HYDRATION

for optimal sports performance

A SPECIAL REPORT FROM

PEAK PERFORMANCE

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Introduction

A bag of salty warm water shaped by a few bones. It's not the most glamorous description of the human body, but it pretty much sums up the reality! And given that our bodies contain more water than anything else, it's hardly surprising that hydration has a profound effect on sports performance.

But why a special report on hydration? After all, doesn't staying properly hydrated involve nothing more than drinking plenty of fluid before, during and after exercise I hear you ask? Well actually, it's not quite as simple as that. Exactly how much should you drink? Can you over-drink? At what point does dehydration start to really impair performance? What kind of sports drink is best? Should the kind of sport you perform dictate the kind of sports drink you consume? How does your diet affect your hydration needs? What about alcohol, caffeine and dehydration? All of these questions and many more are answered in this special report.

One of the really fascinating aspects of hydration and sports performance is that despite a wealth of previous studies, research continues to throw up surprising new discoveries. It may be one of the oldest and most thoroughly covered topics in sports nutrition, but it's clear that there's still much to learn. And that's why we hope you'll find this special report invaluable; if you adopt only half of the recommendations it contains, you'll steal a real performance advantage over your contemporaries, because hydration really does matter!

Andrew Hamilton BSc Hons MRSC ACSM
Editor

Sports drinks or water: what is the best choice for sports performers?

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

At a glance:

- The fundamentals of fluid replacement are outlined;
- The importance of electrolyte minerals (esp. sodium) and glucose in hydration is explained;
- Recommendations are given for fluid replacement and sports drinks use pre, during and post-exercise.

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

Water is the medium in which the biochemistry of the body takes place. Every one of our trillions of cells both contains and is bathed in a watery medium. It's hardly surprising, therefore, that we have developed mechanisms for keeping the water content of the body pretty constant. Because some water is continually being lost in urine (in the process of excreting waste products), a constant throughput of water is required to maintain fluid balance. This balance is controlled principally by the kidneys and the thirst mechanism. When total body water drops, hormonal messages are sent to the brain to create thirst. Excessive water intake, on the other hand, stimulates an increase in urine production.

As well as providing the perfect chemical environment for our bodies, water has another extraordinary property – the ability to stop our bodies overheating by evaporating via the skin in the form of sweat. This is particularly important during exercise, when heat output rises dramatically.

At rest, the average 70kg adult consumes around 0.25 litres of oxygen per minute, which equates to about 70 watts of heat output. But when running at six-minute-mile pace, oxygen consumption rises 16-fold to over four litres per minute and heat output rises to over 1,100 watts! Unless the ambient temperature is sufficiently low, this extra heat cannot be radiated or carried away through convection quickly enough to prevent heat build-up, so heat loss via evaporative cooling (*ie* sweating) has to occur.

For a 70kg runner running at this pace, the approximate energy burn rate is around 1,000kcal per hour. In warm conditions it would take over 1.5 litres per hour of sweat evaporation to remove the extra heat generated. When you take into account the fact that some sweat will drip off the skin without contributing to evaporative cooling, it is easy to see how runners can lose two litres of fluid per hour or more in hot conditions. And since fluid losses of just 2% of body weight (that's 1.5 litres from our 70kg runner) can cause a significant drop in performance, our mythical runner could be in trouble in less than an hour without taking extra fluid on board!

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

But the process of 'fixing' carbohydrate into muscles in the form of glycogen also requires water; each gram of glycogen fixed into muscle fibres requires around 3g of water, which is why you often feel thirsty after a high-carbohydrate post-training meal. If you don't drink to aid this process, water is simply drawn out of the bloodstream, leading to dehydration.

Fluid, then, is vital for adequate recovery – not just to replace water lost through sweating, but also to help replenish lost glycogen.

'Fluid is vital for adequate recovery – not just to replace water lost in sweat but also to help replenish glycogen'

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

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

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

1. Although the amounts lost in sweat are generally small in proportion to total body stores, prolonged heavy sweating can lead to significant mineral losses (particularly of sodium). Drinking pure water effectively dilutes the concentration of electrolyte minerals in the blood, which can impair a number of normal physiological processes. An extreme example of such an impairment is 'hyponatraemia', when low plasma sodium levels can be literally life threatening *(see box overleaf)*.
2. Drinks containing electrolyte minerals – particularly sodium – are known to promote thirst, thereby stimulating

a greater voluntary intake of fluid[3]. There is also evidence that drinks containing sodium enhance the rate and completeness of rehydration after a bout of exercise[4].

3. When the electrolyte minerals – again particularly sodium – are present in appropriate concentrations, the rate of fluid absorption from the small intestine into the rest of the body appears to be enhanced, especially in conjunction with small amounts of glucose[5]. This is particularly important when rapid uptake of fluid is required, such as during strenuous exercise in the heat.

Pre-exercise hydration is principally a function of your fluid intake patterns and diet. The use of glycerol to induce a state of

Hyponatraemia – the dangers of fluid overload

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

The lower the blood sodium and the faster it falls, the greater the risk of life-threatening consequences. A drop in plasma sodium concentration to 125-135mmol/L often results in little more than gastrointestinal symptoms, such as bloating and nausea. Below 125mmol/L, the symptoms become more severe and can include confusion, throbbing headache, wheezy breathing, swollen hands and feet, unusual fatigue and reduced coordination. Below 120mmol/L, the risk of seizure, coma and death is increased.

Hyponatraemia in athletes is often, although not always, caused by excessive drinking. During exercise, urine production is decreased, reducing the body's ability to excrete excess water, while at the same time sodium losses are increased through sweating. The combined effect makes it much more likely that the body's sodium content will be significantly diluted.

hyper-hydration before long events in very hot conditions is covered elsewhere in this report, so we won't dwell on it here. Suffice it to say that if the fundamental dietary and normal fluid intake patterns are right, good pre-training/competition hydration will be the norm – not something that requires special attention a few hours before the event!

As for post-training/competition rehydration, the most reliable indicator is body weight, and your fluid replacement needs are considered in detail on page 6 of this issue. Research evidence suggests that fluids containing significant amounts of electrolytes (especially sodium) have a slightly greater impact in restoring hydration than fluids with little or no electrolytes/sodium(6).

However, the amount of sodium in the drink is critical. American scientists compared rehydration efficiency using each of the following(7):

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

'Hydrating an exercising human body is not as simple as topping up a leaking bucket!'

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

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

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

- *Intestinal absorption* – the rate of absorption across the intestinal wall.

Optimal fluid absorption requires rapid gastric emptying and efficient uptake in the intestine.

Contrary to what you might expect, fluid absorption tends to take place in the small intestine rather than the stomach. Studies have shown that the larger the volume of fluid in the stomach, the more rapid the emptying into the small intestine, which means that maintaining a large fluid volume in the stomach by repeated drinking will maximise the rate of fluid (and nutrient) delivery to the small intestine[8,9].

Gastric emptying rate is also influenced by fluid composition. Early studies showed that, regardless of their electrolyte or glucose content, solutions with a lower overall concentration (or osmolality) than body fluids were emptied as rapidly as plain water[10,11]. With glucose solutions, for example, this would allow for a concentration of up to 2.5% (2.5g per litre of water). At the time it seemed that concentrations above this threshold would slow gastric emptying. But more recent work has established that drinks containing glucose concentrations of up to around 4-5% are emptied as rapidly as water[12].

Beyond a concentration of 5%, glucose solutions are emptied more slowly from the stomach, but they can nevertheless result in a faster delivery of glucose overall[13]. This is because the increase in glucose per unit volume delivered by these more concentrated drinks more than makes up for the reduced volume absorbed; where fluid replacement is of a lesser importance than energy replacement, more concentrated drinks may be preferable.

In recent years, there has been a growing trend towards the use of short chain glucose polymers, such as maltodextrins, in fluid/energy replacement drinks. The theory is that glucose polymers are emptied more rapidly from the stomach than pure glucose.

However, the evidence is far from conclusive and the various studies that have been carried out have reached conflicting

Glycerol myths and reality

For most people, taking a glycerol/water solution before an event produces an increase in total body water (hyper-hydration). The question, however, is whether this extra water in the body actually enhances performance, and to date there is no clear-cut evidence to suggest that it does. It is true that after ingestion glycerol stays in the body and holds water with it, but the unanswered question is whether this extra water increases hydration within the cells or simply increases the amount of water swilling around in general circulation?

Overall, the current weight of evidence is tilted slightly in favour of a glycerol hyper-hydration protocol, but only in events where substantial dehydration is likely to be a problem. Moreover, there is still no agreement about the best way to take glycerol solution, or about whether certain kinds of plain water hyper-hydration protocols might offer similar benefits.

Unless your event is long and taking place in hot/humid conditions, resulting in unavoidable dehydration, there is probably little point in using glycerol. Not only are there unlikely to be any performance benefits, but glycerol ingestion can cause stomach upsets, together with headaches and blurred vision at higher doses. If you are tempted to try glycerol, make sure you've tried other hydration methods first. Glycerol should be considered only as a last resort.

conclusions[14-17]. This may be because concentrated beverages are known to increase the volume of gastric and intestinal secretions. It's possible, therefore, that the total volume of stomach contents may have been greater when solutions containing glucose rather than polymers were drunk, even though the amount of the ingested drink remaining in the stomach was the same. This would affect gastric emptying rates (remembering that gastric emptying is more rapid with high volumes of fluid in the stomach).

However, while the evidence that glucose polymers can offer a significant advantage over pure glucose is thin on the ground, there's almost no evidence to suggest that the emptying rate of polymer solutions is slower than that of free glucose solutions with the same energy content. Indeed, most studies have reported that polymer solutions are generally emptied faster, if not significantly so.

After gastric emptying, ingested fluids are absorbed in the small intestine. Pure water, or very dilute solutions, diffuse readily across the intestine. However, research has shown that dilute glucose/electrolyte solutions with a concentration that is slightly less than that of plasma maximise the rate of water absorption[18]. The researchers found that optimum hydration from the intestine was obtained with a solution containing 60mEq (1.38g) of sodium and 111mmols (20.0g) glucose per litre of water.

Where energy (*ie* glucose) replacement is the main goal, studies have shown that uptake from the small intestine into the body rises as the concentration of glucose rises in the intestine. This is simply because there is more glucose available per unit volume for absorption.

'Studies have shown that fructose is absorbed more slowly than glucose and that it promotes less water uptake'

However, very concentrated solutions of glucose (more than 6%) can have an adverse effect on fluid balance. This is due to the process known as osmosis, whereby water separated by a permeable membrane (in this case the intestinal wall) passes from a more dilute to a more concentrated solution. When you ingest a drink with a very high concentration of glucose, the fluid in the bloodstream (on the other side of the intestinal wall) will be relatively dilute by comparison. And the osmotic pressure exerted by the very concentrated glucose solution will actually draw water out of the bloodstream and into the intestine. This results in a loss of available body water, effectively increasing dehydration.

Although it has a chemical structure similar to glucose, the fruit sugar fructose diffuses passively across the intestinal wall. Studies have shown that fructose is absorbed more slowly than glucose and that it promotes less water uptake[19]. Moreover, fructose is known to exert a greater osmotic pressure, which means that, for a given concentration, it is more likely to draw water into the intestine, which can cause abdominal distress. These properties tend to make pure 'fructose-only' drinks less desirable than glucose-only drinks in terms of energy replacement. However new research suggests that small amounts of fructose added to glucose can provide superior energy and fluid uptake *(see elsewhere in this report)*.

A study on cyclists compared the effects of glucose and fructose in a 6% solution during a 1hr 45min bout of cycling[20]. By comparison with glucose, fructose was associated with more gastrointestinal distress, a greater loss of plasma volume, higher levels of stress hormone and substantially poorer exercise performance!

Properly formulated carbohydrate/electrolyte drinks can and do increase hydration (and, as a bonus, supply extra carbohydrate to working muscles), so it's hardly surprising that they really do enhance performance when fluid loss is an issue[21-29]. But what's the best strategy for individual athletes? And how do you decide on the best drinks for you? Here are some simple guidelines derived from the evidence referred to in this article:

Pre-exercise

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

Post-exercise

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

Mid-exercise

- For events lasting less than 30 minutes, mid-exercise fluid replacement isn't necessary, since it's not possible to lose enough fluid to affect performance in such a short space of time;
- Weather and exercise intensity affect fluid needs; the higher the temperature, humidity and exercise intensity, the greater the rate of fluid replacement required;
- Gastric emptying is most efficient when there is a high fluid volume in the stomach, so your best strategy is to start exercise with fluid on board and drink little and often to keep it topped up;
- Gastric emptying is also affected by the concentration of a drink. As a rule, the more concentrated the drink, the slower it empties;
- Plain water empties rapidly as do low concentration (hypotonic) drinks and isotonic drinks. More recent research also suggests that energy drinks containing up to 4-5% glucose also empty as rapidly as water. However, drinks containing glucose and sodium are absorbed from the intestine more rapidly than plain water;
- More concentrated drinks (more than 6%) leave the stomach more slowly, but still manage to deliver more carbohydrate. Where energy replacement is the priority, these drinks are recommended, although they are less efficient for hydration;
- Where hydration is the priority, water, isotonic or low concentration glucose drinks will all suffice, though hypotonic/isotonic electrolyte/glucose containing drinks may be absorbed more rapidly from the intestine;
- Whatever sports drink you choose, ensure it contains electrolyte minerals;
- Where hydration is your goal, water is okay but high volumes of plain water are not recommended where profuse and prolonged sweating occurs (more than 3-4 litres lost) because of the risk of sodium dilution. If water is your preferred drink, consider using salt tablets in these circumstances;

- The evidence in favour of glucose polymer drinks is mixed. Overall, they may confer a slight advantage in terms of gastric emptying, but be prepared to pay more!
- Pure fructose or pure fruit juice drinks are not absorbed rapidly and may cause abdominal distress;
- Never experiment with a new drink during competition. Try it in training first to see how your body tolerates it!
- Choose a drink you find palatable. If it doesn't taste nice, you won't drink it, no matter how advanced the formula!

Andrew Hamilton

Sports drinks jargon buster

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

- Isotonic drinks provide the body with water, energy and electrolytes in a form enabling the water to be absorbed as rapidly as possible. Studies have shown that fluid is rapidly emptied from the stomach when it contains roughly the same concentration of dissolved substances as that of blood serum – a value of 280 milli-osmoles/kg for you technophiles out there! At this concentration, a drink is said to be 'isotonic' or at the same concentration as your body fluids. During exercise, energy in the form of carbohydrate, and electrolyte minerals, such as sodium, potassium, calcium and magnesium, are lost along with water. When these substances are dissolved in water at an isotonic concentration they not only help replace lost fluid more rapidly than even plain water but also help replace some of the lost energy and minerals. However, research has demonstrated that drinks containing dissolved glucose at higher than isotonic concentrations (up to 5%) can be emptied from the stomach just as rapidly, and can therefore replace lost energy more rapidly. Although not strictly isotonic, these drinks offer all the fluid replacement benefits of isotonic drinks and are often marketed as such.

- Energy drinks are less about replacing lost fluid and more about keeping the working muscles supplied with energy during very long and sustained workouts. Energy drinks need to contain much higher concentrations of soluble carbohydrates than isotonic drinks, because an isotonic solution of carbohydrate struggles to provide energy at a sufficient rate to replace what is lost during intense exercise. The disadvantage of energy drinks is that their high carbohydrate concentrations tend to slow down the rate of water absorption, particularly during hard exercise. They are therefore best reserved for longer endurance events performed in more temperate conditions, where a very high rate of fluid replacement is not quite so critical.
- Recovery drinks, as the name suggests, are taken after training to supply the muscles with everything they need for recovery, including water, carbohydrate and amino acids. These drinks often contain such additional nutrients as electrolyte minerals, vitamins needed to aid metabolism of the ingested carbohydrate, and protein and more exotic co-factors designed to accelerate recovery. Because they're taken after training, rapid gastric emptying and absorption is not a priority.

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How to calculate your personal fluid needs

Back in 2004, I wrote about some of the work on testing of fluid balance I had been engaged in with professional football clubs* (PP196, April 2004). *This work provoked much interest in the football world and carried some important lessons for athletes in other sports too. The key finding to emerge from those studies is that there is no standard answer to the following questions commonly asked by athletes:

- ***What is the best drink?***
- ***How much of it should I consume?***

At a glance:

- The general recommendations for fluid intake during exercise are discussed;
- The potential shortfalls of using generalised fluid intake guidelines are outlined;
- A method of determining your individual optimum fluid intake during exercise is given.

Many factors will combine and interact to determine the answers to those questions. However, the answers will vary according to the nature of the event and the weather conditions at the time, so there is not even a standard answer for any given individual. It is important that athletes recognise this fact and stop searching for a single solution to all their needs.

Many expert committees have toiled long and hard over the questions, but none has as yet had the courage to admit that they cannot come up with an answer. This has led to the publication of numerous sets of guidelines that appear, at first sight, to provide answers.

The American College of Sports Medicine (ACSM), for example, has published guidelines for endurance athletes recommending that 'During exercise, athletes should start drinking early and at regular intervals in an attempt to consume fluids at a rate sufficient to replace all the water lost through sweating (*ie* body weight loss), or consume the maximal amount that can be tolerated'[1].

The ACSM also advises: 'During intense exercise lasting longer than 1h, it is recommended that carbohydrates be ingested at a rate of 30-60 [grams per hour] to maintain oxidation of carbohydrates and delay fatigue. This rate of carbohydrate intake can be achieved without compromising fluid delivery by drinking 600-1,200 [ml per hour] of solutions containing 4%-8% carbohydrates (*ie* 40-80g per 100ml).

The International Marathon Medical Directors Association (IMMDA) has recommended a fluid intake of something between 400 and 800 ml per hour, with the higher rates being appropriate for faster or heavier runners and the lower rates for slower runners and walkers[2].

The problem with both sets of recommendations is that they are too inflexible. The ACSM guidelines can be interpreted as encouraging runners to drink as much as they can: this may be more than is necessary and can lead to problems of water overload and even hyponatraemia (a potentially dangerous fall in the blood sodium level – see box on page 14). Even at the narrower range set by the IMMDA, 400ml will not be enough for a heavy runner on a hot day, while 800ml is likely to be too much for a light runner taking five hours to complete a marathon on a cold day.

The only sensible advice is for individual athletes to take personal responsibility for developing their own hydration plan, and this is implied in the first ACSM recommendation, encouraging runners to drink just enough to replace fluid lost in sweat. That means looking at what you currently do, assessing that against what you should be doing and seeing if any changes need to be made. There are now many surveys of how much people drink in endurance races, and of how much these same people sweat.

If we look at what people actually do, we can use as an example a paper published by Tim Noakes and his colleagues in the *British Journal of Sports Medicine*[(3)]. They weighed 258 competitors before and after an Ironman distance triathlon held in South Africa in 2000 and 2001. Analysis of the results showed that weight change ranged from a loss of 8.0kg (10.7% of the pre-race weight) to a gain of 3.0kg (3.7%). In other words, some people finished the race severely dehydrated while others drank so much that they gained weight. There was no measure of how much fluid competitors consumed during the race, but we can guess that those who lost most weight probably drank a lot less than those who gained weight.

'Some top football players put away almost two litres of fluid in a 90-minute training session while others drank almost nothing!'

Footballers' fluid intake

I and my colleagues have measured the fluid intakes of many top football players in training; it's a simple matter of weighing their drinks bottles before and after training, having made sure that they drink only from their own bottles – and that no-one else does! We saw that some players would put away almost two litres of fluid in a 90-minute training session while others drank almost nothing. They all did the same training and they all had access to the same drinks, so why this large difference?

At present, there are no good explanations for why some people sweat copiously while others hardly sweat at all. If you're a sweaty person, you just have to learn to cope with it. What we do tend to find, though, is that those who drink most are not necessarily those who sweat most; and this is consistent with the belief that thirst is not closely related to sweat loss – at least not when this amount is relatively small – and therefore not a reliable guide to fluid needs.

There is some evidence that the people who drink most are those who begin a training session already dehydrated: we don't yet know if this applies to a race situation, but it seems reasonable to suspect that it does.

The fact that fluid gains and losses could be measured in so many competitors in a race situation and in top professional footballers in training shows it's not hard to do. In fact, it can be achieved by anyone with access to a set of scales. Just weigh yourself before and after a long run and you'll have a good idea of whether you are a sweaty runner or not. Sweaty runners should probably be encouraged to drink more than their counterparts who merely 'glow' while exercising.

How much should you drink?

There has been a tendency to move away from the ACSM suggestion that everyone should aim to replace as much fluid as they lose in sweat with the aim of finishing the race weighing the same as when they started. There is probably no real danger to either performance or health from mild levels of dehydration. Yes, severe dehydration will certainly result in a loss of performance capacity, but a little dehydration means less weight to carry over those last few miles, and that may confer some benefits.

As a rule of thumb, during an endurance event you should aim to drink just enough to be sure you lose no more than about 1-3% of your pre-race weight. That may seem a difficult strategy to put in place, but all you need are a set of scales, some common sense and a sense of personal responsibility.

First, you need to record your body weight before and after as many of your long runs as you can. Weigh yourself at the last minute before going out, after that last-minute visit to the toilet. It is best to do this without any clothes, as even a vest and shorts can soak up a lot of sweat and make you seem heavier after the run than you really are.

Weigh yourself as soon as you get back again and note the two measurements in your training diary. (You do keep a training log, don't you? At any rate you should if you are at all serious about training.) You should also log the approximate distance and duration of the run, and perhaps also how you felt while running. Make a note, too, of whether you were wearing T-shirt and shorts or full tracksuit, hat and gloves.

If you have had anything to drink during the run, you need to know how much and add it to the amount of weight lost. Kitchen scales are perfectly good for weighing your drinks bottle. However, if you use a bottle with calibration marks on the side, you don't need to weigh it at all. You'll soon get the hang of this weighing and measuring, and once it is part of your routine it should be no inconvenience at all.

The sums are much easier to calculate if you work in kilograms and litres rather than pounds and pints, since 1kg of weight loss is roughly equal to one litre of sweat, while 1lb of weight loss is four fifths of a (standard British) pint. There are some errors in these calculations, as you will also be using up some stored fuels in the form of carbohydrate and fat, but these can be ignored with no great loss of accuracy.

'Once you know what your sweat losses are likely to be in a particular set of conditions, you can plan for race day'

Another thing to note is the weather conditions. Your local paper will give you the temperature for the previous day, so you can look this up and add it to your other measurements. Ideally, you should also note the humidity (information available from your nearest weather station and on the internet). How much effort you put into gathering this data will depend on how serious you are about going for that performance on race day.

After a few weeks, you should begin to see some patterns emerging. You will probably lose more weight (sweat) on longer runs, when you run faster, or when the weather is warmer or more humid. You can get rid of the first of these sources of variability by calculating your sweat rate per hour. This may be as little as 200-300ml or as much as 2-3 litres, depending on your physiology, your running speed, clothing and conditions. If you collect enough measurements, you should be able to allow for each of these factors and get an idea of how much you should be drinking in any given set of conditions.

Once you know what your sweat losses are likely to be in a particular set of conditions, you can plan for race day. You know the distance, you know how fast you plan to run and you have seen the weather forecast. That's all you need to know in order to plan your drinking strategy.

Two hypothetical examples

Let's take a look at how this might work in practice, using two different hypothetical examples:

1. You weigh 70kg and you plan to run for three hours at a temperature of 20°C. You know that you sweat about 1 litre per hour at this pace and temperature, so you can expect to lose about three litres of sweat. Because you want to lose no more than about 2-3% of your body weight – that's 1.4-2.1kg, or 1.4-2.1 litres of fluid – you should aim to drink something between 900ml and 1.6 litres during the race. That's about 300-500 ml per hour, rather less than most of the recommendations suggest and probably a lot more comfortable.
2. You weigh 60kg and plan to run 10 miles in about 62 minutes on a hot day (about 25°C). You will sweat about 2.2 litres in that hour. A 2-3% loss in body weight represents 1.2-1.8 litres of fluid, so you should plan to drink about 400-1,000ml. This is a wide range, and you can probably opt for something near the lower end of it.

See, it's not really so difficult after all!

Ron Maughan

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Half-time hydration and refuelling for maximum fulltime performance

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

At a glance:

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

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

The traditional approach to half-time nutrition usually involves a cup of tea and a slice of orange, and like many nutritional practices that have stood the test of time, this almost certainly has some merit. Similarly, other foods such as high-carbohydrate cakes, confectionery and even jelly babies have been advocated because they contain useful energy. Some scientific papers have even recommended snacks like pretzels because they contain high levels of sodium[1].

'Some scientific papers have even recommended snacks like pretzels because they contain high levels of sodium!'

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

So what are the main factors to consider when planning nutrition in the half-time interval? Since the first World Congress on the Science of Football was held at Liverpool in 1987, there has been much published research on the physical demands of football and other team sports, and the nutritional status of participants. Fluid, electrolyte and carbohydrate needs have been studied during training and in match simulations, as well as the effects of dietary manipulations on

Inappropriate and devious strategies...

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

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

sport-specific skills. Fatigue has been observed as a transient phenomenon during matches and general performance declines towards the end of matches. However, the underlying factors responsible for fatigue during football are still not fully understood[3,4].

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

Physical demands of team sports

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

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

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

'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'

carbohydrate depletion, associated with reduced exercise capacity and poor concentration – effects that may be compounded by dehydration. Both dehydration and muscle glycogen depletion have been associated with injury and accidents, so efforts to prevent these affecting performances could have repercussions well beyond the immediate match.

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

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

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

The impact of carbohydrate supplementation during the half-time interval could well depend upon the prior eating habits of the player. Similarly, the rehydration needs, and therefore the efficacy of half-time rehydration strategies, will depend on the pre-game hydration status as much as the playing conditions and player work rates. Researchers from Pennsylvania State University recently investigated the effect of dehydration and rehydration on basketball skill. Urine tests showed that some subjects taking part in the experiment were already dehydrated when they arrived at the experiment venue, even though they had been encouraged to stay well hydrated the day before each trial[10].

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

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

Just enough and no more

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

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

While dehydration resulting in a loss of body mass of 2% or greater can result in reduced endurance exercise capacity, and sprinting and sport-specific skills can be adversely affected by losses of 3% or more[3,10], players are able to tolerate a level of dehydration. There's no merit in encouraging players to consume more fluid than required to maintain performance, because this would be the equivalent of sending players out with a weight vest! However, any change in body mass should not be calculated by the difference between that immediately prior to the match and half-time, but instead baseline body mass should be established by early morning measurements taken before any carbohydrate loading has taken place[13].

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

Individual differences

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

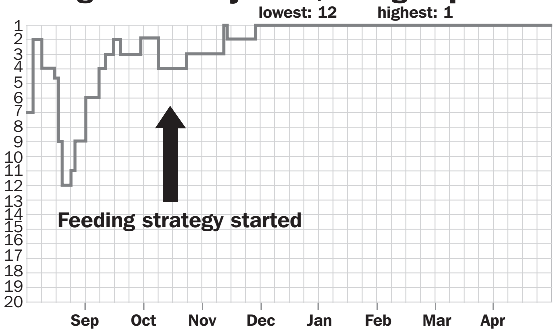
Nutrients, especially electrolytes, may prevent fatigue and reduce muscle cramps in the second half. The most important electrolyte lost in sweat is sodium and research has shown a wide individual variation in sodium losses – as low as the equivalent of 1g of salt to over 6g in 90 minutes. Assuming that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

However, 6g is the suggested total maximum daily salt allowance recommended by the UK Food Standards Agency and there has been considerable pressure from the government

CASE STUDY

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

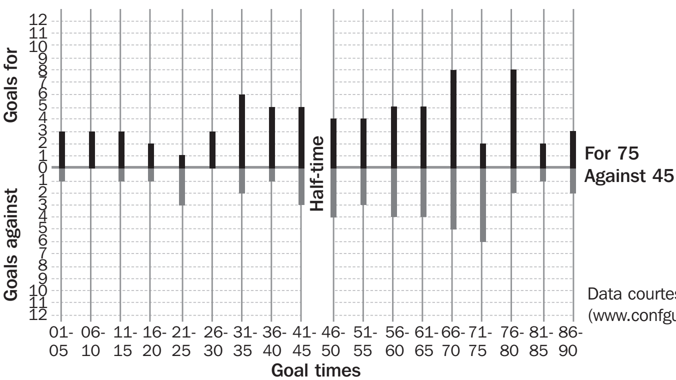
Accrington Stanley 2005/6 league position



Data courtesy of Confguide (www.confguide.com)

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

Goal times (minutes) and numbers 2005/06



Data courtesy of Confguide (www.confguide.com)

‘Research on many games players suggests that the status of other nutrients is often poor, and minerals such as zinc, magnesium and calcium (found as electrolytes in sweat) and other minerals such as iron may be sub-optimal prior to matches’

for food producers to reduce the amount of sodium in food[14]. It is not clear if ‘high sodium sweaters’ are so because they consume a high-sodium diet or for other reasons. It is clear, however, that sweat losses of 6g in 90 minutes cannot be sustained unless consumption is increased beyond the current recommended daily maximum. Unseasonably hot weather and reduced sodium foods may combine to leave players potentially short of this important electrolyte.

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

Half-time carbohydrate

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

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

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

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

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

Tim Lawson

Summary

Do

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

Don't

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

Jargon buster

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

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Glycerol – can it enhance hot weather endurance performance?

One of the surprise results of the Athens 2004 Olympic Games was American Deena Kastor's bronze in the women's marathon. Afterwards it was revealed that she had imbibed a glycerol solution as part of her pre-race preparation in a bid to enhance and maintain hydration in the scorching heat of Athens. Was this a factor in her success? Can it really help athletes to keep hydrated? How does it work – and are there any downsides to its use?

At a glance:

- The scientific theory of the potential benefits of glycerol ingestion is explained;
- The evidence for and against the use of glycerol to enhance sports performance is assessed;
- Conclusions are drawn and recommendations for athletes are made.

Glycerol is a 3-carbon molecule, which is produced naturally in the body as a result of normal metabolism. Although classed as an alcohol, glycerol plays a number of important roles in the body. For example, phosphoglycerides, which consist of a glycerol backbone bonded to two fatty acid chains and another alcohol, are an important component of cell membranes. Glycerol is also used to store fatty acids in the body; in this process, three fatty acid chains are chemically bonded to a glycerol molecule – hence the term 'triglyceride'.

Pure glycerol is a sweet-tasting clear syrupy liquid which, when mixed with water solutions, is able to increase their concentration or, more technically, their osmolarity. Because the human body requires the osmolarity of body fluids to remain fairly constant, ingesting glycerol stimulates the absorption and retention of water in order to counter the increase in osmolarity that would otherwise occur.

To put it another way, ingesting a solution of glycerol and water allows the ingested water to be retained by the body and excreted only when the extra glycerol is either removed by the kidneys or broken down by the body[1]).

'A solution of glycerol and water allows the ingested water to be retained by the body and excreted only when the extra glycerol is either removed by the kidneys or broken down by the body'

Endurance athletes competing in hot and humid conditions need to maintain maximum hydration, since fluid losses of as little as 1.5 litres can significantly impair performance. Moreover, studies have shown that many athletes do not drink enough to offset dehydration during competition, even with unlimited access to fluid[2].

A temporary state of hyper-hydration can be achieved by drinking lots of water in excess of the body's needs. However this situation is very transitory because the consequent fall in osmolarity stimulates the kidneys to remove most of the excess water within an hour, requiring frequent trips to the loo, which are not exactly conducive to fast race times!

However, adding glycerol to the water prevents this drop in osmolarity and can prolong the period of hyper-hydration for up to four hours, which explains its use by athletes seeking to enhance endurance performance in hot weather conditions[3].

On the face of it, increasing and maintaining hydration levels in endurance athletes seems a sure-fire way of enhancing hot weather performance. And there is no doubt that ingesting glycerol solutions does increase water retention by anything up to a litre[4,5]).

The question is, however, whether this increased hydration translates directly into superior hot-weather performances. And this is where things start to get a bit less clear.

Glycerol v orange juice

A study carried out in 1990 investigated whether glycerol hyper-hydration altered sweating, regulation of body temperature and cardiovascular function during exercise in a hot environment

(42°C and 25% relative humidity)[3]. Six averagely fit people completed three 90-minute runs at around 60% of their VO2max after drinking either orange juice, diluted orange juice or glycerol solution.

After glycerol ingestion, subjects produced, on average, 500ml less urine and retained 700ml more total body water than those in the no-glycerol groups. Glycerol-treated subjects also sweated more and had smaller increases in core temperature throughout the 90 minutes of exercise. However, the small sample size and the relatively low work rate used in the trial means its results should be interpreted with caution.

Two subsequent studies examined the effects of glycerol ingestion in 11 subjects of moderate-to-high endurance fitness[6]. Over a 90-minute period, the subjects consumed either a glycerol solution or a placebo drink; then, an hour later, they cycled at 74% of their VO2max until they could not maintain their pedalling cadence above 60rpm (revolutions per minute).

As expected, glycerol intake increased pre-exercise body water by 730ml and decreased excreted urine volume by 670ml. But, more importantly, subjects who had taken glycerol exercised significantly longer to fatigue, averaging around 94 minutes compared with just 73 minutes for those on placebo.

The researchers then went on to look at whether these positive effects were still evident when carbohydrate was ingested at the same time, as would be the case for most athletes during prolonged endurance events. Seven highly trained endurance athletes completed the same trial described above, but this time the subjects in both groups also consumed a 5% glucose solution at the rate of 3ml per kg of body weight every 20 minutes.

Analysis of the results showed that, while the glycerol solution still led to the retention of more body water, it was now just 100ml more than for those on placebo. Similarly, the difference in excreted urine volume was reduced to 92ml. Nevertheless, glycerol still prolonged the time taken to reach fatigue (123 minutes compared with 99 for those on placebo!).

Other studies have cast doubt on the efficacy of glycerol, with two subsequent investigations failing to find any significant benefits[4,7]. However, both of these studies used very gentle exercise intensities (around 50% VO2max), which makes their results less relevant to athletes. An earlier study also showed no benefits, but as well as using a low exercise intensity (50% VO2max), this one also lacked a pre-exercise hyper-hydration procedure, which makes its results fairly meaningless[8].

On balance, this early research comes down firmly in favour of glycerol. More recent research, however, is rather less clear-cut. Benefits were observed in a study of six endurance-trained cyclists, who ingested either a glycerol solution or the same volume of placebo two hours before undertaking 90 minutes of steady state cycling at 98% of lactate threshold in dry heat (35°C, 30% relative humidity)[9]. The cyclists were also allowed to ingest a carbohydrate drink (6% solution) at 15-minute intervals during the ride. Afterwards, they cycled for a further 15 minutes while their power outputs were assessed.

‘While early research favours glycerol, more recent findings are rather less clear-cut’

As expected, pre-exercise urine volume was lower when taking glycerol solution and heart rate was also significantly reduced. And, although the researchers failed to find any significant metabolic differences (such as lactate accumulation) between the glycerol and placebo groups, the work performed in the 15-minute assessment period was 5% higher in those taking glycerol.

Another, arguably more relevant, study on triathletes also found benefits with glycerol use[10]. Seven male and three female triathletes completed two Olympic-distance triathlons two weeks apart, one on a hot day (30.5°C) and the other on a warm day (25° C). The triathletes were randomly assigned to consume either a glycerol solution or placebo, plus a carbohydrate solution in both cases , over a 60-minute period, two hours before each triathlon.

Although there were no significant differences in sweat loss between the glycerol and placebo conditions, glycerol-supplemented triathletes excreted a smaller volume of urine and subsequently retained more fluid than those on placebo.

More importantly, however, athletes on placebo performed significantly worse under hot conditions than those on glycerol by comparison with their performances under warm conditions. The average extra time taken by placebo triathletes in hot weather was 11 mins 40 secs, compared with just 1 min 47 secs extra for those on glycerol.

Protection from the heat

The researchers also discovered that most of this performance improvement occurred during the final 10k run leg of the triathlon on the hot day. And they concluded that glycerol hyper-hydration may provide some protection against the negative effects of competing in the heat.

However, two studies on glycerol and performance published last year came to rather less positive conclusions. The first compared glycerol and water hydration regimens on tennis performance[11]. Eleven male subjects completed two trials, each consisting of three phases:

1. Hyper-hydration with or without glycerol over 2.5 hours;
2. Two hours of exercise-induced dehydration;
3. Rehydration with or without glycerol over 90 minutes.

In the second trial, those who had taken glycerol reverted to water alone and vice versa. After each phase, subjects completed 5m and 10m sprint tests, a repeated-effort agility test, and tennis skill tests.

As expected, glycerol hyper-hydration increased fluid retention (by around 900ml) by comparison with placebo. However, the exercise-induced dehydration resulted in similar losses of weight (from fluid loss) in both groups. Despite the fact that this loss was modest (less than 3%), the measured sprint times were significantly slower for both groups after phase 2 than after phases 1 and 3, while there were no significant differences between groups for the agility and tennis skill tests.

The researchers concluded that, while the glycerol regimen provided better hydration status than placebo, this was not reflected in performance benefits.

Another study conducted last year set out to compare the effectiveness of glycerol and water hyper-hydration in cyclists working under hot, humid conditions[12]. Seven moderately-to-well trained subjects ingested either a glycerol solution or the same volume of placebo 2.5 hours before a race-simulation exercise, in which they cycled as far as possible over a 60-minute period. While the glycerol group sweated more during the trial, there were no significant between-groups differences in core temperature, power output and total distance cycled.

Although there appears to be conflicting evidence about the performance benefits of glycerol hyper-hydration, you might think it fair to assume that it definitely enhances water retention.

However, a recent Canadian study reported on a trained triathlete who retained more water with water alone than with glycerol[13]. The researchers postulated that this might have happened because the plain water was integrated into the body fluid pools more slowly than the glycerol solution. With just one subject, it is difficult to draw firm conclusions, but this study suggests there are some people who respond unusually to glycerol administration, and this may help to explain why some glycerol studies have drawn a blank.

‘Overall, the current weight of evidence is tilted in favour of glycerol, but only in events where substantial dehydration is likely to be a problem’

It is fair to say that, for most athletes, imbibing a glycerol solution does produce an increase in total body water. What is less clear is whether this actually enhances performance. This is partly because we don’t fully understand how glycerol works in the body. We do know that the kidneys don’t excrete glycerol rapidly so that it stays in the body and holds water with it. But more research is needed to find out whether glycerol works by increasing the amount of fluid inside cells or in the circulation.

No consensus on glycerol usage

Overall, the current weight of evidence is tilted in favour of glycerol, but only in events where substantial dehydration is likely to be a problem – *ie* long, strenuous events in hot and humid conditions. However, there is no consensus on the best way to take glycerol solution, or on whether certain kinds of plain water hyper-hydration protocols might offer similar benefits.

So should you take glycerol? Unless your event is long and due to take place in hot/humid conditions, resulting in unavoidable dehydration, there is probably little point. The evidence also suggests that taking glycerol before less vigorous events is not particularly worthwhile.

And where the benefits are likely to be marginal, you should also be aware that glycerol ingestion is associated with such side effects as stomach upsets, headaches and blurred vision at higher doses. If you are tempted to try glycerol, make sure you've tried proper hydration strategies using good old water or fluid replacement drinks first! Glycerol should be considered as a last resort, not the first.

If you do decide to try glycerol, you might like to use the protocol that produced significant hyper-hydration in one of the studies mentioned above[5]. Bear in mind, though, that it involves drinking nearly two litres of fluid, which will lead to a weight increase of 3% for a 70kg athlete and 4% for one weighing 50kg! If you're a runner, you may find that this extra mass outweighs, quite literally, any potential performance benefits!

Here is Montner's glycerol ingestion protocol, beginning 150 minutes (2.5 hours) before exercise:

- l0 minutes – drink 5ml per kg of your body weight of a 20% glycerol solution (1 part glycerol to 4 parts water);
- l30 minutes – drink 5ml/kg of water;
- l45 minutes – drink 5ml/kg of water;
- l60 minutes – drink 1ml/kg of a 20% glycerol solution and 5 ml/kg of water;
- l90 minutes – drink 5ml/kg of water;
- l150 minutes – begin exercise.

Andrew Hamilton

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Caffeine and alcohol – just how dehydrating are they?

Do you do drugs? Think long and hard before you answer, because the answer is, very probably, yes! Like it or not, alcohol and caffeine are drugs that most of us consume regularly as part of our diet. Like all drugs, they have side effects, one of which is common to both – a 'diuretic' (water-loss) effect. But how strong is this effect, and is a diet containing these drugs detrimental to the goal of optimum hydration?

At a glance:

- The physiological effects of caffeine and alcohol in the body are outlined;
- Research into their effects on hydration, both before and after exercise, is summarised;
- Recommendations for athletes wishing to maintain optimum hydration status are made.

Trimethyl xanthine (more commonly known as caffeine) belongs to a family of naturally occurring compounds found in a number of plants. The most common sources of caffeine in western diets include coffee, tea, cocoa and its derivatives (such as chocolate), and kola nuts. Caffeine is also added to a number of carbonated beverages, particularly cola drinks.

Part of the reason for the popularity of caffeine-containing beverages is that caffeine is a central nervous stimulant. Caffeine blocks the binding to nerve cells of a substance called adenosine, which normally acts to slow down nerve cell activity. The resulting increased nerve activity stimulates the release of the hormone epinephrine (adrenaline) which, in turn, leads to such effects as increased heart rate and blood pressure, increased blood flow to muscles and the release of glucose by the liver. Caffeine also increases brain levels of the neurotransmitter dopamine, which is involved in cognitive (thinking) processes, alertness and memory.

'Like it or not, alcohol and caffeine are drugs that most of us consume regularly'

Caffeine is popular with athletes for a very different reason – it appears to enhance performance (especially endurance performance). The exact mechanism remains unclear, but its ergogenic properties may be linked to a reduced rate of muscle glycogen consumption during the initial stages of exercise, a lower perceived rate of exertion (making strenuous efforts feel easier), or its adrenaline-like effects, which stimulate more calcium to enter muscle cells during contractions, thus boosting the potential power of muscular activity.

However, a possible downside to caffeine use is its diuretic effect, because at higher doses caffeine is known to promote some water loss, due partly to increased blood flow to the kidneys and partly to reduced reabsorption of sodium by the body. However, this diuretic effect is also governed by the concentration of caffeine in any given drink. For example, an

Typical caffeine content of common consumables

(Approximate figures, depending on preparation methods)[1,2]

Item	Caffeine content
Chocolate	
Bittersweet	25mg/oz (875mg/kg)
Milk	3-6mg/oz (100-210mg/kg)
Cocoa	0.5mg/fl oz (17mg/litre)
Coffee	
Brewed (drip)	4-20mg/fl oz (130-680mg/litre; 40-170mg/5fl oz cup)
Decaffeinated	0.4-0.6mg/fl oz (13-20mg/litre)
Instant	4-12mg/fl oz (130-400mg/litre)
Espresso	100mg/fl oz (3,400mg/litre)
Cola/carbonated drinks	
Coca Cola classic	34mg/12fl oz can (100mg/litre)
Diet Pepsi	36mg/12fl oz can (105mg/litre)
Red Bull	80mg/8.3fl oz can (337mg/litre)
Teas/other infusions	
Black tea, brewed (USA)	2.5-11mg/fl oz (85-370mg/litre)
Black tea, brewed (other)	3-14mg/fl oz (100-470mg/litre)
Black tea, canned iced	2-3mg/fl oz (70-100mg/litre)
Black tea, instant	3.5mg/fl oz (120mg/litre)
Green tea	2.5mg/fl oz (85mg/litre; 8-30mg per tea bag, *ie* one serving)
Decaffeinated tea	0.5mg/fl oz (17mg/litre; 1-4mg per tea bag, *ie* one serving)

espresso coffee provides around 100mg of caffeine in just 50ml of water, but you'd have to drink around a litre of weak black tea to obtain the same amount of caffeine, significantly hydrating your body in the process!

How detrimental is caffeine to hydration in athletes? An early study on the effects of high-dose pre-exercise caffeine ingestion found no significant impact on hydration[3]. In a double-blind trial, trained runners exercised to exhaustion on a treadmill at 70-75% of VO2max on two separate occasions under the following conditions:

1. After taking high-dose caffeine tablets, administered at the rate of 5mg per kg of body weight, two hours before exercise, followed by 2.5mg per kg 30 minutes before;
2. After taking placebo tablets.

Venous blood samples were taken every 15 minutes during exercise, and afterwards water loss and sweat rates were calculated from the difference between pre- and post-exercise body weight. The researchers found that, by comparison with placebo, caffeine ingestion produced no significant difference in plasma volume, sweat rate or overall water loss.

Conflicting findings

These findings appear to conflict with those of a more recent study on coffee and hydration[4]. Twelve healthy volunteers were asked to abstain from caffeine for five days and then follow a standardised diet for the next two days. On day one of the standardised diet, their fluid requirement was met purely by mineral water; the next day they received the same total amount of fluid, but with the mineral water partly replaced by six cups of coffee containing 642mg of caffeine. This regime led to an increase in 24-hour urine excretion, leading to a negative fluid balance and a concomitant decrease in body weight of around 0.7kg.

The researchers also measured total body water (using a technique called bioelectrical impedance analysis) and found it had decreased by 2.7%, while urinary excretion of sodium and potassium increased by 66% and 28% respectively.

The results of this study should be interpreted cautiously by athletes, for the following reasons:

- The five-day caffeine 'washout' period was an artificial device which regular caffeine users would not normally use;
- There was no control group, so the fluid losses could have arisen from other factors, such as the standardised diet;
- The study included no exercise component.

A similar study considered the effects on hydration of different levels of caffeine consumption[5]. Eighteen healthy men consumed each of four different drinks: pure water, water plus cola, water plus diet cola and water plus coffee. Body weight, urine output and blood samples were measured before and after each treatment, and there were no significant differences in the effect of the various combinations of beverages on hydration status.

The researchers concluded that their results did not allow them to support the standard advice to 'disregard caffeinated beverages when calculating daily fluid intake'. To put it another way, cutting out caffeinated drinks in order to improve hydration may well be counterproductive unless such drinks are replaced by an equivalent volume of non-caffeinated drinks.

Further evidence that caffeinated drinks aren't the villains they are sometimes made out to be comes from two studies carried out last year. The first studied the effect of tea on hydration in 13 members of expeditions based at Mount Everest base camp – at an altitude of 5,345m[6]. Hydration is a particular problem at such altitudes because of a phenomenon called 'altitude diuresis', whereby large amounts of water are lost via the lungs because of the very low air pressure and temperatures.

Two 24-hour trials were conducted: a 'tea' condition, in which hot brewed tea formed a major part of fluid intake, and a 'no-tea' condition, where tea was excluded from the diet. All subjects were denied other caffeinated beverages, foods and alcoholic drinks. Analysis of the results showed that tea made no difference to urine output or other markers of hydration status. In fact, the only reported difference was in mood, with tea-drinking subjects reporting significantly reduced fatigue!

'Drinking tea made no difference to urine output or other markers of hydration status. In fact, the only reported difference was in mood, with tea-drinking subjects reporting significantly reduced fatigue!'

The second study looked at the effects on rehydration of caffeinated beverages consumed during the recovery period after strenuous workouts in the heat[7]. Ten partially heat-acclimatised athletes completed three successive days of twice-daily two-hour practices in warm conditions (23°C). In a double-blind cross-over design, the athletes rehydrated either with Coca-Cola (containing 100mg of caffeine per litre) or the decaffeinated variety. Although urine was a darker colour at one point with the caffeinated cola, all other measures of hydration status, including urine output, body weight and total body water were similar. The researchers found little evidence to support the idea that caffeinated drinks have an adverse effect on hydration during post-exercise recovery.

Alcohol and hydration

Alcohol, technically known as ethyl alcohol or ethanol, has been around for a long, long time. Prehistoric man discovered that the fermentation of fruit and vegetables produced alcohol and believed it had therapeutic properties. As civilisation spread, so did the use of alcohol. But it was only comparatively recently that the side effects and toxicity of alcohol were fully understood.

Although small amounts of alcohol are known to reduce the risk of coronary heart disease and facilitate social interaction by promoting relaxation and lowered inhibition, the possible effects of excessive intakes are now known to include cancers of the mouth, larynx and oesophagus, liver damage, high blood pressure, diabetes, stroke, mental disorders, lowered immunity, reduced fertility and sexual performance, social and domestic problems, poor work performance and an increased risk of accidents and injuries.

Problems connected with alcohol use now affect as many as eight million people in the UK alone – and this number is rising. Almost one-in-three adult men and nearly one-in-five women now drink more than the recommended limits of 14-21 weekly units for women and 21-28 for men. While it is unlikely that health-conscious athletes or fitness enthusiasts would exceed these limits, there is still a performance issue with lower doses of alcohol: hydration.

How alcohol dehydrates

Alcohol promotes water loss by depressing production of the antidiuretic hormone called vasopressin, which acts on the kidneys, concentrating the urine by promoting the reabsorption of water and salt into the body. Vasopressin helps to regulate the concentration of fluids in the body, and interference with its action leads to an increased loss of body fluid from urination, which can contribute towards dehydration. To make matters worse, alcohol-induced water loss can lead to the additional loss of such minerals as magnesium, potassium, calcium and zinc, which are not only important nutrients but are also involved in the maintenance of fluid balance and nerve and muscle action.

'By contrast with caffeine, the evidence on alcohol and hydration is quite damning'

Although alcohol use beyond the recommended limits is known to be detrimental to health (and thereby to athletic performance), what evidence is there that sensible use has any ill effects? In particular, can alcohol use impair hydration status? By contrast with caffeine, the evidence is quite damning.

A UK study examined the effect of alcohol consumption on the restoration of fluid and electrolyte balance after exercise-induced dehydration[8]. In four separate trial conditions, six subjects consumed drinks containing 0, 1, 2, and 4% alcohol over 60-minute period, beginning 30 minutes after the end of a dehydrating exercise session. Although a different beverage was consumed in each condition, the volume remained constant at just over two litres (equivalent to 150% of body mass loss during exercise – the amount recommended for efficient hydration).

The researchers found that the total volume of urine produced in the six hours after rehydration tended to increase in line with the alcohol content of drinks. Furthermore, the increase in blood and plasma volume during this rehydration period was markedly slower with the 4% beverage and did not ultimately rise significantly above the dehydrated level! The researchers concluded that while alcohol has a negligible diuretic effect when consumed in dilute solution (2% or less), drinks containing 4% or more of alcohol tend to delay the recovery process.

Another study investigated the effects of alcohol on pulse rate and blood volume during orthostatic tilting (changing from lying down to an upright posture)[9]. Ten men and as many women drank non-alcoholic beer mixed with either alcohol (1.1g per kg of body weight) or an equivalent volume of water. Pulse rate, blood volume and blood alcohol concentration were monitored for the next eight hours, and the alcohol group were found to develop a significant relative fluid deficit, beginning two hours after ingestion and averaging 0.5 litres by three hours.

Further evidence of the detrimental effects of alcohol on hydration comes from a more recent study examining the effects of alcohol after a cycle ergometer test[10]. Eleven active men cycled on the ergo and one hour later drank either alcohol (0.7g per kg of body weight) mixed with flavoured water or an equivalent volume of flavoured water alone (placebo). Measurements of a range of blood markers were taken at one, five and 22 hours.

As expected, both groups showed a drop in plasma volume after training, but this had been restored in both groups an hour after the drinks were consumed. The alcohol group (unsurprisingly) experienced a big rise in blood alcohol after their drink, but after five hours, their blood alcohol levels had fallen back to zero.

However both groups were also tested for blood viscosity (stickiness). After cycling, viscosity was raised in both groups (probably through dehydration), but while the viscosity steadily returned to normal levels in the placebo group, levels in the alcohol group remained raised, even at 22 hours, despite the fact that their plasma volume values had returned to normal. In other words, although the alcohol had left the bloodstream and hydration appeared normal in terms of blood plasma volume, the blood of those who had consumed alcohol during the recovery phases was still behaving as though the body was dehydrated! The implication is that alcohol during post-exercise recovery may have longer lasting effects than simply impairing rehydration.

‘Alcohol during post-exercise recovery may have longer lasting effects than simply impairing hydration’

In conclusion…

Caffeine and alcohol are widely-used drugs, and it's not hard to understand why. They are pleasurable to consume, and not at all bad for health in moderate doses. Tea and cocoa beans are stuffed to the brim with health-protecting antioxidants, as is red wine! Moreover, small amounts of alcohol are believed to reduce the risk of coronary heart disease.

But what of their effects on hydration? When it comes to caffeine, the oft-repeated advice to cut out caffeinated drinks to boost hydration seems well wide of the mark. Not only is there scant evidence that drinks containing even moderate levels of caffeine exert a diuretic effect, but cutting out these drinks and not replacing them with at least an equivalent volume of non-caffeinated beverages would actually lead to poorer hydration.

Normal-strength tea and coffee therefore appear to be perfectly acceptable either before or after exercise, although you should remember that sodium/electrolyte drinks may be a better strategy after strenuous exercise in the heat. The only caveat is that if you habitually abstain from caffeine, suddenly introducing it in the form of strong drinks may exert a mild diuretic effect.

The post-exercise use of alcohol is more problematical, and the evidence suggests that, unless you consume very weak alcoholic drinks (2% by volume or less), alcohol should be completely avoided until you are fully hydrated. And because alcohol takes 36 hours to completely clear the system, athletes should refrain from its use for at least 48 hours before an event.

If you do find yourself in a situation where drinks are flowing, drink weak beers for preference, avoid wine and spirits and aim to consume one soft drink for every alcoholic one.

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Carbohydrate drinks – can fructose enhance hydration and endurance?

Despite the numerous claims to the contrary by the sports nutrition industry, real advances in sports nutrition are comparatively rare. But recent research into carbohydrate absorption and utilisation is heralding a new breed of carbohydrate drink, which promises improved hydration and genuinely enhanced endurance performance.

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 hydration and endurance benefits of mixed carbohydrate drinks containing fructose is presented;
- Recommendations for endurance athletes are made.

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 is oxidised. That's

‘Given that stores of precious muscle glycogen are limited, can ingesting carbohydrate drinks during exercise help offset the effects of glycogen depletion by providing working muscles with another source of glucose?’

important because the amount of oxygen available to working muscles isn’t unlimited – it’s determined by your maximum oxygen uptake (VO2max).

Secondly and more importantly, unlike fat (and protein), 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 right carbohydrate loading strategy can maximise glycogen concentrations, which can extend the duration of exercise by up to 20% before fatigue sets in[1]. Studies have shown that the onset of fatigue coincides closely with the depletion of glycogen 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 can oxidise 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 glycogen stores beforehand.

Given that stores of precious muscle glycogen are limited, can ingesting carbohydrate drinks during 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 little positive 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 that ingested carbohydrate in such drinks actually contributed little to energy production in the working muscles[4].

Later that decade, however, it became clear that carbohydrate ingested during exercise can indeed be 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 litre of water) carbohydrate solution per hour[8-11]. More importantly, 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 can delay the onset of fatigue during prolonged cycling and running as well as improving the power output that can be maintained[12,13].

Drink formulation

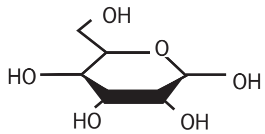
The research findings above have helped to shape the formulation of most of today's popular carbohydrate drinks. Most of these supply energy in the form of glucose or glucose polymers (see box right for explanation) at a concentration of around 6%, to be consumed at the rate of around 1,000mls per hour, so that around 60g per hour of carbohydrate is ingested. Higher concentrations or volumes than this are not recommended because not only does gastric distress become a problem, 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 over 1,200kcals 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 in 2006 by scientists at the University of Birmingham in the UK indicates that this may indeed be possible.

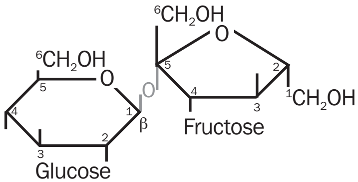
CARBOHYDRATE BUILDING BLOCKS

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.

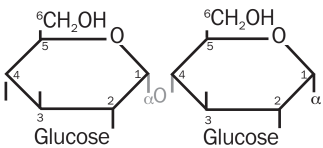
Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is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



GLUCOSE



SUCROSE (TABLE SUGAR) = GLUCOSE + FRUSTOSE



MALTOSE ('BREWERS SUGAR') = GLUCOSE + GLUCOSE

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 any advantage[3].

But, at about the same time, a Canadian research team were experimenting with giving mixtures of two different sugars (glucose and fructose) to cyclists. In one experiment cyclists pedalled for two hours at 60% of VO2max while ingesting 500mls of one 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-13 so the researchers could see how well they were absorbed and oxidised for energy by measuring the amount of carbon dioxide containing carbon-13 exhaled by the cyclists (as opposed to unlabelled carbon dioxide, which would indicate oxidation of stored carbohydrate). The key finding was that 100g of the 50/50 glucose fructose mix produced a 21% 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.

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.

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 drank 1,950mls 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).

The results showed that while the pure glucose and glucose/maltose drinks produced an oxidation rate of 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 on page 68)*, 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 was being 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 opposite)*.

The 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 (*eg* in 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 (1.0g glucose/ 0.5g fructose);
- Water (control).

'The rate of water uptake from the gut into the bloodstream was significantly higher with glucose/ fructose than with pure glucose'

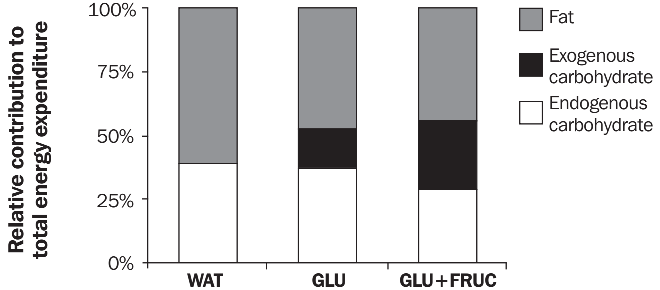
The water used in the drinks was also radio-labelled (to help determine uptake into the bloodstream) and the cycling trials were conducted in warm conditions (32°C) to add heat stress. Exercise in the heat results in a greater reliance on carbohydrate metabolism, which is thought to be due to increased muscle glycogen utilisation, and is associated with higher levels of fatiguing lactate concentrations.

There were a number of important findings from this study:

- During the last hour of exercise, the oxidation rate 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 (*ie* stored) 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 with pure glucose.

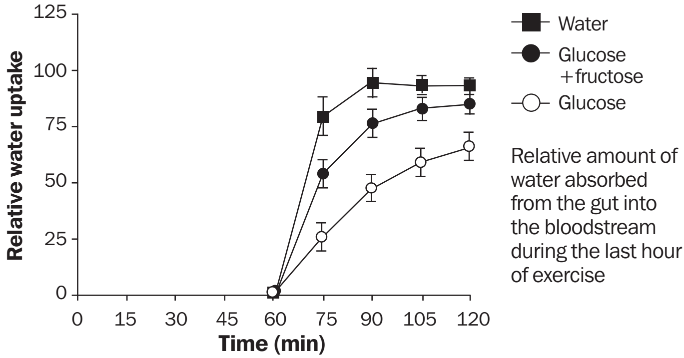
Although no direct muscle glycogen measurements were made, the kinetics of the rate of appearance and disappearance of

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

glucose in the bloodstream from the drinks led the researchers to postulate that the extra carbohydrate oxidation observed could be as a result of increased liver oxidation, or the formation of non-glucose energy substrates during exercise, such as lactate, which is known to be an important fuel for exercising muscles. More research is needed to determine the exact mechanisms involved.

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?

That's the question scientists at the University of Hertfordshire are currently trying to answer in a double-blind, placebo controlled study to test commercially available drinks, which was set up earlier this year. The main goal is to compare the effects on cycling performance of a popular glucose/glucose polymer (containing very low levels of fructose – ~3-4%) drink with a 2:1 glucose/fructose drink (trade name of 'Super Carbs' – 33% fructose) on cycling performance. The results of these trials are yet to be published, but according to the research team, the initial findings are 'very promising'.

Recommendations for athletes

If you're an endurance athlete, is it worth rushing out and trying to get hold of a glucose/fructose drink to use during training/competition? Despite the promising initial research, the cautious approach would be to hold back until scientists have confirmed beyond doubt that these drinks really do confer a performance advantage.

However, fructose is cheap, which means these drinks are no more expensive than conventional glucose/glucose polymer drinks; as all the indications are that any performance differences produced by a glucose/fructose drink will be positive, there's certainly no harm in a 'try it and see approach', and possibly much to gain.

Having said that, it's important to remember that conventional glucose/glucose polymer drinks can still confer proven advantages for endurance athletes when taken during training or competition; both glucose/glucose polymer and glucose/fructose drinks can boost endurance performance over using nothing at all! But should the initial findings above be confirmed, the future for glucose/fructose carbohydrate drinks looks bright.

Andrew Hamilton

Jargon buster

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 of lactate
Radio-labelled – Where a normal atom in a compound (eg glucose) is replaced by a chemically identical atom, 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 an extra neutron in the nucleus
Transporter proteins – Large molecules that sit in cell walls and assist in the transport of substances in and out of the cell
Brush-border membrane – Densely packed protrusions (microvilli) on the intestinal wall, which help maximise nutrient absorption

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Sports drinks – can you have too much of a good thing?

There's no doubt that ensuring optimum fluid and carbohydrate replenishment is vital for maximising sport performance. But while this strategy is fine for competition, some scientists are wondering whether the routine use of carbohydrate/fluid replacement drink during training could actually hinder the process of training adaptation rather than enhance it

At a glance:

- The background to sports drink use in training is given;
- The relationship between sports drink use, growth hormone release and training adaptation is explained;
- The potential implications of this relationship and how they might impact on the way we use sports drinks in the future are discussed;
- Recommendations for coaches and athletes are given.

During the last 20 years an increasing body of research literature has suggested that appropriate fluid intake is imperative to ensure good performance[1,2]. Research has also demonstrated that a 2% weight loss attributable to dehydration is the first time an individual will feel thirsty, but that this level of dehydration can be associated with a 20-30% drop in performance[2].

Given this evidence, the practice of using carbohydrate-electrolyte (sports) drinks to enhance the rate of fluid uptake by the tissues has become widely accepted – a practice for which there's also good evidence[3]. Indeed, current guidelines suggest that fluid composition should be around 2-8% carbohydrate and 10-60mM (0.58-3.48g per litre) of salt[3].

'The question posed here is whether there are any circumstances where ingesting sports drinks could actually be disadvantageous?'

Recently however, Tim Noakes has questioned the extent to which such guidelines for fluid intake are efficacious or even necessary[4]. He disputes, for example, the 'fact' that high levels of fluid intake are necessary to prevent heat stroke in athletes, describing this as a 'foundational myth'. That is, it has been stated as so by well-known, well-respected scientists and so has been automatically accepted without challenge and without good evidence to support it. Noakes further suggests that research findings which contradict the accepted wisdom do not receive as much exposure by the devotees of the 'foundational myth' so further adding to the perpetuation of the 'myth'.

Can sports drinks be disadvantageous?

There remains some disagreement about how beneficial sports drinks are, but the question posed here is whether there are any circumstances where ingesting sports drinks could actually be disadvantageous. In most situations, where maximising performance is the aim, following the normal guidelines will reduce any chance of underperformance. However, in extremely

Human growth hormone

Human growth hormone (hGH) is secreted into the general circulation from the pituitary gland in 6-12 discrete pulses per day. The most powerful non-pharmacological stimuli are sleep and exercise. High-intensity exercise (such as sprinting) results in the highest value measured in the blood but this quickly returns to baseline (resting values). High-intensity endurance efforts result in moderately high concentrations that are sustained post exercise (ie taking from 60-90 minutes to return to baseline after exercise). The exact purpose of the exercise-induced growth hormone response (EIGR) is not known. However, hGH is known to stimulate breakdown and use of fat (in the presence of cortisol) and stimulates IGF-1 release from the liver. It has also been associated with good bone health and a good exercise capacity. For all of these reasons EIGR is suggested to be of value in health and exercise and may potentiate generally positive adaptations to exercise.

hot conditions, simply drinking sports drinks ad lib could, in the medium to long term, actually cause problems.

I recall an incident with a table tennis player in just such circumstances. Over a number of days of competition in a non-air-conditioned hall in Malaysia this player was consuming around 12-15 litres of sports drink per day! At 80g per litre that means consuming an extra 1,200g of carbohydrate per day and the athlete was concerned because he appeared to be putting on weight. Clearly, in this situation, occasionally the player should have been drinking plain water and limited the amount of sports drink taken.

During training, an inadequate water intake can limit human growth hormone (hGH) secretion[5]. However, ingesting only water can also have its drawbacks. In extreme events, such as the 52-mile Comrades Marathon in South Africa, there have been reports of hyponatremia (an excessive dilution of blood sodium, which can be fatal)[4,6,7]. In a sporting context it should be pointed out that this is extreme and as such is very rare. The point here is that both extremes – only ever drinking copious amounts of water alone or copious amounts of sports drink – are unlikely to be the best thing to do, even though sports drink manufacturers would prefer the latter!

'It's possible to speculate that the ingestion of sports drinks may lead to the suppression of growth hormone response associated with exercise'

Sports drinks and growth hormone suppression

It's possible to speculate that the ingestion of sports drinks may lead to the suppression of growth hormone response associated with exercise (a bad thing) because we know that elevated levels of blood sugar can inhibit the secretion of hGH *(see box opposite)*.

The exact benefit or purpose of exercise-induced growth hormone response (EIGR) has yet to be determined. However, there are a small number of adults who have growth hormone deficiency (GHD) and can therefore provide us with an insight into some of the likely benefits of a normal hGH profile.

Those with GHD have central obesity (*ie* excess fat deposition in the abdomen), increased blood fat levels and a restricted exercise capacity. Accordingly, it is logical to assume

'Perhaps before, during and for ninety minutes after exercise, at or above lactate threshold, only water plus electrolytes should be consumed in training'

that a normal growth hormone profile is associated with, and may even directly contribute to, improvements in exercise capacity and adaptation.

From research evidence, we know that hGH does promote the use of fat as an energy source[(8)]. In addition, hGH has been demonstrated to enhance protein/muscle synthesis[(9,10,11)]. This is partly accomplished by hGH causing release of insulin-like growth factor-1 (IGF-1) from the liver[(12)] and from inhibition of myostatin, the protein that normally acts as a 'brake' to the production of more muscle than is necessary[(13)].

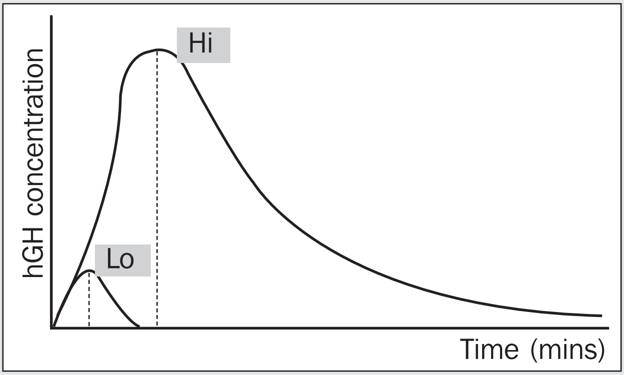
At the 1998 World Swimming Championships in Perth, Australia, a female Chinese swimmer was sent home for allegedly trying to smuggle a flask containing numerous vials of rhGH into the country. Wild speculation followed in the Australian press and much of the discussion centred around the perceived fat reducing/muscle building properties of growth hormone. However, given that it takes weeks to see any benefits of this type affecting performance, the puzzle remains as to why, within days of competition, the Chinese would want to use rhGH. In fact, a more likely explanation is that rhGH could be taken on one day and affect the way in which the muscle uses energy the next.

So how does all of this relate to sports drink intake? Well, drinking sports drinks will elevate blood glucose, and this in turn tends to halt the secretion of hGH. So perhaps, if hGH is integral to maximising adaptation to training, taking sports drinks routinely will not result in the best adaptation.

A sustainable rise in hGH secretion is seen with exercise of more than 10 minutes' duration above an intensity associated with lactate threshold[(14)] *(see Figure 1)*. So, perhaps before, during and for 90 minutes after exercise at or above lactate threshold, where the objective is to optimise training-induced adaptation, only water plus electrolytes should be consumed in training.

However, in other training conditions, and especially before, during and after competition, where the objective is to maximise performance, carbohydrate-electrolyte (sports) drinks should be used. Clearly, extremes are less desirable – eg

Figure 1: Exercise intensity and growth hormone release



Graph illustrating the work of Felsing, Brasel and Cooper (1992), demonstrating that 10 minutes or more at an intensity above lactose threshold (LT) results in a sustainable rise in hGH which then returns close to baseline 60-90 minutes post-exercise. 'Hi' represents 10 minutes of exercise at intensity equivalent to, or just above, that associated with the LT. 'Lo' represents five minutes of exercise at an intensity below LT.

always drinking only water or only sports drinks – so the aim of training should be considered when deciding which fluid to ingest. Consequently, the suggestion is that 'periodisation' of fluid intake be considered.

Periodisation

Traditionally, periodisation refers to the cycling of training intensity and duration in blocks known as microcycles (up to 14 days), mesocycles (2 weeks – 6 months) and macrocycles (6 months – 4 years). These were developed in recognition of the training principles of specificity and reversibility. In other words, 'use it or lose it'.

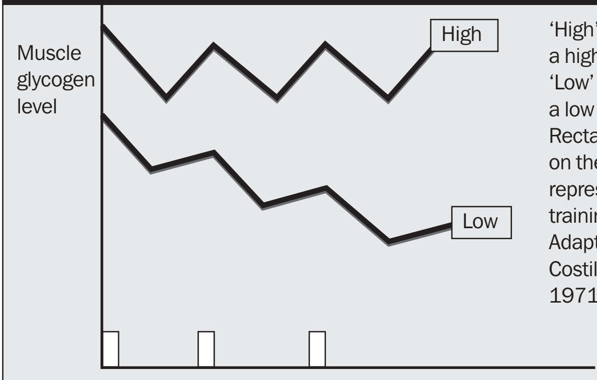
The problem is that it is not possible to train every physiological system maximally all of the time, but if a stimulus is not applied at least every two weeks then detraining can begin. So the best coaches draw up long-term plans which are of increasing detail and complexity in the short term and increasing flexibility and less detail as we move from medium to long term.

If certain foods or drinks affect the rate of adaptation then a form of periodisation could, and perhaps should, be implemented. Generally, this would be best applied with reference to the aims and objectives of individual training sessions. Currently, this is an untested speculation and only a randomised, controlled study will provide sufficient evidence that this suggestion results in an improvement in adaptation and longer-term performance.

However, adding weight to the supposition that carbohydrate should be periodised, Professor Bente Pedersen gave a lecture at the 2007 American College of Sports Medicine (ACSM) conference held in Denver, Colorado. Her lecture was entitled 'Signalling muscle to adapt – training low and competing high'. Her talk referred to mounting evidence that partially depleted muscle carbohydrate stores ensure an environment in which muscle adapts to the training stimulus more powerfully[15, 16].

This in contrast to much of the previous work in which training with partially depleted muscle carbohydrate stores has been demonstrated to be sub-optimal[17] *(see Figure 2)* and linked with the risk of unexplained underperformance syndrome (UPS)[18]. Hence there may be a case to be made for the use of training when muscle carbohydrate stores are low, but because

Figure 2: Effects of successive days of training on muscle glycogen stores



'High' refers to a high CHO diet. 'Low' refers to a low CHO diet. Rectangles on the x-axis represent training periods. Adapted from: Costill *et al*, 1971.

Twice-daily training

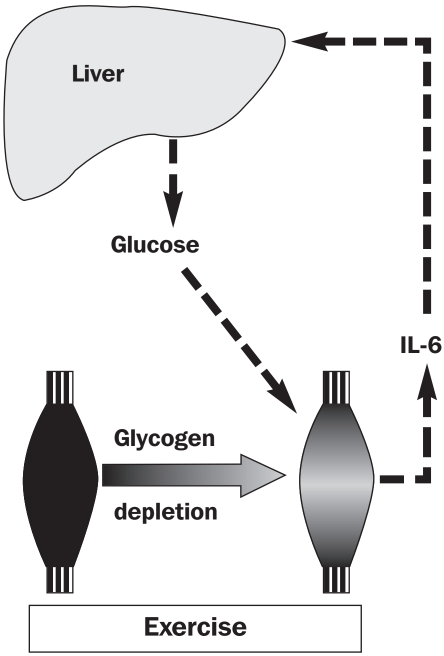
There are many interesting points raised by Professor Pedersen's ACSM presentation. Applied physiologists and coaches often attempt to induce adaptations that will enhance performance. However, understanding more of the basic science allows us to better construct the right training programmes and the right environment to get closer to optimising adaptations and maximising performance. Issues that have come out of this article include the potential benefits of training twice every second day rather than once every day. By training twice in one day, the adaptation stimulus is increased on the second occasion because muscle carbohydrate stores are low. On the following day having an easy or rest day increases the activation of genes, which can further enhance adaptation. Improved understanding also allows us to appreciate how periodisation works by applying greater specificity and avoiding detraining by getting the timing right with respect to intensity, duration and recovery.

of the known risks of UPS, such training should be used with great caution. Indeed, Pedersen quite rightly urges caution as it appears that getting the balance right has yet to happen by design so the risks are high.

More than 1,000 genes are activated by exercise and many of these regulate adaptation to training. Such diverse areas as response to stress, aerobic metabolism, anaerobic metabolism and strength are affected. Examples include genes activated in exercised muscle that have low glycogen stores such as PGC-1 (a gene that is upregulated in human muscle during recovery from exercise training) and PDK4 (a key regulator of fat oxidation in human skeletal muscle).

In addition, it is known that acute exercise increases mRNA and protein synthesis, and Professor Pedersen presented data to demonstrate that this is enhanced further in muscle that is low in glycogen. A training study was presented in which one leg was exercised hard, using single-leg cycling to partially carbohydrate-deplete the muscles of that leg. Twice daily training was then used on both legs and then a test administered

Figure 3 - Cytokine production and muscle glycogen



Schematic diagram depicting production and release of IL-6 from skeletal muscle as glycogen depletion occurs during prolonged exercise. The figure also illustrates the hypothesis that IL-6 released by contracting skeletal muscle may serve as a signal to enhance glucose production by the liver. (*From Keller et al, FASEB Journal 2001; 15:2750*)

to examine the time to exhaustion. The leg trained while having low glycogen stores took longer to become exhausted. Muscle biopsies subsequently revealed a greater increase in some oxidative genes for mitochondrial enzymes in the low-glycogen leg in comparison with the high-glycogen leg.

In addition to increased gene activation, the release of certain cytokines has been shown to be further enhanced in exercise in association with low muscle glycogen. Cytokines are factors associated with the immune system and are increasingly being demonstrated to have signalling roles – ie their release can inhibit or activate metabolic pathways in cells or tissues in various parts of the body. One such cytokine is IL-6; studies in which IL-6 is infused during exercise have demonstrated an increase in the use of fat in muscle. Muscle with sufficient carbohydrate will not release as much IL-6 hence demonstrating that a more pronounced adaptation is seen with low muscle glycogen stores *(see Figure 3, opposite)*.

Practical advice

The primary purpose of this article is to provoke thought on the issue, make athletes and coaches aware of such possibilities and alert them to this issue so they can be looking for it in the literature. Clearly there is a lot more research required and it is likely that applied scientists rather than pure scientists will find the answer. I believe it is well worth reiterating the advice above that this should not be experimented with until more is known. Athletes are only human and, as long as there is a risk, underperformance is all too likely.

The occasional use of water containing only electrolytes before, during and after training sessions may be worth experimenting with, but again let me caution coaches out there 'less is more'. My recommendation for the time being would be to attempt this no more than once per month with exercise at an intensity associated with lactate threshold and above. Athletes and coaches may also want to experiment with the practice of twice daily training every second day as another means of enhancing growth-hormone mediated adaptation.

Richard Godfrey

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Jargon buster

Exercise-induced growth hormone response – The secretion of growth hormone from the pituitary gland that occurs above a certain exercise threshold
rhGH – recombinant human growth hormone – Growth hormone which has been produced by cultured bacteria which have been genetically modified by having the gene for human growth hormone inserted into the genome
Unexplained underperformance syndrome – The more accepted term for what used to be called 'overtraining syndrome'; the name was changed because the reason for underperformance and illness associated with exercise is not known
Glycogen – The form of carbohydrate stored in muscle and liver
mRNA – A molecule transcribed from the DNA of a gene, which serves as a template and encodes the amino acid sequence of a protein
Cytokines – Substances that stimulate growth, differentiation and functional development of other cells
IL-6 – A cytokine released from a number of different cells and tissues

Hydration – surprising findings uncovered by the latest research

Hydration is simple isn't it? Well, no actually! New research suggests that optimum hydration is not just about 'drinking plenty' and hoping for the best. It actually requires a good deal more thought.

At a glance:

- The controversy surrounding current drinking guidelines is outlined;
- Recent and conflicting research on the effects of various levels of dehydration on sport performance is summarised;
- Recommendations for athletes seeking the optimum level of hydration for their particular event are made.

Optimum sports nutrition can be tricky to get your head around sometimes; not only does it require some understanding of the body's basic biochemistry, it's also a constantly evolving area of research. And while the importance of maintaining hydration in sport is relatively straightforward compared to other aspects of sports nutrition and has been studied for longer than just about any other area, new research continues to turn up surprising findings.

Lies and damn lies?

A good example of this is the controversy that currently surrounds the advice given to athletes wishing to maintain optimum hydration. Official advice to athletes to drink enough to replace fluid lost in sweat during endurance events is coming under increasing attack from scientists. In 2006, the renowned exercise physiologist Professor Tim Noakes claimed in a hardhitting leading article in the *British Journal of Sports Medicine* that case against 'over-drinking' was proven 20 years earlier and that official advice has been influenced by the marketing needs of the sports drink industry[1]. Meanwhile, Australian researchers called on the American College of Sports Medicine (ACSM) and other official bodies to revise their current fluid replacement guidelines in the light of their recent finding that even quite large fluid losses don't lead to dehydration or heat illness[2].

The Australian researchers set out to measure core temperature in 10 participants in the 2004 Ironman Western Australia event (using a special telemetry system swallowed in a pill), and to relate this to the triathletes' hydration status after the event. In particular, they wanted to test two theories:

1. That the progressive dehydration commonly experienced by Ironman triathletes (reflected in body weight reduction) would be linked with rises in core body temperature;
2. That the athletes' bodies would adequately regulate their own body temperature and that no relation would be found between finishing hydration status and core body temperature.

'Over-drinking is not only unnecessary to maintain thermo-regulation, it could also put people at risk of hyponatraemic encephalopathy – a life threatening dilution of plasma sodium levels'

What they discovered surprised them; while fluid losses led to an average fall in body mass of 2.3kg (about 3% of body weight), the athletes' core body temperature averaged only a modest 1°C above normal resting temperature, while other measures of dehydration, including plasma levels of sodium and urine concentration, stayed within normal ranges.

The inescapable conclusion was that there was simply no evidence that a 3% reduction in body mass during an Ironman competition in moderate ambient conditions causes athletes to reach the kind of core body temperatures that would lead to heat stroke. This appears to conflict with the ACSM guidelines advising 'endurance athletes to drink to replace the total amount of fluid lost in sweat and not to rely on thirst as a guide to their fluid needs'. The ACSM's 'Hydration Consensus Statement' published in 2005 and still featured as current best practice on its website at the time of writing (November 2007) states the following[3]: "A body water deficit of greater than 2% of body weight marks the level of dehydration that can adversely affect performance."

In a commentary on the Australian findings, Prof Noakes wrote: "This confirms that the body regulates its thermal response during prolonged exercise within a very safe range, independent of the extent of weight lost. Ironman triathletes can be assured that their brains will take care of their bodies during exercise, and that there is no need to follow industry favourable guidelines to drink to excess to ensure their safety." Indeed, he went on to add: "over-drinking' is not only unnecessary to maintain thermoregulation, but it could also put people at risk of hyponatraemic encephalopathy – a life threatening dilution of plasma sodium levels."

However, it's important to add an important caveat here, namely that the levels of hydration required for safety and for optimum performance may not be the same. One could equally ask whether those 10 subjects competing in the Autralian Ironman could have performed better if they had consumed more fluid and reduced their dehydration levels?

Running economy and dehydration

The Australian findings (that 3% dehydration produced little in the way of adverse effects) were somewhat surprising for those weaned on the conventional 'hydration maintenance wisdom'. However, later that year, a US study looked in to the effects of 5% dehydration (*ie* quite severe) on running economy[(4)]. Running economy refers to the biochemical and biomechanical efficiency of running; for any given running speed, the lower the oxygen requirement to maintain that speed, the greater the running economy.

In the study, ten highly trained collegiate distance runners (mean age 20yrs, mean body mass 66.7kg, mean VO2max [maximum oxygen uptake] 66.5mls/kg/min) participated in four experiments on separate days; two trials were performed in a fully hydrated state and two in a dehydrated state (a water loss corresponding to 5.5 and 5.7% body mass – *ie* around about 3 litres).

In each hydration state (*ie* fully hydrated and 5% dehydrated), the subjects performed one 10-minute treadmill run per day (in an ambient temperature of 23 degrees C environment) at either 70% VO2max or 85% VO2max. The researchers measured a number of variables including hormone levels, body temperature, cardiovascular function and perceived rates of exertion.

The results were surprising to say the least; there were no significant differences in running economy between any of the combinations of hydration states and workloads. Likewise, there were no differences in perceived rates of exertion or in post-exercise lactate concentration. However, the 5%+ dehydration did result in higher heart rates, rectal temperatures and blood levels of a hormone called norepinephrine (associated with stress) indicating an increased physiological strain.

Why is this surprising? Well think about it; 5% or more dehydration is very severe – a water loss of 2 and a half times that commonly accepted to be the threshold of reduced performance. Moreover, studies have shown that running economy is normally fairly sensitive to physiological disturbances, dropping significantly when fatigue sets in. To achieve 5% dehydration in reasonably temperate conditions, a runner would have to run for long periods beyond the 2% dehydration point that is claimed to produce significant performance drop. Some caution is needed – this is just one study and in longer runs, 5% might produce higher core temperatures than were measured in this study – but this study does lend support to the notion that the commonly accepted guidelines on drinking and hydration need revisiting!

Dehydration and motor skills

Just to throw a spanner in the works however, some recent evidence suggests that the 2% dehydration threshold may be relevant for sportsmen and women participating in sports where complex motor skills are important.

In a double blind, randomised study on basketball players at Pennsylvania State University, US scientists set out to investigate the effects of three hydration strategies on fifteen basketballers (age 12 to 15 years) who underwent three separate 2-hour exercise sessions in hot conditions with different drinking strategies[5]:

1. No drinks consumed leading to 2% dehydration (loss of fluid equivalent to 2% of body mass);
2. Consumption of a 6% carbohydrate/electrolyte drink to maintain hydration levels (*ie* 0% dehydration);
3. Consumption of a flavoured water placebo drink to maintain hydration levels, but with no added carbohydrate/electrolyte.

After each exercise session, there followed a recovery period after which the subjects performed an orchestrated sequence of continuous basketball drills designed to simulate a game (12-min quarters with a 10-min halftime. The researchers looked at a number of performance measures and component drills required during basketball; these included various individual and combined shooting percentages (3-point, 15-foot, free-throw shots), sprints (suicides, court widths), lateral movements (zigzags, lane slides), and defensive drills (combining lateral and front-to-back movement) times.

Compared with the flavoured water drinking strategy, 2% dehydration significantly impaired shooting ability. However, consuming the carbohydrate/electrolyte drink improved shooting compared with flavoured water. Moreover, the carbohydrate/electrolyte drinking strategy significantly improved total defensive drill times compared to no drinking.

These results (produced by 2% dehydration) appear to be at odds with the Australian research quoted earlier, showing that 3% dehydration put Ironman athletes at no significant risk of heat stroke. In reality however, these two findings aren't necessarily contradictory; 'no increased risk of heat stroke' is not the same as 'optimum physical performance'. Moreover, the basketball study looked at performance indicators (*eg* shooting) that involve a significant motor skill component; had the researchers tested only the basketballers' endurance or strength, they may have found that 2% dehydration produced no adverse effects.

It's also noteworthy that the use of water alone did not improve drill times compared to no drinking – *ie* 2% dehydration did not adversely affect performance. In fact, it was only the carbohydrate/electrolyte drink that improved drill times, indicating a positive 'carbohydrate feeding effect'. This is in line with other research demonstrating that carbohydrate administration has a positive effect on cognitive processing and motor skills[6].

More recent evidence of dehydration drawbacks

Some researchers have cautioned against 'over-hydration'. The argument is that not only is 100% fluid replacement unnecessary for performance gains, it may even be detrimental. The reasoning is that mild dehydration doesn't hinder performance and may even boost performance in sports where overcoming gravity is important (*eg* uphill cycling, running, field sports etc.). So for example, a 70kg athlete who becomes 2% dehydrated will lose 1.4kg of water, which means he or she will weigh 1.4kg less. This means 1.4kg less to lug around and a potential 2% increase in power/weight ratio. Or to put it another way, less power output will be required for a given speed.

'Some researchers have cautioned against 'over-hydration' because mild dehydration doesn't hinder performance and may even boost performance in sports where overcoming gravity is important'

But is this theory borne out in reality? That's the question that Australian scientists at the Australian Institute of Sport in Canberra set out to answer in a very recent study on simulated uphill cycling in the heat and dehydration due to unreplaced sweat losses[7].

In the study, eight well-trained cyclists performed a 2-stage ride:

- Stage 1 – a 2-hour ride at 53% maximal aerobic power (MAP) on a stationary ergometer;
- Stage 2 – a cycling hill-climb 'time-to-exhaustion' trial at 88% MAP on their own bicycle on an inclined treadmill (8%) at approximately 30 degrees C.

Stage 1 was potentially dehydrating; however, some of the subjects were given 2.4 litres of a 7% carbohydrate drink during stage one (designed to replace fluid losses), while others were given an identical amount of carbohydrate but in the form of gels with just 0.4 litres of water. The net result was that both groups received identical carbohydrate, but the drinks group ingested an extra two litres of water compared to the gels group.

This in turn meant that the drinks group went into the hill-climb trial with virtually no net fluid loss compared to their pre-trial status, whereas the gels group showed a net weight loss of around 2.5kg (*ie* around 3.5% dehydration).

The results revealed the following:

- Rectal temperatures before the hill-climb increased by 0.6C (38.9 vs. 38.3C) in the dehydrated (gel) group compared to the hydrated (drinks) group;
- Heart rates increased by 12 beats per minute (158 vs. 146) in the dehydrated group compared to hydrated group;
- Last but not least, despite the fact that the dehydrated cyclists were significantly lighter (around 2kg) than the hydrated cyclists and therefore required less power to sustain a given speed uphill, their time to exhaustion was drastically reduced; compared to the hydrated cyclists, those who were dehydrated achieved times to exhaustion that were 13.8% lower!

Now, 3.5% dehydration is not mild and way beyond the '2% threshold' often quoted for performance losses. However, this study does indicate that in sports where work is performed against gravity, it's erroneous to assume that the reduction in weight that occurs when fluid losses take place will automatically result in enhanced performance due to an increased power/weight ratio. More research will be needed to determine at what point any performance gains to reduced weight via fluid losses are wiped out by performance losses due to the physiological effects of dehydration itself.

Dehydration and strength

Finally, it's also worth adding into the mix some recent and fascinating research carried out at the University of Connecticut on the effects of dehydration on the hormonal response to training – specifically the levels of testosterone, cortisol and the testosterone/cortisol (TC) ratio[8]. This ratio is important for any athletes wishing to maintain muscle mass for increased strength and power and/or reduced injury risk;

testosterone is an anabolic hormone associated with muscle accretion while cortisol is a stress hormone associated with high energy demands and muscle tissue breakdown.

Nine collegiate runners completed four 10-minute treadmill runs differing in pre-exercise hydration states. These were:

- Fully hydrated at 70% VO2max
- Fully hydrated at 85% VO2max
- 5% dehydration at 70% VO2max
- 5% dehydration at 85% VO2max

Blood samples were taken immediately after and again 20 minutes after exercise and analysed for lactate, testosterone, cortisol, and T/C ratio.

The results showed that for a given intensity, heart rates, VO2max and blood lactate were similar between fully hydrated and 5% dehydrated states, suggesting that (remarkably) dehydration did not measurably increase the physiological stress associated with dehydration of the exercise bouts. Furthermore, the hydration state of the runners had no measurable effect on testosterone concentrations before, during, or after exercise at either intensity.

However, regardless of exercise intensity, pre-exercise and 20 min post-exercise cortisol concentrations were greater during 5% dehydration full hydration and the resulting T/C ratio was lower, indicating an increased likelihood of muscle tissue catabolism (breakdown). In plain English, running (or performing other types of exercise) while in state of dehydration caused an unfavourable shift in the resulting hormone balance, by producing a more catabolic environment compared to full hydration. And as we've already stated, catabolism is something that most athletes try to minimise!

Making sense

On the face of it, there seems to be a lot of conflicting information in some of the recent research, but it's actually quite possible to make sense of it all. Let's just summarise the main points raised here:

- **Safety** – the current evidence suggests that even 3% dehydration for sustained periods *doesn't* pose a health risk for athletes; Over-drinking to ensure you lose no fluid at all during training or competition therefore seems unwarranted;
- **Performance** – this is where it gets tricky. 5% dehydration didn't seem to adversely affect running economy and perceived rates of exertion at 70 and 85% of VO2max (although it did increase levels of circulating stress hormones). However, a more modest 2% dehydration did adversely affect basketball skills; it could be that athletes performing sports where skill is a major factor are more prone to the detrimental effects of relatively mild dehydration;
- **Power to weight ratio** – in sports such as cycling and running, where power to weight ratio is important, the potential benefits of dehydration-induced weight loss could well be outweighed by performance drop – certainly, 3.5% dehydration appears to be detrimental to endurance performance;
- **Strength and power** – dehydration at 3%[4] and 5%[8] seems to increase levels of circulating stress hormones, which is undesirable for any athlete wishing to maintain or build maximum strength and power. There are also implications here for immunity, as exercise-induced stress hormone release is known to be associated with decreased post-exercise immunity[9].

In the light of these findings, what is the best hydration strategy to maximise performance and minimise any detrimental effects? Athletes whose sports involve a large skill component should ensure that they remain well hydrated; 2% fluid loss may be too much to maintain optimum performance and a target of maximum fluid loss of 1% of body weight may be a better option. Endurance athletes may get away with up to 2% fluid loss, but any higher may put them at risk of reduced performance, even allowing for a potential gain in power to weight ratio.

Given the link between dehydration and stress hormone release, strength and power athletes should pay particular attention to remaining well hydrated. In fact all athletes should endeavour do so when training; the odd foray into the dehydration zone may be harmless in competition, but regular episodes of dehydration during training (where it's relatively easy to control your fluid intake) are undesirable.

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