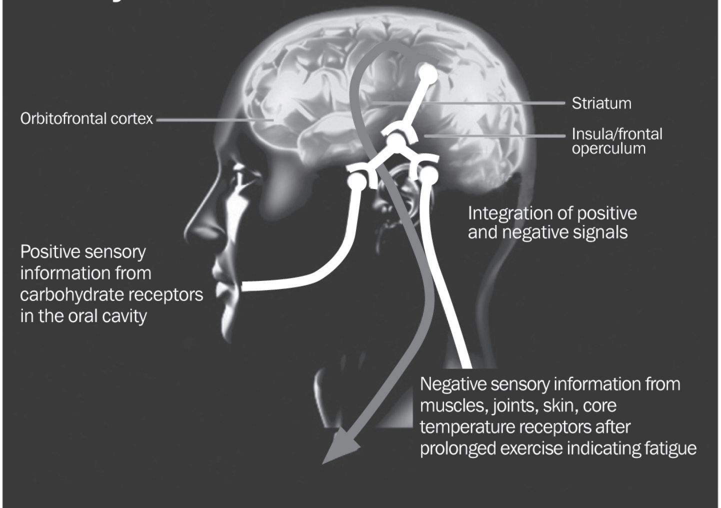
In follow-up studies conducted at the University of Birmingham, brain scans using a technique known as fMRI were used to see if there was increased activity in certain areas of the brain with a carbohydrate mouth rinse that was not present with a placebo mouth rinse[11]. Indeed the study revealed that with a carbohydrate mouth rinse, certain areas of the brain such as the reward centre and areas involved in motor control were activated. The areas investigated included the insula/frontal operculum, orbitofrontal cortex and striatum *(see figure 1)*.

During strenuous exercise many incoming signals arising from muscle, joints, lungs, skin and core temperature receptors are sent to the brain. Over time, these signals will be perceived as unpleasant and consciously or unconsciously this will lead to an inhibition of motor output. This is often called 'central fatigue'.

Athletes tend to regulate their physical activity to keep their levels of discomfort within acceptable limits. It is not clear exactly which pathways are involved in this inhibitory activity but it seems plausible that the signals arising from the

'These findings suggest that there are receptors in the mouth that detect carbohydrate and that these receptors are separate from those that detects sweetness'

Figure 1: A simplified model of the actions of a carbohydrate mouth rinse



Carbohydrate receptors in the mouth send positive signals to three main areas in the brain (insula/frontal operculum, the orbitofrontal cortex and the striatum). These signals are integrated with negative signals from the periphery and an appropriate motor output is generated.

carbohydrate receptors in the mouth are counteracting some of these negative signals. Perhaps the sensors are telling the brain that: 'you have nothing toworryabout,becauseenergyison itsway!' The exact nature of the communication is unknown but the studies clearly show that there is a huge amount of communication between mouth and brain, even before any carbohydrate is delivered.

Sweetness or carbohydrate

Another question that arises is whether it's the carbohydrate that has this effect or the sweetness or taste of the drink? Interestingly, the brain centres that responded to a carbohydrate mouth rinse did not respond to sweetness. When a drink with artificial sweetener was used to rinse the mouth no activation of these areas occurred. However, when a maltodextrin solution, which is a carbohydrate that is not sweet and has virtually no taste, was used, these areas of the brain were equally activated to glucose.

Together, these findings suggest that there are receptors in the mouth that detect carbohydrate and that these receptors are separate from the receptor that detects sweetness. However, such 'carbohydrate receptors' have not yet been identified in humans. These findings are also in agreement with some of the performance studies we conducted. When we compared a sweet and a non-sweet carbohydrate and asked cyclists to perform another 40km time trial we observed similar performance improvements(12).

During what type of exercise does mouth rinsing work?

Carbohydrate ingestion seems to work when the exercise is longer than 30 minutes. Exercise shorter than that does not seem to benefit from carbohydrate intake(13). Recently a study showed that mouth rinsing with a CHO solution increased total distance covered during a self-selected 30-minute run in comparison with mouth rinsing with a colour and taste-matched placebo(14). Similar results were obtained during a 60-minute self-paced run(15).

In another study, the influence of ingestion and mouth rinsing with a carbohydrate solution on the performance during a high-intensity time trial (~1h) was investigated in trained subjects(16). Subjects either rinsed around the mouth or ingested a 6% carbohydrate solution or placebo before and throughout a time trial. In the mouth rinse conditions, time to complete the test was shorter with the carbohydrate mouth rinse (61.7 minutes) than with placebo (64.1 minutes). Interestingly in this study, when drinks were swallowed and not rinsed, there was no difference between the placebo and carbohydrate drinks.

Also, in another study at the University of Birmingham, a 1.9% improvement in time-trial performance was observed with a carbohydrate mouth rinse compared with placebo. In two other studies no effect was observed when subjects ingested a

'The effect of a carbohydrate mouth rinse is convincing and seems to be significant for exercise lasting 30-60 minutes'

breakfast before the time tria[17] or during running[18]. So overall, the effect of a carbohydrate mouth rinse is convincing and seems to be significant for exercise lasting 30-60 minutes. It is not clear whether shorter exercise can benefit and it is unlikely that the mouth rinse effect can override some of the other factors that cause fatigue during more prolonged exercise.

In practice

So what does all this mean in terms of practical advice? Well, it appears that it's not necessary to take on board large amounts of carbohydrate during exercise lasting approximately 30 minutes to one hour. Simply rinsing your mouth with carbohydrate may be sufficient. I have often seen athletes with lollypops and little sweets in their mouth before and during competition. Maybe that's a practical solution?

It must also be said that in most conditions, the performance effects with the mouth rinse were similar to ingesting the drink, so there does not seem to be a disadvantage in taking the drink (although occasionally athletes may complain of gastro-intestinal distress when taking on board too much fluid). Of course when the exercise is more prolonged (two hours or more), carbohydrate becomes a very important fuel and it is essential to take it on board.

We will see what the future holds but it's not difficult to imagine some messy feed zones with athletes taking sports drinks and then spitting them out on other athlete's shoes. A final word of caution however; if you use this practice in Singapore you may be fined $500!

Table 2: Summary of studies currently in the literature that have investigated the effects of a carbohydrate mouth rinse on performance

Authors	Exercise	Effect (+ is enhancing)	Performance effect
Carter et al	~1h cycling	+2.9%	Improved
Pottier et al	~1h cycling	+3.7%	Improved
Rollo et al	30 mins running	+2.0%	Improved
Rollo et al	1h running	+2.0%	Improved
Chambers et al	~1h cycling	+1.9%	Improved
Beelen et al	~1h cycling	+0.5% (ns)	No effect
Witham et al	~1h running	-0.3%	No effect

NB: 'ns' = non-significant effect

Carbohydrate rinsing – putting the theory into "practice"

● Rinsing your mouth with carbohydrate during exercise can improve exercise performance in events lasting 30-60 minutes, even when carbohydrate is not ingested;
● To use this technique, the mouth should be rinsed with a carbohydrate solution every 10 mins or so;
● A lollypop or sweets can also be used but care should be taken to ensure you don't swallow it or choke on it!;
● Carbohydrate drinks used for rinsing should be higher than 6% concentration (6 grams per 100ml) and it is probably more effective to use a 10-20% solution (10-20 grams per 100ml);
● It is okay to drink the carbohydrate as well but this is not needed to get the beneficial effect. If you drink it make sure your don't drink amounts that would cause gastro-intestinal distress;
● Be aware that a keeping a carbohydrate solution in your mouth and swirling it around your teeth can be detrimental to dental health.

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Train low, race high: why less carbohydrate could equal more

At a Glance

This article:
- Summarises the 'train low, race high' theory and why it could be potentially beneficial;
- Looks at the very latest research into low-glycogen training;
- Suggests how athletes can use these findings in their own training routines

In recent years, a novel nutritional regime of carbohydrate feeding and training that seems to turn conventional thinking on its head has emerged. Since then, the 'train low, race high' approach has steadily been gaining currency. **Andrew Hamilton** *looks at the very latest research in this area and how it translates into training recommendations for athletes…*

When it was first proposed as a useful nutritional approach to training, the 'train low, race high' theory ruffled plenty of feathers because it stood conventional wisdom about carbohydrate feeding on its head. To briefly recap, train low, race high is a theory born out of genetic evolution of the human race, and which suggests that training when muscle carbohydrate stores are low might actually be advantageous for performance.

The reasoning behind the theory goes something like this: our gene selection in the Late Palaeolithic era (when our ancestors roamed the plains as hunter-gatherers) would have been strongly influenced by the need to ensure survival during periods of famine, with certain genes evolving to regulate efficient intake and utilisation of fuel stores – so-called 'thrifty **genes**'.

These genes would have enabled our forebears to utilise energy more efficiently, enabling them to forage for food and escape predators even when enduring famine conditions. As hunter-gatherers, without agriculture, they wouldn't have had access to abundant supplies of 'carbohydrate-dense' crops and cereals but in order to survive, physical endurance and the occasional high-intensity burst of energy would still have been needed.

Thrifty genes and exercise

What's fascinating is that there's convincing evidence that our genetic makeup has remained essentially unchanged over the past 10,000 years and certainly not changed in the past 40-100 years[1] , which almost certainly has profound implications for the 21st century athlete. In recent years, a number of 'exercise genes' involved in the adaptation to exercise and training have been identified, and some it seems are also affected by the biochemical environment in the muscle – eg how much muscle **glycogen** is present or circulating levels of **hormones and other signalling molecules** released when exercise is performed[2,4] .

The obvious question, then, is this: given that these genes have evolved to help us maximise our adaptation to and physical capacity in a low-carbohydrate environment, is the almost universally recommended high-carbohydrate diet for athletes disadvantageous in any way? Or to put it another way, could vigorous activity in a carbohydrate-depleted state (as would have been the norm for our ancestors) possibly produce better training adaptations in the modern athlete? A number of scientists are increasingly confident that (thanks to our thrifty genes), lower levels of muscle glycogen during training

Jargonbuster

Enzyme
Large protein molecules that enable biochemical reactions to occur that would otherwise either not occur, or occur too slowly

Genes
The basic unit of inheritance. A gene is a segment of DNA that specifies the structure of a protein or an RNA molecule

Glycogen
An insoluble form of carbohydrate stored in muscles and liver

Hormones and other signalling molecules
Molecules that 'instruct' cells what to do

Table 1: Maximal power output and time until exhaustion at 90% of maximal power output before and after 10 weeks of training and total work before and after 10 weeks of training[6]

	Pre-training		Post-training	
	Low glycogen leg	High-glycogen leg	Low glycogen leg	High-glycogen leg
Time to exhaustion (mins)	5.0	5.6	19.7	11.9
Total work performed (kJ)	22	25	114	69

might stimulate certain metabolic pathways in the body, resulting in better muscular adaptation to training[5] .

Twice daily, alternate day endurance training

One of the earliest and most well respected studies to look into the effects of low-glycogen training compared the training adaptations in muscle produced by performing leg extension exercise either twice a day on alternate days, or once a day on consecutive days[6]. Exercising twice daily resulted in muscles performing an identical volume and intensity of training, but doing so in a low glycogen state during the second session of the day.

The striking finding was the very significant gain in both time to exhaustion and total work performed in the twice daily, low-glycogen trained muscles compared to daily trained muscles *(see table 1)*. In addition, the Danish researchers discovered that the low-glycogen trained muscles became better at burning fat for energy and soaking up carbohydrate to store muscle glycogen once carbohydrate feeding was resumed.

The implications of these findings were startling because they seemed to completely contradict one of the most universally accepted tenets of sports nutrition – that muscle glycogen depletion should be avoided at all costs. In plain English, this research indicated that although low muscle glycogen content is known to blunt performance on the day, when it comes to *training adaptation*, this might not be a reason to avoid glycogen depletion.

New research, new questions

Very recent human studies have added weight to the notion of train low, race high theory, particularly for producing desirable metabolic effects such as increased fat burning. However, they have also raised important questions because these metabolic effects didn't seem to translate directly into increased performance *(see box 2)*.

For example, Australian scientists have studied the effects of a cycling programme in which selected sessions were performed

Box 1: Recent animal studies on low-carbohydrate training

The favourable metabolic effects observed in the Danish study above have also been observed in recent animal studies. For example, in a study carried out in 2008, researchers demonstrated that when rats exercised on a treadmill in a glycogen-depleted state, the resulting increase in circulating fatty acids raises levels of a gene-activating molecule called PPAR∂, which in turn switches on fat-burning genes and boosts endurance[7].

In the same year, another study on swimming endurance in rats found that in addition to increasing fat-burning capacity, low-glycogen training was able to boost levels of a muscle protein called GLUT4[8]. GLUT4 is an important protein that sits in the muscle cell walls, and is required for the transport of glucose from the bloodstream into muscle cells (eg after a high-carbohydrate meal when cells can 'soak up' blood glucose and store it as muscle glycogen). This probably explains why in the Danish study above, training performed in a low-glycogen state enhanced the resting concentration of muscle glycogen following subsequent feeding and why a 'train low, race high' strategy may be particularly effective before an important event.

with low muscle glycogen content on training capacity and subsequent endurance performance[9].

In the three-week study, seven endurance-trained cyclists/triathletes trained once daily, alternating between 100-min steady-state aerobic rides (AT) one day, followed by a high-intensity interval training session (HIT; 8 x 5 minutes at maximum self-selected effort) the next day. Another seven subjects trained twice every second day, first undertaking AT, then 1-2 hours later, the HIT. In this second group of course, the HIT session was completed in a low-glycogen state.

Forty-eight hours before and after the first and last training sessions, all subjects completed a 60-minute steady-state ride followed by a 60-minute performance trial. Muscle samples were taken before and after the steady-state ride and rates of fat and carbohydrate oxidation were measured.

The results showed that, compared to the daily training group, the low-glycogen group experienced favourable metabolic changes, including higher levels of resting muscle glycogen, higher rates of whole body fat oxidation, and higher levels of key enzymes involved in fat oxidation and aerobic energy production.

However, unlike the rat study *(see box 1)*[7], levels of a similar gene transcription activator (PPAR-gamma) remained unchanged. More importantly perhaps, while cycling performance improved by approximately 10% in both groups, there was no additional improvement whatsoever in the twice daily, low-glycogen group.

Meanwhile, similar results were obtained in a study that used running as a training model, carried out by scientists at Liverpool John Moores University[10]. Although this study did not have subjects following a strict low-glycogen training regime, it did examine the effects of reduced carbohydrate availability, by restricting carbohydrate drink use.

Three groups of recreationally active men performed six weeks of high-intensity intermittent running, four times per week. Groups 1 and 2 consumed a 6.4% glucose or placebo solution respectively. Both groups trained twice a day, two days per week. Drinks were taken immediately before every second training session and at regular intervals throughout exercise. Group 3 meanwhile trained once daily per day, 4 days per week and consumed no beverage throughout training.

Those in group 2 (who were training in a low-glycogen state during their second run) had significantly higher post-training levels of an enzyme called succinate dehydrogenase, a key enzyme in aerobic metabolism and one which indicates that the low-glycogen training had induced a greater level of aerobic adaptation. However, when the researchers looked at performance such as improvements in maximal oxygen uptake and distance covered on the **Yo-Yo Intermittent Recovery Test**, there were no significant differences between the groups. The researchers concluded that ‘training under conditions of reduced carbohydrate availability provides an enhanced stimulus for inducing oxidative enzyme adaptations of skeletal muscle, but this did not seem to translate into improved performance during high-intensity exercise’.

Low glycogen and strength

Finally, it's worth reiterating that there still doesn't seem to be any evidence that low-glycogen training is beneficial for very high-intensity exercise, such as resistance training. When Australian scientists examined the influence of pre-exercise muscle glycogen content on the activity of several genes involved in the regulation of muscle growth in seven male strength-trained subjects, they found that lowmuscle glycogencontent hadvariable effects on the activity of these genes involved in glycogen synthesis and importantly, any differences in the activity rates were completely abolished after a single bout of heavy resistance training(11). The scientists concluded that 'commencing resistance exercise with low muscle glycogen does not enhance the activity of genes implicated in promoting muscle hypertrophy'.

This notion also finds favour with a leading scientist in this field, Dr Keith Baar. He believes that if anything, weight training in a glycogen-depleted state may decrease training adaptations. This is because the transcriptional changes (activating genes) following resistance exercise are no different in a glycogen-depleted state (unlike endurance training) and the greater metabolic stress of training with low glycogen can actually reduce muscle protein synthesis. Therefore, strength training in a glycogen-depleted state should be avoided!

Jargonbuster

Transcription activator
A protein that controls whether genes are switched on or off

Yo-Yo Intermittent Recovery Test
A test that evaluates an individual's ability to repeatedly perform intervals over a prolonged period of time

Box 2: Train low, race high questions

The evidence for train low, race high benefits so far looks fairly promising but we still need answers to the following questions:

- How long and frequently should low-glycogen training be carried out to see a significant performance gain?
- How depleted do muscle glycogen stores need to be to see maximum benefits?
- Could low-glycogen training benefit all endurance events, or just longer ones?
- What kind of variations can we expect between athletes? Are there some athletes who will respond particularly well or badly to low-glycogen training?

Box 3: Potential drawbacks of low-glycogen training

● Increased secretion of stress hormones leading to lowered post¬
exercise immunity and increased risk of upper respiratory tract infections; l
Reduced length of training sessions due to fatigue induced by low glycogen;
● Increased risk of burnout and overtraining;
● Reduced hydration in hot-weather training (muscle glycogen is stored in muscle tissue with three times its own weight of water); l
● Increased muscle tissue damage and breakdown, leading to potential losses in muscle mass; l
● Possible strength losses in sports where simultaneous strength and endurance training is required.

Should you train low and compete high?

If you're new to the 'train low, race high' concept, there's a lot of information to take in here, so let's begin by summarising what the current research says about the subject:

1. Training with lower levels of glycogen in the muscles appears to elicit greater endurance adaptations in muscles, such as improved aerobic efficiency and increased capacity to burn fat compared to training with high levels of muscle glycogen;

2. This greater metabolic adaptation almost certainly occurs as a result of enhanced activation of so-called 'thrifty' genes;

3. There is no such advantage when strength training; indeed, low-glycogen training may actually be disadvantageous for strength and power athletes;

4. High levels of muscle glycogen are always recommended for maximum performance on any given day (eg during competition); while training with low glycogen stores may enhance long-term adaptation, actual performance during this training will not be enhanced and may well be diminished;

5. It's still unclear as to the exact performance benefits of low-glycogen training. Although there are undoubtedly favourable

Box 4: How to train in a glycogen-depleted state

To obtain the positive effects of low-glycogen training, you first need to decrease your muscle glycogen levels by about 30-35%. This is easily achieved by performing your chosen activity (running, cycling etc) at around 70% of your maximum heart rate for 30-60 minutes without consuming a carbohydrate supplement.

Stage two consists of a training session in the depleted state. This session can be performed immediately, or following a fast of 1-3 hours. The second session should include some high intensity work, as this type of training is particularly effective at activating the molecular targets that improve endurance performance (see table 2, right). Needless to say, the mode of exercise in the first and second sessions needs to be the same (eg cycling followed by cycling or running followed by running). It's also important to stress that caution is required; you should monitor your performance carefully to determine whether low-glycogen training is affecting your recovery and therefore the overall intensity/quality of your training.

metabolic changes after low-glycogen training, the results are rather mixed as to whether these changes translate into performance gains.

The last point is worth emphasising. Although the initial evidence is looking promising, there are a number of questions that we need to answer before we know categorically whether a train low, race high approach offers real performance advantages over conventional training approaches *(see box 2)*.

It's also worth adding that low-glycogen training carries with it a number of risks and drawbacks *(see box 3)* and these should be considered carefully before plunging headlong into a train low, race high strategy.

Despite all these caveats, however, a number of exercise physiologists are convinced that some low-glycogen training can yield real benefits for endurance athletes. There's no doubt that for maximum performance on the day of a competition, you need to start your event with maximum glycogen reserves. However, training is about trying to teach your body to become as efficient as possible at producing energy – your actual performance during training is of lesser importance. So this is the time when it might be worth including some regular low-glycogen workouts. By doing so, you can stimulate your 'thrifty genes' to enhance your energy efficiency and production, which when combined at a later date with high-glycogen stores, could help you achieve a PB. Box 4 and table 2 give some suggestions on how to introduce some low glycogen training into your routine.

Remember, though, to be cautious. If you do decide to experiment with some low-glycogen training, only do so once or twice a week and for limited periods. Be sure, too, to watch very carefully for symptoms of overtraining and fatigue.

Table 2: Suggestions for low-glycogen training*

Sport	Depletion session	Adaptive session
Marathon	● 1h @ 75% HRmax	● 6 x 800m at 1 mile pace with 1.5min recovery, or ● 4 x 1200m at 3k race pace with 3min recovery, or ● 2 x 2 miles at 10k pace with 10min recovery, or ● 1h at 75% HRmax
Road cycling	● 1h @ 70% HRmax	● 6 x 5min at 95% HRmax with 2min recovery ● 2 x 20min hills @ 80% HRmax
Swimming	● 20 x 150m @ medium-high effort 15 sec rest ● 30 x 100m @ medium-high effort 15 sec rest	● 15 x 50m with 10sec recovery, or ● 10 x 200m with 20sec recovery, or ● 4 x 400m with 40sec recovery All with increasing intensity
Triathlon	● 4h bike with no supplementation Low CHO dinner	● Morning – 3h ride with 3 x 10min @ 90% maximum power output, or ● Morning – 1h run with 2 x 1 mile at 10k pace
Football/soccer	● 30min run @ 75% HR max	Regular training with team, skills sessions, repeated sprints, ball skills, etc
Rugby/US football, sprinting, rowing, time trial cycling	This type of training is not recommended	

**courtesy of Dr Keith Baar, Functional Molecular Biology Lab, University of California*

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Notes

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