# BEST OF THE NOUGHTIES

## a decade of breakthroughs in sport science

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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# CONTENTS

# 21st Century breakthroughs for maximum performance!

The march of science and technology is relentless; nanotechnology, ultra high-speed electronic communications and sub-atomic particle accelerators creating the same conditions encountered at the birth of our universe; these are just some of the amazing developments that we've already witnessed during the early years of the 21st Century.

The good news for sportsmen and women is that these breakthroughs aren't just restricted to esoteric technology and science. The first ten years of the new millennium have also witnessed an explosion in our understanding of human performance, resulting in some major advances for athletes whose goals is to train and compete faster, harder and longer, and to recover more rapidly.

In this special report, we've gathered together many of the major groundbreaking research findings to emerge over the past decade and which have been reported in Peak Performance. Many of these breakthroughs have completely rewritten the rulebook on training, and even more importantly, all of them can be readily practically applied to significantly boost your performance.

The icing on the cake is that because they've been gleaned from the frontiers of sports science, these research findings will also give you a cutting edge over your competitors; indeed, so new are they that many elite coaches are still unaware of them and how they will change the way we train in the future.

If winning is important to you, this special report will be invaluable. As history has shown us time and time again, the appliance of science is very often the difference between athletes who go on to reach the very top and those who fall by the wayside. So why not put science on your side and put your competitors in the shade!

**Andrew Hamilton**, BSc Hons MRSC ACSM

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# Oxygen kinetics – start smart for a mean finish!

## At a glance

- The concepts of $VO_2$ kinetics and the $O_2$ deficit are introduced;
- The importance of $VO_2$ kinetics to exercise performance is explained;
- New research on interventions that influence $VO_2$ kinetics is presented;
- Practical recommendations for enhancing $VO_2$ kinetics and exercise performance are provided.

**The way your body transports and uses oxygen during the initial stages of vigorous exercise might not sound very exciting, but exciting new research suggests that understanding this process and adjusting your pre-race preparation accordingly can result in truly remarkable performance gains. Professor Andy Jones explains**

Endurance sports rely primarily on oxidative (aerobic) metabolism for energy supply. It's not surprising therefore that factors related to oxygen ($O_2$) transport and consumption such as the maximal oxygen uptake ($VO_2$max), **economy of movement**, and the fraction of the $VO_2$max that can be sustained without a significant accumulation of lactate in the blood (the lactate threshold, LT) are important determinants of endurance exercise performance[1].

These parameters of aerobic fitness are typically measured during an incremental-type exercise test in which the exercise intensity is very low to begin with but then increases progressively until the athlete is unable to continue, and they can provide

**Jargonbuster**

**Economy of movement**
The oxygen cost of exercising at a certain speed or covering a given distance – the lower the oxygen uptake, the more economical an athlete is considered to be

**$VO_2$ kinetics**
The dynamic behaviour of $O_2$ uptake in the transition from rest to exercise

**$O_2$ deficit**
The amount of energy which has to be supplied by anaerobic metabolic processes in the early minutes following the start of exercise due to the slow increase in $O_2$ uptake

invaluable information on various aspects of physiological function and the responses to training. However, the manner in which the work rate is imposed during these tests does not accurately reflect the metabolic loading that an athlete will experience at the start of an endurance competition. That's because at the beginning of a race, an athlete will be required to accelerate up to race pace within just a few seconds. The energetic consequences of this abrupt increase in energy turnover in the working muscles can be profound.

## The oxygen deficit

When the race commences and the athlete quickly accelerates to attain their desired race pace, the energy turnover in the contracting muscle cells, *ie* the rate at which the high-energy compound ATP is broken down to produce energy and continually re-synthesised, increases abruptly. Indeed, the metabolic rate might increase six- to 10-fold within just a few seconds of the starter's gun firing!

The muscle's store of ATP would only be sufficient to allow exercise to be continued for a few seconds but, fortunately, ATP can be re-synthesised in a variety of ways to allow exercise to continue. Ideally, the increased muscle energy requirement would be matched by an instantaneous increase in the rate of energy supply from oxidative metabolism (in which $O_2$ is consumed as a fuel in the muscle and energy is produced for the re-synthesis of ATP). However, as can be seen in figure 1, the energy supplied from oxidative metabolism, as reflected by the measurement of $VO_2$ at the mouth, increases relatively slowly and might only approach the required 'steady-state' value after some 2-3 minutes have elapsed.

The behaviour of $VO_2$ following the onset of exercise, including the rate at which it rises, is known as '**$VO_2$ kinetics**'. Because $VO_2$ kinetics is relatively slow, at least when compared to the instantaneous increase in muscle energy turnover, other energy-producing metabolic pathways must be called on to meet the demand. The extent of this demand is contained within the concept of the '**$O_2$ deficit**' (*see figure 1*). The $O_2$

**Figure 1: Oxygen uptake response at start of exercise**

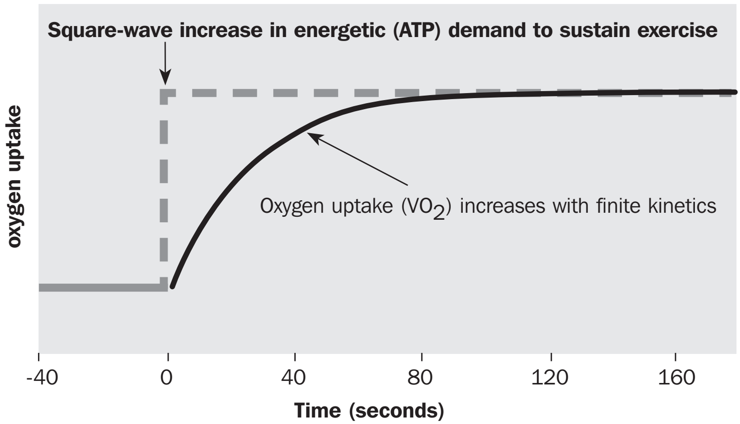


**Figure 1:** *Schematic of the response of $VO_2$ following the onset of constant-intensity exercise (time zero). Note that the ATP demand in the contracting muscle cells increases abruptly but that the $VO_2$ response (reflecting the energy supplied by oxidative metabolism) increases relatively slowly, only reaching the required steady-state level after about 2 minutes in this example. The area between the dashed line and the solid line represents the $O_2$ deficit and is the amount of energy that must be supplied by anaerobic processes.*

deficit simply represents the difference between the amount of energy that is required to perform exercise at the desired intensity for a certain period of time and the amount of energy that is supplied through oxidative metabolism in this same period. It follows therefore that an amount of energy equivalent to the $O_2$ deficit must be supplied almost exclusively by non-oxidative or 'anaerobic' processes to make up the shortfall.

We know that the muscles' other store of high-energy phosphate compound, called phosphorylcreatine (PCr), falls immediately following the onset of exercise, and is only restored when exercise is stopped. In addition, the process of anaerobic glycolysis, in which muscle glycogen is reduced to lactic acid to liberate energy, is accelerated to meet some of the increased energy demand. While these non-oxidative mechanisms of energy production are essential to allow exercise to continue during the period within which the rate of oxidative metabolism is still increasing towards the required level, there are some negative consequences to their utilisation.

*'It is important to recognise that the biochemical environment established within the muscle cells early in exercise can dictate the subsequent muscle metabolic responses and thus have a major impact on performance later on in the event'*

The larger the $O_2$ deficit, the greater the breakdown of muscle high-energy phosphates and the greater the activation of anaerobic glycolysis, which results in reduced concentrations of PCr and possibly ATP, and increased concentrations of metabolic by-products such as ADP, inorganic phosphate, lactate and hydrogen ions in the contracting muscles. Moreover, because anaerobic glycolysis is a relatively inefficient process, muscle glycogen stores will be more rapidly depleted than if the same amount of ATP were generated with oxygen.

All of these factors have been associated with the process of muscle fatigue and thus, the build up of a large $O_2$ deficit in the early minutes of exercise would be expected to adversely affect endurance performance. Even during events such as the marathon (in which the 2-3 minute period over which the initial $O_2$ deficit is incurred might represent only 1-2% of the total exercise duration), it is important to recognise that the biochemical environment established within the muscle cells early in exercise can dictate the subsequent muscle metabolic responses and thus have a major impact on performance later on in the event.

## $VO_2$ kinetics in endurance athletes

From the above it is clear that the more rapidly the rate of oxidative metabolism can increase (*ie*, the faster the $VO_2$ kinetics), the better the likely consequences for endurance exercise performance. Indeed, it is no coincidence that elite endurance athletes have extremely fast $VO_2$ kinetics and that sedentary, elderly, and diseased subjects have much slower $VO_2$ kinetics.

The $VO_2$ response follows a near-exponential time course for the first few minutes following the onset of exercise, and **exponential responses** can be characterised mathematically using something called the '**time constant**'. Exponential processes are normally defined mathematically and when plotted on a graph against time, have a characteristic growth or decay curve. However, you can think of them as processes in which the rate of growth or decay at any particular time is related to the quantity present or number present at that time. An exponential process is considered to be essentially complete when four time constants have elapsed; thus, for $VO_2$ kinetics, a time constant of 40 seconds (which is characteristic of healthy but untrained subjects) means that a $VO_2$ 'steady-state' would be reached within approximately 160 seconds. In contrast, elite endurance athletes have been reported to have time constants of 15 seconds or less (steady-state attained in about 40-60s), while patients with advanced cardiovascular, pulmonary or metabolic diseases have time constants of up to 90 seconds (steady-state attained in about 6 minutes)!

For the same increase in metabolic rate above the resting rate, the size of the $O_2$ deficit incurred by the elite athlete could be three to four times lower than the young sedentary subject and six to eight times lower than the patient. While the other parameters of aerobic fitness ($VO_2$max, economy, and **lactate threshold**) will also discriminate between these three types of subject, the importance of these rather dramatic differences in $VO_2$ kinetics in explaining differences in exercise performance should not be underestimated. Indeed, in the patient, the extremely slow $VO_2$ kinetics will lead to rapid muscular fatigue even during mild exercise tasks, thus preventing them from comfortably carrying out the activities of daily living. In the endurance athlete, earlier attainment of the required $VO_2$ for the race will not only reduce the accumulation of metabolites that might impair exercise performance but will also 'spare' some of the limited amount of available anaerobic energy for use later in the race, for example in a sprint finish.

*'In patients, extremely slow $VO_2$ kinetics lead to rapid muscular fatigue even during mild exercise tasks'*

## Interventions to enhance $VO_2$ kinetics

*Training*

Perhaps unsurprisingly, the most potent stimulus to enhancing $VO_2$ kinetics is endurance exercise training, which will both enhance $O_2$ supply to muscle and improve the capacity of the

**Jargonbuster**

**Exponential response**
A change in rate of growth or decay that is dependent on the quantity already present

**Time constant**
The time required for 63% of an exponential response to be attained; the response will be complete when four time constants have elapsed

**Lactate threshold**
The exercise speed above which lactate accumulates in the blood

muscle to utilise the $O_2$ supplied. As an example of the potency of endurance exercise training in enhancing $VO_2$ kinetics, we recently reported that six weeks of endurance training could significantly speed $VO_2$ kinetics (time constant reduced by about 30%, from approximately 32s to 23s)[2]. Such impressive adaptations would certainly be expected to result in enhanced exercise performance.

Interestingly, while it is known that 'endurance training' in general terms can enhance $VO_2$ kinetics, it is presently not known whether specific types of training (for example, interval training, or high volume training) can bring about a more impressive adaptation of $VO_2$ kinetics. However, it has been reported that runners who specialise in longer distances have faster $VO_2$ kinetics than those who specialise in middle distance events [3]. Paula Radcliffe, the world record holder for the women's marathon has the fastest reported $VO_2$ kinetics, with a time constant of just 8-9 seconds! However, while these data suggest that $VO_2$ kinetics might be most sensitive to high-volume endurance training, it should be remembered that genetics play a major role in the determination of many aspects of the physiology of champion endurance athletes.

*'Warm-up' exercise*

In already highly trained endurance athletes, the potential for additional training to impact on $VO_2$ kinetics is likely to be limited. However, there is one acute intervention that appears to have the potential to enhance exercise performance by altering the $VO_2$ kinetic response to exercise; namely the warm-up. In this context, however, 'warm-up' appears to be something of a misnomer because neither passively elevating muscle temperature using hot baths, nor performing a relatively lengthy but low-intensity warm-up, significantly influences $VO_2$ kinetics[4]. Rather, relatively high-intensity 'prior exercise', which significantly elevates blood lactate (to a concentration of approximately 2-4 millimoles per litre [2-4 mM]) immediately before the main exercise challenge (*ie* race), is necessary if $VO_2$ kinetics are to be enhanced.

**Figure 2: Influence of prior high-intensity exercise on $VO_2$ kinetics**

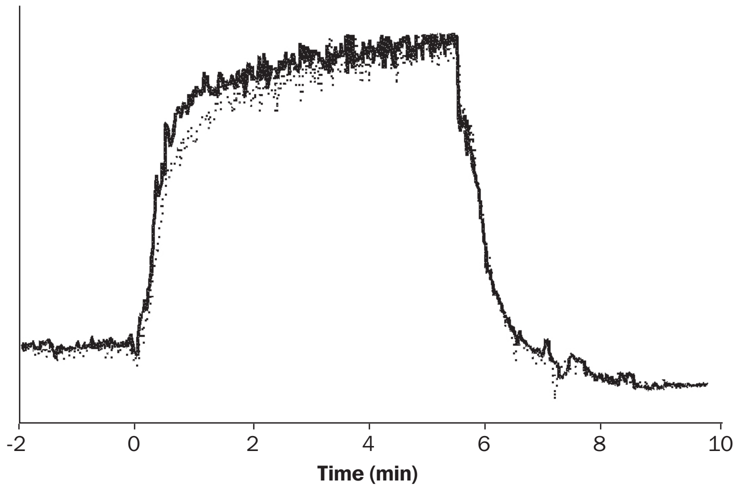


**Figure 2:** *The influence of prior high-intensity exercise on $VO_2$ kinetics during subsequent high-intensity exercise. The feinter, broken line represents the response of $VO_2$ to an initial bout of high-intensity exercise performed without any preceding warm-up exercise, while the solid line represents the response to an identical bout of exercise performed 6-10 minutes later. Note that, overall, the $VO_2$ kinetics appear to be speeded in the second exercise bout. This favourable change in $VO_2$ kinetics is associated with enhanced exercise performance.*

Several studies have shown that the performance of prior high-intensity exercise leads to an overall speeding of $VO_2$ kinetics, and to a meaningful enhancement of endurance exercise performance (*figure 2*). For example, researchers working at the Universities of Exeter and Aberystwyth, in the UK, reported that prior high-intensity exercise enhanced the $VO_2$ response and increased the time-to-exhaustion by as much as 30-60% during subsequent near maximal intensity exercise [5]. It is noteworthy that the scale of the improvement in performance resulting from this simple procedure was considerably greater than the improvements caused by illegal practices such as EPO abuse.

Although commencing a race with elevated blood lactate values might at face value appear to be unwise, the role of **acidosis** *per se*, in eliciting fatigue has recently been questioned[6]. Exactly why the performance of prior high-intensity exercise should result in a favourable alteration of $VO_2$ kinetics is not entirely clear but there are a number of possible explanations:

- The accumulation of several of the by-products of high-intensity exercise, including lactic acid, will increase muscle blood flow and thus make more $O_2$ readily available to muscle;
- It's likely that the performance of prior high-intensity exercise will 'prime' the **muscle mitochondria**, thereby reducing the inertia to increasing oxidative metabolism within the muscle cells themselves;
- It appears that prior high-intensity exercise favourably alters the pattern of muscle fibre recruitment during subsequent exercise with consequent positive effects on muscle performance[7].

While the effect of prior high-intensity exercise on $VO_2$ kinetics and performance is certainly impressive, athletes who perform interval training will be familiar with the effects: the second repetition in a set invariably feels easier than the first, despite the fact that recovery from the first repetition is incomplete. It seems odd therefore why so few athletes apply this experience to their preparation for athletic competition.

*Warm-up intensity*

The available evidence appears to indicate that a warm-up that does not elevate blood lactate above the resting concentration of approximately 1 mM will not significantly enhance $O_2$ kinetics or exercise performance. In contrast, a warm-up that is sufficiently intense to elevate blood lactate concentration to

## Jargonbuster

**Acidosis**
An increase in hydrogen ion concentration (decrease in pH) in body fluids

**Muscle mitochondria**
The 'power plants' within cells, which provide energy via aerobic metabolism

approximately 2-4 mM can profoundly alter $VO_2$ kinetics and has the potential to enhance exercise performance[5].

Caution is required however; a warm-up which is either too intense, or which does not incorporate enough recovery time such that blood lactate concentration immediately before the competition is greater than approximately 6 mM, might have a detrimental effect on overall exercise performance despite having positive effects on $VO_2$ kinetics[8]. In this situation, it is likely that muscle PCr levels have not recovered and/or that metabolites which have been associated with the fatigue process (for example, inorganic phosphate, and hydrogen and potassium ions) are elevated to the extent that they interfere with muscle power output and hence reduce exercise performance.

Given the complexity of the various factors that can interact to determine the efficacy of pre-competition warm-up procedures, it seems likely that these are sub-optimal in a large proportion of athletes. It is recommended therefore that athletes experiment with the duration and intensity of their 'warm-up' activities and the duration of the recovery period that elapses between the warm-up and the competition.

*Pacing*

One other strategy that might also have the potential to enhance exercise performance through effects on $VO_2$ kinetics is that of appropriate pace allocation during competition. Several recent studies have suggested that in some athletic events (typically those in which the time to complete the distance lies between approximately 1 and 10 minutes), a fast-start pacing strategy might be beneficial to performance[9]. The mechanism for this effect is unclear and further research is required. However, in a recent study (unpublished), we found that a fast-start pacing strategy resulted in faster $VO_2$ kinetics in the transition to high-intensity exercise. With the proviso that the start is not so fast that the anaerobic capacity is depleted and fatigue is accelerated, it appears plausible that a pacing strategy which stimulates a more rapid increase in $O_2$ at

*'One other strategy that might also have the potential to enhance exercise performance through effects on $VO_2$ kinetics is that of appropriate pace allocation during competition'*

the onset of exercise and thus reduces the $O_2$ deficit might be beneficial in athletic events performed with an energy demand which is at or above the $VO_2$max.

## Summary

In conclusion, the behaviour of $VO_2$ in the transition from rest to exercise is an important and often-overlooked determinant of endurance exercise performance. Athletes, coaches and sport scientists should consider the implications and the applications of $VO_2$ kinetics in relation both to training and competition. Although various illegal and/or impractical interventions might enhance various aspects of $VO_2$ kinetics, the most profound effects result from legal and simple interventions: training, 'warm-up' and, perhaps, pacing strategy. In particular, it is possible that athletes can gain a distinct performance advantage over their competitors by optimising the intensity of their warm-up activities. Devoting some time to exploring the most effective warm-up strategy might well pay dividends in terms of enhanced sports performance.

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# Compression clothing – can it help you squeeze out a PB?

## At a glance

- An explanation of compression clothing is given and how it may enhance proprioception;
- Research on the benefits of compression clothing for aerobic and anaerobic performance is presented;
- The role of compression clothing in enhancing recovery is discussed.

**21st Century technology marches on and the use of compression clothing such as elastic shorts, tights and vests has mushroomed over the last decade. But what's the science behind compression clothing and how can athletes harness the full pontential of these garments? Andy Harrison and Kevin Thompson investigate**

Initial studies on the use of compression garments focused on postoperative patients and the potential protection that compression could provide against a venous **thrombosis**. These studies demonstrated an increase in venous blood flow in the lower extremities. Following these findings in the clinical population, scientists began investigating the effects of compression clothing on an athletic performance, initially focusing on power-based sports.

American scientists investigated the effect of compression shorts on power production during maximal effort vertical

**Jargon Buster**

**Thrombosis**
A blockage preventing the flow of blood, caused by a clot (half solid lump) of blood

**Proprioception**
The ability to perceive joint movement and position in space, involving a variety of neural pathways coming from receptors in the skin, muscle, ligament and joint capsule

jumps(1). Varsity volleyball athletes completed 10 maximal countermovement (*ie* with knee bend) vertical jumps, one every three seconds as cued by an auditory signal. Although the compression shorts did not influence maximal jump power, the results demonstrated that the athletes were better able to maintain power output during the repeated efforts. The investigators suggested that using the compression shorts increased the athletes' ability to resist fatigue.

The effect of compression shorts on explosive activities was further explored in a 2003 study(2). Varsity track athletes, specialising in sprint or jump events, were used to compare custom fit compression shorts with loose-fitting gym shorts. Significant increases in countermovement jump height plus significant reductions in muscle oscillation during landing were reported in the compression clothing group. In this same group, 60m sprint times were not affected but average hip angle was reduced. Although not measured as part of the study, this suggests that stride frequency was increased.

There are many possible mechanisms via which compression clothing may have enhanced performance in these power-based activities. There is evidence that augmented **proprioception** may have provided an improvement in technique, while the reported reduction in the oscillatory displacement of the muscle may have promoted enhanced neurotransmission and mechanics at the cellular and molecular level.

## Compression clothing and oxygen cost

More recently, scientists have focused their attention on whether compression clothing can positively influence physiological parameters during sub-maximal activity. Researchers examined the effects of wearing compression tights on oxygen cost during sub-maximal running exercise(3). In a two-part study, six trained runners were assessed using an indoor 200m track.

Firstly, aerobic energy cost was evaluated at 10, 12, 14 and 16km/h. Secondly, the increase in energy cost over time (often referred to as the 'slow component' – expressed as the difference in $VO_2$ values between minute 2 and the end of exercise) was

## What is compression clothing?

Although it comes in various guises, the main feature of compression clothing is its high Lycra content, which imparts a stretchy quality to the material. The amount of Lycra in the fabric determines how strong the compression effect is. Different manufacturers use differing proportions of Lycra; some anecdotal reports from users suggest that around 70% Lycra seems to produce a good effect.

Compression clothing is designed to be worn next to the skin and its aim is to provide compression to the underlying tissue and muscle without restriction or discomfort. Some garments are constructed using 'panels' of high Lycra content to target certain muscle groups while allowing mobility around joints.

Over recent years its upper body use under the shirts of team sport athletes has become increasingly popular, while lower body use has been prevalent for a number of years in track athletes – the UK's Paula Radcliffe being a well-known example.

determined via the completion of a 15-minute continuous run corresponding to 80% of the subjects' $VO_2$max.

Results showed a significantly lower energy cost, compared with that of the control group (wearing conventional shorts), at only 12 km/h, although similar trends were noted at 10 and 14km/h. Significant reductions in $VO_2$ slow component were also reported compared with classic elastic tights (26%) and conventional shorts (36%).

Although no consensus currently exists as to the exact causes of the $VO_2$ slow component during prolonged exercise, several variables have been identified, including muscle oxygen availability, cardiorespiratory work and blood lactate concentration. However, recent evidence seems to point towards motor unit recruitment patterns in the aetiology of the $VO_2$ slow component[3].

The study above aimed to evaluate the effects of wearing compression tights on some traditional 'muscle efficiency' indices. As with the power-based studies, the researchers concluded that the positive effect of wearing the compression clothing may arise due to an enhancement of the motion pattern by increasing proprioception and muscle coordination. However, this study also showed a reduction in the metabolic cost of running at a specific speed. A reduction in muscle oscillation (which occurs because of the repetitive impact loading during running) was speculated to have enhanced performance and the authors went on to suggest that wearing a lower-body compressive garment may reduce muscle fatigue by supporting more active muscles and applying pressure in such a way as to support muscle fibres in their contraction direction.

## Compression clothing and blood lactate

The favourable effects of compression clothing on the muscle pumping action of the cardiovascular system have led scientists to speculate whether increases in venous return could assist in the removal of blood lactate from exercising muscles.

In one of the first exercise-related trials, scientists tested six male college students to determine the effects of wearing compression stockings on exercise response[4]. The students completed both a treadmill ($VO_2$max test) and bicycle ergometer (3 separate 3-minute bouts at 110% of their $VO_2$max) assessments. The results from both tests showed a decrease in post-exercise lactate concentration when the compression clothing had been worn during the exercise. The investigators concluded that the compression stockings were increasing the lactate retained in the muscles, thereby reducing the amount released into the blood.

The garments used in the above studies are commercially designed for long-term wear in sports and training. It is common practice, however, for power lifters to use tightly bound wraps around various joints of the body to enhance force production. Anecdotally, the use of ‘super-suits’ in power lifting appears to enhance high force development for 1RM lifts. Such ‘suits’ are considered extreme compression as lifters can only tolerate them for short periods. The level of compression exerted by the garments discussed in this article is much lower.

A team of American scientists investigated whether even this lower level of compression added a significant external resistance to the actions of the contracting musculature whilst exercising[5]. Active subjects were asked to complete **isokinetic** knee extension/flexion movements (3 sets of 50 maximal efforts) and their maximal number of squats (at 70% 1RM). The primary finding from the study was that the comfortable compression levels found in the commercial garments did not have a negative effect on force production or total work capacity of the thigh muscles.

This study suggests that the use of commercially available compressive shorts does not add any significant amount of resistance to repetitive muscle actions, that would add an additional fatigue factor leading to diminished performance. In fact, other studies have reflected that any small opposing torque may reduce injury by assisting the eccentric action of the hamstrings, *eg* at the end of the recovery phase whilst running[2,6]. Further injury prevention may be afforded by compression clothing via the reported reduction in muscle oscillation on landing from a jump[2].

*'Wearing a lower-body compressive garment may reduce muscle fatigue by supporting more active muscles and applying pressure in such a way as to support muscle fibres in their contraction direction'*

In addition to the above, there is evidence to suggest that compression clothing may improve exercise performance by reducing the impact of hot and/or humid conditions on the body's thermoregulatory system[7]. It is well documented that heat strain as a result of an elevated core body temperature can cause a reduction in exercise performance. In humans, the primary means of cooling the body during exercise is through the evaporation of sweat from the skin surface. Increases in skin and core temperature and a reduction in cooling efficiency are observed when clothing interferes with the evaporation of sweat from the skin. It has been suggested that compression clothing assists the rate of evaporation by facilitating a faster transfer of sweat from the skin to the fabric. Once there, the sweat can be transported through the fabric and dispersed more quickly and evenly over a larger area allowing evaporation to be maximised. If this is the case then athletes would feel cooler during exercise and perceive the activity as being less difficult.

**Jargonbuster**

**Isokinetic**
Muscular contraction that occurs at a constant velocity over the range of motion

**Creatine kinase**
A marker of muscle cell damage; strenuous exercise that damages skeletal muscle cell structure has been shown to increase blood CK activity

## Compression clothing and recovery

Recent compression clothing research has focused predominantly on its possible potential to aid post-exercise recovery. A New Zealand study has examined the effectiveness of four interventions on the rate and magnitude of muscle damage recovery, as measured by **creatine kinase** (CK)[8].

Monitored before, immediately after, 36 and 84 hours after competitive rugby matches, 23 elite male rugby players were randomly assigned to complete one of four post-match recovery strategies:

- Contrast water therapy (CWT – 1 minute cold followed by 2 minutes hot repeated 3 times, immersed in a bath to shoulder level);
- Compression tights (CT);
- Low-intensity active cool-down (ACD);
- Passive recovery (PR).

Unsurprisingly, the poorest rate of post-match recovery was observed following the PR intervention, with a significantly lower rate of recovery compared to all of the other strategies. Interestingly, no significant difference in CK recovery was observed between CWT, CT and ACD at any of the time points.

In another study, a group of untrained women wore a compression sleeve for five days after performing two sets of 50 arm curls using an isokinetic dynamometer, with a maximal eccentric muscle action superimposed every fourth passive repetition[9]. Results demonstrated that swelling, perceived muscle soreness and any impact to elbow joint range of motion were all reduced in those subjects that had used the compression sleeve. The compression sleeve group also demonstrated an increase in the rate of force production recovery. Furthermore, the investigators noted a decrease in the magnitude of CK elevation post muscle damage in the compression group, suggesting an enhanced removal of the by-products caused by the activity bout.

The same researchers repeated the above study, but with untrained males, in order to examine if the same benefits of compression clothing were observed[10]. As in the previous study,

| **Proposed performance benefits of compression clothing:** | **Proposed recovery benefits of compression clothing:** |
|---|---|
| 1. Enhanced proprioception | 1. Optimisation of blood flow |
| 2. Reduced muscle oscillation | 2. Reduced blood pooling |
| 3. Enhanced lactate removal | 3. Reduced swelling |

the subjects performed two sets of 50 passive arm curls, after which a compression sleeve was applied to their arm and worn for five days. Once again, the compression treatment group had a reduced amount of swelling, perceived muscle soreness and loss of elbow joint range of motion. An increase in the rate of force production recovery was also noted as was a significantly lower circulatory CK concentration post activity compared to the control group. The scientists suggested two possible reasons for this: 1) the release of these damage markers was attenuated as a result of the compression treatment; or 2) the compression aided in their clearance and removal from the injured area. This study suggests that the use of compression clothing may be a viable post-activity recovery option; the fact that this strategy is simple, requiring no equipment and/or facilities and can be completed/continued in transit makes it especially attractive.

*‘Compression clothing may be a viable post-activity recovery option; the fact that this strategy is simple, requiring no equipment and/or facilities and can be completed/continued in transit makes it especially attractive’*

## Summary

Too often modern athletic clothing is worn simply as a fashion garment. However, for those individuals involved in intense and/or competitive activity, the literature would suggest that compression clothing may provide both a performance and a recovery aid. The mechanisms that mediate any performance gains appear to be related to a considerable number of variables including enhanced proprioception, reduced muscle oscillation, enhanced lactate removal and/or psychological factors (*ie* subjects like the feel of the garments and perceive that they can improve performance).

It appears that there is a dynamic continuum ranging from the extreme mechanical support compression level (*ie* ‘super-suits’) to lower compression levels that engage other biological mechanisms. This suggests that there may be a subtle ergonomic interplay between the garment and natural biological mechanisms. Certainly it indicates that the use of different types and amounts of compression in garment construction should be a consideration and may need to be sport/purpose specific.

The researchers investigating the effects of compression clothing on explosive activities reported that the material used in their custom-fit compression garment was capable of attenuating impact forces and that this may provide some benefit if worn during contact sports(2). Future garment construction and/or areas of the body targeted may need to reflect the specific biological mechanisms and demands of the sport for which it's intended.

Strenuous training and competition places an enormous demand on the physical and physiological reserves of athletes. Individuals vary in their ability to cope and in their tolerance of competitive stressors. The regeneration of normal metabolic reserves should be a priority and the practices to promote recovery should commence immediately post training or competition. The use of compression clothing appears to provide an economical and effective strategy that offers a practical alternative or additional recovery method. However, as with other recovery interventions, the optimal duration and combination with other methods requires further investigation.

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# Going for the burn

## At a glance

- The fundamental mechanisms of fat oxidation during exercise are outlined;
- The factors affecting fat oxidation are discussed and the concept of '*Fatmax*' is explained;
- Nutritional and training strategies to maximise fat burning are considered.

**Fat burning has always been a popular and often-used term among endurance athletes. But 21st Century science is lifting the lid on how best to achieve it. Asker Jeukendrup looks at the latest research**

The term 'fat burning' refers to the ability to oxidise (or burn) fat, and thus to use fat – instead of carbohydrate – as a fuel. Fat burning is often associated with weight loss, decreases in body fat and increases in lean body mass, all of which can be advantageous for an athlete.

It is known that well-trained endurance athletes have an increased capacity to oxidise **fatty acids**. This enables them to use fat as a fuel when their carbohydrate stores become limited. In contrast, patients with obesity, insulin resistance and type II diabetes may have an impaired capacity to oxidise fat. As a result, fatty acids may be stored in their muscles and in other tissues. This accumulation of lipid and its metabolites in the muscle may interfere with the insulin-signalling cascade and cause **insulin resistance**. It is therefore important to understand the factors that regulate fat metabolism, and the ways to increase fat oxidation in patients and athletes.

## Jargonbuster

**Fatty acids** – a type of fat having a carboxylic acid group (COOH) at one end of the molecule and a methyl (CH3) group at the other end, separated by a hydrocarbon chain that can vary in length

**Insulin resistance** – the condition in which normal amounts of insulin are inadequate to produce a normal insulin response from fat, muscle and liver cells

**Neuronal (beta-adrenergic) stimulation** – signals sent from the central nervous system to the tissues via beta receptors

## Fat oxidation during exercise

Fats are stored mostly in (subcutaneous) adipose tissue, but we also have small stores in the muscle itself (intramuscular triglycerides). At the onset of exercise, **neuronal (beta-adrenergic) stimulation** will increase lipolysis (the breakdown of fats into fatty acids and glycerol) in adipose tissue and muscle. **Catecholamines** such as adrenaline and noradrenaline may also rise and contribute to the stimulation of lipolysis.

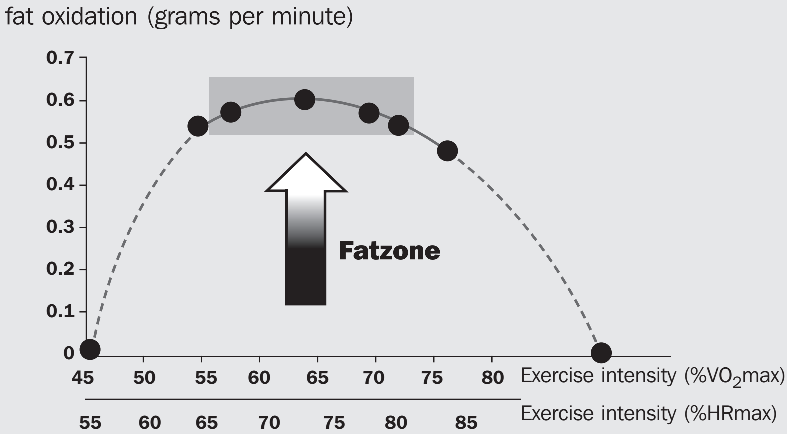
As soon as exercise begins, fatty acids are mobilised. Adipose tissue fatty acids have to be transported from the fat cell to the muscle, be transported across the muscle membrane and then be transported across the **mitochondrial membrane** for oxidation. The triglycerides stored in muscle undergo similar lipolysis and these fatty acids can be transported into the mitochondria as well. During exercise, a mixture of fatty acids derived from adipocytes and intramuscular stores is used. There is evidence that shows that trained individuals store more intramuscular fat and use this more as a source of energy during exercise [(1)].

Fat oxidation is regulated at various steps of this process. Lipolysis is affected by many factors but is mostly regulated by hormones (stimulated by catecholamines and inhibited by insulin). The transport of fatty acids is also dependent on blood supply to the adipose and muscle tissues, as well as the uptake of fatty acids into the muscle and into the mitochondria. By inhibiting mobilisation of fatty acids or the transport of these fatty acids, we can reduce fat metabolism. However, are there also ways in which we can stimulate these steps and promote fat metabolism?

## Factors affecting fat oxidation

*Exercise intensity* – One of the most important factors that determines the rate of fat oxidation during exercise is the intensity. Although several studies have described the relationship between exercise intensity and fat oxidation, only recently was this relationship studied over a wide range of intensities[(2)]. In absolute terms, carbohydrate oxidation

## Figure 1: Exercise intensity and fat oxidation




Exercise intensity (expressed as %HRmax and %$VO_2$max) and fat oxidation. Fat oxidation increases from low to moderate exercise intensities, peaks at *Fatmax,* and decreases as the exercise intensity increases further. The grey area represents the Fatzone: a range of exercise intensities where fat oxidation is high.

increases proportionally with exercise intensity, whereas the rate of fat oxidation initially increases, but decreases again at higher exercise intensities (*see figure 1*). So, although it is often claimed that you have to exercise at low intensities to oxidise fat, this is not necessarily true.

In a series of recent studies, we defined the exercise intensity at which maximal fat oxidation is observed, called '*Fatmax*'. In a group of trained individuals it was found that exercise at moderate intensity (62-63% of $VO_2$max or 70-75% of HRmax) was the optimal intensity for fat oxidation, whereas it was around 50% of $VO_2$max for less trained individuals [2,3].

However, the inter-individual variation is very large. A trained person may have his or her maximal fat oxidation at 70%$VO_2$max or 45%$VO_2$max, and the only way to really find out is to perform one of these *Fatmax* tests in the laboratory. However, in reality, the exact intensity at which fat oxidation peaks may not be that important, because within 5-10% of this intensity (or 10-15 beats per minute), fat oxidation will be similarly high, and only when the intensity is 20% or so higher will fat oxidation drop rapidly (*see figure 1*).

This exercise intensity (*Fatmax*) or 'zone' may have importance for weight-loss programmes, health-related exercise programmes, and endurance training. However, very little research has been done. Recently we used this intensity in a training study with obese individuals. Compared with interval training, their fat oxidation (and insulin sensitivity) improved more after four weeks steady-state exercise (three times per week) at an intensity that equalled their individual *Fatmax* [4].

*'We recently found that green tea extracts increased fat oxidation during exercise by around 20%'*

*Dietary effects* – The other important factor is diet. A diet high in carbohydrate will suppress fat oxidation, and a diet low in carbohydrate will result in high fat oxidation rates. Ingesting carbohydrate in the hours before exercise will raise insulin and subsequently suppress fat oxidation by up to 35%[5] or thereabouts. This effect of insulin on fat oxidation may last as long as six to eight hours after a meal, and this means that the highest fat oxidation rates can be achieved after an overnight fast.

Endurance athletes have often used exercise without breakfast as a way to increase the fat-oxidative capacity of the muscle. Recently, a study was performed at the University of Leuven in Belgium, in which scientists investigated the effect of a six-week endurance training programme carried out for three days per week, each session lasting one to two hours[6]. The participants trained in either the fasted or carbohydrate-fed state.

When training was conducted in the fasted state, the researchers observed a decrease in muscle glycogen use, while the activity of various proteins involved in fat metabolism was increased. However, fat oxidation during exercise was the same in the two groups. It is possible, though, that there are small but significant changes in fat metabolism after fasted training; but, in this study, changes in fat oxidation might have been masked by the fact that these subjects received carbohydrate during their experimental trials. It must also be noted that training after an overnight fast may reduce your exercise capacity and may therefore only be suitable for low- to moderate- intensity exercise sessions. The efficacy of such training for weight reduction is also not known.

*Duration of exercise* – It has long been established that fat oxidation becomes increasingly important as exercise progresses. During ultra-endurance exercise, fat oxidation can reach peaks of 1 gram per minute, although (as noted in *Dietary effects*)fat oxidation may be reduced if carbohydrate is ingested before or during exercise. In terms of weight loss, the duration of exercise may be one of the key factors as it is also the most effective way to increase energy expenditure.
*Mode of exercise* – The exercise modality also has an effect on fat oxidation. Fat oxidation has been shown to be higher for a given oxygen uptake during walking and running, compared with cycling(7). The reason for this is not known, but it has been suggested that it is related to the greater power output per muscle fibre in cycling compared to that in running.

*Gender differences* – Although some studies in the literature have found no gender differences in metabolism, the majority of studies now indicate higher rates of fat oxidation in women. In a study that compared 150 men and 150 women over a wide range of exercise intensities, it was shown that the women had higher rates of fat oxidation over the entire range of intensities, and that their fat oxidation peaked at a slightly higher intensity(8). The differences, however, are small and may not be of any physiological significance.

## Nutrition supplements
There are many nutrition supplements on the market that claim to increase fat oxidation. These supplements include caffeine, carnitine, hydroxycitric acid (HCA), chromium,

conjugated linoleic acid (CLA), guarana, citrus aurantium, Asian ginseng, cayenne pepper, coleus forskholii, glucomannan, green tea, psyllium and pyruvate. With few exceptions, there is little evidence that these supplements, which are marketed as fat burners, actually increase fat oxidation during exercise (*see table 1*).

*'Environmental conditions can also influence the type of fuel used. It is known that exercise in a hot environment will increase glycogen use and reduce fat oxidation, and something similar can be observed at high altitude'*

One of the few exceptions however may be green tea extracts. We recently found that green tea extracts increased fat oxidation during exercise by about 20%[4]. The mechanisms of this are not well understood but it is likely that the active ingredient in green tea, called epigallocatechin gallate (EGCG – a powerful polyphenol with antioxidant properties) inhibits the enzyme catechol O-methyltransferase (COMT), which is responsible for the breakdown of noradrenaline. This in turn may result in higher concentrations of noradrenaline and stimulation of lipolysis, making more fatty acids available for oxidation.

*Environment* – Environmental conditions can also influence the type of fuel used. It is known that exercise in a hot environment will increase glycogen use and reduce fat oxidation, and something similar can be observed at high altitude. Similarly, when it is extremely cold, and especially when shivering, carbohydrate metabolism appears to be stimulated at the expense of fat metabolism.

## Exercise training

At present, the only proven way to increase fat oxidation during exercise is to perform regular physical activity. Exercise training will up-regulate the enzymes of the fat oxidation pathways, increase mitochondrial mass, increase blood flow, *etc.*, all of which will enable higher rates of fat oxidation.

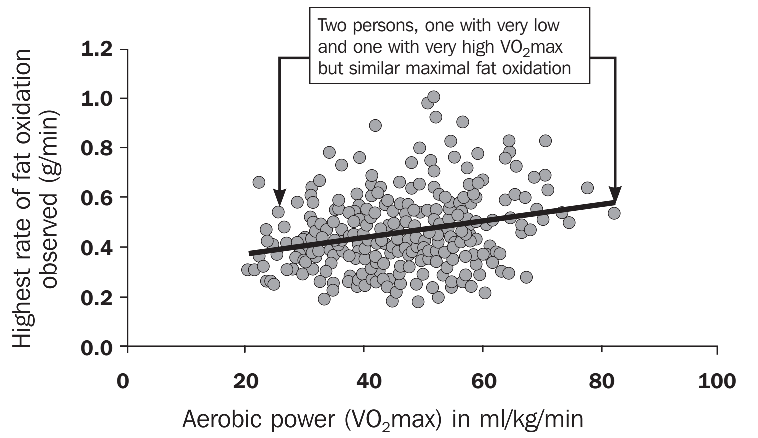
Research has shown that as little as four weeks of regular exercise (three times per week for 30-60 minutes) can increase fat oxidation rates and cause favourable enzymatic changes[10]. However, too little information is available to draw any conclusions about the optimal training programme to achieve these effects.

## Table 1: Nutrition supplements and the scientific evidence that the supplement increases fat metabolism

| Nutrition supplement | Evidence | Fat-burning properties or claims |
|---|---|---|
| Caffeine | ●●●○○ | Caffeine stimulates lipolysis and the mobilisation of FAs. These actions might occur indirectly, by increasing the circulating catecholamine levels; or directly, by antagonising receptors that normally inhibit hormone-sensitive lipase and FA oxidation. In some, but not all, conditions this can result in increased fat oxidation. |
| Carnitine | ○○○○○ | Carnitine is essential for fat oxidation, as it is needed to transport fatty acids into the mitochondria. Studies have shown, however, that carnitine supplementation may not result in increased muscle carnitine supplementation and therefore it is not surprising that no effects on fat oxidation have been found. Nevertheless, it is one of the supplements aggressively marketed as a fat burner. |
| Chromium | ○○○○○ | Chromium was a very popular supplement a few years ago and was associated with insulin sensitivity and fat burning. There is no evidence that chromium has any effect on fat metabolism. |
| Guarana | ●●○○○ | The active constituent of guarana, guaranine, is nearly identical to caffeine and is likely to have similar properties. Compared with caffeine, there has been far less research on guaranine. |
| Ginseng (Asian or Panax) | ○○○○○ | Asian ginseng (Panax ginseng) has been a part of Chinese medicine for over 2,000 years, and was traditionally used to improve mental and physical vitality. However, evidence for its fat-burning properties is lacking. |
| Green tea | ●●●○○ | The active constituents in green tea are the polyphenols, particularly the catechin epigallocatechin gallate (EGCG). However, green tea also contains caffeine. A recent study found that after taking green tea extract, fat oxidation during exercise rose by about 20%. |
| Hydroxycitric acid (HCA) | ○○○○○ | HCA is a derivative of citric acid that is found in a variety of tropical plants. There is no evidence that it has any effect on fat metabolism. |
| Tyrosine | ○○○○○ | L-tyrosine is a nonessential amino acid that serves as a precursor to catecholamines. The assumption is that more tyrosine results in chronically elevated catecholamine concentrations and increased lipolysis. However, there is no evidence to support this. |

The scientific evidence is indicated with ●●●●● meaning very strong evidence and ○○○○○ limited to no evidence.

**Figure 2: Maximal fat oxidation as a function of aerobic power ($VO_2$max). Data from [9].**




In one study we investigated maximal rates of fat oxidation in 300 subjects with varying fitness levels. In this study, we had obese and sedentary individuals, as well as professional cyclists [9]. $VO_2$max ranged from 20.9 to 82.4ml/kg/min. Interestingly, although there was a correlation between maximal fat oxidation and maximal oxygen uptake, at an individual level, fitness cannot be used to predict fat oxidation. What this means is that there are some obese individuals that have similar fat oxidation rates to professional cyclists (*see figure 2*)! The large inter-individual variation is related to factors such as diet and gender, but remains in large part unexplained.

## Weight loss exercise programmes

Fat burning is often associated with weight loss, decreases in body fat and increases in lean body mass. However, it must be noted that such changes in body weight and body composition can only be achieved with a negative energy balance: you have to eat fewer calories than you expend, independent of the fuels you use! The optimal exercise type, intensity, and duration for weight loss are still unclear. Current recommendations are mostly focused on increasing energy expenditure and increasing exercise volumes. Finding the optimal intensity for fat oxidation might aid in losing weight (fat loss) and in weight maintenance, but evidence for this is currently lacking.

It is also important to realise that the amount of fat oxidised during exercise is only small. Fat oxidation rates are on average 0.5 grams per min at the optimal exercise intensity. So in order to oxidise 1kg of fat mass, more than 33 hours of exercise is required! Walking or running exercise around 50-65% of $VO_2max$ seems to be an optimal intensity to oxidise fat. The duration of exercise, however, plays a crucial role, with an increasing importance of fat oxidation with longer exercise. Of course, this also has the potential to increase daily energy expenditure. If exercise is the only intervention used, the main goal is usually to increase energy expenditure and reduce body fat. When combined with a diet programme, however, it is mainly used to counteract the decrease in fat oxidation often seen after weight loss [11].

## Summary

Higher fat oxidation rates during exercise are generally reflective of good training status, whereas low fat oxidation rates might be related to obesity and insulin resistance. On average, fat oxidation peaks at moderate intensities of 50-65%$VO_2max$, depending on the training status of the individuals[2,8], increases with increasing exercise duration, but is suppressed by carbohydrate intake. The vast majority of nutrition supplements do not have the desired effects. Currently, the only highly effective way to increase fat oxidation is through exercise training, although it is still unclear what the best training regimen is to get the largest improvements. Finally, it is important to note that there is a very large inter-individual variation in fat oxidation that is only partly explained by the factors mentioned above. This means that although the factors mentioned above can influence fat oxidation, they cannot predict fat oxidation rates in an individual.

## Jargonbuster

**Catecholamines** – hormones and neurotransmitters that generally activate metabolism. The most abundant catecholamines are adrenaline, noradrenaline and dopamine

**Mitochondrial membrane** – the membrane surrounding the mitochondrion, where aerobic energy metabolism takes place. The membrane is impermeable to many substances, such as fatty acids, which need transporters to enter

**Chylomicrons** – large lipoprotein particles created by the absorptive cells of the small intestine to transport fatty acids to the liver and other tissues

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# Maximising strength – time to tear up the old rulebook?

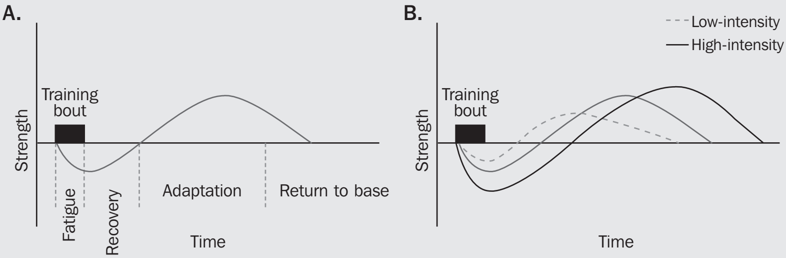
## At a glance

- The physiological responses to strength training are outlined and the role of a key regulator of muscle growth called mTOR is explained;
- Research showing how to optimise mTOR activation and so increase muscle growth is presented;
- Practical training recommendations are given for maximum strength gains.

**For thousands of years, athletes have used resistance training to increase their strength and performance. But as Keith Baar and Mike Gittleson explain, 21st Century science is revealing that the traditional methods of resistance training might not be the most effective way to do this...**

Over 2,500 years ago, Milo of Crotona, a Greek farmer and Olympic wrestler, performed his morning exercises with a calf draped across his shoulders. As the calf grew so did Milo's strength. At the time of the Olympiad, his strength was so great that he could complete his exercises with the calf, now a full-grown bull, on his shoulders, making his strength unparalleled. The scientific theory described in this fable has been termed the 'overload principle' – *ie* that strength gains occur as a result of systematic and progressive exercise of sufficient frequency, intensity and duration to cause adaptation.

**Figure 1: A schematic diagram of the adaptation of muscle to a single bout of exercise**




A) Acute resistance exercise progressively results in fatigue, recovery, and adaptation.
B) Changing the intensity of the resistance exercise decreases (low-intensity) or increases (high-intensity) the time of each of the phases after resistance exercise.

While we have recognised the importance of the overload principle for a very long time, the exact frequency, intensity and duration of exercise to maximally increase muscle strength is still open to debate. A number of factors impact optimal training frequency, how hard to train and how long to train. These include the equipment and coaching available, individual rates of recovery after hard weight training and the individual's ability to sustain intense exercise.

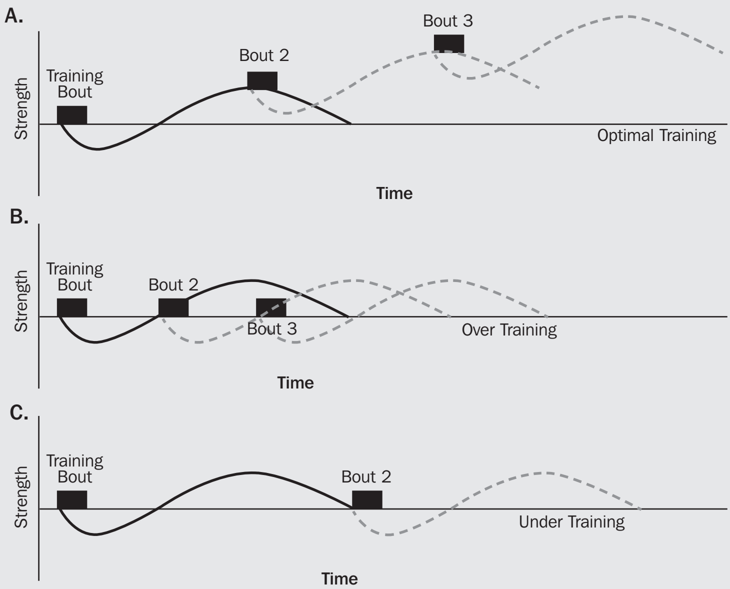
*'The heavier the weight, or the greater the absolute amount of power produced by the muscle, the better the activation of mTOR'*

## Response to training

It is easiest to view an individual's response to resistance exercise in pictorial form (*see figure 1*). A training session can be separated into four phases (*see figure 1A*):
1. The training bout itself where the muscle fatigues and strength decreases;
2. The recovery phase, including both the immediate recovery from the exercise and the delayed recovery when damaged muscle fibres are removed and replaced;
3. The adaptation or supercompensation phase;
4. The return phase where any strength gains from the bout of exercise are lost.

Changing the intensity of the exercise increases or decreases the length of each of the phases (*figure 1B*) making it even

**Figure 2: Schematic representation of the effect of timing training on the adaptive response**




The effects on strength over a period of time of A) optimal timing of training, B) training too frequently and C) not training frequently enough

harder for the strength coach to time the next training session.

The goal of the athlete and coach is to provide the next training session at the optimal frequency (*see figure 2*). If each of the sessions is optimally timed (at the peak of the adaptation phase), the athlete will increase strength at a maximal rate. If the sessions are too frequent (as is common for elite athletes – *see figure 2B*), the muscle doesn't have sufficient time to adapt and strength gains are slow. Poor strength gains are also seen if the sessions are not frequent enough.

## Molecular response to training

So what is it that actually causes an increase in strength? One possibility is that muscle repair results in a newer, stronger muscle.

But while it is true that muscles repair themselves after a training session, there's nothing in the repair process itself that causes the muscles to grow stronger. This can be seen by comparing muscle strength following a training session to muscle strength after a minor muscle injury. In both cases, muscle repair has occurred. However, only the training session increases muscle strength.

*'Over the past 10 years molecular exercise physiologists have identified the key regulator of muscle protein synthesis after strength-training. The technical name for this protein is the 'mammalian target of rapamycin', or mTOR for short'*

If not repair, then what? In every scientific model of muscle hypertrophy (growth), including mice, rats, rabbits, chickens and humans, the first response to a strength-training session is an increase in protein synthesis. If the increase in protein synthesis is more than the increase in muscle breakdown, the muscle will get bigger and stronger.

Over the past 10 years molecular exercise physiologists have identified the key regulator of muscle protein synthesis after strength-training. The technical name for this protein is the 'mammalian target of rapamycin', or mTOR for short. The activity of mTOR is directly related to the intensity of the training session and, over time, to the increase in muscle size and strength(1) (*see figure 3*).

## Maximising muscle growth

If activating mTOR is the key to increasing strength, then understanding how to maximally activate this enzyme will tell us how to optimise our strength-training. To do this, we have to understand what turns mTOR on and off, and from a number of beautiful scientific studies, this is now clear.

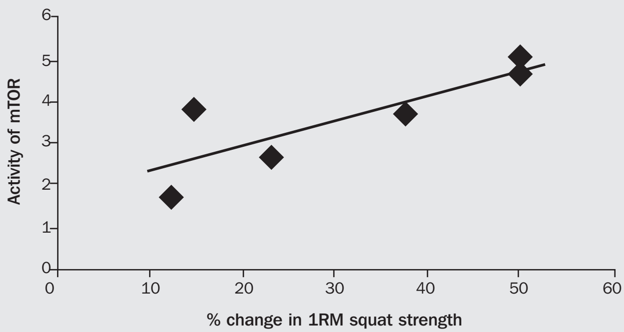
The load on a muscle is directly related to the activation of mTOR. This means that the heavier the weight, or the greater the absolute amount of power produced by the muscle, the better the activation of mTOR(2). The only time where this relationship is not seen is when the weight-lifting is done while blood flow is restricted, but this is only really applicable to populations that can't lift heavy weights for medical reasons. Therefore, the goal should be to lift as much weight as possible.

On the other side of the equation, mTOR activity is blocked by metabolic stress. This means that we want to use as little muscular ATP (an energy yielding molecule used in muscle contraction) as possible when we are doing our resistance training. The best way to decrease ATP consumption is to not work very long and to do exercises that use less ATP. Put together, this means that the best way to increase the activity of mTOR is to do exercise at high absolute power and low energy cost.

There are two ways to produce high power in muscle (*see figure 4*). The first is to perform shortening (concentric) muscle contractions with a medium amount of force, while the second is to perform lengthening (eccentric) contractions at a high force. Because of the architecture of our muscles we are able to produce about 1.8 times as much force when our muscles are lengthening than when they are shortening, resulting in much more power (even though it is negative).

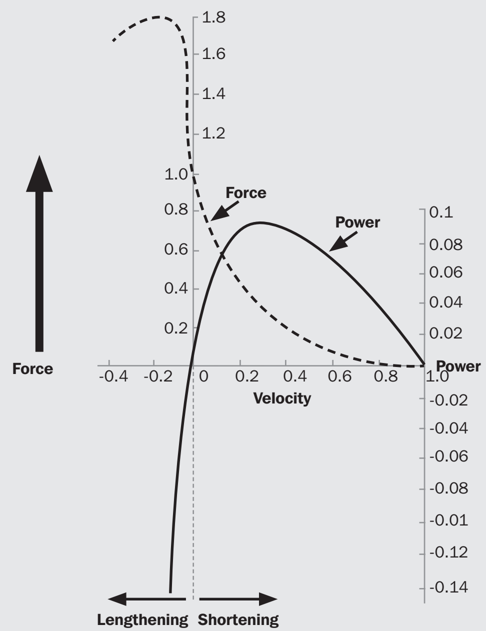
Even though shortening and lengthening contractions can both result in high absolute power, they have very different energy costs. Shortening contractions are the most energy-consuming contractions, isometric contractions are the least energy-consuming (but result in the lowest amount of power) and lengthening contractions are in-between, requiring one-half of the ATP of shortening contractions[3]. This information suggests

**Figure 3: The relationship between the activity of mTOR and strength gains**




The activity of muscle protein synthesis regulator mTOR 30 minutes after strength training is directly related to the increase in squat strength after 14 weeks of training. This suggests that mTOR activity causes muscle growth.

**Figure 4: Force-velocity (relative power) relationship in muscle**




The force-velocity relationship in muscle is depicted by the red line with the relative power superimposed with the black line. Note that there are two areas where there is high power, one during shortening (positive power) and one during lengthening (negative power).

activation of mTOR (and therefore strength gains) should be greatest when training with forced lengthening contractions against a very high load.

## Training to maximise mTOR activation

The type of contraction is one thing that can be used to maximise mTOR activation, but are there others? The short answer is yes. Here, we will discuss one nutritional strategy and a few training programme factors that can maximise activation of mTOR.

One of the things that can activate mTOR inside muscles is an increase in circulating blood amino acids (from digested protein). Specifically, foods that are high in the branched chain amino acids (*eg* leucine) such as milk, can increase the response to resistance exercise. We have known for some time that adding amino acids to a strength-training programme can improve the resulting increase in strength, and now we think that we know why. When amino acids are taken into muscle, they can directly activate mTOR and improve protein synthesis and muscle growth.

There is also the suggestion that when we consume amino acids might be important in the effects on mTOR and protein synthesis, but this is still controversial. We have just finished experiments that suggest that the if amino acids are taken within one hour after training they will have a bigger effect then if they are taken later. This is because we have found that the 'leucine transporter' is increased in muscle between 30 and 90 minutes post-training and this might be important in mTOR activation and therefore strength gains.

It is important to remember that keeping amino acid levels high for extended periods of time can actually result in a decrease in both protein synthesis and insulin sensitivity[4]. Therefore, it is unwise consume to excessive amounts of protein.

*'Keeping amino acid levels high for extended periods of time can actually result in a decrease in both protein synthesis and insulin sensitivity. Therefore, it is unwise consume to excessive amounts of protein'*

## Programme features to optimise mTOR activation

Although we said we want to maximise power when we train, there is a caveat. The highest absolute power is seen when performing fast lengthening contractions with a lot of weight (high jerk), or heavy plyometric exercises. This type of exercise is very effective in activating mTOR, but unfortunately can be very bad for tendon health, and as a result can lead to injuries. Since the tendon adapts more slowly than muscle, if heavy plyometric exercises are used, providing adequate recovery time following these exercises is absolutely essential.

Another consequence of the slow recovery rate of tendon for high-jerk resistance exercise is the use of periodised training. Non-linear periodised programmes result in greater strength gains than traditional linear progression methods. Athough it

## Box 1: Programme rules for maximising mTOR activation and strength gains

**Target:** The weight is increased when the athlete completes a fixed number of repetitions. Targets are normally used at the beginning of a training program, when increases are made more rapidly.

**Range:** Contains both upper and lower limits of repetitions (*eg* six to eight reps). When the athlete performs the reps at the lower limit of the range (*ie* six reps) the weight remains the same and the number of repetitions increases through the range. The weight is increased only when the athlete completes the upper limit of the repetition range (*ie* eight reps) and the number of repetitions is decreased to the lower limit.

**Number of repetitions:** As stated above, sets should last no longer than 60 seconds. Therefore, each set should have no more than 10 reps. Since forced repetitions are to be used, the maximal number of positive reps should be eight so that two forced reps can be added.

**Adding weight:** When progressing, the weight added should be at least twice the smallest weight available in the gym – *eg* if the smallest weight in the gym is 1kg, the smallest weight that should be added is 2kg.

**No progression:** If the athlete shows no progress for three workouts, the weight is reduced. The weight removed should be half of the last added weight and the number of reps should stay the same.

**Momentary muscular failure:** Momentary muscular failure is achieved when the athlete can no longer either lift the weight or provide resistance during the negative phase.

has been demonstrated numerous times, there doesn't seem to be a reason for this at the muscle level. Instead, this likely represents the fact that the majority of elite athletes are overtraining and periodically decreasing the load allows the required rest for muscle adaptation and tendon recovery from the high-jerk exercises.

An alternative way to promote tendon health is to use slow lengthening, or forced contractions. This type of movement has been shown to improve tendon health and recovery from injury. Further, since there is no need for prolonged tendon rest periods, linear progression programmes can be used effectively when this type of movement is included.

Second, since minimising metabolic stress is one of the keys to activation of mTOR, each set should last less than 60 seconds.

This is the amount of high-energy phosphate stored in a normal muscle. Any longer and the muscle will turn on processes that shut down mTOR, decreasing the response to the training. When performing controlled repetitions this means a maximum of 10 reps per set is optimal for strength gains.

Last, in order to minimise the metabolic stress of each set, the programme should preferably consist of only one set, which should end with two to three forced repetitions. If more than one set is used, enough time must be taken between sets to allow full recovery of phosphocreatine and ATP. This takes two to three times as long as the exercise itself (around two to four minutes).

## Putting together a strength programme

So how can these ideas be put together into a coherent programme to optimise strength gains? What follows is a programme built on the molecular ideas described above and the experience of 30 years of working with elite strength athletes. This programme is a linear progression system that uses one set to momentary muscular failure and push-pull methodology to maximise power and minimise metabolic stress (*see box 1 on previous page*).

## Correct form

*During the positive phase:*

- Limit momentum: *do not* bounce or throw the weight upwards;
- Limit leverage: *do not* change the angle of any joint other than the target joint;
- Constant tension throughout the exercise: *do not* rest on the way down or at the bottom of the movement;
- Shortening of the target muscle should take one to two seconds; the weight should then be stopped at the top of the movement before lowering the weight with tension during the lengthening phase.

*During the negative phase (forced repetitions):*

- When the athlete can no longer lift the weight, the coach and athlete combine for a number of forced repetitions. In this phase, the coach assists in the shortening phase and then challenges the athlete to lower as much weight as possible taking six to eight seconds. The coach can also provide extra resistance if needed.

## Push-pull methodology

To minimise the metabolic stress on each muscle group, athletes should progress from a pushing exercise to a pulling exercise and vice-versa. A pushing exercise is a movement away from centre of body during the shortening contraction of the target muscle (*eg* chest/shoulder/triceps press, leg extension, leg press). A pulling exercise is a movement toward centre of body during the shortening contraction of the target muscle (*eg* pulldown, row, biceps curl, leg curl). Progressing from a pushing to a pulling exercise allows full recovery and resynthesis of ATP and PCr in helper muscles between exercises, decreasing metabolic stress and allowing better activation of mTOR.

*‘To minimise the metabolic stress on each muscle group, athletes should progress from a pushing exercise to a pulling exercise and vice-versa’*

## Recovery

After a workout, your body begins recovery by replenishing oxygen supply, high-energy phosphate fuels and glycogen (carbohydrate) in muscle, and importantly begins to degrade and synthesise muscle proteins. This requires rest and proper nutrition. The amount of rest varies from athlete to athlete and with the intensity of exercise as discussed above, while proper nutrition can be as simple as consuming 6g of essential amino acids and 35g carbohydrate (700mls of skimmed milk is sufficient to provide these) within 30 minutes of training[5].

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# Explosive strength training – can it blow away conventional methods?

## At a glance

- The conventional approach to strength training using 'task failure' protocols is summarised;
- The use of explosive contractions for achieving maximum muscle activation is discussed;
- New research on explosive strength training is presented, including potential advantages over conventional approaches.

**In years gone by, the conventional resistance training wisdom has been that performing two or three sets to failure is the best way to achieve rapid strength gains. However, as John Sampson explains, groundbreaking new research suggests that less may be more...**

Athletic performance in many sports demands the development of muscle strength, which is required for other performance related characteristics, notably speed and power. Muscle strength is routinely developed through prolonged participation in a structured resistance exercise programmes. Yet despite extensive research in the area, the adaptive mechanisms contributing to maximal strength adaptation are not yet fully understood.

Skeletal muscle is an extremely sensitive and highly adaptive tissue; consequently almost any overload applied to the muscle

## Box 1: Brain and muscle contractions

Muscle contractions are ultimately controlled and regulated by the brain. Muscles are controlled by motor units, and when a motor unit is activated, it causes the group of muscle fibres it controls to contract. This is often referred to as the 'neural control of force' and is predominantly a function of the number of active motor units and the rate at which they fire. The level of motor unit activity is directly proportional to the level of force required to complete a task.

will result in some form of adaptation (ie strength gain). In the case of athletes, even sub-optimal resistance training programmes can result in some positive adaptations. However, long-term adherence to such a resistance training programme is unlikely to result in optimal strength gains and in some cases may even lead to reduced performance capabilities and an increased risk of injury.

A number of key principles are applied during resistance exercise programmes. Legend suggests Greek athlete Milo of Croton lifted and carried a calf on his shoulders each day from birth until it became fully grown; as the animal grew in size so did his strength. This legend clearly demonstrates the importance of applying a progressively increasing external load!

The mechanical loading of muscle as a consequence of the external load is perhaps the most important consideration of any resistance-training programme. Research has consistently indicated that moderate to heavy loads are required in order to gain an increase in muscle size, muscle activity and muscle strength. Correspondingly, an extensive review of the literature and current guidelines published by the American College of Sports Medicine (ACSM) suggest relatively heavy loads that equal, or are in advance of 80% of a one-repetition maximum (1RM) are required in order to achieve optimal strength gains (1).

Resistance exercise programmes can be modified not only by the external load, but also by the speed of contraction, and level of induced fatigue. Altering resistance exercise programmes in just one of these ways will induce a distinct

### Jargonbuster

**One-repetition maximum (1RM)**
The maximal load you can lift one time only unassisted through the complete range of motion

**Motor units**
Function to transport information from the central nervous system to muscle fibres. A single motor unit consists of a motor neuron and all of the muscle fibres it innervates

skeletal muscle response. However, the combined effects of adjusting training in two or more of these areas simultaneously will result in more complex physiological interactions that may either hinder or improve training related strength gains. Unfortunately, we still have insufficient evidence to fully understand the complex interactions between load, movement speed and the extent of muscular exhaustion induced by the level of work (eg completed number of sets and repetitions).

## Optimum strength training protocol

Everybody knows that a structured resistance training programme results in increased muscle size (hypertrophy), and that a larger muscle has the potential to produce greater levels of force. When first starting out in resistance training you may have noticed increases in your muscular strength, but no increase in the size of your muscles. Strength gains without muscle size increase are generally attributed to an increased level of 'muscle activation' – ie better recruitment of motor units that 'fire' muscle fibres (*see box 1*).

Maximal activation of muscle fibres during resistance exercise is essential for maximal strength gains. When completing a set of resistance exercises, you'll no doubt be aware of an increase in the difficulty of exercise as you complete an increased number of repetitions. This is because motor units fatigue and in an attempt to maintain the desired force output, more motor units are recruited. Consequently the level of muscle activity increases as the muscle attempts to maintain the required force to overcome the load. This explains why training to the point of repetition failure is seen as an important consideration in resistance training program design.

Repetition maximum loading regimes were first credited by Delorme [(2)] and later Delorme and Watkins [(3)] who conducted a series of investigations examining the effect of progressive-resistance training in exercise rehabilitation. This research proposed the completion of 10 repetitions using a load which was consequently heavy enough to result in 'task failure' (muscular exhaustion) on the 10th repetition. This loading

## Box 2: Exercise efficiency

Human movement results in an energy cost as a consequence of the mechanical work performed. Thus if the same amount of work can be completed at a lower energy cost, the movement can be considered more efficient. For resistance training to be successful, we expect certain adaptations to occur (ie increased strength and muscle size). Therefore, if one training programme demands a lower energy cost, but results in the same adaptations as a second, the first programme can be considered as more efficient.

technique was termed a 10-repetition maximum (10RM). Some 60 years later, repetition maximum loading regimes remain the dominant resistance-training model utilised across research literature and in gyms across the world. Task failure has therefore become closely affiliated with maximal strength adaptation and most resistance exercise programmes advocated by coaches and fitness trainers result in high levels of muscular exhaustion.

However, research into the necessity for such high levels of induced fatigue is far from conclusive. Most resistance trainers apply the use of multiple sets in order to achieve maximal strength gains, yet there's conflicting evidence surrounding the use of multiple versus single set strength training programmes. The concept of high levels of workload and induced fatigue as a prerequisite for strength adaptation is thus far from proven.

*'Explosive muscle contractions result in the rapid generation of force, increase the rate of motor unit firing and reduce motor unit recruitment thresholds'*

Increasing the number of sets performed in a resistance training session is not the only way to influence the level of muscular exhaustion. Research has compared the effects of allowing brief inter-repetition rest periods within a resistance exercise programme. Two of the studies in this area have again produced conflicting evidence[4,5].

Each of these studies examined two resistance exercise protocols that were performed against a relatively heavy external resistance:

- One protocol induced high levels of fatigue by directing participants to complete repetitions without rest, to the point of task failure (muscular exhaustion);

- The other protocol had participants performing the same number of repetitions but with a 30 second inter-repetition rest period, thus allowing time for recovery in between repetitions.

The strength gains resulting from this 'high fatigue' exercise regime were compared to those undergoing the lower fatigue protocol. One of the studies found that those in the high fatigue group achieved greater strength gains, while the other study observed no difference between the groups. This poses a dilemma; one set of results proposes an important role for high levels of muscle fatigue, yet the other suggests this is not necessary!

*'The necessity of repetition failure has also been questioned; a number of research studies have suggested similar strength gains can be achieved despite a reduction in the level of induced fatigue'*

## Repetition failure

The necessity of repetition failure has also been questioned. A study carried out in 2006, compared the strength gains achieved in a group performing exercise sets to the point of repetition failure and those of a second group who performed the same total number of repetitions but over a greater number of sets (*ie* where repetition failure wasn't induced). This research again suggested similar strength gains were achieved in both groups despite a less exhaustive stimulus applied in the group performing a greater number of sets.

A number of research studies have therefore suggested similar strength gains can be achieved despite a reduction in the level of induced fatigue. An important point to make here however is that all groups ultimately performed the same relative amount of work, thus the efficiency of exercise was no different between groups (*see box 2*).

Some researchers have advocated the use of single set training programmes, which they believe increases exercise efficiency without compromising strength gain but this is an area of much contention. However, an important interaction between repetition speed and the level of induced fatigue may exist. Repetitions can be performed quickly or slowly and both

### Box 3: Explosive contractions and limb movement

The attempt to perform an explosive contraction is regarded as an effective method of improving high-speed muscle adaptations, even when contractions are performed in the absence of limb movement, against an isometric resistance. Thus, it appears the intent to contract rapidly is more important than the actual movement of the limb [8].

methods have been used across research in the area.

A review of purposefully 'slow training' discusses the mechanical effects of such training [7]. In short, the researchers highlighted that repetitions performed slowly increase the time it takes to complete each muscle contraction over any given range of motion (effectively increasing the time a muscle is subjected to tension). However, they also pointed out that as a function of increasing the time under tension, the load must decrease. Considering the well defined relationship between external loading and muscular adaptation, this appears to directly contradict the well accepted notion that associated resistance training adaptations are proportional to load.

Increasing the time spent performing a muscular contraction is not the only way to increase total time a muscle is under tension. The same effects can be achieved by increasing the number of completed repetitions. Both methods increase the level of muscular exhaustion and will eventually lead to task failure. However, neither effectively increases the efficiency of resistance exercise.

## Explosive contractions

In contrast to purposefully slow training, repetitions can also be performed as fast as possible. Such training is often termed as 'explosive' or 'ballistic'. Remember, in order to stimulate muscle and achieve maximal strength gains during resistance exercise, you need to achieve maximal muscle activation. Explosive muscle contractions result in the rapid generation of force, increase the rate of motor unit firing and reduce motor unit recruitment thresholds.

Explosive muscle contraction can lead to superior activation of muscle. However, in order to perform an explosive movement, the external load needs to be reduced and (as we have discussed) a relatively heavy external load is required in order to gain maximal strength adaptation. Proponents of purposefully slow training have claimed that this makes explosive training less efficient.

It is, however, possible to attempt an explosive contraction against a heavy external load. High levels of force production are required whenever you attempt to initiate a high-speed movement. This is due to inertia; if you attempt to accelerate a mass very rapidly, much more force must be generated to overcome inertia compared to a slower movement with less acceleration.

Performing explosive contractions against relatively heavy loads is also likely to increase power related performance characteristics, while resulting in equal strength related adaptations as performing contractions against the same load at lower speeds (9).

The combination of a heavy external load combined with maximum contraction speed has also found favour in one-set resistance exercise training programmes. For example, researchers in Australia examined the effect of one and three sets of resistance exercise performed at either fast or slow speeds on maximal strength adaptation over a six-week resistance exercise programme with each set resulting in task failure (10). The results of this research highlighted that one set of heavy load exercise performed at fast speeds resulted in similar strength gains as three sets of exercise performed at slower speeds. Furthermore, no additional benefit was observed from performing three sets at the faster speeds. Thus a 'heavy load, explosive contraction' may be a key performance related variable in this area.

## New research

The idea that 'heavy load, explosive contraction' resistance exercise can increase the efficiency of exercise has also been

**Figure 1:** Shows the similar strength gains achieved by the conventionally trained (group 1) and the fast, explosively trained (group 2) subjects

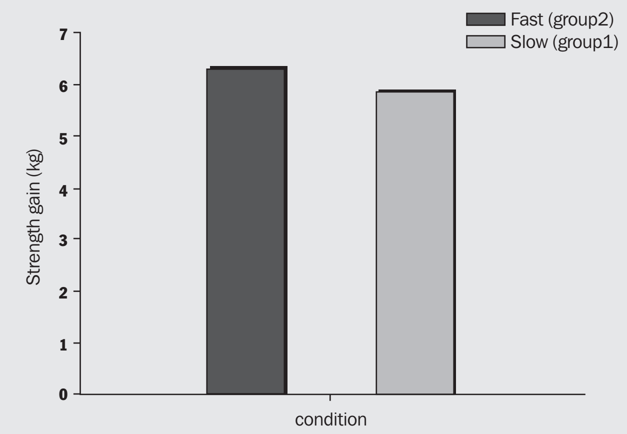
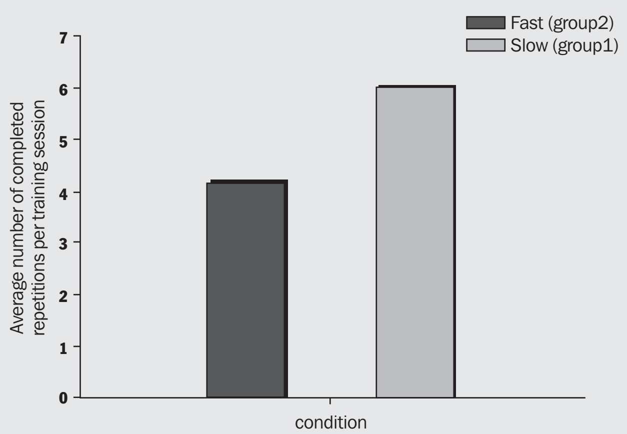



**Figure 2:** Shows the difference in work volume performed by the two groups. Note how the fast, explosively trained subjects (group 2) performed around 30% fewer reps than subjects in group 1 yet still achieved similar strength gains



supported by research from our laboratory at the University of Wollongong, Australia. We manipulated the level of completed work (and thus the level of induced muscle fatigue) and the speed at which repetitions were performed.

One exercise group performed four sets of resistance exercise using a relatively heavy external load, resulting in repetition failure after approximately six repetitions. Meanwhile, a second group were also asked to perform four sets of exercise against the same relatively heavy external load, but we imposed a work reduction on this group by asking them to perform only four repetitions. We also asked this group to complete repetitions as fast as possible (ie explosively), whilst repetition speed in the first (task failure) group was controlled to a four-second cadence; a two-second muscle-shortening phase (normally associated with lifting a weight) and a two-second muscle-lengthening phase (normally associated with lowering a weight).

After 12 weeks of resistance exercise, we found similar strength gains in both groups. These findings are significant; not only did the second (explosive) group performed 30% less total work than the first, they also achieved the same strength gains without working to failure (*see figures 1 and 2*). Moreover, the similar gains in strength between groups were also accompanied by similar increases in muscle size and muscle activity, suggesting no benefit in any area of strength adaptation from a more exhaustive exercise routine performed by the first group.

*'The idea that 'heavy load, explosive contraction' resistance exercise can increase the efficiency of exercise has also been supported by research'*

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# Train low, compete high – why less could equal more!

**According to the theory of evolution, humans evolved as hunter-gatherers, experiencing cycles of feast and famine, punctuated with obligate periods of physical activity and rest. Tens of thousands of years on, our genetic makeup remains substantially unchanged and as Andrew Hamilton explains, new research research indicates this could have significant implications for athletes seeking an optimum feeding strategy in the run up to competition…**

As a sportsman or woman, you'll also certainly be aware of the importance of dietary carbohydrate for maximising performance. Carbohydrate is body's premium grade of fuel for exercise because not only it can be stored where it's needed, it can also be rapidly converted to energy in the muscles. This explains why numerous scientific studies have demonstrated beyond doubt that consuming ample carbohydrate, before, during and after exercise can dramatically extend endurance, especially when working at higher intensities.

However, in today's high-tech, digital 21st Century world, it's easy to forget that our basic metabolism and physiology is hardly any different from that of our ancient forebears. That's not very surprising really as **genes** regulate most metabolic processes in the body, and convincing evidence shows that our genetic makeup has remained essentially unchanged over the past 10,000 years and certainly not changed in the past 40-100 years(1).

Our gene selection in the Late-Palaeolithic era (when our

**Jargonbuster**

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

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

**Gene expression**
The term used to describe the 'switching on' of genes

ancestors roamed the plains as hunter-gatherers) would have been strongly influenced by the need to ensure survival during periods of famine, with certain genes evolving to regulate efficient intake and utilisation of fuel stores – so-called 'thrifty genes'. These genes would have enabled our forebears to utilise energy more efficiently, enabling them to forage for food and escape predators even when enduring famine conditions. As hunter-gatherers, without agriculture, they wouldn't have had access to abundant supplies of 'carbohydrate-dense' crop and cereals but to survive, physical endurance and the occasional high-intensity burst of energy would still have been needed.

## Thrifty genes and exercise

This gene selection in ancient times still has profound implications for the 21st Century athlete. In recent years, a number of 'exercise genes' involved in the adaptation to exercise and training have identified, and some of these genes it seems are also affected by the biochemical environment in the muscle – *eg* how much muscle **glycogen** is present or circulating levels of **hormones and other signalling molecules** released when exercise is performed[2-4].

One of the most obvious questions therefore is that given these genes have evolved to help us maximise our adaptation to and physical capacity in a 'low carbohydrate' environment, is the almost universally recommended high-carbohydrate diet for athletes disadvantageous in any way? Or to put it another way, could training in a carbohydrate-depleted state (as would have been the norm for our ancestors) possibly produce better training adaptations in the modern athlete? Some scientists are now speculating that (thanks to our thrifty genes) lower levels of muscle glycogen during training might stimulate certain metabolic pathways in the body, resulting in better muscular adaptation to training[5].

## Twice daily, alternate day endurance training

One of the earliest studies to look into the effects of low-glycogen training was carried out by Danish scientists who compared the training adaptations produced by exercising either twice a day on alternate days, or once a day on consecutive days(6). In this study, seven healthy, untrained men performed knee extensor exercise with one leg trained using a low-glycogen protocol and the other leg trained using a high-glycogen protocol. This was achieved in the following way:

- On day 1, both legs were trained at 75% of maximum power output for one hour followed by two hours of rest in a fasting state, after which one leg (the low-glycogen leg) was trained for an additional 1 hour with the other (high glycogen) leg rested;
- On day 2, the low-glycogen leg was rested while the high glycogen leg trained for one hour.
- This 2-day training cycle was repeated for ten weeks, with two rest days per week.

In between these training sessions, the subjects consumed a high-carbohydrate diet consisting of 70% carbohydrate, 15% protein and 15% fat. The net effect of this training protocol therefore was that both legs performed an identical volume and intensity of training, but the whereas the high-glycogen leg was trained once daily with high initial levels of glycogen, half of the training performed by the low-glycogen leg was conducted in a low glycogen state (*ie* the second hour on day one of the 2-day cycle).

**Table 1. Maximal power output and time until exhaustion at 90% of maximal power output before and after 10wk of training and total work before and after 10wk of training**

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

**Jargonbuster**

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

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

After ten weeks, the subjects performed a test a 'time to exhaustion' test carried out at 90% of maximum power, the results of which are shown in table 1 on previous page:

As expected, ten weeks of intense training brought about significant performance increases in both the low and high glycogen legs. However, what was striking was the very significant gain in both time to exhaustion and total work performed in the low-glycogen trained leg compared to the high-glycogen leg. In addition, the researchers discovered the following:

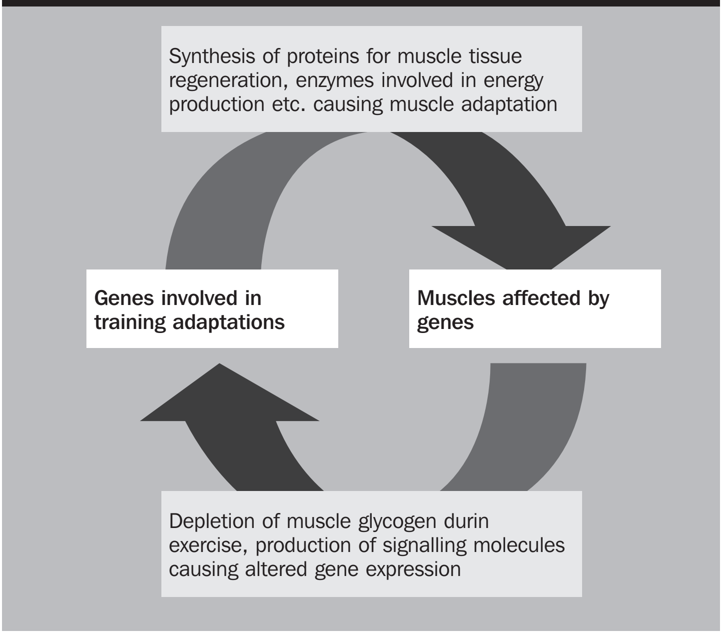
- Training twice a day every second day (*ie* with 50% of the training performed in a low-glycogen state) enhanced the resting concentration of muscle glycogen following subsequent feeding;
- The activity levels of an **enzyme** called 3-hydroxyacyl-CoA dehydrogenase (HAD) activity increased significantly in the low-glycogen protocol; HAD levels provide a good marker for the proportion of energy obtained from the oxidation of fat;
- Both training protocols enhanced the levels of an enzyme called citrate synthase (CS), but the low-glycogen protocol produced a much more pronounced response. CS is a pivotal enzyme in energy production because it controls the initiation of a sequence of biochemical reactions known as the 'citric acid cycle', which lie at the 'metabolic crossroads' of energy production. As rule of thumb, high levels of CS indicates greater mitochondrial activity – remember the mitochondria in each and every one of the 50 trillion or so cells in your body can be thought of as the cells' powerhouses or energy factories!

## Genes and training adaptation

The implications of these findings were pretty startling because they seemed to completely contradict one of the most universally accepted tenets of sports nutrition - that muscle glycogen depletion should be avoided at all costs. In plain English, this research indicated that although low muscle glycogen content is known blunt performance on the day, when it comes to *training adaptation*, this might not be a reason to avoid glycogen depletion. The researchers went on to give a possible explanation - namely that when training with a low muscle glycogen content, the activity of a number of genes involved in training adaptation were enhanced.

A key question to arise from this research is *how* low-glycogen training might improve endurance adaptation? It's well understood that our genetic makeup plays a major role sporting ability and prowess. However, this isn't a one-way process because in recent years, studies have shown that low muscle glycogen content affects **gene expression** and hence training adaptation[3,7] and we now know that physical activity influences the expression of genes in the body. The interaction between genes and physical activity is therefore very much a 2-way process (*see figure 1*).

**Figure 1: Schematic representation showing how muscles and genes interact with each other and that training adaptation is a two-way process**



**Jargonbuster**

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

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

More detailed evidence on metabolic effects of low-glycogen training has come from some recent animal studies. For example, a study by US scientists showed that training rats on a treadmill, while at the same time giving them a drug that activated certain genes by boosting a **transcription factor** known as PPAR∂ resulted a 70% increase in the rats' treadmill endurance at 50% $VO_2$max compared to no drug[8].

PPAR∂ increases levels of enzymes required to burn fat for fuel - exactly the same kind of changes seen when training in a glycogen-depleted state – and is itself activated by the by-products of fat burning. Because exercising in the glycogen-depleted state increases circulating fatty acids (there's less carbohydrate available to burn) and the oxidation of fat during exercise, increased PPAR∂ activation occurs, which in turn results in greater activation of so-called 'thrifty' genes.

In another study, Japanese researchers looked at the effects of a continuous low-carbohydrate diet after long-term exercise on a protein called GLUT-4 in the muscles of rats[9]. GLUT-4 is an important protein that sits in the cell walls, required for the transport of glucose from the bloodstream into the cell (eg for example after a high-carbohydrate meal when cells can 'soak up' blood glucose and store it as muscle glycogen).

The rats were divided randomly into four groups:
- Normal chow diet (sedentary);
- Low-carbohydrate diet (sedentary);
- Normal chow diet (exercise);
- Low-carbohydrate diet (exercise).

Rats in the exercise groups swam for six hours per day in two 3-hour bouts separated by 45 minutes of rest. The 10-day exercise training resulted in a significant increase in the GLUT-4 protein content in the rats' muscles compared to those who hadn't swum. Crucially however, the levels of GLUT-4 in the low-carbohydrate exercising rats increased by an additional 29% compared to normal diet exercising rats.

This indicates that in addition to adaptations in fat-burning capacity, low-glycogen training seems able to boost muscle

GLUT-4, which would further improve the ability of recovering muscle to synthesise and store glycogen once carbohydrate is available again. It would also explain why, in the Danish study above, training performed in a low-glycogen state enhanced the resting concentration of muscle glycogen following subsequent feeding and why a 'train low, race high' strategy may be particularly effective before an important event.

## Problems with train low, race high theory

So far, the train low, race high theory is looking promising. However, while there's certainly evidence in favour of this approach, it should be pointed out that other studies have produced less than conclusive results. For example, Australian scientists have studied the effects of a cycling program in which selected sessions were performed with low muscle glycogen content on training capacity and subsequent endurance performance[10].

In the 3-week study, seven endurance-trained cyclists/triathletes trained once daily, alternating between 100-min steady-state aerobic rides (AT) one day, followed by a high-intensity interval training session (HIT; 8 x 5 minutes at maximum self-selected effort) the next day. Another seven subjects trained twice every second day, first undertaking AT, then 1-2 hours later, the HIT. In this second group of course, the HIT session was completed in a low-glycogen state.

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

The results showed that the compared to the daily training group, the low-glycogen group had higher levels of resting muscle glycogen, higher rates of whole body fat oxidation, and higher levels of key enzymes involved in fat oxidation and aerobic energy production. However, unlike the rat study above[8], levels of a similar gene transcription activator (PPAR-gamma) remained unchanged. More importantly perhaps,

*'Compared to the daily training group, the low-glycogen group had higher levels of resting muscle glycogen, higher rates of whole body fat oxidation, and higher levels of key enzymes involved in fat oxidation and aerobic energy production'*

while cycling performance improved by approximately 10% in both groups, there was no additional improvement whatsoever in the twice daily, low-glycogen group.

Meanwhile, similar results were obtained in a study that used running as a training model, carried out by scientists at Liverpool John Moores University earlier this year[11]. Although this study did not have subjects following a strict low-glycogen training regime, it did examine the effects of reduced carbohydrate availability, by restricting carbohydrate drink use.

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

The training produced significant improvements in maximal oxygen uptake and distance covered on the '**Yo-Yo Intermittent Recovery Test**', in all 3 groups, with no difference between the groups. By contrast, those in group 2 (who were training in a low-glycogen state during their second run) had significantly higher post-training levels of an enzyme called succinate dehydrogenase, which is a key enzyme in aerobic metabolism. The researchers concluded that 'training under conditions of reduced carbohydrate availability provides an enhanced stimulus for inducing oxidative enzyme adaptations of skeletal muscle, but this did not seem to translate into improved performance during high-intensity exercise.

Finally, it's worth adding that there doesn't seem to be any evidence that low-glycogen training is beneficial for very high-intensity exercise, such as resistance training. Australian scientists examined the influence of pre-exercise muscle glycogen content on the activity of several genes involved in the regulation of muscle growth[12]. In the study, seven male strength-trained subjects performed one-legged cycling exercise to exhaustion to lower muscle glycogen levels in one leg compared with the other (control) leg, and then the following day completed a unilateral bout of resistance training.

What the researchers discovered was that while low muscle glycogen content had variable effects on the activity of these genes involved in glycogen synthesis, any differences in the activity rates were completely abolished after a single bout of heavy resistance training. The scientists concluded that 'commencing resistance exercise with low muscle glycogen does not enhance the activity of genes implicated in promoting muscle hypertrophy.'

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

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

## Should you train low and compete high?

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

1. Training with lower levels of glycogen in the muscles appears to elicit greater *endurance* adaptations in muscles, such as improved aerobic efficiency and increased capacity to burn fat compared to training with high levels of muscle glycogen;
2. This greater metabolic adaptation almost certainly occurs as a result of enhanced activation of so-called 'thrifty' genes;
3. There is no such advantage when strength training; indeed, low-glycogen training may actually be disadvantageous for strength and power athletes;
4. High levels of muscle glycogen are always recommended for maximum performance on any given day (*eg* during competition); while training with low glycogen stores may

### Box 1: Potential drawbacks of low-glycogen training

- Increased secretion of stress hormones leading to lowered post-exercise immunity and increased risk of upper respiratory tract infections;
- Reduced length of training sessions due to fatigue induced by low glycogen;
- Increased risk of burnout and overtraining;
- Reduced hydration in hot-weather training (muscle glycogen is complexed with three times its own weight of water);
- Increased muscle tissue damage and breakdown, leading to potential losses in muscle mass;
- Possible strength losses in sports where simultaneous strength and endurance training is required;
- Unsuitable for diabetics and those susceptible to blood sugar swings (low-glycogen training can disturb blood sugar levels).

enhance long-term adaptation, actual performance during this training will not be enhanced and may well be diminished;
5. It's still unclear as to the exact performance benefits of low-glycogen training. Although there are undoubtedly favourable metabolic changes after low-glycogen training, the results are rather mixed as to whether these changes translate into performance gains.

The last point is worth reiterating. Although the initial evidence is looking promising, we don't yet have enough data from studies to tell us categorically whether a train low, race high approach offers real performance advantages over conventional training approaches. Among the questions that still need answering are: How long and frequently should low-glycogen training be carried out to see a significant performance gain? How depleted do muscle glycogen stores need to be to be to see maximum benefits? Could low-glycogen training benefit all endurance events, or just longer ones? Finally, and very importantly, what kind of inter-individual variations can we expect between athletes? Are there some athletes who will respond particularly well or badly to low-glycogen training?

It's also worth adding that low-glycogen training carries with it a number of risks and drawbacks (*see box 1*) and these should

## Box 2: How to train in a glycogen-depleted state

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

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

**Table 2: Suggestions for low-glycogen training***

| Sport | Depletion Session | Adaptive session |
|---|---|---|
| Marathon | 1h @75% HR max | 6 x 800m at 1 mile pace with 1.5m recovery or,<br>4 x 1200m at 3k race pace with 3min recovery, or<br>2 x 2 miles at 10k pace with 10min recovery<br>1h at 75% HRmax |
| Road Cycling | 1h @70% HR max | 6 x 5min at 95% HRmax with 2min recovery<br>2 x 20min hills @ 80% Wmax |
| Swimming | 20 x 150m @ medium-high effort 15 sec rest<br>30 x 100m @ medium-high | 15 x 50m with 10 sec recovery, or<br>10 x 200m with 20sec recovery, or<br>4 x 400m with 40sec recovery |
| | effort 15sec rest | All with increasing intensity (1st med - last race pace) |
| Triathlon | 4h bike with no supplementation<br>Low CHO dinner | Morning – 3h ride with 3 x 10min @ 90% Wmax, or<br>Morning – 1h run with 2 x 1 mile at 10k pace |
| Football/Soccer | 30min run @ 75% HR max | Regular training with team, skills sessioins, repeated sprintsm ball skills, etc |
| Rugby/US Football, Sprinting, Rowing, Time trial cycling | This type of training is not recommended | |

*courtesy of Dr Keith Baar, Functional Molecular Biology Lab, University of California be considered carefully before plunging headlong into a train low, race high strategy.

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

Once again though, it should be stressed that *caution* is the name of the game. If you do decide to experiment with some low-glycogen training, only do so for limited periods, and not at times of stress or tiredness. Be sure too to watch very carefully for symptoms of overtraining and fatigue. Remember, our ancient forebears were just trying to survive – not attempting to set PBs or break endurance/speed records!

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# Carbohydrate drinks: a new breed for a new century

## At a glance:

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

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

Before we go on to discuss carbohydrate formulations, it's worth recapping just why carbohydrate nutrition is so vital for athletes. Although the human body can use fat and carbohydrate as the principle fuels to provide energy, it's carbohydrate that is the preferred or 'premium grade' fuel for sporting activity.

There are two main reasons for this. Firstly, carbohydrate is more oxygen-efficient than fat; each molecule of oxygen yields

**Jargonbuster**

**Glycolysis**
The partial but rapid breakdown of carbohydrate without oxygen

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

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 ($VO_2$max).

Secondly and more importantly, unlike fat (and protein), carbohydrate can be broken down very rapidly without oxygen to provide large amounts of extra ATP via a process known as **glycolysis** during intense (anaerobic) exercise. And since all but ultra-endurance athletes tend to work at or near their **anaerobic threshold**, this additional energy route provided by carbohydrate is vital for maximal performance. This explains why, when your muscle carbohydrate supplies (glycogen) run low, you sometimes feel as though you've hit a 'wall' and have to drop your pace significantly from that sustained when glycogen stores were higher.

## Carbohydrate storage

Endurance training coupled with the right carbohydrate loading strategy can maximise glycogen concentrations, which can extend the duration of exercise by up to 20% before fatigue sets in[1]. Studies have shown that the onset of fatigue coincides closely with the depletion of glycogen in exercising muscles [2,3].

However, valuable as these glycogen stores are, and even though some extra carbohydrate (in the form of circulating blood glucose) can be made available to working muscles courtesy of glycogen stored in the liver, they are often insufficient to supply the energy needs during longer events.

For example, a trained marathon runner can oxidise carbohydrate at around 200-250g per hour at racing pace; even if he or she begins the race with fully loaded stores, muscle glycogen stores would become depleted long before the end of the race. Premature depletion can be an even bigger problem in longer events such as triathlon or endurance cycling and can even be a problem for athletes whose events last 90 minutes or less and who have not been able to fully load glycogen stores beforehand.

Given that stores of precious muscle glycogen are limited, can ingesting carbohydrate drinks during exercise help offset the effects of glycogen depletion by providing working muscles with another source of glucose? Back in the early 1980s, the prevailing consensus was that it made little positive contribution. This was because of the concern that carbohydrate drinks could impair fluid uptake, which might increase the risk of dehydration. It was also mistakenly believed that ingested carbohydrate in such drinks actually contributed little to energy production in the working muscles [4].

Later that decade, however, it became clear that carbohydrate ingested during exercise can indeed be oxidised at a rate of roughly 1g per minute[5-7] (supplying approximately 250kcals per hour) and a number of studies subsequently showed that this could be supplied and absorbed well by drinking 600-1,200mls of a solution of 4-8% (40-80g per litre of water) carbohydrate solution per hour[8-11]. More importantly, it was also demonstrated both that this ingested carbohydrate becomes the predominant source of carbohydrate energy late in a bout of prolonged exercise[10], and that it can delay the onset of fatigue during prolonged cycling and running as well as improving the power output that can be maintained [12,13].

*'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 is indeed possible'*

## Drink formulation

The research findings above have helped to shape the formulation of most of today's popular carbohydrate drinks. Most of these supply energy in the form of glucose or glucose polymers (*see box right for explanation*) at a concentration of around 6%, to be consumed at the rate of around 1,000mls per hour, so that around 60g per hour of carbohydrate is ingested. Higher concentrations or volumes than this are not recommended because not only does gastric distress become a problem, but also the extra carbohydrate ingested is simply not absorbed or utilised.

But as we've already mentioned, 60g per hour actually amounts to around 250kcals per hour, which provides only a modest replenishment of energy compared to that being expended during training or competition. Elite endurance athletes can burn over 1,200kcals per hour, of which perhaps 1,000kcals or more will be derived from carbohydrate, leaving a shortfall of at least 750kcals per hour. It's hardly surprising, therefore, that one of the goals of sports nutrition has been to see whether it's possible to increase the rate of carbohydrate replenishment. And now a series of studies carried out by scientists at the University of Birmingham in the UK indicates that this is indeed possible.

## Carbohydrate type and performance

Many of the early studies on carbohydrate feeding during exercise used solutions of glucose, which produced demonstrable improvements in performance as discussed. In the mid-1990s, some researchers experimented by varying the type of carbohydrate used in drinks, for example by using glucose polymers or sucrose (table sugar). However, it seemed that there was little evidence that these other types of carbohydrate offered 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 $VO_2$max while ingesting 500mls of one of five different drink mixtures[14]:

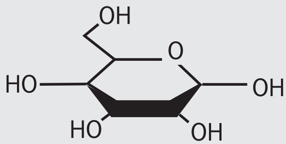
- 50g glucose;
- 100g glucose;
- 50g fructose;
- 100g fructose;
- 100g of 50g glucose + 50g fructose.

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

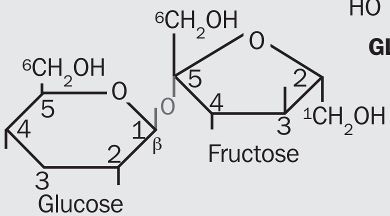
## Carbohydrate building blocks

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.

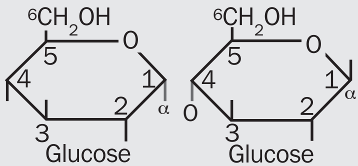
Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is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

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

## 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.

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 $VO_2max$[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 opposite*), maltose is composed of just two chemically bonded glucose molecules, whereas sucrose combines a glucose with a fructose molecule. This suggested that it was the glucose/fructose combination that was being absorbed more rapidly and therefore producing higher rates of carbohydrate oxidation.

## Fructose connection

The same team had also performed another carbohydrate ingestion study on eight cyclists pedalling at 63% of $VO_2$max 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

### Jargonbuster

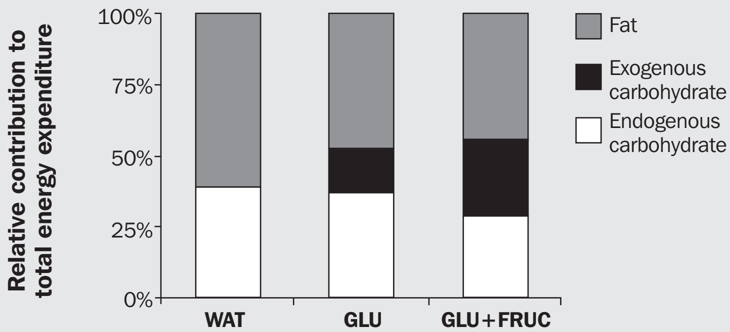
**Radio-labelled**
Where a normal atom in a compound (eg glucose) is replaced by a chemically identical atom, but one carrying a different number of neutrons (isotope) making it possible to track the fate of that compound using a technique known as spectrometry

**Carbon-13**
A carbon atom with an extra neutron in the nucleus

**Transporter proteins**
Large molecules that sit in cell walls and assist in the transport of substances in and out of the cell

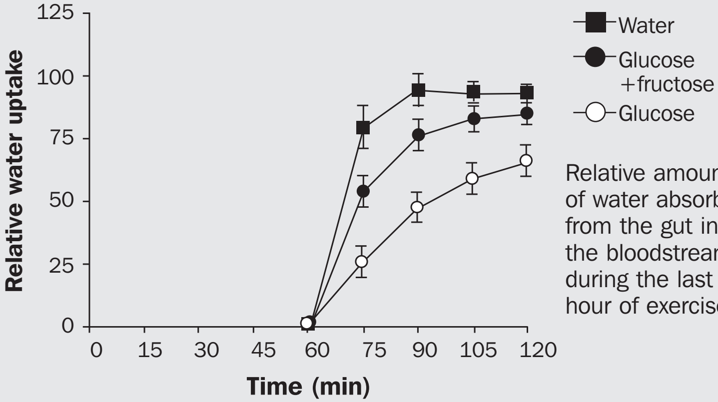
**Brush-border membrane**
Densely packed protrusions (microvilli) on the intestinal wall, which help maximise nutrient absorption

**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

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% $VO_2$max 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$^{o}$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.

## Performance gains

So far, so good, but how do these drinks translate into performance under race conditions? The same team of researchers in Birmingham have carried out further research, which shows that the benefits outlined above of a glucose/fructose combination drink do translate into better performance [19]. In this study, eight trained male cyclists were recruited (average age 32 years, average VO2max 64.7mls/kg/min) and cycled for 2 hours at 55% of VO2max followed by a 1-hour time trial in which subjects had to complete a set amount of work as quickly as possible. During these trials, the subjects ingested one of 3 drinks per trial:

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

*'The results showed that ingestion of the glucose/fructose drink resulted in an 8% quicker time to completion of the 1-hour time trial compared with the glucose-only drink and a 19% improvement compared with the water placebo drink'*

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

## Practical advice

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. Even better, it seems that glucose/fructose drinks actually enhance performance under real race conditions. The icing on the cake is that these drinks are no more expensive than conventional glucose/glucose polymer drinks, so it seems that future for glucose/fructose carbohydrate drinks looks bright.

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

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# Sports drinks: should you be adding protein to the mix?

**At a glance**

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

**One of the most noticeable trends in sports nutrition over the last decade is the addition of protein to carbohydrate-energy drinks. The manufacturers claim this gives enhanced performance and recovery for athletes but do these claims stand up to scientific scrutiny? Mike Saunders investigates**

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

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

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

## Why add protein to your beverage mix?

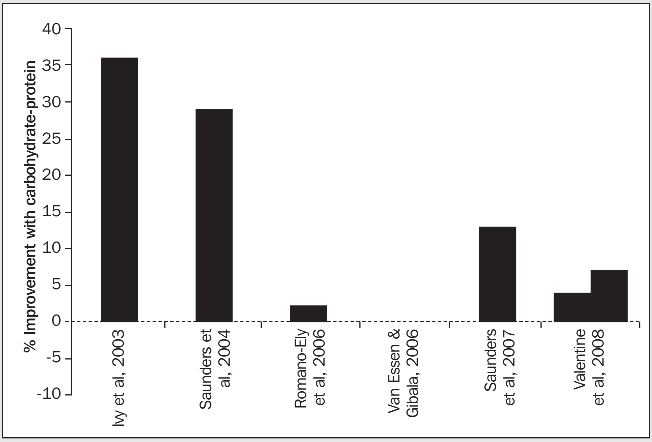
The potential advantages of carbohydrate-protein sports drinks have centred on two primary claims:

- Enhanced endurance performance;
- Better recovery following training.

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

At least three studies have been published in the past few years reporting that the consumption of carbohydrate-protein sports drinks improves cycling endurance. Researchers from the University of Texas examined cycling performance during three hours of varied-intensity cycling, intended to simulate competitive cycling conditions(2). Following this period, the

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




athletes rode to exhaustion at a standardised intensity. The study participants rode significantly longer (26.9min) when receiving a carbohydrate-protein beverage, than when receiving carbohydrate-only (19.7min), with both sports beverages significantly outperforming a placebo beverage.

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

## Questions

The studies above have sparked considerable debate regarding the merit of protein in sports drinks and at least three issues remain to be resolved:

**Jargon Buster**

**Ergogenic**
Producing a positive effect on performance

**Hyponatremia**
Low blood sodium levels

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

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

**1. Were calorie content differences responsible for performance benefits?** – Each of the studies above compared beverages that were matched for carbohydrate content. Thus, protein was added to theoretically 'optimal' concentrations of carbohydrate (6-8%) in the drinks. However, this approach resulted in higher caloric content in the carbohydrate-protein beverages. It's possible therefore that the **ergogenic** effects were due to these additional calories.

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

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

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

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

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

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

*'Some studies have shown that protein ingestion may influence central fatigue, allowing maintained focus and mental performance'*

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

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

## Box 1: Carbohydrate-protein drinks and exercise recovery

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

performance benefit occurred in the final 20km and most of the difference occurred in the final 5km. This resulted in a significant (3%) improvement in late-exercise performance time over the final climb.

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

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

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

## Protein balance

As an endurance athlete, you are probably not striving to build large, bulky muscles but you need sufficient muscle mass to sustain force production throughout exercise. Researchers from the Netherlands studied protein balance in endurance athletes receiving carbohydrate or carbohydrate-protein beverages[9]. When athletes received a carbohydrate beverage during six hours of cycling and running, protein balance remained in a negative state throughout exercise and during four hours of post-exercise recovery. However, when a carbohydrate-protein beverage was consumed during exercise, protein synthesis was increased and protein breakdown was decreased, resulting in a positive protein balance during and following exercise, suggesting that carbohydrate-protein ingestion during exercise can produce some favourable outcomes for your muscular recovery.

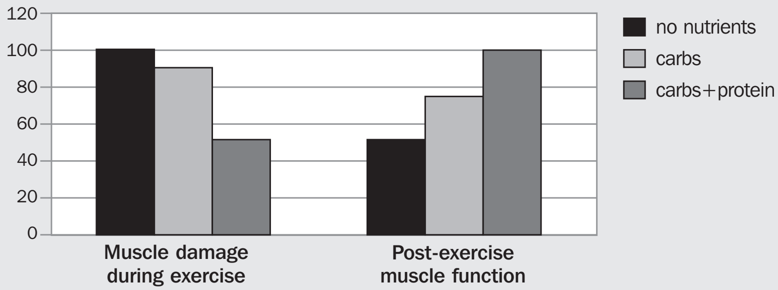
*'There are a growing number of athletes, coaches and scientists who believe that carbohydrate-protein beverages do produce some benefits for their athletes'*

## Muscle damage

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

In a more recent study therefore, we examined the effects of a carbohydrate-protein beverage, which was provided at 15-minute intervals during prolonged cycling, but not afterwards[6]. Consumption of the carbohydrate-protein drink

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




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

## Subsequent exercise

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

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

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

## Optimum protein content

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

Because carbohydrate is the primary fuel during intense endurance exercise, it is logical to assume that the optimal amount of protein should probably be lower than carbohydrate

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

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

content (about 4-8% by volume (*ie* 40-80g per litre) in most commercially available sports drinks.

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

*'The harder and more frequently you train, the more potential benefit you may receive from optimal nutritional strategies for recovery'*

## Summary

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

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# ‘Tuning up’ performance – music and video as ergogenic aids

## At a glance

- Music can be used to enhance emotions and emotions have a powerful ergogenic effect on performance;
- An athlete’s response to music is highly individualised but can be assessed using the music mood regulation scale;
- The use of music as an ergogenic aid and preparation technique is explained in the context of a case study from boxing;
- Practical advice is given on how to put together a video sequence to enhance performance.

**Elite professional sport is now so competitive that few elite athletes can afford to ignore the psychological skills and techniques required to enhance mental toughness. The first decade of the 21st Century has seen the development of a number of creative approaches to developing psychological skills, such as listening to carefully selected music and watching personal motivational videos. Andy Lane evaluates these new techniques, explains how they can be assessed and suggests ways in which they can be incorporated into training**

## Music as an ergogenic aid

Music can play an important part in the preparation process for sport performance. The sight of athletes wearing headphones in warm-up areas before competition is commonplace, and club anthems are often played as teams come out to play. The proposed performance-enhancing effect of crowd noise and crowd singing is also well documented anecdotally.

Sport psychology researchers have recently sought to move from anecdotal to scientific knowledge in this area. The development of a scientific evidence base for the effects of music and motivational videos requires researchers to design appropriately controlled studies that seek to control for a number of factors that could affect the results. The scientific base for these new ideas is emerging with encouraging results from initial tests.

Cutting-edge research to investigate the effects of music on psychological states is led by my academic sparring partner and former Brunel University colleague, Dr Costas Karageorghis. Karageorghis suggests that music may elicit a number of psycho-physiological responses that lead to improved performance.

There are four main areas in which music may benefit performance:

1. Listening to music may narrow the attention of the performer, and consequently this could divert the performer's attention away from feelings of tiredness and fatigue;
2. Listening to music also has an influence on arousal states, and hence, in pre-competition situations, may be used to stimulate or calm the performer;
3. Music has innate rhythmical qualities that individuals may respond to and which can make performing seem easier by allowing for the synchronisation and emulation of movement patterns to the music;
4. Listening to music may increase positive mood and decrease negative mood.

In a series of studies, research has demonstrated that listening to motivational music before performance is associated with increased strength[1]. Research has found that listening to music is associated with enhanced mood states, with listeners perceiving exercise to be less exhaustive[2].

A key question stemming from this work is what type of music leads to improved performance. The answer is unfortunately not straightforward. Karageorghis argues that a multitude of factors need to be considered in the selection of music designed to enhance performance, which could be summarised under four headings [3,4]. Musical factors such as lyrics, harmony and melody, and personal factors, such as socio-cultural background, associations and preferences, are proposed to determine the motivational qualities of an individual piece of music:

- **Rhythm response –** music with a high tempo rhythm is good for high-energy tasks, while a slow rhythm is more suitable for low-energy tasks;
- **Musicality –** refers to the harmony and melody in the song;
- **Cultural Impact –** musical preference tends to be formed during adolescence and there are huge differences in personal preferences reflecting the age and background of listeners. For example, it's not surprising that 19-year-old athletes tend to prefer different music to 30-year-old athletes. My preference is to listen to the Sex Pistols whilst exercising – a style of music not shared by many in the gym;
- **Association –** this relates to the time of release, whether the individual follows the music of the artist, or, as in the case of the theme tune to *Rocky*, powerful images are associated with the music.

*'Cutting-edge research to investigate the effects of music on psychological states suggests that music may elicit a number of psycho-physiological responses that lead to improved performance'*

The development of a 'music rating scale' provides researchers and practitioners alike with a tool to select motivational music for athletes [3,4]. What emerges from this research, and something that could be predicted using common sense, is that the vast range of musical preferences make it difficult to select tracks that suit all athletes.

The theoretical explanation for this effect, and one that is helpful in developing a way forward, is 'self-regulation theory'. This is concerned with how people learn to change their emotions. Through experience, individuals learn to recognise the effects of what they do on how they feel and, importantly, become aware of this link.

It is important to recognise the individual nature of self-regulation theory and develop individually tailored

## Integrating music and video into training

A question that I am frequently asked by athletes and coaches is, 'How do I integrate sport psychology training into normal practice?' Although almost all athletes recognise the importance of psychology in terms of its impact on performance, few take time to practise psychological skills. Sitting in a changing room with your eyes closed engaging in imagery or relaxation techniques is only likely to work in an environment where such activities are socially accepted. Psychological practice in training is clearly more difficult as it tends to be less socially acceptable. One advantage of using music and motivational videos is that they build on what athletes tend to be doing already.

Let's consider a training session for a hypothetical athlete. It's a typical session and the aim is to improve physical fitness. The session involves a 10-minute warm-up, followed by a weight-training session involving sets of five repetitions at 90% of one repetition maximum with two minutes' rest between each set. The session lasts for an hour and ends with a 10-minute warm-down.

### During the session

Sit down before the session and remind yourself what the goals are for that session (working on the assumption that you're working to a plan and each session has short-term goals that build to long-term goals). Music can be used to accompany this process with a view to developing the appropriate psychological state. Motivational videos can be developed to enhance skill development or raise emotions that enhance performance. A motivational video I used with a professional boxer was a film showing him successfully completing an extremely physically demanding task. Watching this before high-intensity training increases emotional states associated with high activity. Both imagery and motivational video can provide an excellent basis for imagery sessions to enhance good technique and raise motivation.

### During the session

Music can be a powerful aid during a fitness training session. Use a selection of appropriately motivating music (ideally played using a portable MP3 player). For the most demanding parts of the session, music that enhances emotional arousal should be played, with sedative music played in rest periods to enhance recovery, lower arousal and thereby increase attentional control.

### After the session

Record the session in your training diary. Comment on the extent to which each goal was achieved. Reflect on the effectiveness of music as a strategy to raise motivation, and personal motivational videos either to raise emotional arousal or improve technique. Consider how you will make these goals more challenging in future sessions.

interventions. For example, soul music might promote happiness for some people; heavy metal might make others happy. Two people may therefore select two completely different choices of songs or pieces of music when choosing music in terms of its ergogenic properties.

## Susceptibility to music

In a study that asked athletes how they regulated unpleasant and potentially harmful mood states, athletes reported listening to music as a strategy for regulating anger, confusion, depression, fatigue and tension, and for raising vigour (5). However, an important point that also emerges from this study is that some athletes find music more influential than others. Selecting appropriate music for some athletes could lead to potent effects, and it is worth identifying these athletes before starting work.

In an attempt to provide coaches with a scale to identify athletes who respond to music, as a strategy to enhance psychological preparation, a series of studies were conducted to develop a valid and reliable scale (6,7,8). This scale uses questions such as, 'If you need to feel energetic, how effective is listening to music as a strategy to achieve this feeling?' and, 'If you are feeling worried, how effective is listening to music as a strategy to change this feeling?' to assess how susceptible an athlete may be to music.

## Case study

To illustrate how music can be integrated into an athlete's preparation, I'll use a case study from work with a professional boxer (9,10). We introduced music because the boxer found traditional relaxation techniques awkward and ineffective. Indeed, it transpired that he already used music to change his emotional states as a normal part of the training cycle and listened to music during the middle of the day to try to relax in between training sessions.

Following exploration of the type of music that was effective, we developed a series of CDs to be used for relaxation. The

### Jargonbuster

**Somatic anxiety**
The physical manifestation of anxiety, characterised by butterflies in the stomach, excessive visits to the toilet, increased heart rate and sweaty palms

growing use of portable MP3 players, which can store programmed music selections, means that athletes can now quite literally carry around their relaxation strategy.

The boxer also used music in the final stages of preparation for a World Championship contest. With a televised World Championship contest, a boxer will know the exact time of the fight and this allows the support team to develop carefully planned warm-up routines. This was something we developed and prepared for in the weeks leading up to the contest.

Music is an ideal medium around which to plan a warm-up routine. A two-hour build-up was developed, using music as the trigger to change what was happening during the warm-up:

- two hours before competition calming and relaxing music was played;
- 90 minutes before competition the music changed to more upbeat music;
- 45 minutes before competition, when the warm-up (both physically and psychologically) starts to build up, the music became more motivational and upbeat.

However, care was needed not to over-arouse, because the plan for the early rounds was to fight a particular strategy. To do this, it was important that the athlete remained calm, especially since over-arousal is linked with a loss in attentional control.

The music routine was integrated into the boxer's final few training sessions, whereby the warm-up sequence was rehearsed before key sparring sessions. Fortunately, boxing lends itself to this approach because boxers compete far less often than tennis players do, for example (where this approach could be used for less important games rather than in training).

Discussions with the boxer revealed that listening to the theme tune played as he entered the ring generated moderate to intense emotions even if it was played away from competition. When his theme tune ('Let me entertain you' by

Robbie Williams) came on the radio on the way to training, he went silent. 'It takes me back to the moment I get in the ring,' he said.

This is possibly not surprising as evidence shows that physical symptoms, or **somatic anxiety**, is at its highest shortly before competition, and therefore he would associate listening to the song with that period before competition. The music was used in conjunction with imagery sessions in which positive self-talk regarding the contest was rehearsed so that the athlete felt in control of his emotions as the music was played. When the theme tune is played shortly before competition it can help sharpen the athlete's mind in preparation for the contest.

## Video as an ergogenic aid

A strategy that can be used in conjunction with music is video footage. This work has been pioneered by Roberto Forzoni, a sport psychologist at the English Institute of Sport[11]. Forzoni has developed relatively short video clips that are accompanied by an athlete's preferred music, or music that targets a specific psychological state that could be used in training and before competition. Consistent with the ease with which music can be used in preparation through improved technology, many athletes have access to DVD players, often through their own laptop computer.

Videotaped sessions of key training sessions and competition are extremely helpful in my work in professional boxing. Videotaping and analysing sparring and training sessions prove to be a very effective way of developing psychological skills. The boxer, coach and sport psychologist view videotape sessions on a 3ft-square screen in a lecture theatre at my university. These are then repeated throughout the programme.

Video analysis of the sparring sessions leads to detailed discussion on the strengths and limitations of performance, and the strengths and weaknesses of his opponent. For each opponent we would have details of the number of punches thrown for each 30 seconds of each round; ratio of head-to-

| Top 10 tips for producing effective personal motivational videos |
|---|
| **1** Keep the personal motivational videos short – three minutes is an ideal length. |
| **2** Use slow motion effects showing the athlete performing excellent skills. |
| **3** Show a close-up of the athlete's face. This will arouse an emotional response making the personal motivational video a more powerful tool. |
| **4** Use inspirational music to score the personal motivational video. Combinations are endless. |
| **5** Use graphics to start the video, leading the athlete to the theme of the personal motivational videos, and then at appropriate points through the production. |
| **6** Use dissolve fades from normal to slow motion sequences to maximise the effects. |
| **7** Try to minimise the variety of special effects, particularly transitions (there is a temptation to use many different effects on the same personal motivational videos, which may reduce the impact of the message). |
| **8** Include short (10sec) clips of athlete-preferred role models where appropriate. |
| **9** Synchronise the video footage with the music score, and in particular the lyrics, where possible. Many fantastic opportunities to reinforce messages are missed when this synchronisation is not used and you will be amazed how many opportunities will occur to do this. |
| **10** Be prepared to invest time and experiment with clips, music and graphics to produce the ideal combination. |

body punches, the number of counter-punches that were thrown, jabs etc.

Regardless of the opponent, we observe that boxers tend to show consistent habits. For example, one boxer may move predominantly to one side and throw fewer punches in the first half of a round. This information was used as the basis for goal setting for technical sessions and imagery scenarios, while training was focused around exploiting the opponent's weaknesses.

An aspect of developing personal motivational videos is the cost of equipment and time it takes to make the video. As computer technology becomes more sophisticated and computer memory becomes cheaper, the ability to put together three-minute clips with associated music becomes easier.

However, Forzoni does suggest that a downside to personal motivational videos stems from the time it takes to produce them. He allows a minimum of one hour for every minute produced, emphasising that this is minimum time. Forzoni has also suggested 10 top tips for producing personal motivational videos. These are listed opposite:

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# Bicarbonate: why it's making a 21st Century return!

## At a glance

- The background and history of bicarbonate supplementation is discussed;
- New research on bicarbonate supplementation as a training aid is presented;
- The findings are explained and recommendations given.

**It's been used in baking for years and briefly found favour with athletes, but as Keith Baar and Andy Philp explain, brand new research suggests that taking sodium bicarbonate before you train really could lead to better endurance performance...**

During intense training, our muscles produce a substance called lactate and hydrogen ions (acid) faster than we can use or get rid of them. The result is a build up of these by-products in the exercising muscle. People have long believed that this increase in acid and lactate is a direct cause of fatigue. However, scientists still argue over this point despite over a century of investigation.

Our bodies have a number of protective mechanisms that try to prevent the build up of acid. One of the most important of these is bicarbonate, which is alkaline – *ie* it helps neutralise acid. Bicarbonate is not only used as a raising agent in baking, but is also made throughout our bodies. One of the biggest bicarbonate producers is the stomach, where bicarbonate is

## Box 1: How to decrease the intestinal distress associated with drinking sodium bicarbonate

The biggest hurdle to using bicarb is what it can do to your gut. Dr David Bishop (team sport research group, University of Verona, Italy), the world expert in the effects of bicarb on human performance, has come up with and used a method, which, it is claimed, results in few if any gut problems.

The key part of the strategy is that the bicarb solution is taken in two doses, one hour apart. He suggests taking 0.1g baking soda per kilo of body weight around 90 minutes before exercise and then again 30 minutes before exercise. Breaking the dose in two drastically reduces stomach problems, while still providing enough bicarb to keep the alkalinity of the blood higher 80 minutes later.

made as a by-product in the process of making our digestive juices. After we eat, the rush to make stomach acid results in an increase in bicarbonate released into the bloodstream. This 'alkaline tide' is what makes us feel sleepy after a meal – not what will help us improve performance.

## Bicarbonate in the body

During exercise, bicarbonate is initially made as a way to get rid of the carbon dioxide ($CO_2$) produced by our muscles. The increased requirement for **ATP** to power our muscles results in an increase in $CO_2$ production as a by-product of the breakdown of fats and carbohydrates. In the blood that feeds the muscle, $CO_2$ and water ($H_2O$) are converted to $HCO_3^-$ (bicarbonate) and $H^+$ (acid) by red blood cells using the **enzyme** carbonic anhydrase. At the lung, the reaction is reversed and the $CO_2$ and water are released in the breath. This allows us to exhale the waste and maintain the correct acid/alkaline balance in our muscles.

For years, this was believed to be the reason that the **lactate threshold** and the **ventilatory threshold** coincided. The idea was that, at our lactate threshold, oxygen delivery to the muscles was insufficient and this resulted in a shift towards energy production without oxygen and the production of lactate and hydrogen ions. Since acid production was turned on, the increase in acid would mean the process above was accelerated, resulting in a sharp rise in ventilation.

While the theory of the relationship between the lactate and ventilatory thresholds makes sense, it doesn't appear to be right. Newer studies show that oxygen delivery to the muscle is not limited during sub-maximal exercise, so that a lack of oxygen in our muscle cells isn't what causes lactate production(1). What we really think causes both the lactate and ventilatory thresholds is a rise in the 'fight or flight' hormone called adrenaline, and a change in which muscle fibres we use. As the exercise intensity rises, we start to use more **type II glycolytic muscle fibres**. These fibres produce more lactate than **type I or type II oxidative fibres**, resulting in increased lactate accumulation in the blood.

At the same time, there is a sharp rise in adrenaline. This is because as the intensity of exercise increases it becomes a greater stress on our body and this activates the flight or flight response: releasing adrenaline. The rise in adrenaline causes our muscles to break down stored carbohydrate (glycogen) faster and decreases blood flow to the liver and kidneys (where lactate is normally removed from the blood), contributing to the accumulation of lactate. Adrenaline also directly increases our respiratory rate, contributing to the ventilatory threshold.

## Bicarbonate and performance

No matter their cause, lactate and ventilatory threshold play a significant role in performance. The higher that we can get our speed/power at lactate threshold, the better our performance will be. Therefore, if we can focus our training on increasing speed/power at lactate threshold, we can maximise our performance adaptation.

One way might be to boost the amount of bicarbonate that we have in our blood on the day of the big event. The extra bicarbonate should buffer the acid our muscles produce and therefore increase the intensity we can maintain before lactate begins to build up in our blood.

People have tested the effects of bicarbonate on performance for over 75 years, on the premise that acid accumulation limits

### Jargonbuster

**ATP**
Adenosine triphosphate – the universal 'energy currency' molecule in the body.

**Enzymes**
Proteins produced in the body that accelerate biochemical reactions, which would otherwise happen too slowly or not at all.

**Lactate threshold**
The exercise intensity at which lactate begins to accumulate rapidly.

**Ventilatory threshold** The exercise intensity that produces a relatively large increase in breathing rate for a small increase in intensity.

**Jargonbuster**

**Type II glycolytic fibres**
Muscle fibres used primarily during higher-intensity exercise, which are capable of contracting when oxygen availability is limited.

**Type I and II oxidative fibres**
Endurance muscle fibres used primarily during lower-intensity, longer-duration exercise, when oxygen availability is high.

our endurance performance.

In 1931, scientists showed that drinking a solution that contained baking soda (sodium bicarbonate or bicarb) prior to exercise could improve running performance [2]. These experiments were confirmed 2 years later, but a huge amount of conflicting research in the following 75 years has made people question whether bicarb can really be used as an ergogenic aid.

Beyond the scientific uncertainty, one of the biggest concerns with using bicarb on the day of performance is that drinking large amounts of baking soda can cause severe intestinal distress (read bloating, nausea and diarrhoea). Since these types of complications are the last thing anyone wants to have to deal with on the day of competition, a lot of athletes have quite understandably shunned the use of bicarb (but see box 1 for tips on decreasing intestinal problems when taking bicarb).

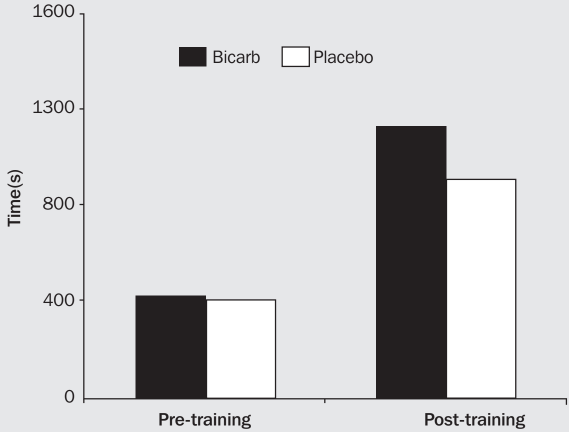
## Bicarb training research

While the effects of bicarb on the day of the competition are uncertain and the potential negative effects on the gut might make an athlete unlikely to use bicarb for an important event, there might be good reasons to use bicarb *during training*. In the last three years, two studies have come out showing that taking bicarbonate during training improves performance.

In the first study, 16 moderately trained women exercised three times a week for eight weeks[3]. One group drank a bicarb solution at 90 and 30 minutes prior to performing each high-intensity interval training session (containing 0.2g of bicarb per kilo of bodyweight) while group two drank a similar tasting salt solution.

In weeks one and two, each subject performed six to nine 2-minute intervals on a bike at 140% of their initial power at lactate threshold. The number of intervals and the relative intensity increased every second week until they were performing twelve 2-minute intervals at 160% of the power at lactate threshold in week seven. For week eight, the number of intervals was decreased to six to nine again, but the power was increased to 170%. Before and after training the subjects

## Figure 1: How training with bicarb increases endurance




Time to fatigue during a constant-load exercise test performed at 100% of pretraining $VO_2$max. Although both groups improved their endurance after the 8-week training programme, the bicarb group had a bigger improvement (41%) than the group that drank a salt solution.

performed both a graded exercise test for peak $VO_2$ and a time to fatigue test to measure endurance.

In the group that took the bicarb, the alkalinity, the concentration of bicarb, and the amount of lactate in the blood was higher during each training session. This tells us that the drink was absorbed and had the effect of making the blood less acidic. After the 8-week training programme, both groups improved their peak oxygen uptake ($VO_2$) by approximately 18%. However, the group that took bicarb before each training session improved their power at lactate threshold 9.6% more than the group that took the saline solution.

As discussed above, power at lactate threshold is one of the most important parameters for determining endurance performance. Therefore, it was not surprising to see that the bicarb group showed a 41% greater improvement in time to fatigue (*see figure 1*). While this isn't a direct measure of

**Jargonbuster**

**Mitochondria**
Compartments within a cell that generate most of the cell's supply of adenosine triphosphate (ATP), which is used as a source of chemical energy.

performance, the increased endurance and improved power at lactate threshold are strongly associated with better performance.

After discovering that drinking bicarb during training improved performance in humans, some of the same scientists went on to try to determine how bicarb might be exerting its positive effects [4]. To do this, they switched from people to rats, allowing a more controlled experiment and detailed analysis of muscle adaptation to training. They split the rats into three groups:

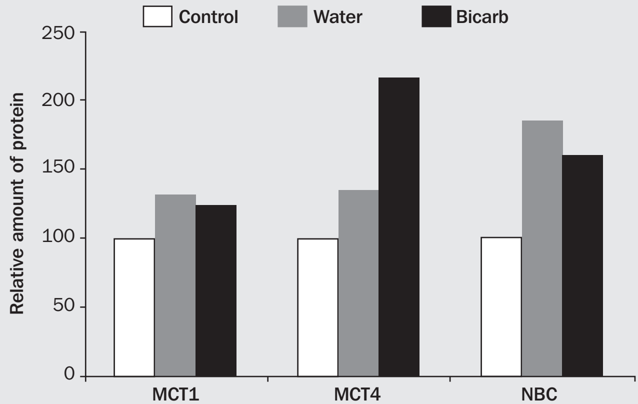
- A control that didn't exercise or take bicarb;
- An exercise group that drank water;
- An exercise group that drank a bicarb solution 30 minutes before exercise.

Like the human subjects in the first study, the rats increased their training from six to twelve 2-minute intervals, but with a running speed increase of 37 to 52 metres/min over the five weeks of the study.

At the end of training, the bicarb-drinking group had increased the number of **mitochondria** in one of their running muscles 7.5% more then the water group even though the animals did exactly the same amount of work. The authors of the study also found that the bicarb group increased the production of the transporter protein called MCT4, which helps remove lactate from the muscles (*see figure 2*). The fact that there was a greater rise in mitochondria tells us that adding baking soda to your training schedule would result in better performance even if you were to do no more work.

When we saw this data, we were excited by the fact that simply adding bicarb increased the number of mitochondria in muscle. The fact that they only measured this in a 'slow' muscle was interesting because we think that the greatest effect would be in fast twitch muscle where the ability to increase mitochondria is the strongest. Since the number of mitochondria in our fast muscles is one of the best determinants of speed/power at lactate threshold, we wondered whether the

**Figure 2: How training with bicarb increases the protein that transports lactate out of muscle**




The amount of three different transporter proteins in rat muscle following 5 weeks of interval training; the bicarb group had a significantly bigger increase in the protein that transports lactate out of muscle (MCT4) than the water group.

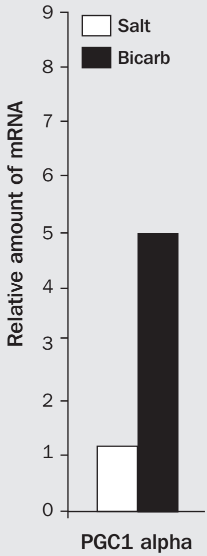
improved performance was due to a direct effect of bicarb on our mitochondria.

To study this question, Andy Philp performed a series of experiments on isolated muscle cells. The logic is that if bicarb is exerting its benefits on muscle cells and not the whole body, by just feeding the cells bicarb, we should see the same effects that the researchers above saw in people and rats.

So, Andy set up a (unpublished at the time this report went to press) cells study in which one cell culture got a salt solution and the other got a solution containing about the same amount of bicarb as would have been circulating in the human study [3]. After three days of treating the cells in this way, we saw an increase in the amount of mitochondrial protein in the cells of approximately 50% (*see figure 3 overleaf*).

The reason for this increase in mitochondrial protein appears to be that bicarb is able to directly turn on a regulator

## Figure 3: Bicarb increases the protein that controls mitochondria




The amount of mRNA (a molecule that serves as a blueprint for the production of protein) of PGC1alpha (the protein that determines how many muscle mitochondria we have) in cells following 3 days of treatment with bicarb. The amount of mRNA in the bicarb group is five times higher than the control (A Philp et al unpublished).

of the number of mitochondria in our cells. The amount of this protein, PGC1alpha, is one of the most important factors in making new mitochondria. Simply adding bicarb to the cells resulted in a 5-fold increase in PGC1alpha. This increase in PGC1alpha is almost identical to what is seen after endurance exercise. These data tell us that simply taking bicarb may provide some of the same effects as exercise!

The other interesting findings from this study are that the cells that got the bicarb treatment consumed more energy at rest, they were better able to transport glucose, and they contained more of the glucose and lactate transporters. This tells us that after three days treatment with bicarb, the cells looked more like those in the muscles of an endurance athlete, because endurance athletes have a higher resting metabolism and are better able to take up lactate and sugar from the blood.

The last question that remained was whether the adaptation is a direct effect of the bicarb or whether it is an effect of increasing the alkalinity around the cells. To study this question, Andy employed another popular agent used to control acid/alkaline balance, called sodium citrate. When Andy did the same experiments using citrate, he saw a small increase in PGC1alpha, but not as much as during the bicarb experiments. So, this means that it's the bicarb that acts directly on our muscle cells to increase mitochondria rather than any change in acid/alkaline balance.

## Bicarbonate of soda and dietary sodium intake

The chemical formula for bicarbonate of soda is $NaHCO_3$ – *ie* it contains sodium. In fact, just over 27% of the weight of bicarbonate of soda comes courtesy of the mineral sodium. This is important because a 70kg athlete ingesting 0.2g of bicarbonate of soda per kilo of bodyweight would be ingesting 14 grams of bicarbonate, which provides around 3.8g of dietary sodium. This amount of sodium is the same as would be provided by 9.5g of salt, which is significantly over the current recommended daily limit of 6.0g of salt per day for health.

Is this amount of sodium harmful to health? Although the average sedentary Briton currently consumes around 9 grams of salt per day (considered too high), athletes who train hard and perspire heavily lose significant amounts of sodium and are therefore unlikely to be adversely affected by occasional daily intakes of 9 grams. However, it certainly makes sense for anyone considering regularly using bicarbonate of soda to try and minimise additional dietary salt (from high-salt foods) wherever possible.

Andrew Hamilton BSc Hons MRSC

## Conclusions

Drinking baking soda solution before exercise means that there is high bicarb concentration in the blood during exercise. Doing high intensity intervals directs that blood to the 'fast twitch' muscle fibres (that do a lot of the work at high intensity). The bicarb is taken up in these fast fibres and acts to increase the mitochondrial controller (PGC1alpha). The increase in PGC1alpha signals these fast fibres to make more mitochondria. As discussed above, power at lactate threshold reflects the amount of mitochondria we have in our fast twitch muscle fibres. Therefore, by targeting these fibres with training and nutrition, we can improve their adaptation and, by extension, our performance.

*'We were excited by the fact that simply adding bicarb increased the number of mitochondria in muscle'*

So using sodium bicarbonate during training could be an inexpensive but powerful tool to add to your training regime. It would have a positive effect at any point in training, but the biggest effect on performance will be when you are trying to improve speed/power at lactate threshold using high intensity workouts.

### References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4. *Am J Physiol Endocrinol Metab. 2007  293: E916-22*

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