Training for DISTANCE RUNNING

A SPECIAL REPORT FROM

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The research newsletter on stamina, strength and fitness

Training for DISTANCE RUNNING

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From the editor

Distance running is perhaps a vague term. After all 100m is a distance, and there are some people I know who'd describe it as long-distance! However for the sake of this special report we will define distance using Olympic races. The races in between the blue ribbon events, the 400m and marathon, are what we might describe as distance running. That means the 800m, 1500m, 5000m and 10000m. The 800m is perhaps a little short but it is included because of the energy system it requires.

This talk of Olympics may have some less ambitious athletes running scared rather than running 'distances'. There's no need to worry though. Whilst the articles in this report are appropriate for elite athletes, they are just as beneficial for social runners seeking to improve times, or competitive runners aiming to compete in fantastic events such as the Great North Run.

The opening chapters in this report will get runners thinking about their body composition, firstly muscle fibres then percentage body fat. In the third chapter a former European 5000m champion discusses training intensity. The fourth and fifth chapters question running posture and techniques, vital for injury-avoidance and top performance. Chapter six investigates the dreaded stitch which could leave you keeling over, in need of refreshment. Luckily the final chapter introduces a new carbo-drink for distance runners.

I hope this special report helps everyone from Sunday morning joggers to gold medal hunting Kenyans achieve great times in their chosen 'distance'.

Sam Bordiss

Why distance runners cannot afford to ignore the vital contribution of fast-twitch muscle fibres

This opening chapter focuses on getting the most out of muscle fibre for endurance activity. Biopsies are used to determine what types of fibres exist within our muscles. A special needle is pushed into the muscle and a grain-of-rice-size piece of tissue extracted and chemically analysed. Two basic fibre types have been identified via this process: slow-twitch (also known as type I or 'red' fibres) and fast-twitch (aka type II or 'white' fibres). Type II fibres, as we shall see, can be further sub-divided into type IIa and type IIb variants.

Slow-twitch muscle fibre contracts at almost half the speed of fast-twitch fibre – at 10-30 twitches per second compared with 30-70. Slow-twitch fibre has a good level of blood supply, which greatly assists its ability to generate aerobic energy by allowing plentiful supplies of oxygen to reach the working muscles and numerous mitochondria.

Mitochondria are cellular power plants; they function to turn food (primarily carbohydrates) into the energy required for muscular action, specifically adenosine triphosphate (ATP). ATP is found in all cells and is the body's universal energy donor. It is produced through aerobic and anaerobic energy metabolism and, consequently, through the associated actions of both slow and fast-twitch muscle fibre.

Slow-twitch fibre is much less likely than its fast-twitch counterpart to increase muscle size (hypertrophy), although well-trained endurance athletes have slow-twitch fibres that are slightly enlarged by comparison with sedentary people. The most notable training effects, however, occur below the surface. Subject to relevant endurance training, these unseen changes include:

- An improved aerobic capacity caused by fibre adaptation. Specifically this involves an increase in the size of mitochondria, boosting the ability of the fibres to generate aerobic energy;
- An increase in capillary density, which enhances the fibres' capacity to transport oxygen, and thus to create energy;
- An increase in the number of enzymes relevant to the Krebs cycle – a chemical process within muscles that permits the regeneration of ATP under aerobic conditions. The enzymes involved in this process may actually increase by a factor of two to three after a sustained period of endurance training.

Blood lactate plays a crucial role in energy creation which is not, as many people mistakenly assume, restricted to the latter stages of intense exercise. Lactate is actually involved in energy production in our muscles at all times, although response to lactate generation varies according to fibre type. A brief consideration of this process will begin to explain why the relationship between fast and slow-twitch fibre is crucial to optimum endurance.

Fast-twitch fibres produce the enzyme lactate dehydrogenase (LDH), which converts pyruvic acid (PA) into lactic acid (LA). The LDH in slow-twitch muscle fibre however, favours the conversion of LA to PA. This means that the LA produced by the fast-twitch muscle fibres can be oxidised by the slow-twitch fibres in the same muscle to produce continuous muscular contractions.

When LA production reaches a level where it cannot be recycled to generate steady-state aerobic energy, endurance exercise moves into anaerobic territory – with less reliance on oxygen and more on stored phosphates for energy production. There will come a point, under these conditions, when an athlete reaches their 'lactate threshold', at which point further exercise becomes increasingly difficult and the athlete is forced to slow down and ultimately stop.

As we shall see later, this 'anaerobiosis' and its exercise-halting effect may be as much a consequence of brain activity as of muscular limitations, especially under extreme endurance conditions.

Well-trained endurance athletes are able to generate blood lactate levels that are 20-30% higher than those of untrained individuals under similar conditions. This makes for significantly enhanced endurance as their muscles no longer drown in lactate but rather 'drink' it to fuel further muscular energy. To continue the analogy, the untrained individual's muscles would get 'drunk' on lactate after just a few intervals – or should that be rounds!

As noted, failure to train fast-twitch fibre to contribute to endurance performance will result in lactate threshold being reached – and performance arrested – at a much earlier point. Unlike the 100m sprinter, who can ignore his slow-twitch fibres altogether in training without damaging performance, the endurance athlete has to train all fibre types in order to maximise sustained muscular energy.

Athletes are made rather than born

Most people are born with a relatively even distribution of fast and slow-twitch fibres, suggesting that power and endurance athletes are 'made' rather than born. As exercise physiologists McKardle, Katch and Katch point out, 'studies with both humans and animals suggest a change in the biochemical-physiological properties of muscle fibres with a progressive transformation in fibre type with specific and chronic training' (1).

Table 1, overleaf, shows the extent to which fibre type can be 'altered' after training for selected endurance activities, although whether these changes are lasting is open to debate, as we shall see.

We have shown how slow-twitch fibre adapts to endurance training. Now let's take a look at how fast-twitch fibres respond.

- Type IIa or 'intermediate' fibres can, in elite endurance athletes, become as effective at producing aerobic energy as slow-twitch fibres found in non-trained subjects. Like slow-twitch fibres, these fibres (and their type IIb counterparts) will benefit from an increase in capillary density. In fact, it has been estimated that endurance training that recruits fast and slow-twitch muscle fibre can boost intramuscular blood flow by 50-200% [2];
- Type IIb fibres can play a much more significant role in sustained energy release than had been assumed, according to research carried out by Essen-Gustavsson and associates [3]. These researchers studied muscular enzyme changes brought about by endurance training and concluded that type IIb fibres were as important to endurance athletes in terms of their oxidative energy production and the clearance of exercise-inhibiting phosphates as type IIa fibres.

A raft of relatively recent research indicates that intense training efforts – *eg* three-minute intervals at 90-95% of max heart rate/over 85% of VO2max, with three-minute recoveries – are great ways to boost lactate threshold (as well as VO2max, economy and strength). These 'lactate-stacker' sessions, by their very nature, rely on fast-twitch fibre to generate power. Note, though, that these workouts are very tough and stressful and should be used judiciously.

Endurance gains can be made much more quickly through capillary adaptation in fast and slow-twitch fibre with anaerobic training methods, such as the lactate stacker workouts, than with

Table 1: Percentage slow-twitch fibre in male deltoid (shoulder) muscle

Endurance athlete	% slow-twitch fibre in deltoid muscle
Canoeist	71%
Swimmer	67%
Triathlete	60%

Adapted from McKardle et al [5]

less intense aerobic training. Although it is possible to train fast-twitch fibre to take on more of the slow-twitch blueprint, taken to extremis – especially through the use of slow-twitch steady state training – this may not actually be the best strategy for endurance athletes.

The marathon runner Alberto Salazar once said that he aimed to train aerobically hard enough to lose his ability to jump [4]. In other words, he was trying to convert all his fast-twitch fibres into slow-twitch ones in terms of their energy-producing potential so that they could contribute all their energy to his marathon running.

However, for a variety of reasons, losing all fast-twitch speed and power ability may not actually be a good idea. For example, at the end of a closely-fought marathon there may be a need for a sprint, requiring fast-twitch fibre input. This becomes yet more appropriate when considering middle distance running.

Even more specifically, there is the anaerobic/aerobic component of an endurance activity to consider, and the speed required to complete it competitively. An 800m race calls for an anaerobic energy contribution of around 40%, and athletes in these disciplines must be fast and powerful to succeed.

Fast-twitch fibres have to be trained accordingly; it's no good turning them into plodders with an emphasis on slow-twitch, steady state work, if they are needed to produce a short or sustained kick and a sizeable energy contribution.

The recent research into lactate stacker sessions and the vital role of lactate threshold as the key endurance performance variable further substantiates the need for the development of a high-powered endurance contribution from fast-twitch fibres.

Despite virtually undisputed evidence that all muscle fibre types will adapt to a relevant training stimulus, it is less certain whether these changes are permanent. One of the few studies concerned with the long-term effects of endurance training was conducted by Thayer *et al*, who looked at muscle-fibre adaptation over a decade [6]. Specifically, they compared skeletal muscle from the vastus lateralis (front thigh) in seven subjects who had participated in 10 years or more of high intensity aerobic training with that of six untrained controls.

They found that the trained group had 70.9% of slow-twitch fibres compared with just 37.7% in the controls. Conversely, the trained group had just 25.3% fast-twitch fibre, compared with 51.8% in the controls. The researchers concluded that endurance training may promote a transition from fast to slow-twitch fibres, and that this occurs at the expense of the fast-twitch fibre population.

Fibre reversion after inactivity

However, it seems that slow-twitch (and fast-twitch) muscle fibre tends to revert back to its pre-training status after a period of inactivity (although aging may provide an exception to this rule, as we shall see later). In fact, the theory is that muscle fibre has a fast-twitch default setting. This is entirely logical: since we use our slow-twitch fibres much more than our fast-twitch ones on a daily basis, a period of inactivity would de-train slow-twitch fibre and allow fast-twitch fibre to regenerate and convert back to a faster contraction speed. The interesting and slightly less logical aspect of this process is that it does not necessarily require speed training, as demonstrated by research on muscle tissue rendered inactive by accident or illness (7).

'It is possible that athletes 'learn' how to tolerate pain and consequently become better able to recruit their muscle fibre'

When it comes to recruiting winning muscle, it is impossible to overlook the vital role of the brain. Muscle fibre can only function at the behest of our brains, and it is possible that athletes 'learn' how to tolerate the pain associated with lactate build up, for example, and consequently become better able to recruit their muscle fibres.

Recently, research has begun to appear on the so-called 'central governor', which is seen to be the determinant of the body's ability to sustain endurance activity by tolerating increasing intensities of exercise. It has been argued that the governor's setting can be altered through the experience of intense exercise and a corresponding shift in willpower to permit greater endurance perseverance. This theory has been substantiated by evidence that muscles can still hold onto 80-90% of ATP and some glycogen after intense endurance efforts – *ie* when the athlete has 'decided' to stop exercising.

It has been suggested that the body – and, for our purposes, its muscles – will always hold onto some crucial energy-producing materials, just in case it is called upon to react in an emergency. This is seen as a legacy of the unpredictable past that confronted our prehistoric ancestors, who never knew if they would need a bit more energy to flee from a sabre-toothed tiger after a long day's hunting and gathering!

The central fatigue hypothesis

Closely related to the thoughts on the 'governor' is the 'central (nervous system) fatigue hypothesis', postulating that the brain will 'shut down' the body under certain conditions when there is a perceived threat of damage to vital organs, irrespective of an individual's fitness. The conditions specifically identified to trigger central fatigue are high altitude and high temperatures, although researchers believe it could also swing into play under less taxing conditions.

The famous exercise physiologist and runner Tim Noakes states: 'There is no evidence that exhaustion under these conditions is associated with either skeletal muscle 'anaerobiosis' or energy depletion…. There is sufficient evidence to suggest that a reduced central nervous system recruitment of the active muscles terminates maximum exercise'[8].

Various methods have been used to try to trick the brain into keeping muscle fibre recruitment going under extreme conditions. With regard to high temperatures, these involve 'pre-cooling' strategies, such as ice baths or ice helmets. These and similar strategies are designed, quite literally, to cool the brain and extend the body's 'heat stop switch' threshold.

As mentioned previously, aging also has an influence on the development of endurance muscle fibre, with fast-twitch fibre declining much more rapidly than its slow-twitch counterpart – by as much as 30% between the ages of 20 and 80. By contrast, endurance athletes can expect to maintain their slow-twitch fibres and even increase them by as much as 20%, over a sustained training career. The trouble is, though, that without fast-twitch fibres endurance performance will inevitably decline.

In summary, then, developing your endurance capacity relies on a number of adaptations, as follows:

- Enhancing the already high oxidative capacities of slow-twitch fibres;
- Improving the capacity of fast-twitch fibres to contribute to endurance activity, taking account of distance and the need for both sustained and 'kicking' power. This process may, in fact, hold the physiological key to optimising endurance performance;
- Working on mental strategies to develop increased endurance tolerance and the sustainable contractile properties of all muscle fibre types;
- Using pre-cooling techniques to delay physiological shut-down.

John Shepherd

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Running and body fat – walking the tightrope of optimum performance

All runners know that excess body fat can hinder running performance. However the relationship between running performance, dietary intake and fat levels is not quite as straightforward as it seems

Although it's immediately apparent that there are substantial differences in physical characteristics between sprinters and long distance runners, elite runners at all distances come in a variety of shapes and sizes, and there are perhaps too many exceptions to make all but the broadest generalisations. Generally speaking though, sprinters have powerfully developed musculature of the upper body and of the legs, while distance runners have low body mass, with smaller muscles and extremely low body fat levels.

The one outstanding anthropometric characteristic of successful competitors in all running events is a low body fat content. The textbooks tell us that the body fat stores account for about 15-18% of total body weight in normal young men, and in young women the figure is about 25-30%.

'Normal', of course, is changing, and those ranges should be qualified as being normal for healthy people. Most of this fat is not necessary for energy supply and is simply extra weight that has to be carried throughout the race. This is not to say that people carrying extra fat cannot complete a longer distance race – they just can't do it in a fast time.

Our fat stores are important and the fat cells play many key roles. As well as acting as a reserve of energy that can be called upon at times of need, fat is important in the structure of tissues, in hormone metabolism, and in providing a cushion that protects other tissues.

An excess of body fat, however, serves no useful function for the endurance athlete. It can help the sumo wrestlers, and perhaps may not even be a disadvantage for the shot putter, but not the runner. Extra fat adds to the weight that has to be carried, and thus increases the energy cost of running. Even in an event as long as the marathon, the total amount of fat that is needed for energy supply does not exceed about 200g for the average runner.

A very lean male 60kg runner with 5% body fat will have 3kg of fat; a typical elite 55kg female runner with 15% body fat will have more than 8kg of body fat. Non-elite runners will commonly have at least twice this amount, and many runners further down the field will be carrying 20kg or more of fat.

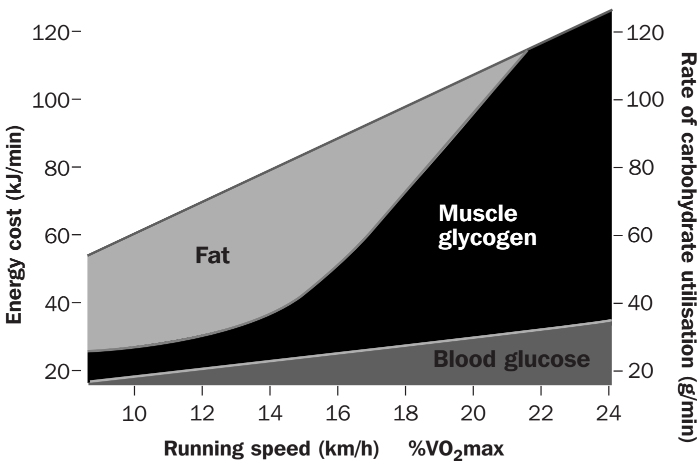
Although not all of this is available for use as a metabolic fuel, the amount of stored fat is greatly in excess of that which is necessary for immediate energy production. Within limits, reducing this will lead to improvements in performance, but if the loss is too sudden or too severe, then performance and health may both suffer.

It is probably not sensible for men to let their body fat levels go below about 5% and for women below about 10-15%. There's good evidence that the immune system is impaired when body fat stores are too low[1]. A reduced ability to fight infections means more interruptions to training and more chance of being sick on race day.

For female athletes, there are some very immediate consequences of a low body fat level, including especially a fall in circulating oestrogen levels[2]. This in turn can lead to a loss of bone mass, causing problems for women in later life through an increased risk of bone fracture. Equally, though, performance will suffer if the body fat level is too high, so staying healthy and performing at peak level is a real challenge.

Fat typically contributes about half of the total energy cost of a long run (this is very approximate, and will depend on speed, fitness, diet and other factors). The graph *(opposite)* shows that at low running speeds, the total energy demand is low and most of the energy supply is met by oxidation of fat, with only a small contribution from carbohydrate in the form of muscle glycogen

Contribution of fuel sources as a function of running speed



The left-hand vertical axis shows total energy expenditure in kilojoules per minute (kJ/min); the red shaded area at the bottom represents the contribution of blood glucose to energy supply level; the pink and black shaded areas show the relative contributions from fat and muscle glycogen respectively to energy demand.

and blood glucose (which is continuously being replaced by glucose released from the liver).

As speed increases, the energy cost increases more or less in a straight line, but the relative contribution from fat begins to decrease, with muscle glycogen becoming the most important fuel. The problem with running slowly to reduce body fat levels is that it takes a long time, because the rate of energy expenditure is too low. Run too fast, and you burn only carbohydrate, leaving the fat stores more or less untouched.

Importance of fat

To get an idea of the importance of fat, you can try the following sums. For simplicity, we'll assume that:

- The energy cost of running is about 1 kilocalorie per kilogram body mass per kilometre;
- The energy available from fat oxidation is 9 kilocalories per gram;

- About half of the energy used in a run will come from fat (this amount will actually be greater at low speeds and for fitter runners, and will also be higher if the run is completed after fasting overnight as opposed to just after a high carbohydrate meal).

Example 1

If you weigh 50kg, the total amount of energy you will use in a 10km run is 50x10 = 500kcals. If all of the energy were to come from fat, this would use 500/9 = 56 grams of fat. Half of this is 28 grams fat (almost exactly one ounce in old units).

Example 2

If you weigh 80kg the total energy cost of running a marathon (42.2km) is 80x42.2 = 3,376kcals. If all of the energy were to come from fat, this would use 3,376/9 = 375 grams. Half of this is 188 grams or around 7oz.

Three things emerge from this:

1. The amount of fat you need for even a marathon is small compared to the amount stored; a 70kg runner with 20% body fat has 14kg of stored fat. A 60kg runner with 30% fat has 18kg.
2. Even though the amounts of fat used may seem small, regular running will nibble away at the fat stores – good news if your aim is to use exercise to control or reduce your body fat levels. A runner who uses 28 grams three times per week will lose about 3.5kg of fat over the course of a year. The results are not immediate but, if you persist, the cumulative results are impressive.
3. Running speed does not figure in the equation. If you run for 40 minutes, you might do 5km or you might do 10km.

Body fat and performance

In a study of a group of runners with very different levels of training status and athletic ability, scientists observed a significant relationship between body fat levels and the best time that these runners could achieve over a distance of 2 miles [3].

Strategies for controlling weight and body fat while maintaining training

- Pay attention to the portion sizes you consume at meals to ensure that overeating does not occur due to habit;
- Use well chosen snacks between meals to maintain fuel levels for training sessions or to avoid excessive hunger, but avoid snacking for entertainment, for comfort or just to keep others company. Snacks can often be organised by saving part of a meal for a later occasion, rather than by eating extra food;
- Use low-fat – or at least reduced-fat – strategies in choosing foods and while cooking or preparing meals;
- Make meals and snacks more 'filling' by including plenty of salads and vegetables, by taking higher-fibre options when these are available, and by including low-glycaemic forms of carbohydrate;
- Keeping a food diary in which you write down everything you eat and drink for a week will help to identify the difference between your ideal eating plan and your actual intake. Many people are unaware of the habits that sabotage their eating goals.

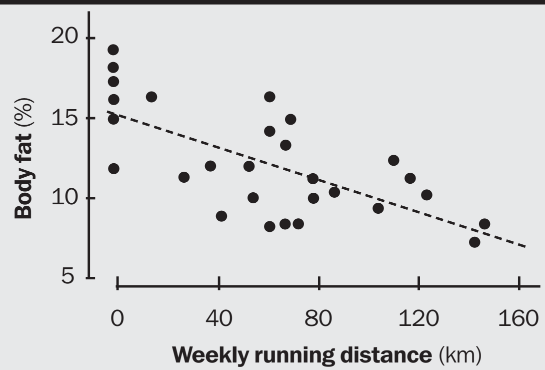
Although these results indicated that leaner individuals seem to perform better in races at this distance, some complicating factors have to be taken into account.

The relationship between body fat and race time may at least in part be explained by an association between the amount of training carried out and the body composition. It would hardly be surprising if those who trained hardest ran fastest, and it would also not surprise most runners to learn that those who train hardest also have the lowest fat levels. Indeed, body fat content does tend to decrease as the volume of training increases, as we found out some years ago when we studied a group of local runners in Aberdeen[4].

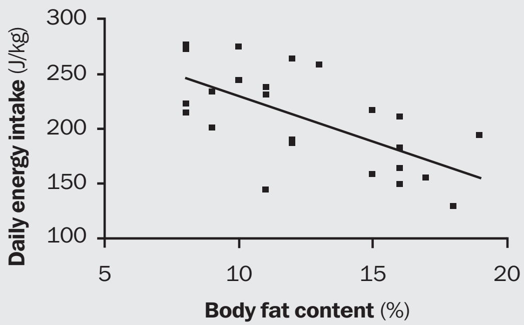
We recruited a group of runners who had been running for at least two years, and asked some sedentary colleagues to act as a control group. All had maintained the same body weight for at least two months before we measured them, and all had had a constant level of physical activity over that time. We measured body fat levels and also got a record of the weight of all food and drink consumed over a one-week period.

As you can see from the following graphs, the runners covering the greatest distance in training had the lowest body fat levels. They also ate more food than those who did less running. There are, of course, some people who do not fit the line as well as others, but there are many factors that explain this variability. We would expect the people who eat more to be fatter, but no! The subjects who did most running had the lowest levels of body fat, even though they did eat more. Thus, we can separate food intake from body fatness if we add exercise to the equation.

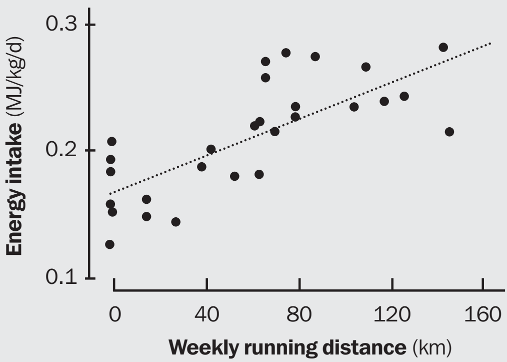
Relationship between body fat and weekly running distance



Relationship between calorie intake and body fat



Relationship between energy intake and weekly running distance



How is body fat measured?

There are problems in applying the standard methods for assessment of body composition to athletic populations, and it is not clear that any of the methods commonly used for the general population is entirely reliable. At health clubs and elsewhere, fat levels are usually assessed by use of skinfold callipers to measure the thickness of the fat layer that lies below the skin at various different sites on the body. The results are then fed into an equation that predicts the body fat level based on a comparison with more accurate measurements made on a group of 'normal' people. Predictive equations for estimating body fat content based on indirect methods are unreliable for several reasons, not least because the equations that are generated from normal populations are not applicable to elite athletes. Such methods have been widely used, but the results of these measurements must be treated with caution, especially if you are an athlete.

Fat levels in elite runners

Skinfold thickness estimates of body composition in 114 male runners at the 1968 US Olympic Trial race gave an average fat content of 7.5% of body weight, which was less than half that of a physically active but not highly trained group[5]. Since then, similar measurements have been made on various groups of runners, and the findings are fairly consistent.

The low body fat content of female distance runners is particularly striking; values of less than 10-15% are commonly reported among elite performers, but are seldom seen in healthy women outside sport. The occasional exceptions to the generalisation that a low body fat content is a pre-requisite for success are most likely to occur in women's ultra-distance running, and some recent world record holders at ultra-distances have been reported to have a high (in excess of 30%) body fat content. However, this probably reflects the under-developed state of women's long distance running; as more women take part, the level of performance can be expected to rise rapidly, and the elite performers are likely to conform to the model of their male counterparts and of successful women competitors at shorter distances.

Although there's an intimate link between body fat levels and running performance, it's important to remember that reducing fat levels will not automatically guarantee success and may even be counter-productive. If you reduce fat by a combination of training and restricting diet, you are walking a fine tightrope. While a reduction in body fat may well boost running performance, cut down food intake too drastically and not only will training quality suffer, but the risk of illness and injury also increases dramatically.

Ron Maughan

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Time-efficient running – should you run less to run faster?

Ever since the marathon boom of the early 1980s, high-mileage training has been the accepted paradigm among middle and long distance coaches. However cutting back the miles and concentrating on quality is not only more time-efficient, it can also produce superior results for all but very elite runners

In every walk of life there are trends, and in spite of our claims to open-minded scientific principles, this applies to training theories as much as to clothes or automobiles. Let's take mileage, for a start. Back in the 1950s, interval training was perceived to be the only way to success. Then along came Percy Cerutty, coaching Herb Elliott. Herb won the Olympic 1,500m title in a world record time at the age of 21, leading most of the way.

This was evidence enough for many people to switch away from boring interval training on the track and go running up sandhills instead. Almost simultaneously came the Lydiard system, based on running 100 miles a week, which was the basis of the gold medals and world records of Peter Snell and Murray Halberg, and this became the key to success.

The American physiologist David Costill established the fact that at up to about 80km a week there is a straight-line relationship between mileage per week and improvement in VO2max, which added scientific credibility to practical experience [1]. From the start of the marathon boom in the 1980s, high mileage has been the theme of all middle and long distance coaching. Exceptions have been rare, partly because coaches have not dared to go against the trend, and partly because, for professional marathon runners with all day to train, mileage is the answer.

However, what applies to full-time marathon runners does not necessarily apply to those running shorter distances. What Costill did not do (because there are too many variables involved) was to compare the results of, say, 50km per week of intensive training against 80km of steady running.

Tim Noakes, whose book *The Lore of Running* remains the bible of most distance coaches, sets out several basic principles, one of which is always do the minimum amount of training, which is not as paradoxical as it may appear [(2)]. What he means is: do the minimum amount you need to achieve your goal. If you don't reach your goal, you can always do more.

Low-mileage

Let's take a couple of examples. Steve Jones broke the world marathon record in a time of 2.08.05, and later ran a 2.07.13 marathon, on about 80 miles a week. No European runner has improved much on this time, even though some have gone to 150 miles a week or more.

Looking at the 5,000m and 10,000m distances, when I broke the European record for three miles, my average mileage for the previous ten weeks was 28 miles a week, including warm-ups and races. The training was hard, but it didn't take much time, with sessions such as 15 x 400m with a 50-second recovery, or 2 x 2,000m fast. An actual week of training during that summer is shown below:

Mon: warm-up, 2,800m time trial, on grass;
Tues: 6 x 880yd on track, averaging 2mins 10secs;
Wed: 8 x 700m on grass;
Thurs: warm-up, fast strides, 2 x 440yd in 56 and 58 seconds;
Fri: rest;
Sat: warm-up, 2-mile race.
(total miles for the week = 30)

In the following three weeks I ran fewer miles but had 10 races (mostly club races) where I led all the way. If I could run 13min

12sec for three miles on 28 miles a week, while working full-time, then this kind of training is going to be perfectly adequate for an athlete trying to break 30 minutes for 10k – and more than adequate for someone trying to break 40 minutes! You may argue that natural ability has a lot to do with these performances, but all anyone can do is fulfil their genetic potential. In my case, even though I doubled my mileage in later years, I merely equalled that time, never improved on it.

In 2004, a study was published which showed that a three-days-per-week training programme produced significant gain in aerobic power[3]. The runners were put onto a training regime that consisted of just three carefully structured running workouts per week, and as a result showed a marked (4.8%) improvement in their VO2max. In a follow-up trial, 25 runners were put on to a three-days-per-week marathon training schedule. After 16 weeks, 21 of the runners started the race; all finished, 15 with personal bests, and four of the remaining six ran faster than in their previous marathon.

A trial like this is not, strictly speaking, scientific evidence, because the numbers were small and there was no control group. Several of them were first-timers, and we have no information about whether the participants were aiming for sub-three hours, sub-four hours or sub-five hours. Almost any group of runners will show improvement if they are part of a closely monitored programme, particularly those at the slower end. The fact that they showed an average of 8% reduction in body fat suggests that they were not very fit to start with. What was significant, though, was that the low mileage did not prevent them from running a full marathon. Based on their own ability, they were given schedules with one endurance session, one tempo session and one speed session per week. They were also encouraged to do two days a week of cross training, such as cycling or strength training.

The point about training is that it is specific to the event. If you want to run a 31-minute 10k (*ie* at five-minute mile pace) then you have got to become really efficient at running at that pace. You can work on your oxygen uptake and lactate tolerance by running at a faster pace, and you can work on your endurance, heat tolerance and mental strength by running longer distances, but speed endurance is what counts.

If there is a single session that I would nominate as the key to success at 5k and10k, it is 'long rep' training – sessions like 3 reps of 1 mile or 5 reps of 1,200m for the 5k runner, and 5-6 reps of 1 mile or 4-5 reps of 2,000m for the 10k runner.

10k programme

When you are preparing a training schedule, the objectives should always go at the top of the page. For a 10k runner these should be:

- Increase aerobic fitness;
- Increase speed endurance;
- Maintain or increase endurance;
- Avoid injury.

A time-efficient programme would look like this:

Week 1 (no race)

- **Tues:** 10 mins warm-up, 10 x 45 secs uphill fast, 10 mins warm-down;
- **Thurs:** 6-mile run, including 3 x 8 mins fast, 2 mins jog (10k pace);
- **Sat:** 10 mins warm-up, 2 x 15 mins threshold pace (2 mins recovery);
- **Sun:** 8-10 mile run, starting slow, finishing faster.

Total mileage 24-26

Week 2 (racing week)

- **Tues:** 1-mile jog, 2-3 mins stretching, 12 x 400m at 5k pace (60 secs recovery), 800m warm-down;
- **Thurs:** 5-mile run, including 8 x 2 mins fast, 1 min slow;
- **Sat:** 15 mins warm-up, 8 x 150m fast stride, 5 mins jog;
- **Sun:** warm-up, race 5-10 miles, warm-down.

Total mileage 21-26

This programme would run for 8-10 weeks, with the idea of making each two-week block harder than the one before. In the racing week the focus is on performing well in the important races.

Marathon programme

For a marathon runner, the priorities would be:

- Increase endurance;
- Improve aerobic fitness;
- Avoid injury.

A time-efficient two-week programme would look like this:

Week 1 (no race)

- **Tues:** warm-up, 8 x 800m on track (90 secs recovery jog) at 5k pace;
- **Thurs:** 10 mins warm-up, 2 x 20 mins at threshold pace;
- **Sat:** 10 mins warm-up, 6 x 1 mile off road, (3 mins recovery) at 10k pace;
- **Sun:** long run, 18 miles; 6 miles easy, 6 miles at marathon pace, 6 miles a bit faster.

Total mileage 41 approx.

Week 2 (racing week)

- **Tues:** warm-up, 5 sets of [600m at 5k pace/200m jog/ 400m at 5k pace];
- **Thurs:** 8-10 miles run, with 6 x 5 mins fast interspersed with 2 mins slow;
- **Sat:** 5 miles fartlek, off road;
- **Sun:** warm-up, 10-mile or half-marathon race, warm-down.

Total mileage 38 approx.

This programme would start ten weeks before the race, giving four turns of the two-week cycle, followed by a two-week taper. The long 'progressive' runs would be 15, 18, 18 and 20 miles in those four cycles.

The advantages of low-mileage training

Low-mileage training saves time – all the training is purposeful and there's also less likelihood of injury through over-use. However, there are drawbacks including:

- Decreased general endurance, leading to;

- Increased 'vulnerability' – *ie* a more rapid loss of fitness when training is missed;
- An increased chance of injury due to running hard on stiff muscles.

In defence of the low-mileage programme, it's no problem to have an easy day if you are still tired or stiff from the previous session. All training programmes have to be related to the athlete's physical status. The additional easy runs, which many athletes incorporate for therapeutic reasons, could equally be replaced by a walk, a swim or a massage. The running surface is also of crucial importance, because doing every session on the road will increase the chances of injury. Only two road sessions should be performed each non-race week, and using a treadmill in the winter or a synthetic track surface will help decrease impact stress.

Cross-training and alternate training

The essence of low-mileage training is that it allows the busy person to stay very fit with less time commitment, but, if time allows, the addition of cross-training can make it more interesting and boost general endurance. Cycling or rowing, indoors or out, provides excellent cardiovascular training and weight training can increase all-round muscular strength and decrease the chances of injury. I would only recommend swimming as a recovery session, unless the athlete is specifically training for a triathlon.

Bruce Tulloh

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Frequently asked questions about low-mileage training

1. What about loss of endurance? Will this lead to a fall-off in performance? – No training system should be identical all the year round. If you are normally used to running bigger mileages, you can come down to the more intense system for 8-10 weeks to improve your racing performance and then switch back again to build more endurance for the next season.
2. Does following a low-mileage programme affect your long-term progress? – The body's 'memory' is not that long. How you perform depends mostly on what you have done in the last three months, and partly on what you have done in the last six months. There is no problem in moving up in mileage – I was able to move up to 120 miles a week when it was necessary. The problem comes from sustained high mileage. Those who are running 80 miles a week in their teens are very unlikely to have a long career. The low-mileage athlete has a much better chance of surviving uninjured.
3. Is it essential that I run four days a week? – In any two-week period, missing one of the eight runs is not crucial, but running three days a week regularly, though still good, is less effective than four.

From faulty movement patterns injuries arise. Here we go back to basic principles in running.

Running is both a very popular competitive sport in its own right and a fitness activity used at all levels, from recreational gym routines to elite sports training programmes. But running requires the body to absorb continuous repeated impact forces, and running-related injuries are a common presentation in any physiotherapy or sports medicine clinic. At the extreme, elite endurance runners will probably require a weekly physiotherapy treatment, all year round, to keep their bodies healthy.

There is a complicated and highly individual interaction between intrinsic (personal) and extrinsic (environmental) factors that may contribute to a running injury. Specifically the research suggests that the biggest predictors of injury are the following two extrinsic factors:

- total volume of running undertaken;
- sudden changes in volume or intensity of running.

By contrast, research is equivocal when it comes to pinpointing specific biomechanical patterns (intrinsic factors) that cause injury. That said, it is probably safe to assume that, for a given amount of weekly running, an individual with an abnormal or inefficient running action is more likely to suffer injury than someone with good mechanics.

It is impossible to say, for instance, that all runners who over-pronate (tilt heavily inwards) at the foot will definitely suffer injury. Every runner will have their own threshold of tolerance to the stresses of running, and it will take a unique combination of factors to tip that runner's body over the threshold and cause injury.

This article describes the biomechanics of running, focusing for each body part on what is considered 'normal' mechanics and then discussing how deviations from that norm may increase stress on the body, and lead to injury. We are confining our scope to distance running, and therefore research from the analysis of running speeds between 12 and 16 kph (about 8 to 6 minutes per mile). The sprint action (9-10 metres per second or faster) is distinct from running at these more moderate speeds.

The running cycle

Running can be seen as a series of alternating hops from left to right leg. The ankle, knee and hip provide almost all the propulsive forces during running (apart from some upward lift from the arms). The running cycle comprises a stance phase, where one foot is in contact with the ground while the other leg is swinging, followed by a float phase where both legs are off the ground.

The other leg then makes contact with the ground while the first leg continues to swing, followed by a second float phase. At running speeds of about 6 min/mile, a single running cycle will take approx 0.7 sec, out of which each leg is only in contact with the ground for 0.22 sec.

It is, not surprisingly, during the stance phase that the greatest risk of injury arises, as forces are acting on the body, muscles are active to control these forces, and joints are being loaded.

Two sub-phases of stance

The first sub-phase is between 'initial contact' (IC) and 'midstance' (MS). IC is when the foot makes the first touch with the ground. MS is when the ankle and knee are at their maximum flexion angle. This sub-phase is called the 'absorption' or sometimes the 'braking' phase. The body is going through a controlled landing; the knee and ankle flex and the foot rolls in

Table 1: Stance phase in running

Sub-phase	from… to…	action
Absorption (braking)	IC (initial contact)	Foot makes first ground contact
	MS (midstance)	Ankle and heel at greatest flexion
Propulsion	MS (midstance)	Ankle and heel at greatest flexion
	TO (toe-off)	Foot leaves the ground

to absorb impact forces. At this point the leg is storing elastic energy in the tendons and connective tissue within the muscles.

The second sub-phase is between MS and 'toe-off' (TO). TO is the point where the foot leaves the ground. The period between MS and TO is known as the 'propulsion' phase. The ankle, knee and hip all extend to push the body up and forward, using the recoiled elastic energy stored during the absorption phase.

This is an efficient way for the body to work. The more 'free' recoil energy it can get from the bounce of the tendons the less it has to make or to draw on from its muscle stores. Research shows that at least half of the elastic energy comes from the Achilles and foot tendons – a reminder of how important the lower leg is to running efficiency.

Ankle, knee, hip mechanics

The ankle, knee and hip motion are described in the side view (sagittal plane). At IC the ankle will be slightly dorsiflexed, around 10 degrees; the knee will be flexed at 30-40 degrees and the hip flexed at about 50 degrees relative to the trunk (a fully extended hip is at 0 degrees when the midline of the thigh and the midline of the body form a straight line through the centre of the pelvis). The further forward the trunk leans, the greater the hip flexion. Prior to IC the hip is already extending (the leg is moving backwards) and so the foot at IC is moving back towards the hips. If the gluteal-hamstrings are not actively pulling the foot backwards prior to IC, then the foot contact will be too far ahead of the hips and the braking forces on the leg are increased.

During the absorption phase the angles change. By MS the ankle dorsiflexion angle has increased to around 20 degrees and the knee has also flexed to 50-60 degrees. This ankle and knee flexion is coordinated to absorb the vertical landing forces on the body, which at distance running speeds are in the order of two to three times bodyweight.

This is where eccentric strength in the calf and quadriceps muscles is required to control the knee and ankle joints, otherwise the knee and ankle would collapse or rotate inwards. In fact the quadriceps and calf muscles are active prior to IC, and at their most active between IC and MS to help control the braking forces. The hip continues to extend through the absorption phase of stance, reaching around 20 degrees of flexion by MS.

'The role of the muscles therefore is to control the joint position'

During the propulsion phase the ankle and knee motion is reversed. By TO the ankle is plantarflexed to around 25 degrees and the knee has re-extended to 30-40 degrees. The hip continues to move to 10 degrees of extension by TO.

Thus during the second half of the stance phase the ankle, knee and hip combine in a triple extension movement to provide propulsion upwards and forwards. The calf, quadriceps, hamstring and gluteal activity during the propulsion phase is less than during the absorption phase, because the propulsion energy comes mainly from the recoil of elastic energy stored during the first half of stance.

The role of the muscles therefore is to control the joint positions, creating stiffness in the leg system that allows the tendons to lengthen and then recoil.During the swing phase between TO and IC the knee and hip flex to maximum flexion angles of 130 degrees and 60 degrees respectively and then re-extend prior to IC, with the ankle dorsiflexing throughout swing to 10 degrees at IC.

Good runners will follow these movement patterns. It is essential that the ankle and knee can quickly control the braking forces and create a stable leg system to allow the tendons to maximise their recoil power. This is where good technique is vital. Too much upward bounce will increase the landing forces, putting greater stress on the joints and requiring more muscle force to control. Runners need to learn to bounce along and not up, by taking quick, light steps.

It is also important to bring the foot back prior to IC using active hip extension as this reduces braking forces and time needed for the absorption phase. The benefits of a 'quick contact' and a 'horizontal' running style will be discussed in the next chapter, 'Beginner's guide to pose'. Good strength in the gluteals, hamstrings, quadriceps and calf muscles will help runners achieve this.

In summary, excessive braking forces can contribute to injury. The correct movement patterns of the hip, knee and ankle combined with correct activation and strength of the major leg muscles will help control braking forces during running and result in a more efficient action using tendon elastic energy and minimising landing forces.

Pelvis and trunk mechanics

The motion of the pelvis and trunk are described in side and rear views (sagittal and frontal planes). The angle of the pelvis from the side view is called the anterior-posterior tilt (A-P tilt), with a positive angle describing a tilt down towards the front. The trunk angle from the side is described relative to the horizontal.

At IC the trunk will be flexed forward between 5 and 10 degrees and the A-P tilt will be 15-20 degrees. During the absorption phase from IC to MS, trunk flexion increases by 2-5 degrees while the A-P tilt remains stable. This slight forward flexing of the trunk during the braking phase helps to maintain the body's forward-horizontal momentum. Gluteal-hamstrings, abdominals and erector spinae are all active to control the trunk and pelvis during the absorption phase.

During the propulsion phase the trunk re-extends to the initial position, so the trunk angle at TO will be similar to that at IC. The A-P tilt however will increase by 5-7 degrees in concert with the extension. This slight shift in the anterior tilt of the pelvis helps to direct the propulsion forces of the leg horizontally. If the pelvis were in neutral then the triple extension of ankle, knee and hip would be directed more vertically.

A slight forward lean and anterior pelvic tilt is thought efficient for running. Too much forward lean may suggest that the posterior chain muscles (hamstrings-gluteal-erector spinae) are not strong enough and this may increase the strain on the hamstrings and back during the running action. Too upright a posture may encourage vertical movement which will increase landing forces. Too much A-P tilt between IC and MS suggests that the gluteals and abdominals do not have the strength to control the pelvis adequately during landing and/or may indicate incorrect quadriceps activation and reduced hip flexibility. Excessive A-P tilt during the propulsion phases is normally associated with tight hip flexors and inadequate range of motion during hip extension. This will reduce the power of the drive from the hip and encourage a compensatory reliance on lumbar extension.

In general, a poor trunk position or lack of pelvic stability is likely to reduce the efficiency of the running action, creating extra load on the leg muscles or increasing stress through the lumbar spine and pelvis. Any of these negative factors can increase the likelihood of injury.

From the rear view the pelvic angle is described as a lateral tilting, with a negative angle meaning the pelvis is tilted down towards the swing leg side. The trunk is described as lateral flexion with a positive angle meaning the trunk is leaning down towards the stance leg side. At IC the lateral pelvic tilt is around –5 degrees (*ie* a small tilt downwards on the contact side). This position may increase slightly (up to 5 degrees) during the absorption phase, although ideally very little movement will occur. At faster running speeds, the lateral tilt will be bigger.

Trunk lateral flexion is about 2 degrees at IC, which increases to 5 degrees at MS. This lateral flexion counterbalances the pelvic tilting. Between MS and TO the pelvic lateral tilt should revert to +5 degrees by TO and trunk flexion should return to 0 degrees (*ie* vertical spine alignment). This balanced spine position allows the propulsion forces to be directed forwards at TO and the positive lateral hip angle supports the knee lift of the swing leg.

The aim of the pelvis and trunk in the frontal plane during stance phase is to be stable and provide balance. The gluteus medius muscles (abductors) are of primary importance in providing lateral stability: their contraction prior to and during the absorption phase prevents the hip from dropping down too far to the swing leg side. The muscles will be acting eccentrically, or even isometrically, to prevent this movement.

An excessive or uncontrolled pelvic tilt increases the forces through the lumbar and sacroiliac joints, and forces the knee of the stance leg to internally rotate, which in turn may increase the pronation forces on the ankle. It is possible to observe a correlation between excessive pronation and excessive pelvic tilting in runners, and it is a good illustration of how one unstable link in the biomechanical chain can have an adverse knock-on effect and increase the risk of injury.

'A poor trunk position or lack of pelvic stability is likely to reduce the efficiency of the running action'

Foot mechanics

The outwards and inwards roll of the foot during running, as seen from the rear view, are called supination and pronation. This rolling action is normal and healthy. It is only excessive pronation or supination that leads to injury.

At IC the foot is in a supinated position, with the rear foot inverted. During the absorption phase between IC and MS, the ankle is dorsiflexing which – because of the way the subtalar joint works – also causes the foot to pronate. Pronation combines rear foot eversion with tibial internal rotation, and allows the foot to be flexible and absorb the impact forces of landing.

At around midstance the foot begins to re-supinate. This inverts the rear foot and externally rotates the tibia, moving the foot into a more rigid position to allow for a stronger push-off and more efficient recoil through the foot and Achilles tendon. You can feel the difference for yourself: roll your heel and ankle inwards and your foot will feel soft and flat. Then roll your heel and ankle out, and your foot should feel strong with an arch.

Pronation and supination both involve three-dimensional movements (heel eversion/inversion, ankle dorsi/plantar flexion and tibial internal/external rotation), which makes them very difficult to measure. The most commonly used approach is to measure the inversion and eversion range of motion of the rear foot during the stance phase, representing the pronation and supination movement patterns.

Inversion and eversion angles are calculated by the angle made between the midline of the calcaneus and the midline of the tibia, viewed from the rear. In normal movement, at IC the rear foot is inverted by 5-10 degrees. The maximum pronation angle will occur around MS and will be an everted position of around 10 degrees.

However, foot mechanics are highly complex and these values must be read as simply one part of the picture. Similarly, you should interpret with caution any qualitative video analysis you make of a runner's rear foot motion. Don't rush to judgement about the need for orthotics based solely on a visual reading of rear foot movement.

An excessive supinator will typically land in the inverted position and then remain inverted during the stance phase. This means that they will lose out on the shock-absorbing benefits of the normal pronation movements. Excessive supinators tend to suffer from injuries to the lateral knee and hip, and can also be prone to stress fractures, because of the higher repetitive impact forces they incur.

Excessive pronators come in three types:

- those who land inverted as normal but rotate across into an excessively everted position (such as 20 degrees);
- those who may pronate normally on landing but then stay everted throughout the stance phase;
- those who seem to pronate through a normal range but do it very rapidly.

We do not know which of these three faulty movement patterns is most likely to lead to injury, but logically all three can be problematic. If a runner spends too long in pronation, the foot will not be in a strong position to assist push-off during the propulsion phase, so the lower leg muscles will have to work harder. If the runner pronates too far or too quickly, the rotation forces acting on the tibia and knee joints may lead to problems. Excessive pronators tend to suffer from anterior knee pain, medial tibial stress syndrome, Achilles and foot soft-tissue injuries.

Upper body and arm mechanics

The main function of the upper body and arm action is to provide balance and promote efficient movement. In the forward horizontal plane the arms and trunk move to oppose the forward drive of the legs. During the braking phase (from IC to MS), the arms and trunk produce a propulsive force and during the propulsion phase (MS to TO) the arms and trunk combine to produce a braking force. This may seem a little weird, but in fact it is an advantage: the out-of-phase actions of the arms and trunk reduce the braking effect on the body and so conserve forward momentum.

In the vertical plane around the centre, the arms and upper trunk also oppose the motion of the pelvis and legs. For example, as the right knee drives up and through in front of the body – producing an anti-clockwise angular momentum – the left arm and shoulder move forwards – creating a clockwise angular momentum and counteracting the knee motion, thereby helping to reduce rotation forces through the body during the whole gait cycle. Although the legs are much heavier than the arms, the shoulders are wider than the hips, so the arms are well positioned for their job of counterbalancing the leg rotation. This may explain why female runners use a slightly wider or rotating arm action to compensate for their narrower shoulders and lighter upper body.

‘The normal arm action has more to do with running efficiency than with injury prevention directly’

The normal arm action during distance running involves shoulder extension to pull the elbow straight back; then, as the arm comes forward, the hand will move slightly across the body.

The arm action has more to do with running efficiency than with injury prevention directly. A good arm action needs to be encouraged to counterbalance lower-limb forces and angular momentum, which may in turn help reduce injury. The arm action also contributes a little to the vertical lift during the propulsion phase which may help the runner to be more efficient, reducing the work done by the legs.

The relationship between biomechanics and injury is specific to each body part. Overall though, poor mechanics of any body part will either increase the landing forces acting on the body or increase the work to be done by the muscles. Both increase the stress, which – depending on the individual and the amount of running – can become excessive and cause injury.

Raphael Brandon

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A beginner's guide to Pose running

If running is natural, why do we keep on injuring ourselves? Here an Australian physio takes a look at a controversial alternative style that claims to reduce the risk of damage.

The popularity of running as a leisure pursuit has increased throughout the past 25 years, reflecting social trends away from organised team sports and towards less time-consuming, more flexible and independent ways of keeping fit and active. Over the same time period there has been an explosion in sports science and sports injury research and therapeutic practice. Among other things, this has produced a wealth of advice on baseline fitness and training for running, and huge advances in footwear technology.

Yet runners keep on injuring themselves. They continue to seek treatment, typically, for Achilles tendinosis, patellofemoral pain, repetitive calf muscle strains, big toe pain and low back pain – and it seems to those of us who have been around the sports therapy world for a while that the incidence of running injuries has not reduced significantly. Is it time to return to the fundamentals of running to find out why so many people are still hurting themselves?

Coaches, trainers, therapists and athletes have no difficulty agreeing that technique has an important role to play in leisure pursuits such as rowing, golf, swimming and ballet, but when I ask my running patients about their technique – whether, for instance, they heel-strike or land with their knees straight – I receive blank expressions. In most sports, enthusiasts will expect to devote months and even years to working on movement technique, whereas with running we tend only ever to focus on how to run faster and/or further, and how much fitter we can get as a result.

In other words, running is practised rather than taught. This leads to the question: is there an optimal running technique that enables athletes to train without fear of injury, with a real reduction in their injury risk – and with the prospect of still being able to improve their performance?

One recently developed technique, called 'pose running', lays claim to be able to do all three things. Pose running was invented by Nicholas Romanov, a Russian scientist now based in Miami and consultant to the British, US and Mexican triathlon associations. During the 1970s and early 80s, Romanov was heavily involved with athlete training in Russia, where he observed that as his athletes turned up the workload, so they would start to break down physically. At that time there was little strength and conditioning training. With a heavy emphasis on improving mileage and speed, the athletes focused on increasing their cardiovascular and respiratory systems, and paid little heed to their underlying running technique.

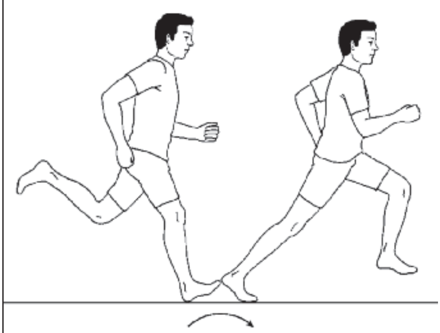
The pose method

Romanov proposes one universal technique for all runners, regardless of speed or distance: a 100m sprinter runs with the same underlying technique as a 10km long-distance runner. The technique is designed to prevent undue strain on the joints and requires a great deal of muscular endurance and resilience.

The elite British triathletes Tim Don, Andrew Johns and Leanda Cave have all adopted the pose method under Romanov's guidance. According to Romanov, the Ethiopian distance champion Haile Gebrselassie and the US sprint legend Michael Johnson are both examples of runners with a natural pose style – 'born with perfect technique'.

The distinguishing characteristic of pose running is that the athlete lands on the midfoot, with the supporting joints flexed at impact, and then uses the hamstring muscles to withdraw the foot from the ground, relying on gravity to propel the runner forward. This style is in clear contrast to the heelstrike method that most runners deploy and which is advocated by some health care professionals *(see Fig 1)*.

Fig 1: Heel-toe running



The concept is simple enough, but the practice is extremely hard to master. It is only with expert tuition and dedicated training that the athlete can perfect the technique. Running in pose is physically demanding, so runners must undertake strengthening drills before starting the programme. Maybe it is this added balance and stability training that allows the athlete to remain injury free? As yet there is no body of research to help answer this question.

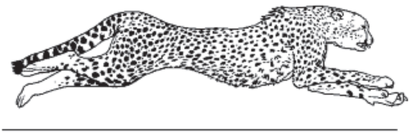
Principles

Running should be easy, effortless, smooth and flowing. We have all seen and heard the heavy runner who pounds away on a gym treadmill. Romanov says the runner is only as good as his change of support and that the runner should have a very high cadence – not a long, extended stride length. In pose running, the key is to maximise your effort in removing your support foot from the ground; good training is essential to ensure that you don't over-stride or create excessive vertical oscillation. The runner should fall forwards, changing support from one leg to the other by pulling the foot from the ground, allowing minimum effort and producing minimum braking to this body movement. The idea is to maximise the use of gravity to pull the runner forward.

The pose method is centred on the idea that a runner maintains a single pose or position, moving continually forwards in this position. Romanov uses two models to explain the rationale behind pose:

- **the mechanical model** – the centre of gravity, which is around the hip position, should move in a horizontal line, without vertical up and down displacement;
- **the biological model** – the rear leg maintains an 'S-like'

Fig 2: the cheetah



form, and never straightens. This notion comes from animals such as the cheetah which do not land on their heels but run on the midfoot and deploy a pulling through action using their hamstrings rather than pushing the foot into the ground *(see Fig 2)*.

Perhaps the most useful imagery to help with this technique is to imagine a vertical line coming from the runner's head straight down to the ground. The raised front leg should never breach this line, but remain behind it. This focuses the effort firmly on pulling the ankle up vertically under your hip rather than extending forward with your quads and hip flexors (front of thighs).

The power behind the pose

Pose is by no means universally accepted by the running fraternity. While top athletes have sought Romanov's help because of injuries, the method does require good scientific research to back it up. It is quite possible that many of the benefits experienced by pose athletes are the result of the rigorous strengthening programmes they undertake.

The training regime's focus on proprioception (joint stability and balance), together with the strong imagery of the technique, changes the physical placement of the limbs and reduces the downward displacement force of the foot on to the ground.

Fig 3: Toe running

That said, I know of people who have tried to run in pose and have sustained injuries such as calf strains and lower back problems, because they did not get their pose stance right and did not have sufficient hip control.

You need to be committed to learning the new technique: once you have decided to learn to run in pose, you cannot expect to chop and change between running styles at will. The technical drills outlined below can be very strenuous and may be harmful if attempted, for instance, at the wrong point in an injured runner's rehabilitation phase. Runners and coaches alike should adopt these drills with proper caution.

How to do it: pose drills

If you are embarking on a serious transition to pose, you should practise the drills (building up the level of difficulty) once or twice daily, three sets of 10 to 15 reps per drill. Drills should be practised for at least a week before attempting to run in pose, and should be performed before a run. All drills should be performed barefoot for added awareness of the movements, on a forgiving surface such as grass or a running track.

The drills fall into three sections:

a) **Basic drills** to reinforce the pose position, the use of the hamstring in pulling the foot from the ground and the feeling of falling forward under the effect of gravity (drills 1-7);
b) **Intermediate drills** to reinforce these feelings (drills 8 and 9);
c) **Advanced drills** to aid speed, balance, strength and reflexiveness (none shown here).

Drill 1 *(Fig 4)*:
Pose stance

This to be practised as a static pose, held for up to 30 seconds. It requires good postural control; no support is allowed. The idea is to challenge the mechanoreceptors in the joints and soft tissues to provide feedback to the brain regarding joint position and muscle tone.

- It is the basic position to hold and to practise balance
- The use of a mirror is recommended
- Shoulder, hip and ankle should always be vertically aligned
- Point of contact with the ground is always the midfoot
- Hip is always held over the support point, which is the midfoot.

Fig 4: Pose stance

Drill 2:
Change of support without moving

- Shift centre of gravity sideways from one leg to the other, maintaining support on the midfoot
- You must feel the weight shift from one leg to the other before pulling up
- It is important to feel the weight shift and then the acceleration of this movement by the pulling-up of the hamstring
- Pull the ankle up vertically under the hip using the hamstring only, not hip flexors or quadriceps
- Allow the leg to drop to the ground – do not drive it down
- Mental focus is on the pulling-up action, not the leg drop.

Drill 3 *(Fig 5)*:
Pony

- This practises changing support using minimum effort and minimal range of movement
- Simultaneously lift the ankle of the support leg while allowing your body weight to shift to the other leg
- Use only the hamstring. Keep in mind your support point on the midfoot (toes will also be in contact).

Drill 4 *(Fig 6)*:
Forward change of support

- This puts the pony into action; practise slowly at first

Fig 5: Pony

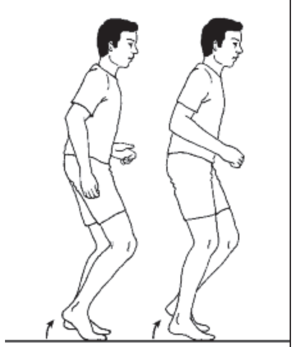
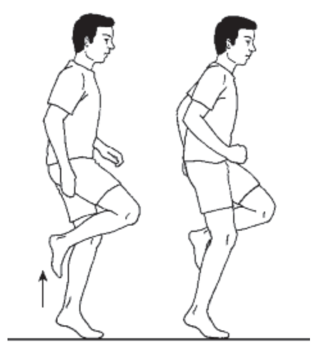


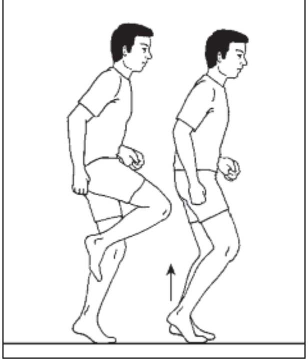
Fig 6: Forward change of support



- Lean slightly forward and simultaneously pull the ankle up under the hip using the hamstring and allow the non-support leg to drop to the ground under the force of gravity
- Make sure the weight transfer is effortless and that the foot is allowed to fall.

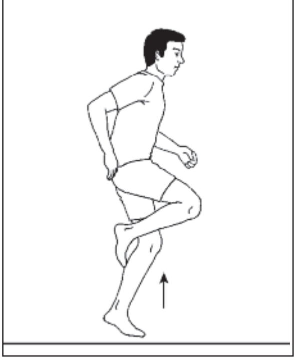
Drill 5 *(Fig 7)*:
Foot tapping
Single-leg drill, 10-15 taps per set
- This emphasises the vertical leg action and use of hamstrings rather than driving the knees up and forward using your hip flexors and quads
- It prevents your foot from being too far out in front of the body, which would cause you to land on your heel and create a braking action
- Aim for rapid firing of the hamstring, lifting the foot from the ground as soon as it touches down
- You must feel the muscles fire and then relax. Avoid a forceful pull all the way up. If you are doing it correctly the lower leg will decelerate after the initial firing and accelerate as gravity returns it to the ground.

Fig 7: Foot tapping



Drill 6 *(Fig 8)*:
Hopping
This movement progresses the tapping drill. The momentum for the hopping support leg should come from the hamstring action on the non-hopping leg. Take care: this is an advanced movement which will place unhealthy stress on structures such as the Achilles/calf muscles if not performed correctly.
- Start by pulling up the non-hopping leg with your hamstring and use the reaction force of the ground to aid this recoil effect
- Do not push with the calf but just lift the ankle with the hamstring and make sure the ankle is relaxed between hops.

Fig 8: Hopping



Drill 7 *(Fig 9)*:
Front lunge

- Single-leg drill which increases the range of movement of the hopping drill. This truly forces you to isolate the hamstring muscles
- Practise initially on the spot until you are stable enough to allow forward movement
- Keep weight on front leg; the back leg drags behind
- Pull ankle vertically up under the hip, using the hamstring
- Keep contact time with the ground as short as possible
- Allow rear leg to follow loosely
- Remember to land on the ball of your foot
- Forward movement is created not by pushing off but by leaning forward from the hips. You drag the rear leg behind you for balance.

Drill 8 *(Fig 10)*:
Switch

- Both ankles are being picked up
- This time you are picking the rear leg up as well with the hamstring
- Transfer weight from one leg to the other as you alternate support
- Keep contact time with the ground to a minimum, only as necessary to change support
- Keep heels off the ground and land on the balls of your feet

Fig 9: Front lunge

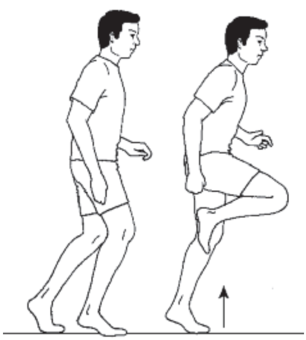
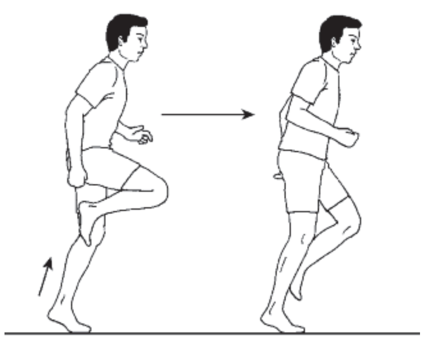


Fig 10: Switch



- Always think of the pose stance: good vertical alignment of shoulder, hip and foot.

Drill 9:
Running lunge
- This is pose running, but with a deliberate emphasis on the speed of the hamstring pull-up
- The aim is to teach the working leg to react as quickly as possible, minimising support time on the ground
- The runner pulls the heel up vertically from the ground but allows it to fall easily to the ground.

Scott Smith

Further reading

Pose Method of Running by Nicholas Romanov (2002), PoseTech Press ISBN: 0-9725537-6-2

'Reduced Eccentric Loading of the Knee with the Pose Running Method', Arendse, Regan E; Noakes, Timothy D; Azevedo, Liane B; Romanov, Nicholas; Schwellnus, Martin P; Fletcher, Graham in Medicine & Science in Sports & Exercise: Volume 36(2) February 2004 pp272-277.

POSE PRINCIPLES IN SUMMARY

1. Raise your ankle straight up under your hip, using the hamstrings;
2. Keep your support time short;
3. Your support is always on the balls of your feet;
4. Do not touch the ground with your heels;
5. Avoid shifting weight over your toes: raise your ankle when the weight is on the ball of your foot;
6. Keep your ankle fixed at the same angle;
7. Keep knees bent at all times;
8. Feet remain behind the vertical line going through your knees;
9. Keep stride length short;
10. Keep knees and thighs down, close together, and relaxed;
11. Always focus on pulling the foot from the ground, not on landing;
12. Do not point or land on the toes *(see Fig 3: Toe running)*;
13. Gravity, not muscle action, controls the landing of the legs;
14. Keep shoulder, hip and ankle in vertical alignment;
15. Arm movement is for balance, not for force production.

A pain in the side – why stitch can turn a sporting demigod into a 'DNF'

When Haile Gebrselassie dropped out of the 2007 London Marathon, no one was more shocked than the man himself. But why should an athlete of his ability and experience be struck down by something as mundane as a side 'stitch'?

The sight of Haile Gebrselassie pulling out of the 2007 London Marathon was almost as shocking to onlookers as Paula Radcliffe's untimely exit from the Olympic Marathon in Athens. The double Olympic 10,000m champion dropped out of the lead group shortly after the 30km mark, clutching his ribs. 'I had a stitch here in my chest and could not continue. I'm not injured I just couldn't breathe,' he told BBC Sport, with more than a tinge of exasperated disbelief in his voice.

The manner of Gebrselassie's exit is almost as surprising as his failure to finish; surely succumbing to stitch is not something that we associate with one of the greatest distance runners who has ever lived? Stitch is what 'fun runners' get – a 'rite of passage' en route to becoming 'real runners', isn't it? However, as Gebrselassie's exit from the London Marathon demonstrates, this is clearly not the case!

The lack of a definitive scientific explanation for a stitch shouldn't really surprise us since it's a very difficult phenomenon to study using normal experimental methods. Experimental scientists generally study a phenomenon by inducing it, or manipulating it, and in doing so they derive a better understanding of its characteristics and the mechanisms that control it.

However, stitch is notoriously unpredictable in its onset, so studying a stitch is very much like trying to study a condition such as acute mountain sickness (AMS); we know AMS occurs in some people when they ascend to altitude, but the symptoms vary between people, AMS doesn't always affect the same person in the same way, and it doesn't affect everyone at the same altitude. This means that the only way you can study AMS is to observe a huge number of people, wait for AMS to develop in some of them, and then record the circumstances under which it occurred.

This 'observational' or epidemiological research generates information that is analysed by cross-referencing many factors in order to tease out the common denominators within the symptomology and physiology. Associations between these factors then provide pointers to the underlying cause(s). But even when these links are identified, the best that can be achieved with epidemiological research methods is circumstantial evidence of underlying mechanisms.

What is a 'stitch'?

One theory is that a stitch is caused by the movements of the stomach and liver, which places strain on the diaphragm ligaments and/or the ligaments supporting the abdominal organs. Another theory is that a stitch is just plain old diaphragm ischaemia (insufficient blood flow for the metabolic demand), and/or a diaphragm spasm (cramp) [1]. A more recent theory is that stitch is a symptom of an irritation of the lining of the abdominal cavity (peritoneum) caused by friction between the abdominal wall and the abdominal organs [1]. However, the jury is still out and there is, as yet, no unequivocal scientific evidence to implicate any one of these potential mechanisms.

So it is for the stitch. Until 2000, there had been no data published on the phenomenon in the medical literature since 1951. Even those data that now exist are primarily epidemiological, and have originated from just one research group in Australia. For example, in one study these researchers administered a questionnaire to 848 people who took part in a 14km run [2]. Twenty seven per cent experienced a stitch and it was twice as common in those who ran in the event than in those who walked.

This tells us that a stitch arises frequently, but what are the common denominators in terms of its occurrence?

Causal factors in stitch

Studies have also used epidemiological techniques in an attempt to identify causal factors, as well as its prevalence. For example, a survey of almost 1,000 regular sports participants in Australia (3) found that the prevalence of stitch declined with increasing age, and that neither gender, nor training experience appeared to influence stitch.

Facts about stitch

Only a few studies have been conducted into the causes of stitch, but here's what we know so far:

1. Stitch is most common during running (almost 10 times more common than in cycling) (3);
2. The site of stitch varies, but is most commonly the mid/lateral abdomen (1);
3. Stitch decreases with increasing age (3);
4. Stitch may be more common in people who train less regularly (3);
5. Stitch is sometimes linked to food or fluid intake(5,6);
6. Stitch is sometimes also associated with shoulder tip pain (3,4);
7. Stitch can lead to difficulty in breathing;
8. Stitch also occurs frequently in horse riding and other sports in which the torso is subjected to movement (team sports and swimming)(3).

In addition, they noted that a stitch was often associated with shoulder tip pain; the shoulder tip is a site for referred diaphragm pain (in much the same way that people get pain in their left arm when they are having a heart attack, pain in the right shoulder is linked to a problem relating to the diaphragm). In another survey from the same research group (4), 1,000 participants in running, swimming, cycling, aerobics, basketball and horse riding were compared. The authors found that the stitch was most common in sports that involve repetitive movement of the torso, either vertically (*eg* running and horse riding), or in longitudinal rotation (*eg* swimming).

There have been only two interventional studies of the stitch, *ie* studies where the experimenters tried to induce a stitch deliberately. In the first of these the experimenters administered a range of different drinks in an attempt to differentiate the influence upon stitch of fluid per se, as well as the effect of the composition of the fluid upon blood flow to the stomach and intestines [(5)]. After ingesting the fluid (14mls per kg body mass) the subjects were required to perform repeated bouts of hard running on a treadmill. They found that the composition of the fluid had little or no effect upon the development of 'stitch'. In a separate part of the study the subjects performed a number of manoeuvres after the onset of stitch in an attempt to alleviate its intensity. The most effective of these were:

- bending forwards while contracting the abdominal muscles, or tightening a belt around the waist;
- breathing through pursed lips with an increased breathing volume.

The second study that attempted to deliberately induce stitch also examined the influence of the composition of different drinks upon the severity and subjective experience of the stitch [(6)]. The researchers selected 40 subjects who were susceptible to stitch, and compared their responses to four treadmill running trials (one control and three test drinks). Drinking fruit juice appeared to be more provocative than the other conditions, but there was no statistical difference between taking no fluid and taking flavoured water, or a sports drink. However, the difference between the sports drink and the other two conditions (water or no drink) was nearly statistically significant and the authors concluded that susceptible individuals should avoid fruit juice and other high carbohydrate drinks before, or during exercise.

So what does all this tell us about the causes of a stitch? The fact that it occurs more often in sports that involve jarring and/or twisting of the torso suggests it's linked to the movement of the body's internal organs, and that factors that are involved in maintaining postural stability may be involved. The shoulder tip pain indicates that the diaphragm muscle may be involved, while the fact that having food or fluid in the stomach increases the prevalence of stitch points to the involvement of organs that are in close proximity to the diaphragm (stomach and liver). Finally, the clincher is the fact that a stitch makes it very, very uncomfortable to breathe. All in all, the evidence adds up to the pain originating from the diaphragm muscle.

The role of the diaphragm

It's pretty well understood by most people that the diaphragm is the main muscle of inhalation, but what is less widely appreciated is that the diaphragm is also a vital part of the group of muscles known as the core stabilisers. The core stabilisers include superficial muscles that form a muscular 'corset', which encapsulates the abdominal compartment of the body, as well as deep muscles that stabilise the spine and pelvis.

These muscles are responsible for keeping the body upright during activities that perturb the centre of gravity, such as bending, jumping, running, riding a horse, etc. They also help to provide a stable 'base' from which other torso muscles can twist the trunk during actions such as throwing, hitting a ball, or even front crawl and backstroke swimming. Perhaps the most important role for the core stabilisers is to protect the spine and pelvis from damage during lifting and any actions that load or impose stress upon these parts of the skeleton.

In its role as a core stabiliser, the diaphragm is activated subconsciously during the preparatory phase of most limb movements [7]. In doing so it raises the pressure inside the abdomen, which acts to increase spinal stability [8]. This function presents no problem when standing still, but when exercising, there's an additional demand placed on the diaphragm that comes from the requirement to breathe more vigorously. Put these two demands together, as occurs during running, and it easy to see how the diaphragm can become 'overloaded' [9].

In other words, the diaphragm is subjected to competing demands in its roles as a vital core stabiliser and the principal muscle of breathing. In addition, because it is surrounded by large, heavy organs (specifically the stomach and the liver below it), there are some situations that make life even more difficult for the diaphragm. If breathing and stride cadence aren't synchronised, the diaphragm can be 'buffeted' by the movements of these large organs as they move up and down under the force of gravity and in synchrony with the foot strike.

Not only does this stretch the diaphragm, but it also means that it must work against the buffeting, which adds considerably to the amount of work it must do. This can be a particular problem on uneven terrain when it's hard to get into a rhythm, and the postural role of the diaphragm and other trunk muscles is also being challenged. Ever had rib ache the day after a cross-country run? That's because your ribcage and diaphragm muscles have been fighting hard to keep you from landing on your face in the mud!

Diaphragm discomfort

As a scientist, I must resist the temptation to apply my personal experience of a phenomenon to its interpretation. However, I have observed a consistent response across a large number of people, and over many years. These observations (combined with the circumstantial evidence that exists within the literature) suggests, to me at least, that a stitch is almost certainly diaphragm discomfort arising because of an inability to cope with the demands that are being placed upon it.

Most people are inherently poor and inefficient breathers; they just let it happen automatically, and pay no attention to the muscles that are used to do it. Of the many muscles involved in breathing, the diaphragm is by far the largest, strongest and most resistant to fatigue. Accordingly, the diaphragm is the muscle that should be employed to undertake the lion's share of the work of breathing, not the rib cage muscles.

Sadly, in my experience, few people use their diaphragm as effectively as they could. In order to do so, they have to re-educate themselves into a way of breathing that was second nature to them as infants. This re-education is possible through a conscious process of focusing inspiratory effort upon the diaphragm, and is best practiced in the first instance while not exercising.

Unfortunately, the conscious shifting of effort towards the diaphragm during running can have an initial downside, and many people find that they experience the most frequent and severe stitch pains they've ever had. However, in my experience, with perseverance over a two- to three-week period, most people also find that the pains gradually reduce in frequency and severity.

My interpretation of this phenomenon is that during the initial phase, the diaphragm is subjected to an increased demand to do more of the work of breathing, leading to overload and ultimately, a stitch. However, over a two/three-week period, the diaphragm does what every other muscle in the body does when you ask it to do more than it's used to – it adapts. This adaptation means that the diaphragm becomes better able to cope with the increased demand and the result is that the stitch no longer occurs. But is this the only way to reduce the risk of a stitch?

In the course of my academic research, I have studied the ways in which breathing limits exercise tolerance and performance for over 15 years. This research led to the development of a device that trains the diaphragm (an inspiratory muscle trainer) by imposing a resistance to inhalation that is akin to lifting a dumbbell. Our laboratory studies have shown that this training improves performance by making exercise feel easier, and by preventing the inspiratory muscles from diverting blood away from the legs during exercise.

The reason this type of training is relevant to stitch is that one of the anecdotal observations of many people who train their inspiratory muscles using such devices is that they no longer experience stitch pain. In addition, some also reported that if they trained their inspiratory muscles within an hour or so of going for a run, they often got a stitch. In other words, they went for a run with the diaphragm in a pre-fatigued state, which predisposed them to getting a stitch. These observations are strongly indicative that stitch is a response of the diaphragm to a situation it can no longer cope with.

Coping with a stitch

So, what should you do if you suffer a stitch during a race? One option is to drop out, which is unfortunately what Gebrselassie felt forced to do, but a stitch doesn't have to spell the end of the race. Stitch pain will subside if you allow the diaphragm to rest, so you can either slow the pace right down, or even walk for a while.

Alternatively, you can give your diaphragm a 'breather' by consciously shifting the work of breathing away from your diaphragm for a few minutes, or until the stitch subsides. This tactic has to be a last resort, because your ribcage muscles will also fatigue if you rely on them too heavily.

Other techniques that are supported by the evidence of one study[5] are to:

1. Bend forwards while contracting the abdominal muscles, or to tighten a belt around the waist;
2. Breathe deeply through pursed lips. A technique that appears effective for some athletes I've worked with is to bend forwards, tighten the abdominal muscles (especially transversus abdominis) and press inwards and upwards (hard!) on the site of the pain with your palm for 10-15 seconds.

Prevention is much better than cure, so let's consider what can be done to minimise the risk of developing a stitch in the first place. The research suggests that ingesting large volumes of food or drink, especially if it's high in carbohydrate, should be avoided immediately before, or during exercise.

However, perhaps the best advice is to train your diaphragm so that it's never faced with a situation that it can't cope with (*see box)*. As we've seen, no amount of ordinary training can do this; if it did, then the likes of Gebrselassie would surely be immune to 'stitch', and he patently isn't. If you don't want to experience the same fate, then a little heavy breathing will help ensure that your diaphragm can cope with anything you care to throw at it!

Inspiratory muscle training (IMT)

IMT requires a specific training device, such as a POWERbreathe. A typical IMT session consists of inhaling against a moderate training load (around 50% of the maximal voluntary contraction force of the inspiratory muscles) for around 30 repetitions (breaths). This magnitude of load corresponds to the 30-repetition maximum (RM) for the inspiratory muscles, *ie* the maximum load that can be sustained for 30 repetitions. This is identified by trial and error (just as you would when identifying the 12-RM for a bench press). This 'foundation training' is undertaken in the standing position twice daily for 4-6 weeks, and a typical session requires just 2-3 minutes. After completing this foundation block, you can move to a more sport-specific training routine. This is achieved by introducing posture specificity to the session in order to challenge both the breathing and postural roles of your inspiratory muscles. If 'eliminating stitch' is the main goal, then specificity can be achieved by challenging the postural stabilising role of the diaphragm while undertaking IMT – *eg* by standing on a wobble board, air pillow, or Bosu ball while performing IMT.

Alison McConnell

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Carbohydrate drinks – can fructose enhance endurance for runners?

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 could herald a new breed of carbohydrate drink, which promises genuinely enhanced endurance performance.

Before we go on to discuss carbohydrate formulations, it's worth recapping just why carbohydrate nutrition is so vital for middle distance runners. 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 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 in1. 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 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 now a series of studies carried out by scientists at the University of Birmingham in the UK indicates that this may indeed be possible.

'One of the goals of sports nutrition has been to see whether it's possible to increase the rate of carbohydrate replenishment'

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.

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:

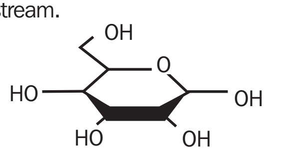
- 1.8g per min of pure glucose;
- 1.2g of glucose + 0.6g per minute of sucrose;
- 1.2g of glucose + 0.6g per minute of maltose;
- Water (control condition).

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, below)*, 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.

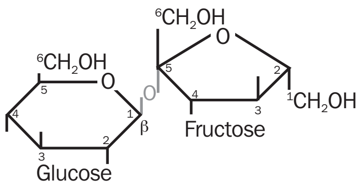
CARBOHYDRATE BUILDING BLOCKS

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.

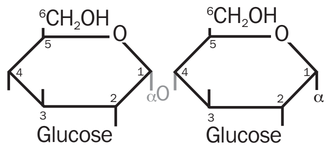
Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is 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

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.

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 above)*.

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 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.

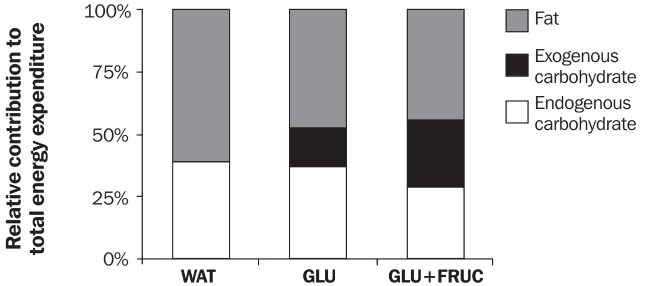
Although no direct muscle glycogen measurements were made, the kinetics of the rate of appearance and disappearance of glucose in the bloodstream from the drinks led the researchers to postulate that the extra carbohydrate oxidation observed could be as a result of increased liver oxidation, or the formation 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?

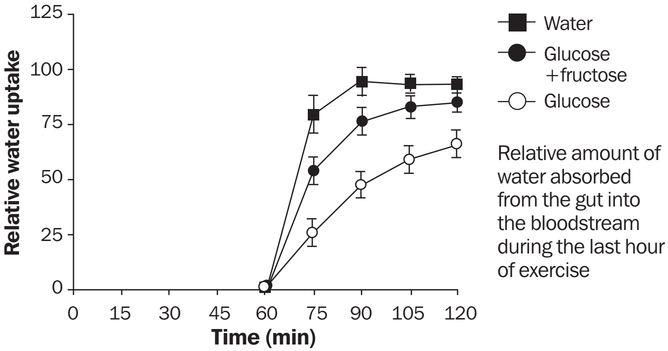
That's the question scientists at the University of Hertfordshire are currently trying to answer in a double-blind, placebo controlled study to test commercially available drinks, which was set up earlier this year. The main goal is to compare the effects on cycling performance of a popular glucose/glucose

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

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

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

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WHAT THE PAPERS SAY

Reports on recent running-related studies

Explosive type strength training enhances distance-running performance

One of the most fundamental rules of training is specificity; if you want to train for an event, your training should replicate the demands of that event. The rule of specificity arises because different events tend to rely on different energy systems in the body (which need to be specifically trained) and also because many disciplines require a specific set of motor skills and neurological adaptations.

However, the reality is that while many endurance events draw heavily on the aerobic energy system, they often also require short high-energy bursts provided by the anaerobic energy pathways (for example, during the sprint for the line) – pathways that are often neglected in training because of the desire to concentrate on endurance performance. But new research by Finnish scientists at the Research Institute for Olympic Sports suggests that this strategy may be counterproductive for endurance runners, and that anaerobic performance can be readily enhanced without increasing training volume or compromising endurance.

In the study, the effects of concurrent explosive strength and endurance training on aerobic and anaerobic performance and neuromuscular characteristics were studied in 25 distance runners, who were split into an experimental group (13 runners) and a control group (12 runners). All of the runners trained for eight weeks with the same total training volume, but in the experimental group 19% of the endurance training time was replaced by explosive-type training, including sprints and strength drills. After the eight-week training programme, all the runners were evaluated for various aspects of performance with the following results:

- Compared to the controls, the maximal speed during a maximal anaerobic running test and 30-metre speed improved in the experimental group by 3.0% and 1.1% respectively;

- The concentric and isometric forces generated during leg extension increased in the experimental group but not in the controls;
- The experimental group improved their muscular force-time characteristics and had rapid neural activation of the muscles (*ie* they were able to generate more power through more rapid muscular contractions);
- The increase in thickness of quadriceps muscles after eight weeks was nearly double in the experimental group compared to the controls;
- Importantly, the maximal speed during an aerobic running test, the maximal oxygen uptake (VO2max) and the running economy (how efficiently the runners used oxygen to for any given running speed) remained unchanged in both groups.

The implications of these findings are clear; if you are an endurance athlete whose event also demands brief bursts of high-intensity work, substituting some of your endurance training (up to 20%) with anaerobic work needn't necessarily involve a drop in aerobic performance, and may even give you a competitive edge.
Int J Sports Med 2007; 20 [Epub ahead of print]

Creatine serum offers no advantages for runners

The cheapest and most popular form of creatine (and the sort used extensively in scientific studies) is creatine monohydrate, a white powder that needs to be mixed with water/fruit juice etc before use. More recently, other more exotic and expensive forms of creatine have appeared, which claim to offer performance benefits over standard creatine. One of these is 'creatine serum', a liquid form of creatine that is claimed to offer a number of other advantages over powdered creatine, including instant absorption, no side effects (such as water retention, bloating or cramping) and complete assimilation into the muscles.

To test this theory, Californian researchers examined the effects of ingesting creatine serum on cross-country runners. All the runners underwent baseline testing by completing a 5,000m outdoor run followed by a VO2max test on the treadmill the same day. The runners were then split into two groups; 13 took the manufacturer's recommended dose of 5mls of serum (2.5g of creatine), while the control group took an inert placebo.

As well as VO2max, heart rates, run times and perceived rates of exertion were recorded. The results showed that runners taking the serum had a significantly lower perceived rate of exertion and also managed longer durations on the incremental VO2max test. However, the actual VO2max figures were not significantly different between serum and placebo groups, and there was also no improvement in 5,000m run time in the serum group.

The scientists went on to conclude that 'their data did not support the ergogenic claims of creatine serum in its current form and dose'.
J Strength Cond Res 2005; 19(4):730-4

The benefits of training backwards

Backward walking and running is recommended for the rehabilitation of overuse injuries and knee joint problems because it increases the strength and power of the quadriceps muscles while reducing compressive forces at the knee joint, preventing overstretching of the anterior cruciate ligament (ACL) and decreasing force absorption.

But that's not all: according to a new study from South Africa, backward locomotion training also improves cardiorespiratory fitness, while causing significant changes in body composition, and may thus be a useful supplement to coventional running training programmes.

This study investigated the effects of a backward training programme on healthy young female university students. Twenty-six students took part in three different baseline tests (body composition, a submaximal treadmill test and a 20m shuttle run test) before and after a six-week training programme.

For the training programme they were divided into two groups:

1. A training group who completed a six-week backward run/walk training programme, consisting of three sessions per week for a total of 18 sessions, with the duration of the sessions progressively increased over the study period;

2. A control group who followed their normal daily activities.

On retesting, the trained group were found to show:

- a significant decrease in oxygen consumption during both submaximal forward and backward exercise on the treadmill (30% and 32% respectively);
- statistically significant decreases in skinfold thickness (19.6%) and percentage body fat (2.4%) at the end of the study period;
- statistically significant increases of 5.2% in maximal oxygen uptake.

The researchers conclude: 'The results of this study provide, for the first time, evidence that backward locomotion can improve cardiorespiratory fitness and possibly lead to positive body composition changes in young women.'
Int J Sports Med 2005; 26:214-219

Why long, slow training runs may be best after all

For some time now, experts have been downgrading the value of long slow workouts for endurance runners in favour of briefer bouts of high intensity exercise.

But now a Spanish study, which followed eight well-trained sub-elite endurance runners during the six-month lead-up to their national cross-country championships, has thrown that wisdom into doubt.

The researchers found that the runners spent most of their training time at low intensities (below 60% VO2max). But they also found evidence to suggest that total training time spent at low intensities was associated with improved performance in highly intense endurance events.

The runners' heart rates were continuously recorded, using a technique called telemetry, during each training session between August and February leading up to the championships, where they competed either in the short race (4.175k) or the long race (10.130k).

The researchers quantified total cumulative time spent by each runner in zone 1 (low-intensity), zone 2 (moderate intensity – 60-85%

VO2max) and zone 3 (high intensity – above 85% VO2max) and then related these to final race performance. Their two key findings were:

- That these regional/national class endurance runners spent most (71%) of their training time in zone 1 and a mere 8% in zone 3;
- That total training time spent in zone 1 was linked with improved performance time during both races, particularly the long one.

'Our findings suggest,' the researchers conclude, 'that total training time spent at low intensities might be associated with improved performance during highly intense endurance events, at least if the event duration is [around] 35 minutes. Interventional studies are needed to corroborate our findings.'

They cannot easily explain these unexpected results but suggest that athletes might engage in a form of 'pacing' that occurs over a very long period of time. 'Just as athletes must distribute their energetic resources within a competition… it appears that they must also perform a certain level of pacing over long periods of time, so that the balance of the training stress and training adaptations remains favourable.'
Med Sci Sports Exerc, vol 37, no 3, 496-504

No link between hydration and cramps

The popular theory that exercise-induced muscle cramping (EAMC) is caused by fluid imbalances, particularly dehydration and abnormalities in blood electrolyte levels, has been overturned by a South African study of ultra-distance runners.

Electrolyte and fluid disturbances have been associated with muscle cramps in certain clinical conditions, explain the researchers, and it is therefore often assumed that EAMC has the same cause despite a lack of evidence to that effect.

They set out to determine whether acute EAMC in distance runners is related to changes in serum electrolyte concentrations and hydration status. A cohort of 72 male runners participating in the Two Oceans Ultra-marathon, a 56k road race held annually in Cape Town, were asked about their history of EAMC and then followed up for the development of the condition during the race.

All subjects were weighed before and immediately after the race to assess changes in hydration status. Blood samples were taken before, immediately after and 60 minutes after the race and analysed for glucose, protein, sodium, potassium, calcium and magnesium concentrations, as well as various markers of hydration status.

Of the 72 runners in the study, 45 had a history of EAMC, while 27 had no previous experience of muscle cramping. In the event, 21 of the 45 runners with a history of cramping suffered acute EAMC either during the race or within 60 minutes of completing it, while 22 of the 27 runners with no history of cramping formed a 'control' group for comparison purposes.

Key findings were as follows:

- All episodes of cramping occurred in the latter half of the race or immediately afterwards, with most affected runners reporting three or more episodes. Most commonly affected muscles were hamstrings (48%) and quadriceps (38%). Most cramps were moderate-to-severe in intensity and best relieved by slowing the pace or passive stretching;
- There were no significant differences between the groups for pre- or post-race body weight, per cent change in body weight, blood volume, plasma volume, or red cell volume, indicating no difference in hydration status;
- Immediate post-race serum sodium concentration was significantly lower in the cramp group, while serum magnesium concentration was significantly higher. However, these differences were considered to be too small to be of clinical significance.

'Furthermore,' report the researchers, 'the decrease in serum sodium concentration following the race in the cramp group is probably related to an increased fluid intake during the race in this group. Although drinking patterns were not measured directly, increased drinking in the cramp group is likely because of the well publicised belief that cramping is caused by dehydration.'

This supposition was supported by the finding that runners with EAMC were less dehydrated than non-cramping runners immediately after the race, with per cent decreases in body weight (pre- to post-race) of 2.9% and 3.6% respectively.

'The results of our study,' conclude the researchers, 'do not support the common hypotheses that EAMC is associated with either changes in serum electrolyte concentrations or changes in hydration status following ultra-distance running. An alternative hypothesis to explain the [cause] of EAMC must therefore be sought.'
Br J Sports Med 2004; 38:488-492

Runner's high: a new explanation

The state of euphoria induced by prolonged exercise was known first as 'second wind' and more recently as 'runner's high'. Scientists originally attempted to explain the experience in terms of the effects of the 'stress hormones' adrenaline and noradrenaline. Then came the 'endorphin hypothesis'. And now we have the 'endocannabinoid hypothesis': a suggestion that the physical and psychological wellbeing experienced by many endurance athletes is due to the exercise-induced activation of endogenous cannabinoids – lipids whose actions in the body resemble those of the active constitutent of cannabis.

This theory, supported by scientific evidence that exercise boosts blood concentrations of endocannabinoids, is given a thorough airing in a review by US researchers published in the British Journal of Sports Medicine.

Their first point is that the endorphin hypothesis – that the runner's high is induced by the release of endogenous opioids in response to exercise – doesn't hold water because, among other lesser reasons, these chemicals are simply too large to cross the blood-brain barrier and exert the central effects that are claimed for them.

The endocannabinoid hypothesis, on the other hand, is supported by the following observations:

- Unlike opioids, endocannabinoids can suppress pain at peripheral sites as well as centrally;
- Unlike opioids, they do not produce such side effects as severe respiratory depression, pinpoint pupils and constipation;
- Endocannabinoids inhibit swelling and inflammation and reduce pain caused by the release of chemicals (such as lactic acid);
- The intense psychological experiences reported by users of cannabis – sedation, reduced anxiety, distortions of time estimation, euphoria,

enhanced sensory perception and feelings of wellbeing – are strikingly similar to the experience of runner's high;

- Research on animals has suggested that one of the principal roles of the endocannabinoid system may be the refinement of movements needed for coordinated locomotion;
- Activation of endogenous cannabinoids through exercise could account for the phenomenon of exercise addiction;
- Endocannabinoids act as vasodilators and bronchodilators, which should make exercise feel easier.

As the authors of the review point out: 'Further research is necessary to characterise the precise nature of this endocannabinoid response to exercise, specifically the relative importance of factors such as the nature of the activity, exercise duration, exercise intensity, sex and age.'

But in the meantime they suggest that the endocannabinoid hypothesis is a feasible alternative to the endorphin theory and should be investigated as such.

Br J Sports Med 2004;38:536-541

Nature and nurture in Ethiopian endurance running success

In the increasingly competitive world of international sport, identifying the key predictors of success has become a major goal for many sports scientists. And nowhere has the hunt been more focused than in East Africa, where the overwhelming success of male endurance athletes has kept the nature v nurture debate simmering.

Saltin's famous study comparing Kenyan and Scandinavian athletes suggested that it was the distance the Kenyans travelled to school on foot in childhood that gave them an edge in endurance athletics.

That theory has now received further backing from a major British study comparing the demographic characteristics of Ethiopian athletes with non-athlete controls from the same country.

An additional fascinating finding was that élite Ethiopian distance runners are ethnically distinct from the general Ethiopian population, raising the possibility that genetic factors might also be involved.

Questionnaires seeking information on place of birth, spoken language (by self and grandparents), distance from and method of travel to school were given to 114 male and female members of the Ethiopian national athletics team and 111 Ethiopian controls, none of whom were regularly training for any track or field athletic events. The athletes were separated into three groups for comparison: marathon runners (34), 5-10km runners (42) and other track and field athletes (38).

After analysis, the main findings were as follows:

- In terms of regional distribution, there was a significant excess of athletes, particularly marathoners, from the Arsi and Shewa regions of Ethiopia. 73% of marathon runners hailed from one of these two regions, compared with 43% of 5-10km runners, 29% of track and field athletes and just 15% of controls. To put those figures in context, Arsi is the smallest of Ethiopia's 13 regions, accounting for less than 5% of the total population, but housing 38% of the marathon athletes in this study;
- The origin of language of all the athlete groups differed significantly from that of the controls. Three separate language categories were used: Semitic, Cushitic and Other; and Cushitic was significantly more predominant in each of the athlete groups than among the controls. The effect was most pronounced in the marathon group, where 75% spoke languages of Cushitic origin compared to 30% of controls;
- In terms of distance travelled to school, the marathon athletes differed significantly from all other groups. 73% of marathoners travelled more than 5k to school each day, compared with 32-40% of the other groups. And marathoners were much more likely to run to school each day than the other groups (68% v 16-31%).

Where does this leave the nature v nurture debate? The findings about travel to school undoubtedly point to environmental influences, as the researchers acknowledge.

'…the results implicated childhood endurance activity as a key selection pressure in the determination of Ethiopian endurance success,' they say. 'With the prevalence of childhood obesity in the United States and Great Britain at an all- time high, and physical activity levels among such populations in stark contrast to the daily aerobic activity of Ethiopian children, these factors may offer an explanation for the success of East-African athletes on the international stage.'

On the other hand, the findings about regional and ethnic origins point to genetic influences. Or do they? The regions of Arsi and Shewa are situated in the central highlands of Ethiopia, intersected by the very same Rift Valley that has been implicated in the success of Kenyan endurance runners. This may seem to support a link between altitude and endurance success. But it doesn't explain why Arsi is also considerably overrepresented in track and field athletes (18%), who would not be expected to benefit from living and training at altitude.

The researchers put forward an alternative, somewhat more prosaic, hypothesis. 'One of the senior Ethiopian athletic coaches informed the investigators that most of the marathon athletes would be found to be from Arsi,' they explain. 'If those in charge of athletic development believe this, it may cause a self-fulfilling prophecy through talent scouts focusing more attention to this region or through increased regional development of athletics.'

What of the findings about language? The fact that most of the marathoners spoke languages of Cushitic origin (mostly Oromigna, the language of Oromo people) 'may reflect a high frequency of potential "performance genes" within this particular group.

'However, it is much more likely,' the researchers add, 'that the distinctive ethnic origin of the marathon athletes is a reflection of their geographical distribution, as primarily Oromo people populate Arsi.

'Although not excluding any genetic influence,' they conclude, 'the results of the present study highlight the importance of environment in the determination of endurance athletic success.'

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Bruce Tulloh was European 5,000m champion in 1962 in a time of 14:00.6. The championship record is now 13:10, but the 2002 title was claimed in 13:38.