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PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

PHYSIOLOGY

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

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

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

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

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

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

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

Whilst innumerable studies have been published concerning training in general, relatively few studies are available on HRV and its application to athletes.

continued on page 2

In this issue

FROM THE EDITOR

Changing times

Change is a double-edged sword; without it, we'd all be stuck in a permanent rut, yet change itself can be difficult to embrace. But this issue of *Peak Performance* contains persuasive arguments for reconsidering some conventional approaches to monitoring performance, sprint training and antioxidant nutrition.

For many athletes, traditional heart rate monitoring is vital for optimising training intensities. But according to Eddie Fletcher, a new breed of heart rate monitors that can also measure beat-to-beat variability looks set to revolutionise the way athletes and coaches monitor longer-term performance and recovery. Will this technology help to ensure overtraining in athletes becomes a thing of the past?

Meanwhile, John Shepherd argues that the conventional training approach used by sprinters should be turned on its head. Instead of the building endurance then speed, he looks at the evidence in favour of emphasising speed all year round, particularly for athletes who need to peak several times per season.

The constantly shifting sands of antioxidant nutrition have left many athletes confused about whether (and, if so, how) they should supplement antioxidant nutrients for maximal protection. That being the case, I've been looking at some new research, which seems to suggest that the answer to this quandary may be found down at the supermarket – and not in a supplement bottle!

Rounding off this issue is Isabel Walker's 'What The Papers Say', which reports new research on when active recovery might not always work, the success of hamstring surgery and the folly of using andro 'prohormone' supplements.

If you're reluctant to embrace change, maybe this issue will persuade you to reconsider!

***Andrew Hamilton BSc MRSC** editor*

At a glance:

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

Most studies involve small numbers of participants, which diminishes the power of the statistics, although since the review paper, significant progress has been made in the practical use of HRV to monitor fatigue accumulation during exercise.

What is heart rate variability?

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

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

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

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

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

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

HRV data can indicate the impact of fatigue due to prior exercise sessions, hydration levels, stress and even the degree of performance anxiety, nervousness or other external stressful influences. Studies have shown that it varies within individuals according to size of left ventricle (inherited trait), fitness level, exercise mode (endurance or static training) and skill (economy of exercise)[(2)]. Body position, temperature, humidity, altitude, state of mood, hormonal status, drugs and stimulants all have an effect on heart rate and HRV[(2)] as do gender and age. The general conclusion is that all of the HRV parameters are higher in men but that this gender difference is confined to men and women below 40-50. There's also an age-related decrease in HRV, although for elderly athletes with a lifelong training history, this decline is reduced.

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

How can HRV be used to enhance athletic performance?

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

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

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

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

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

EPOC

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

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

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

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

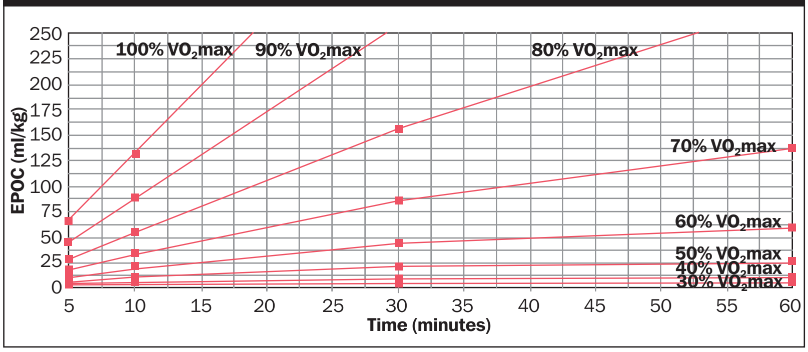
Without EPOC as a measure, the wrong conclusions may be drawn from a training session. You may believe that no improvement has occurred or performance has gone backwards, when in reality the difference is fatigue, and actual performance has improved.

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

The body may appear to recover rapidly from a training session (short-term fatigue) but carry accumulated (long-term) fatigue from training session to training session. This long-term fatigue builds up over time and is one reason why periodised training programmes, which build in easier recovery weeks, are needed. So when comparing sessions using HRV and EPOC, the amount of accumulated fatigue affecting each session can be seen by the difference in EPOC value (see figure 1, below).

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

Figure 1: The effect of training duration and intensity (%VO_2max) on EPOC accumulation



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

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

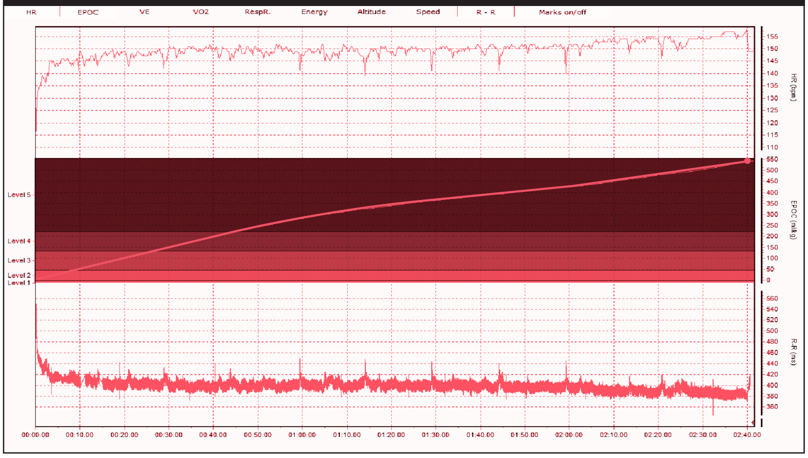
Based on accurate measurement of the time interval between heartbeats and the detected variation, the t6 software (run on a PC) calculates information about the performance of the body during training and displays the data in a user-friendly format for analysis. As the data is updated, the Suunto t6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

HRV and EPOC in action

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

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

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



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

- The top trace is heart rate, which was kept below 90% of maximum with an even rowing pace;
- The middle trace is the EPOC (note that despite a level heart rate the graph continued to increase as fatigue accumulated);
- The bottom trace is the HRV, the R-R intervals (note the slow narrowing of the time interval between beats).

In this particular model there are five levels of EPOC. Recovery from each level is as follows:

- **Levels 1 and 2** – 3 hours to 1 day
- **Level 3** – 1-2 days
- **Level 4** – 1-4 days
- **Level 5** – 2-7 days

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

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

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

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

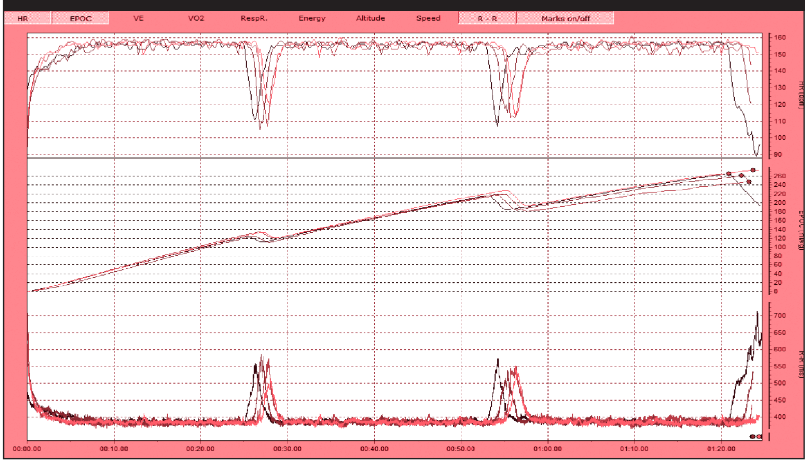
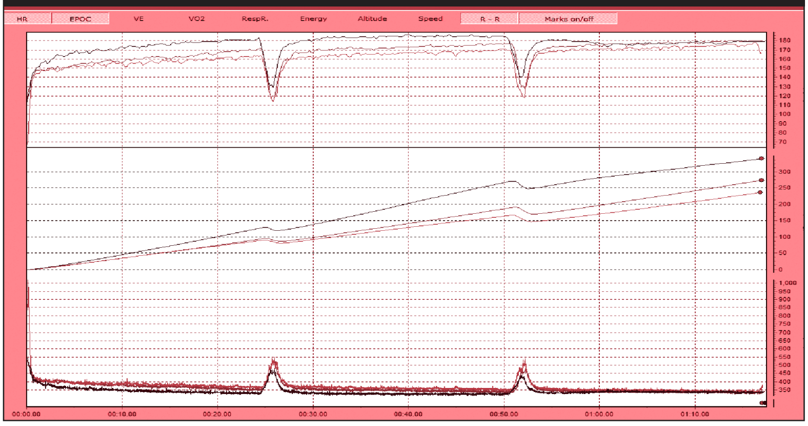


Figure 4: An example of different EPOC values, each session requiring varying recovery periods



Summary

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

Eddie Fletcher MSc is a sport and exercise physiologist and coach specialising in endurance events. He is also author of the 'Suunto Indoor Rowing Guide' and acts as an ambassador for Suunto in the UK

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Building speed before endurance: should athletes turn convention on its head?

At a glance:

- The potential flaws in the traditional 'long to short' approach to speed training are discussed;
- The aerobic requirements of sprint athletes are considered;
- An alternative triple periodised 'short to long' approach to the sprint season is outlined and examples are given;
- The importance of intensity, speed-endurance and sprint speeds in the 'short to long' approach is explained.

The traditional training approach has been to progress speed athletes from slower, aerobic work through to anaerobic speed work as the season progresses. But John Shepherd argues that this methodology is outdated and that convention should be turned on its head

Until quite recently, the prevailing methodology in sprint athlete training has used a 'long to short' training approach. Basically, for this **periodisation** model, the sprinter performs slower aerobic and anaerobic work at the beginning of the training year and then progresses to faster and faster anaerobic work as the season approaches and in-season. Intensity is increased, training volume reduced, and specificity of training increasing accordingly.

However, more recently a 'short to long' approach has become more popular. Coaches such as Charlie Francis (*see box, below*) have been at the forefront of such a shift in thinking. This approach emphasises speed all year round. Sprint workouts, for example, take place in what would normally be the 'slow slog' preliminary stages of training, when an athlete is 'supposedly' building base condition using slower conditioning methods. In the 'short to long' approach, the athlete trains at or near 100% effort throughout. Advocates of this approach claim it will:

1) maximise physical speed development;
2) optimally stimulate the **central nervous system** (CNS);
3) reduce injuries (athletes using the conventional approach can pick up injuries when attempting to sprint after months of much slower work);
4) allow for more speed peaks;
5) minimise the negative effects of de-training on **fast-twitch muscle fibre**.

The 'short to long' approach to sprint training can be seen to reflect the 'undulating periodisation' (UP) theory of training planning (of which more later).

Jargonbuster

Periodisation
The name given to the systematic planning of training using phases, or cycles, designed to bring an athlete to a peak or series of peaks, or maintain them in optimum playing condition over a playing season

Fast-twitch muscle fibre
Contracts up to three times faster than slow-twitch muscle fibre and is crucial for speed and power activities. Type IIa fibres have a relatively fast speed of contraction, which can be speeded up by the 'right' training, while type IIb, fibres are 'pure' out-and-out power and speed fast-twitch fibres

Slow-twitch muscle fibre
Fibres with a slow speed of contraction used during prolonged lower-intensity exercise

Charlie Francis – sprint guru or sprint devil?

Charlie Francis coached (the then fastest man in the world) Ben Johnson to the world record and Olympic title in Seoul in 1988. Johnson, as we know, was subsequently stripped of this and other titles for a doping offence. However, it would be erroneous for us to assume that Francis' athletes only won because they were drug-fuelled. Francis' sprint training methods did add that 'something extra' to the performances of those he coached, and one of these was the 'short to long' approach. Among his many other coaching accomplishments was the fact that at the 1984 Olympics, of the 14 Canadian medals, eight were won by Francis-coached athletes. Not surprisingly, his techniques and thoughts are still in demand today.

How much of an aerobic base does a sprint athlete need?

Aerobic fitness underpins the development of most other types of fitness. The more efficient an athlete's body is at processing oxygen, the quicker it will be able to recover between efforts. In the past it was reasoned that developing good aerobic condition in a sprint athlete would boost speed development. Thus it was not unknown for rugby and football players to go on 10-mile runs, or sprinters to run continuously for up to 30 minutes!

The logic of this approach, however, is questionable when you consider that most of the work performed by sprinters is anaerobic (*see table 1 on page 6*) and too much emphasis on aerobic work can blunt speed; this results from an unnecessary increase in the oxygen-processing capabilities of **slow-twitch muscle fibre** and a 'blunting' of the speed and power generation capabilities of type IIa and type IIb fast-twitch muscle fibre.

Prolonged training with a specific emphasis (*ie* speed) can change fibre type[1,2]. Sprint athletes obviously require a proliferation of fast-twitch fibres – a top class sprinter's leg muscles will possess 70-80% of fast-twitch fibres – and the 'short to long' approach never loses sight of this, as it maximises the opportunity of changing fibre type to express speed.

So how much aerobic training is necessary in a speed/sprint training programme? Charlie Francis recommends that for training a 'mature' 100, 200 or 400m runner, the development of base fitness with an aerobic element requires relatively little attention[3]. He advocates only a short six-week period at the beginning of the training year.

Training immature athletes (less than five years of consistent sprint training) will require a slightly greater aerobic conditioning emphasis and Francis identifies an 8-12 week development phase at the beginning of the training year. Both these durations should allow sufficient time to plan a double or even a triple periodisation sprint programme using much more specific training (of which more later).

Instead of long, slow distance, tempo running is used as a more appropriate base builder; these runs provide a more relevant anaerobic base of fitness, whilst improving aerobic condition. A typical tempo running workout would be something like three sets of 100m/200m/100m with 50m walk recovery between each run and 300m walk between sets. The runs would be performed at 75% of maximum speed.

Maintaining speed in-season for speed athletes

Undulating periodisation (UP) is probably the sprint and field sports coach's most effective way to maximise the playing condition of his or her athletes. UP basically mixes and matches all of the relevant training ingredients into one training mix. Strength, power, agility, endurance, speed, specific individual and collective playing skills and flexibility are all carefully overlapped and fused together to keep the athlete in peak playing condition.

This requires careful and consistent athlete appraisal on the part of the coach (something that Francis emphasises with his sprint training). It is crucial that coaches are aware that no two athletes will have exactly the same training needs and that individual training programmes will therefore have to be produced (although this may be more difficult for those involved in team games). It should also be noted that athletes from certain sports, such as a football midfielder, will need greater levels of aerobic conditioning than others to allow them to cope with the energy pathway demands of their games. However, even then, anaerobic training is the most important (*see table 1, above*).

Intensity, not volume, is the key to improved sprint performance

Although nearly all athletes increase the volume of their training as they progress from year to year, for sprint athletes it is training *intensity* that is critical. Intensity should increase while volume may remain unchanged or even decrease. The coach needs to monitor carefully the volume of intense work being performed by the athlete and ensure adequate recovery to allow progression and reduce injury risk.

The 'short to long' approach allows the athlete to remain close to absolute sprint condition at any time in the training year. This is why, for sprint athletes, double and even triple periodisation is advocated.

A triple-periodised training programme allows an elite sprint athlete to peak for the indoor season, mid-outdoor season and late outdoor season for Olympic or World Championships. Each peak can elicit a higher level of performance than the previous one, whereas the conventional 'long to short' approach may fail to achieve three optimum speed peaks, as too much time is lost returning to previous speed levels rather than building on them. An exacting sprint coach should attempt to blend all the ingredients of perfect sprint performance into the third peak (acceleration, absolute speed and speed endurance – see figure 1).

The importance of power

Power is also crucial for a sprinter, and the 'short to long' method keeps power on the boil. Francis ensures that complementary training takes place at all times *eg* by maximum strength work in the gym during tempo running phases and even workouts. He doesn't advocate combining flat-out sprint work with near maximum weight lifting, due to the contraindications of the two training methods and the 'strain' that this would place on the CNS. Interestingly, neither does he recommend a weight-training 'channelling' phase (where, after general strength is developed with 'slower' exercises, sport-specific weights exercises are performed with increasing speed). Instead, Francis sees sprinting plus plyometrics exercises as the ultimate '*channeller*'.

Sprint speeds as conditioning ingredients

In order to develop optimum speed, the coach and athlete need to blend carefully sprint speeds. We

Table 1: Work performed by sprinters/other speed athletes and energy pathways

Energy pathway	Duration/comments	Sprint activity relevance – selected examples
Immediate anaerobic	6-8 seconds Type IIb fibre emphasis Targeted by sprint and plyometric activities	100/200m sprinters – very significant 400m sprinters – significant Football goalkeepers and strikers – significant Racket sport players – significant
Short term anaerobic	8-90 seconds Type IIa and IIb fibre emphasis Targeted by sprinting, plyometrics and weight training	100-400m sprinters – very significant Field sport players – very significant Racket sport players – very significant
Aerobic	90 seconds onwards Type I fibre emphasis Targeted by steady paced running	Minimal

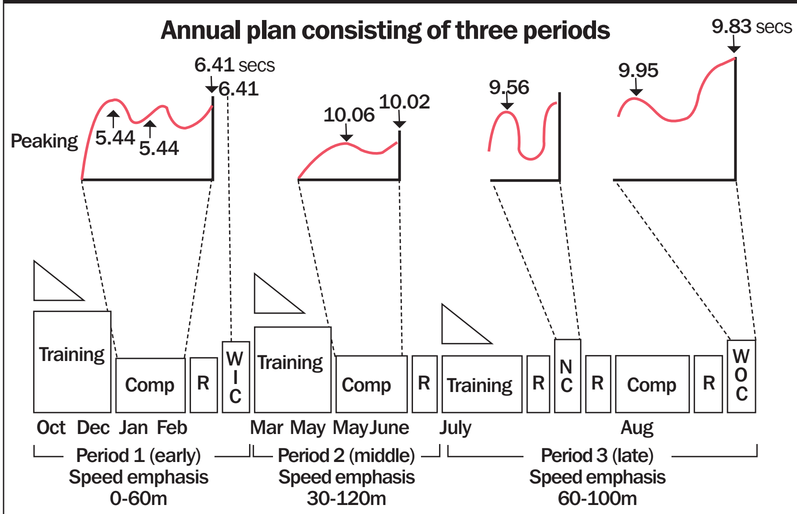
(Adapted from Dintiman, *Sports Speed*, (3rd edition)[4])

Jargonbuster

Central nervous system (CNS)
The largest part of the nervous system, including the brain and the spinal cord, which processes information

Plyometrics
Type of dynamic jumping exercise that allows very fast and powerful muscular contractions that target fast-twitch muscle fibre, such as hopping, bounding and depth jumping

Figure 1: Example of a triple periodisation programme for a sprint athlete



This plan (reflecting Ben Johnson's training) shows how Francis always saw speed as the key training goal, not an overall or peripheral condition. Progressively quicker times are earmarked for each phase and the training designed to bring these about.

Source: *The Charlie Francis Training System* (p101)[3] have noted, for example, that aerobic conditioning becomes much less of a concern for nearly all power athletes as they become more mature. In terms of absolute speed, it is generally recommended that running intensities never fall below 75% of maximum speed. Speeds slower than this will not produce a sufficiently strong stimulatory effect on fast-twitch muscle fibre. Many coaches fail to divide up (in terms of their effects) the percentages of speed that can be generated between 75 and 105% of maximum speed (105% refers to the speed that can be generated through the use of over-speed techniques, such as downhill running and the use of bungees – see *PP* 221).

Various terms have been applied to sprint running speeds based on percentages of effort, such as tempo runs, speed endurance, lactate endurance/maximum speed and over-speed runs. Table 2 (*below*) defines the key types:

Speed-endurance training

Speed endurance is crucial to a multitude of athletes and a lack of it will result in reduced sports capability. A rugby player short of speed endurance may be intercepted and hauled to the ground after making a 60m break for the line, while a 200m runner may have built up a seemingly commanding lead off of the bend, only to be reeled in and passed in the last five metres of the race. In field sports, players make repeated short-lived but intense efforts; the athlete with a high level of speed endurance will experience less 'fade' during a match or workout and will be able to maintain high power outputs. Speed-endurance workouts are therefore crucial to their training.

The 'short to long' approach should be used when developing speed endurance, as well as out-and-out speed. How much of an emphasis the coach places on this will be dependent on the training maturity of the athlete, the point in the season and the specific playing requirements of the athlete's sport. For example, a midfield football player will require greater speed-endurance capability than a goalkeeper, who needs more 'immediate anaerobic pathway' conditioning. George Dintiman is another one of the world's leading speed training experts and he has devised an eight-week speed-endurance training programme designed to increase both immediate and short-term anaerobic fitness. Table 3 (*above*) provides some sample workouts from this programme and shows how it fits with the 'short to long' theory of speed development.

Table 3: Eight-week speed-endurance programme

Week	Workout	Routine and distance	Reps	Rest interval
1	1	Jog 15yd, stride 15yd (75% speed), jog 15yd, walk 15yd	5	No rest between reps; the 15yd walk acts as the recovery phase
2	3	Jog 20yd, stride 20yd (90% speed), jog 20yd, walk 20yd	5	As above
3	9	Jog 25yd, stride 25yd, sprint 25 yd, walk 25yd	7	As above
4	11	Sprint 20yd, jog 20yd, sprint 20yd, walk 20yd	7	As above
5	14	Sprint 20yd 300yd sprint Run on the spot to exhaustion	10 1 2	Walk 10-30 secs 3-4 mins 1 min
6	15	Sprint 40yd 300yd sprint Distance hop to exhaustion	8 2 1 each leg	Walk 10-30 secs 2-3 mins 1 min
7	19	Sprint 20yd, jog 20yd, sprint 20yd, walk 20yd 300yd sprint	15 3	Walk is the recovery phase 2.5 mins
8	21	440yd sprint	4	4-5 mins

Adapted from Dintiman, *Sports Speed* (3rd edition) page 151/152 [4]

Table 2: Sprint speeds as a percentage of maximum speed

Name of speed	Description and comments	Typical workout
Tempo runs	75-85% of max speed, run over 100-300m distances on the track (Francis recommends total weekly distances of 2,000-2,400m)	6 x 200m at 75% effort (speed) concentrating on form. Five minutes recovery between runs
Speed-endurance speed	Sprints over 60-120m designed to improve the sprinter's ability to maintain flat-out speed. This type of training is very intense and should be used with caution, due to its stress on the CNS. Regeneration of the athlete is paramount	2 x 120m 100% sprints – full recovery
95% effort speed	These runs are performed just below flat out. They will blend in flawless technique without over-stressing the athlete and in particular their CNS	3 x 120m with seven minutes recovery between runs
Out-and-out speed	These runs are performed at 100% effort, they are intense and will stress the CNS	2 sets of 4 x 40m sprints from block start – full recovery between runs
Over-speed speed	These runs are performed at 105% of top speed using downhill methods or bungees to achieve this. High level of CNS strain	4 x 30m downhill runs with full recovery

Conclusion

The 'short to long' approach, as stressed, never loses sight of the need to move at maximum speed. It is totally focused on developing this quality. It strips out all the intensities, exercises and energy pathway training methods that are seen to be detrimental to achieving this goal. And crucially, it is very carefully constructed to allow the athlete and his or her CNS to adapt optimally.

John Shepherd MA is a specialist health, sport and fitness writer and a former international long jumper

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Antioxidant protection for athletes: is it time to ditch the pills?

During the last decade, research into antioxidant nutrition and athletic performance has been one of the most rapidly evolving areas of sports nutrition. But while many athletes take antioxidant supplements, the most recent research suggests that there may be more effective approaches to protecting the athletic body. Andrew Hamilton investigates

Although there's plenty of evidence for the theory of antioxidant protection from free radical damage (*see box, below*) to cells generally, the link between antioxidant supplements and protection during athletic performance is poorly understood. Some studies appear to show a benefit[1-4], others have shown little benefit[5-8] and some animal studies have even suggested that large doses of antioxidant vitamins may be detrimental[8-11] (for a full discussion see *PP* 199). Thus the antioxidant story has been characterised by changing scientific consensus and confusion: do athletes really need extra antioxidant protection, and if so what kind and how much?

Table 1: Free radicals and protective nutrients/enzymes
(R = fragment of bigger molecule, – = unpaired electron, H = hydrogen atom, O = oxygen atom)

Free radical species	Protective nutrients/enzymes
The hydroxyl radical: **HO-**	Vitamin C
The alkoxyl radical: **RO-**	Vitamin C
The peroxyl radical: **ROO-**	Vitamin E, glutathione peroxidase, beta-carotene
The hydroperoxide molecule: ROOH (forms **RO-** and **HO-**)	Vitamin C
The alkyl radical: **R-**	Vitamins A, C and E
The superoxide radical ion: **O_2-**	Superoxide dismutase (copper manganese and zinc dependent) and catalase (iron dependent), vitamin C
The peroxide ion: **O_2^{2-}**	Glutathione peroxidase (selenium dependent), vitamin E
Singlet oxygen: **O_2*** (excited state)	Vitamin A (beta-carotene), vitamin C

What is free radical damage?

Free radical damage describes the damage that occurs within cells (for example cell membranes and **DNA**) at a molecular level as a result of 'free radicals'. These free radicals are transient but extremely reactive chemical species that unavoidably occur during oxygen metabolism when fats, proteins and carbohydrates are combined with oxygen in the body to produce energy (aerobic metabolism). For this reason they are sometime called 'reactive oxygen species' (ROS) or 'oxygen free radicals' (*see table 1, above*).

Although our cells have very efficient antioxidant defence systems to quench and neutralise harmful free radicals, these systems are not 100% efficient, and over time biochemical damage gradually accumulates, leading to a reduction in cellular function. Most scientists now believe that accumulated cellular free radical damage lies at the heart of the ageing process and many degenerative diseases such as cancer, autoimmune diseases and Alzheimer's disease. Athletes process and use larger volumes of oxygen and at higher rates than the majority of the population; this explains why many scientists believe that they may benefit from higher intakes of antioxidant nutrients to bolster defences.

Nutrients as antioxidants

Much of the research into antioxidants and athletic protection/performance has centred on nutrients such as vitamins A, C and E and the mineral selenium. Not only are these essential for other functions in the body, they also activate some of the key antioxidant enzymes in the body, which help to defend cells against free radical damage (*see table 1, above*).

Most studies into antioxidants and athletes have involved athletes taking large doses of one or more of these antioxidant nutrients and then observing the effect on a subsequent bout of exercise. In particular, researchers have been keen a) to investigate whether the administration of antioxidant nutrients reduces the amount of oxidative damage caused by exercise and b) to see whether antioxidants actually enhance performance.

The answer to the first part of this question is that there does seem to be evidence that extra antioxidant nutrients can reduce the markers of free radical damage during subsequent exercise, but, as mentioned above, this is by no means clear-cut. In terms of performance gain, there's little evidence to date that antioxidant nutrients can enhance actual physical performance but there may be other benefits associated with taking them.

Jargonbuster

DNA
deoxyribonucleic acid; a double helix-shaped molecule in the nucleus of the cell, which contains the genes instructing that cell how to operate

Muscle soreness

One potential benefit is the reduction in post-exercise muscle soreness, which we reported on in *PP* 210. To recap briefly, we now know that the destructive power of oxygen free radicals can be harnessed positively by immune cells to help break down exercise-damaged muscle tissue as part of the process of tissue repair. We also know that this immune-cell-mediated free radical damage appears to peak roughly 24 hours after exercise, which explains why muscle soreness also peaks then.

However, an optimally functioning antioxidant defence system appears to minimise extraneous free radical damage to otherwise healthy tissue, and may therefore help to minimise the degree of post-exercise muscle soreness; studies have shown that mice fed a compound called PEG-SOD (an extremely powerful free radical deactivator) performing prolonged eccentric exercise exhibited much less delayed-onset free radical damage to otherwise healthy muscle tissue than controls[12].

In our previous review of this subject we reported that, while some studies on supplementing antioxidant nutrients had produced inconclusive results[13,14], others had reported positive results including:

- reduced muscle soreness after shuttle running when taking vitamin C [15];
- reduced exercise-induced DNA damage in immune cells in women when taking vitamins C and E[16];
- enhanced muscle damage repair in older runners running downhill when taking vitamin E[17].

But what does the latest research say on this subject? In an American study earlier this year on vitamin C supplementation and delayed onset muscle soreness (DOMS), 18 healthy men were randomly assigned to one of two groups[18]; the vitamin C group took 3g per day (1g morning, noon and night) of vitamin C for two weeks prior to a heavy exercise session and for four days afterwards, while the control group took placebo (dummy) pills. Both groups then performed 70 eccentric action repetitions of elbow flexion to stress the triceps of the rear arm in such a way as to produce maximum post-exercise soreness. Blood samples were also taken in order to measure creatine kinase (an indicator of muscle breakdown) and oxidised glutathione/glutathione ratio (a measure of free radical damage due to oxidative stress). Among the key findings were the following:

- At all times during the 96-hour period following the exercise, muscle soreness levels were significantly reduced in the vitamin C group compared to the control group;
- The increase in creatine kinase in the vitamin C group was significantly less at 48+ hours after exercise than the control (indicating reduced muscle breakdown);
- The oxidised glutathione/glutathione ratio was lower in the vitamin C group at four and 24 hours post-exercise than the control group (indicating less oxidative damage).

Meanwhile, a study published just two months ago looked at the effects of giving an antioxidant supplemented carbohydrate/protein drink to cyclists riding to exhaustion at 70% VO_2max and then again 24 hours later at 80% VO_2max[19]. Compared to an isocaloric carbohydrate drink without added antioxidants, the antioxidant supplement drink reduced post-exercise muscle soreness and markers of muscle damage, even though the cyclists consumed less carbohydrate on this regime than when taking the carbohydrate-only drink.

However, not all the latest research on supplementing antioxidant nutrients is positive. A study published in the New Year on 22 runners during and after a 50km ultramarathon showed that, compared to a placebo, taking 1,000mgs of vitamin C and 300mgs of vitamin E did not reduce markers of post-exercise muscle damage or the contractile ability of the quadriceps and hamstrings[20].

The fruit and vegetable connection

The weight of evidence for supplementing antioxidant nutrients is on balance more favourable than not, but still far from clear-cut. One possible reason for the mixed results in these studies is that, until recently, researchers have focused on supplementing antioxidant nutrients but have paid scant attention to a huge range of naturally occurring compounds in plant foods called phytochemicals (*see box, below*).

Phytochemicals

Phytochemicals are often responsible for giving a plant its characteristic colours and flavours and many of these compounds display remarkable antioxidant capacities, sometimes tens or even *hundreds* of times greater than those of antioxidant nutrients. Examples include the carotenoid family (found in red and green fruits and vegetables), the flavenoid family (found in citrus fruits), the tocotrienol family (found in nuts, seeds and wheat-germ), and a number of sulphur-containing compounds, such as sulphorane (found in broccoli) and allicin (found in garlic). As a very rough rule of thumb, the deeper and more vivid the colour of the fruit or vegetable, the higher the phytochemical content and therefore its antioxidant activity.

Many nutritionists now believe that dietary phytochemicals are at least as important as the antioxidant nutrients (if not more so) in protecting cells from free radical damage. There's good evidence for this in a US study that looked at the effects of supplemental vitamin C (500mg per day) and vitamin E (400IUs per day) for two months on oxidative damage to DNA by measuring the levels of a marker substance called 8-hydroxy-2-deoxyguanosine (8-OHdG) excreted in the urine in 184 subjects[21].

Compared to placebo, neither vitamin reduced the level of markers of oxidative DNA damage. However, a closer analysis of the subjects' diets showed that higher intakes of fruit and vegetables *did* reduce the amount of DNA damage, regardless of whether they were taking vitamins or placebo – persuasive evidence that the phytochemical content of the diet exerted more of a protective effect than supplemented antioxidant nutrients.

'A closer analysis of the subjects' diets showed that higher intakes of fruit and vegetables reduced the amount of DNA damage, regardless of whether they were taking vitamins or placebo'

Further evidence comes from a very recent study this year on oxidative stress during exercise (30-minute run at 80% of VO_2max), which compared the protective effects of daily supplemented antioxidant nutrients (400IUs of vitamin E and 1,000mgs of C) with a mixed fruit and vegetable juice powder concentrate containing 108IUs of vitamin E and 276mgs of vitamin C[22]. The results showed that while only the vitamin supplements raised blood vitamin levels, both treatments reduced the amount of a marker of oxidative stress called protein carbonyl and by similar amounts. Compared to the vitamin supplements, the fruit/vegetable powder contained less than a quarter of the vitamins C and E, which suggests that additional antioxidant activity in the fruit/vegetable extract (*ie* phytochemicals) may have been important.

Fruit and vegetable research

Unsurprisingly, some researchers have begun to investigate whether diets or fruit/vegetable extracts containing high levels of phytochemicals offer superior antioxidant protection to athletes compared to conventional supplements, and the results so far look promising.

For example, a Spanish study last year tested the effects of an antioxidant-rich beverage containing black grape (81 grams per litre [g/L]), raspberry (93g/L) and redcurrant (39g/L) concentrates on exercise-induced oxidative stress in 26 cyclists[23]. Half the group were randomly allocated to receive the antioxidant beverage 15 minutes pre-exercise and during a 90-minute bicycle ergometer test at 70% VO_2max, while the other half received placebo. Measured protein carbonyl levels were 29% less in the fruit juice concentrate group. Moreover, 8-OHdG increased by 21% in the placebo group, but did not increase in the juice concentrate group.

More evidence for the benefits of brightly coloured fruits and vegetables comes from a Polish study on rowers carried out at the end of last year, which investigated the effect of consuming an increased intake of phytochemicals called anthocyanins (contained in chokeberry juice) on the measures of oxidative stress (free radical damage at a molecular level) in rowers performing intense workouts during a one-month training camp[24].

The rowers were randomly assigned to receive either 150mls of chokeberry juice daily (containing around 34mgs of active anthocyanins) or a placebo. Before and after the supplementation period, the subjects performed a 20-minute incremental rowing exercise test starting at 40% and increasing to 90% of VO_2max. Compared to the placebo, taking the chokeberry juice produced a significant drop in the measures of free radical damaged induced by the strenuous exercise, and this was confirmed by lower levels of activity of an enzyme called glutathione peroxidase, which fights oxygen free radical species in the body.

Although relatively few studies have been conducted into the protective effects of enhanced fruit and vegetable intake in athletes, those that have appear to have produced far more positive results than those using single antioxidant nutrients. But do fruit and vegetables and their extract/juices actually enhance performance?

As we reported in a recent 'What The Papers Say' (*PP* 235), US researchers have looked at the effects of drinking cherry juice on post-exercise muscle damage and soreness[25]. Volunteers drank 12 fl oz of either the cherry juice blend (equivalent to 120 cherries) or a placebo drink twice a day for eight consecutive days and on the fourth day they performed a bout of 2 x 20 maximum eccentric elbow flexion contractions, designed to induce muscle damage and soreness. After the exercises, strength losses averaged 22% with the placebo but only 4% with the cherry juice. Moreover, pain in the elbow flexors peaked at 24 hours with the cherry juice trial whereas it continued to increase in the placebo trial to peak at 48 hours, indicating reduced levels of oxidative damage in the cherry group.

A fascinating study meanwhile examined the relationship between reduced levels of dietary antioxidants and levels of free fatty acids in the blood (a major fuel source for humans at rest and during moderate intensity exercise)[26]. Seventeen trained athletes followed a restricted antioxidant diet (containing about a third of the antioxidant content of a 'high-antioxidant' diet) for two weeks then underwent submaximal and incremental exercise testing to exhaustion. These results were compared to an initial test conducted while they were consuming their habitual high antioxidant diet.

Although the same types and amounts of fats were consumed during both diets, the results showed that circulating blood levels of the fatty acids omega-3 and omega-6 were significantly reduced on the low antioxidant diet and, while the exercise time to exhaustion was the same for both diets, athletes reported a higher perceived rate of exertion during submaximal exercise on the low antioxidant diet.

Practical advice

How can the athlete make best use of the current antioxidant knowledge to maximise protection during training and competition? The first thing to say is that the evidence that taking single doses of antioxidant nutrients such as vitamin C or vitamin E is beneficial is rather patchy; some studies show that single nutrient supplementation can reduce levels of muscle damage and a couple of studies have indicated that vitamin C may help reduce post-exercise muscle soreness. However, plenty of other studies have produced inconclusive results. Supplementing combinations of antioxidant nutrients (*eg* vitamins A, C, E and selenium) may be more beneficial as antioxidant nutrients do not work in isolation in the body but synergistically; a multi-antioxidant nutrient supplement probably makes more sense.

However, athletes should take note of the rapidly growing body of evidence pointing to the protective benefits of phytochemical-rich foods, such as brightly coloured fruits and vegetables. These not only contain antioxidant nutrients but hundreds of other naturally occurring powerful antioxidant compounds.

While the strength and depth of colour gives a very rough rule-of-thumb guide to the antioxidant activity of plant foods, a more scientific approach has been developed that measures the Oxygen Radical Absorbance Capacity (ORAC) of foods. The higher the ORAC score, the higher the potential capacity of a food to 'quench' oxygen free

Table 2: ORAC units for various fruits and vegetables

Food	ORAC units per 100g*
70% cocoa solid dark chocolate	13,500
Pomegranate	10,500
Dried prunes	5,770
Raisins	2,830
Kale	2,410
Blueberries	2,400
Garlic	2,320
Blackberries	2,040
Spinach	1,700
Brussels sprouts	1,580
Strawberries	1,540
Alfalfa sprouts	1,450
Broccoli flowers	1,290
Raspberries	1,220
Beets	1,170
Plums	949
Red pepper	810
Oranges	750
Corn	720
Cherries	670
Onion	560
Aubergine	510
Cauliflower	510
Cabbage	480
Potato	460
Sweet potato	430
Leaf lettuce	410
String bean	390
Carrot	340
Yellow squash	280
Iceberg lettuce	230
Tomatoes	195
Celery	130
Cucumber	110

*Sources: US Dept of Agriculture; Brunswick Laboratories; Journal of American Chemical Society radicals and render them harmless. Natural fruits typically score between 500 and 900 ORAC units per 100 grams and the US Food and Drug Administration (FDA) has recently suggested that a daily consumption of around 7,000 ORAC units may provide optimum antioxidant protection (that's around 5-10 servings of fruit and vegetables per day!).

However, some athletes with a high volume of training may struggle to include such large amounts of fruit and vegetables in their diet. This is because these foods are bulky and tend to contain relatively large amounts of water but low amounts of carbohydrate and very small quantities of protein. A large intake of fruits and vegetables increases satiety and could displace carbohydrate and protein-rich foods from the diet, making the task of muscle glycogen replenishment and recovery more difficult. The key then is to emphasise foods that are especially rich in antioxidant activity – *ie* with high ORAC scores. Some examples of ORAC scores are shown in table 2 on page 10.

But while ORAC scores give a better indication of antioxidant capacity of foods in vitro than mere colour, it's important to realise that the relationship between ORAC scores and antioxidant activity *in the body* is still poorly understood; for this reason, it's important not to sacrifice variety by consuming just one or two high ORAC foods in order to boost ORAC unit intake. Many lower scoring foods may offer particular benefits and work synergistically with other foods. Also beware of relying on some of the very high ORAC food extracts now coming onto the market claiming 20,000 ORAC units or more per 100g. It's not yet known whether such values are accurate or if such concentrated antioxidants can be absorbed by the human body as effectively as those found in natural foods.

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WHAT THE PAPERS SAY

Reports by Isabel Walker

When active recovery doesn't work

Recovery periods involving low-level activity have been shown by many research studies to enhance subsequent performance by comparison with 'passive' – *ie* inactive – recovery. But now a new study from Australia suggests that the opposite is true for team sports involving repeated short-duration sprints.

Nine moderately-trained men, most of whom regularly competed in various team sports, performed four repeated-sprint tests on cycle ergometers (six 4-second sprints every 25 seconds), at weekly intervals. In two of the trials, the sprints were separated by 21s of active recovery, which involved cycling at around 32% of V02max. In the other two trials, the sprints were separated by passive recovery periods, in which the athletes did nothing.

The researchers compared the athletes' performances in the two sets of trials. They also analysed samples of muscle tissue before and after each of the four tests to check levels of phosphocreatine, creatine and lactate in the vastus lateralis muscle in the thigh.

Key results were as follows:

- Peak power outputs produced during sprints 2-6 were significantly lower than for the first sprint, regardless of what type of recovery was used;
- However, there was a significantly lower peak power output and a greater power decrement for the sixth sprint with active recovery than with passive recovery;
- Muscle lactate levels were significantly higher and phosphocreatine somewhat lower after the tests involving active recovery compared with passive recovery, suggesting a suboptimal effect on metabolism.

'These data suggest,' comment the researchers, 'that active recovery does not improve performance and, in fact, may potentially have suboptimal effects on [muscle metabolism] and on performance during exercise that mimics the sprint and recovery durations of an isolated bout of repeated-sprint activity typical of team sports.'

However, since it makes no sense in terms of sport and competition to suggest that team players should stand still between repeated-sprint bouts, the researchers recommend that training for repeated-sprint performance should involve active rather than passive recovery periods. 'This testing or training modification,' they point out, 'will be more specific too, and may better prepare athletes for, the physiological demands of team sport competition.'

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Surgical solution for hamstring tears

Surgical treatment of partial hamstring tears is successful in most cases, even after conservative treatment has failed. That's the encouraging conclusion of Finnish researchers, following the largest study of hamstring surgery to date.

Forty-seven athletes – 32 men and 15 women – with partial hamstring tears had surgery to repair the damage over an 11-year period between 1994 and 2005. They included 13 international-level professional athletes, 15 competitive-level athletes and 19 recreational athletes from a variety of sports, most commonly football.

Forty-two of the patients had been treated conservatively, with unsatisfactory results, and the remaining five had been offered surgery shortly after sustaining their injuries. Ten of the 28 professional and competitive level athletes continued to take part in their sport before surgery but complained of pain, weakness and impaired performance. The other 18 athletes were prevented by their symptoms from performing at all.

The surgical treatment involved reattaching the torn tendons to their point of origin in the athletes' legs. They had to use an elastic bandage for one to two weeks afterwards and were allowed to begin partial weight bearing within two weeks and full weight bearing after two to four weeks.

Follow-up over an average of 36 months showed excellent results in 33 cases (70%) and good results in nine (19%). The best news was that 41 of the athletes (87%) were able to return to their former level of sport after an average of five months.

Hamstring strains and tears are common, potentially disabling and even career-threatening in some cases, the researchers point out. 'According to our results, it seems that excellent or good outcomes may be expected after surgical repair in most cases of partial proximal hamstring tear. However, surgery is technically easier in the acute [early] phase. If conservative treatment is chosen, the possibility of surgical treatment should still be kept in mind,' they conclude, 'especially if the symptoms are prolonged.'
Br J Sports Med 2006; 40:688-691

Andro supplements don't help and can be harmful

Testosterone prohormone supplements like DHEA and androstenedione are not just potentially harmful to health: they don't actually do what they say on the tin. That's the key conclusion of a major review carried out by US researchers.

Dehydroepiandrosterone (DHEA), androstenedione, androstenediol and a range of similar chemical compounds are marketed as prohormone nutritional supplements. They are frequently referred to generically as 'andro' supplements. Proponents claim that these supplements are converted to testosterone or testosterone analogues in the body where they enhance an athlete's adaptations to resistance training and so build muscle.

Sales of androstenedione and 17 similar compounds are now specifically banned by the World Anti-Doping Agency (WADA) and the US Food and Drug Administration, largely because of their supposed anabolic effects. But in fact, a comprehensive review of the research carried out to date reveals that andro supplements produce neither anabolic nor ergogenic effects in men.

According to the reviewers, DHEA, androstenedione, anadrostenediol and related supplements do not enhance the gains in muscle size or strength obtained from strength training alone. Furthermore, the change in hormone levels following the use of these supplements can lead to serious side effects, including heart disease and cancer.

Given these potential dangers and the lack of demonstrable benefits, it hardly seems worth it for athletes to take the risk of failing a drug test. '…the recent classification of androstenedione and related compounds as anabolic steroids may give the impression that testosterone precursor supplements are indeed anabolic, with the unintentional consequence of encouraging [their] use,' the researchers point out. But, in fact, 'there appears to be little or no benefit in using prohormone nutritional supplements. Therefore [their use] should be discouraged by athletic trainers, coaches, educators, researchers and physicians.'
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PEAK PERFORMANCE FORTHCOMING ARTICLES

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