Training for
TRIATHLON

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

Training for
TRIATHLON

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From the editor

In 1978 a US Navy Commander, CDR Collins, organised an Ironman event following an awards dinner debate over who was fitter: swimmers, cyclists or runners. He combined the Waikiki Roughwater Swim, the Around-Oahu Bike Race and the Honolulu Marathon to create an ultimate race. In the list of rules and regulations he added at the bottom ‘Swim 2.4 miles! Bike 112 miles! Run 26.2 miles! Brag for the rest of your life!’ Gordon Haller became the first Ironman, and is no doubt still bragging about it!

Since the 1970s the Triathlon has become more and more popular, for both amateurs and professionals. In Sydney 2000 it made its Olympic debut, making a spectacular splash in front of the Sydney Opera House, capturing the imaginations and ambitions of athletes worldwide. Of course the Olympic distance is more reasonable, with a 1.5km swim, 40km cycle and a 10km run.

To complete a triathlon is on a par with running a marathon, so training and preparation cannot be taken lightly. This special report from *Peak Performance* combines triathlon specific features with cutting edge reports on improving the prerequisite factor, endurance.

We start with a strength and conditioning programme, followed by advice on how to cope with the cycle-run transition. A feature on rest and recovery is in there for serious competitors, followed by an article on emotional control during endurance events, because it will get emotional!

There are then two reports on energy drinks and supplements, which will hopefully help professional triathletes gain an extra edge. Finally there is a case study report about an athlete who pushed himself to the limits in an Ironman event, and lived to tell the tale. Not for the faint hearted!

I hope this report helps all you triathletes to complete your goals, and enhance those bragging rights.

Sam Bordiss

Your complete strength and conditioning programme

Triathlon is a demanding multi-discipline sport, calling for high levels of endurance in the water, on a bike and on the road. And, while triathletes spend most of their time swimming, cycling and running, they also need a supplementary resistance-based conditioning programme to enhance overall performance. In this article, a programme of strength and conditioning exercises suitable for serious competitive triathletes is presented.

When adding a strength programme to your training routine it is important to consider the following questions:

1. What kind of strength development can deliver a performance improvement? The answer depends on two factors – the strengths and weaknesses of the individual athlete and the nature of his/her sport. Obviously an article like this can only address the second factor, so the programme set out is generic rather than specific. However, it is comprehensive enough to provide a reasonable starting point for a more individualised programme.
2. How will the strength workouts enhance rather than detract from your weekly training schedule? Any serious endurance-trained athlete finds it difficult to commit to – and recover from – extra training time, so a strength programme for triathletes has to yield the maximum results with the minimum expenditure of time and energy.

Strength training can improve performance via two main effects: first, the resultant increase in strength can enhance the skill, power or efficiency of the sporting movement; secondly, it will reduce the risk of injury. When designing a triathlon strength programme, you have to consider whether a performance and/or injury benefit is possible for each of the three disciplines. Once you have done this, you have a rational basis for choosing the best exercises. Based on research and my own experience, I recommend that you target performance for running, and injury prevention for running and swimming *(see boxes)*.

The tables that follow set out four routines that make up the whole strength and conditioning programme. When you put all the routines together, you will find at least one exercise targeting each performance or injury prevention benefit for triathlon. Each routine includes no more than six exercises that should be completed once a week. Strength routines 1 and 2 take about 45 minutes, while the core and jumping routines should take around 20 minutes. This level of time investment is realistic for athletes and allows for a beneficial rather than a tiring effect.

How strength and conditioning training reduces triathlon injury risks

It is hard to prove that following a strength programme will result in fewer injuries for elite runners, swimmers and cyclists. However, experience and clinical research supports the use of preventive strengthening exercises in specific muscle groups. For example, strength in the calf and anterior tibialis (the muscles at the front and back of the lower leg) has been linked inversely with Achilles tendon overuse injuries.

Core strength exercises are recommended for both running and swimming injury prevention. Balance between the strength of the quadriceps and the hamstrings is recommended specifically for running injury prevention, while good rotator cuff and scapula muscle function is recommended for swimming injury prevention.

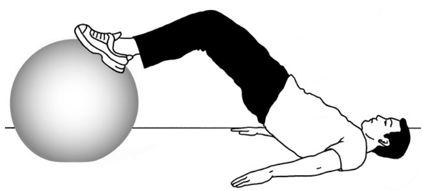
Therefore, triathletes should include in their routines exercises for all the trunk and core muscles, rotator cuff and scapula muscles, together with isolated exercises for the calf and hamstrings.

Strength routine 1

Squat *Strengthens the quadriceps, gluteals and trunk muscles and helps strengthen the legs for running, enabling better control of vertical landing forces. Good squat strength may also help prevent knee injury.* This is performed with a barbell placed across the back of the shoulders. Start with feet shoulder width apart, toes pointing out slightly. Take a deep breath and squat down, taking the hips backwards and feeling the weight pressing down through both heels. Lower yourself to a knee bend of at least 90° (see picture below, right), ideally with the thigh parallel to the ground to ensure optimal gluteal activation. Return to start position while breathing out – this helps support the spine. Start by mastering the technique with 3-4 sets of 8 repetitions with a light bar. Progress to 4 sets of 5 reps with 2-3 minutes' recovery between sets. Aim to increase the weight you can lift for 5 reps.

Swiss ball hammy *Strengthens the hamstrings specific to the running action – with the foot in contact with a surface and the hamstrings acting to extend the hip.* Also strengthens the trunk and hip muscles. Perform this exercise with the soles of your feet on a Swiss ball and your back on the floor. Start with the whole back on the floor, knees slightly bent, with legs up on the ball. Push down through the feet into the ball, pushing the hips up at the same time. Lift hips until there is a straight line through the knee, hip and shoulder, keeping upper back and neck on the floor. Lower down slowly until hips just touch the floor, then repeat. Start with 3 sets of 10 reps with two feet on the ball. Increase to 3 sets of 20 reps. Progress to 3 sets of 5 reps with one foot on the ball. Increase to 3 sets of 15 reps as you get stronger.

Swiss ball hammy



Rear sling *Strengthens the shoulder and rear rotator cuff muscles and so helps prevent swimming injury*. It can also be performed standing on one leg to challenge core stability.Perform with a pulley machine, using a handle attached below hip height. Stand with good posture, holding the pulley handle across the body, palm facing back, a slight bend fixed in the elbow. Using only the shoulder, and keeping the elbow stiff, pull the arm up, across and out. The finish position is with the hand above the head out from the body, palm facing forwards. Retain good posture, without using the trunk or rotating the body during the movement, and finish with shoulders wide and relaxed. Use 2-3 sets of 8-10 reps, aiming to increase the weight lifted for 8 reps.

Front sling *Strengthens shoulder and front rotator cuff muscles and so helps prevent swimming injury*. It can also be performed standing on one leg to challenge core stability. This is the opposite of the rear sling. Start with the pulley handle attached above head height, holding the handle, arm away from the body, palm facing forward. Pull the arm down and across the body, finishing with the hand by the opposite hip and palm facing back. The same coaching points apply as for rear sling. Use 2-3 sets of 8-10 reps of this exercise. Aim to increase the weight lifted for 8 reps.

Trunk twist standing *Specifically recommended for swimming trunk rotation strength, as it is performed with the body in an extended position, similar to that used in swimming*. Stand with broomstick or barbell attached to a long resistance band at one end, feet shoulder width apart, knees soft, with good back posture. Then rotate shoulders, pulling on the band. Focus on the trunk muscles to rotate rather than pushing the bar around with your arms. Keep hips facing forwards throughout. Complete 2-3 sets of 8-10 reps to each side. Increase the strength of the band as you gain strength.

Single-leg calf raise *Specifically strengthens calf muscles to help prevent lower leg running injuries*. It can also be performed barefoot to target the foot muscles as well. Stand on one leg, with the ball of the foot on a small step. Start by lowering the heel until you feel a little stretch in the calf, then push up onto the ball of the foot. You may need to hold onto something for balance, but do not push yourself up with your hands. Complete 3 sets of 10 reps. Increase to 20 reps, then begin to add weight. Use a barbell or a calf raise machine.

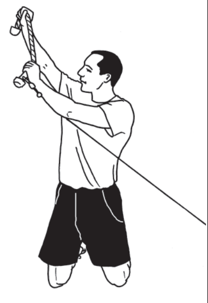
Strength routine 2

Step-up *Strengthens the quadriceps, gluteals and hip muscles and is excellent for running, increasing both leg strength and stability*. Start with a barbell across your back, with one foot on a step, high enough to ensure your knees and hips are bent at an angle of around 900. Push down through the heel of the foot upon the step and extend the leg, rising up onto the step. Then lower down, taking all the weight back onto the same leg, leaving the foot on the step. When the support leg touches down behind the step, begin to push up again. In this way most of the work is done with the leg on the step. Start by mastering the technique with 3-4 sets of 8 reps, progressing to 4 sets of 5 reps with 2-3 minutes' recovery between sets. Aim to increase the weight you can lift for 5 reps.

Russian hamstring curl *Develops excellent hamstring strength, which specifically helps the running in terms of injury prevention and increased propulsion forces*. Start in the kneeling position with a partner pressing down firmly onto your calf muscles from behind, aiming to keep the hip extended and the back in neutral. Slowly lean forward from the knees, using the gluteals to keep the hips straight. The hamstrings will be working very hard to control the movement, using an eccentric contraction. Lean forward as far as your hamstring strength will allow, ultimately aiming for an angle of 45°. If you can, pull yourself back upwards; otherwise fall onto the floor, catching yourself in the press-up position, then push back upwards to the start position. Start by mastering the technique with 2-3 sets of 5 reps. Do not progress until you can control the movement out and back, keeping the back straight. Slowly progress up to 3 sets of 8 reps, going out to 45° and coming back up, holding perfect posture and hip extension.

Up-chop kneel 1

Up-chop kneel 2

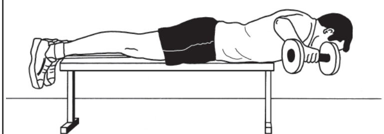


Up-chop kneel *Develops excellent core stability and trunk rotation strength and is therefore useful for both running and swimming*. Kneel next to a pulley machine with a handle attached below hip height. Grasp the handle in both hands to the side of the hip nearest the pulley machine. Lift the arms up and at the same time rotate the shoulders away from the pulley machine, keeping hips facing forwards and arms straight *(see pictures, right)*. Complete 2-3 sets of 8-10 reps both sides. Aim to increase the weight lifted for 8 reps.

Down-chop kneel *Develops excellent core stability and trunk rotation strength and is therefore useful for both running and swimming*. This is the opposite of the up-chop. Begin with the handle attached above head height, grasping the handle in both hands above the head to the side of the pulley machine. Keeping the hips facing front and the arms straight, pull the hands down and turn the shoulders away from the pulley machine. Complete 2-3 sets of 8-10 reps both sides. Aim to increase the weight lifted for 8 reps.

Reverse flies *Develops upper back and rear shoulder musculature and helps stabilise the scapula.* It is included as a swimming injury prevention exercise. Lie face down on a bench with head and neck just off the edge of the bench, holding a dumbbell in each hand, arms straight out to the side. Lift the dumbbells off the floor until the hands are level with the body, arms remaining straight out to the side. Complete 2-3 sets of 8-10 reps both sides. Aim to increase the weight lifted for 8 reps.

Reverse flies



How strength and conditioning training improves triathlon performance

Strength training of the major leg muscles has been shown to improve long distance running performance – specifically running economy – independent of changes in the cardiovascular system. In particular, explosive strength training and plyometric (jumping) training have been proven to be beneficial [1]. The most likely reason for this is that increased strength and recruitment of the major leg muscles boosts the efficiency of the running action. The strengthening of the tendon due to the ability to create a better 'leg spring' may also play a part. Therefore triathletes should include strength and jumping exercises for the major leg muscles in their programmes.

Elite swimmers do perform strength training, but the leg strength exercises that boost power during the dive start and push off the wall in the turns for events in the pool are irrelevant for triathletes, who swim in open water. Core strength, particularly trunk rotation, is recommended for swimming performance, as is upper body strength work to increase the power of the arm pull [2]. However, it could be argued that increased upper body force may not improve the efficiency of the swimming stroke in long-distance swimming. Some swim coaches are concerned that 'muscling' the stroke will create extra drag around the swimmer, which is counter-productive. Therefore, triathletes should include core strength and trunk rotation exercises in their programmes, focusing only on the exercises that are most likely to benefit swim performance.

Elite road cyclists perform little strength training. In fact, it has been shown that elite cyclists have quite high maximal strength of the quadriceps compared with untrained adults of a similar age [3]. This suggests either that they are naturally strong in the legs, or that cycling training produces a strength training effect in the legs. This may be because of the high-force activities that occur naturally in cycle training and racing, including pedalling in high gears, pedalling up hills and intermittent sprinting. The inference is that leg strength training is unlikely to have any performance benefit for road cyclists. Upper body strength training will be detrimental if it increases muscle mass, as this will slow you down. In summary, triathletes don't need to perform any strength exercises specifically for cycling. Any leg strength training gains will occur as a side benefit of the leg exercises chosen for distance running.

Jumping routine

All these exercises are chosen to benefit running efficiency. These explosive jumping movements train both the major leg muscles and the tendons, helping you become more 'spring-like' and therefore more economical. These exercises require a warm-up and can be performed after the end of a steady run without much difficulty, ideally on a soft flat surface such as a soft running track or cricket pitch. Jumping exercises need to be introduced gradually, which is why I advise controlling the number of contacts for each exercise until you are used to performing them every week.

Vertical jumps Stand feet hip- to shoulder-width apart. Squat down slightly, swinging your arms back, and then rapidly jump up as high as you can, driving your arms upwards. Make sure you fully extend your hips, knees and ankles at take-off. Land softly on the balls of your feet and absorb your landing with a squat. Perform 3 x 5 reps, building up to 3 x 10 reps. Take 1-2 minutes' rest between sets.

Mini hurdle hops Set out 5 x 30cm mini-hurdles with about 1 metre space between each. Hop with both feet together over each hurdle with one 'bouncy' contact between each hurdle. Aim to make quick and light contacts with the floor on the balls of your feet, with a small knee-bend. You can pick your knees up into a tuck position over each hurdle if you like, to increase your jump height. Perform 3 x 5 hurdles, building up to 3 x 10, with 1 minute's rest between sets.

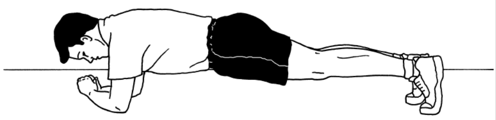
Power skips This is a simple skip, performed very dynamically. The aim is to drive up as high as possible with each skip, then land softly and step onto the other foot to drive up again. Perform 3 sets of 10 skips (5 each leg) and increase to 3 sets of 20 skips.

Core routine

The exercises in this routine are geared to developing good core stability for running and swimming. The routine targets the strength endurance of the abdominal, oblique, low back and gluteal muscles.

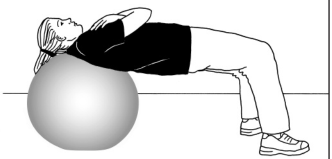
Plank Facing the floor, make a bridge with your body by supporting yourself on elbows and toes, forming a straight line with your body, like a 'plank'. Make sure your low back is in a neutral position, bracing your stomach to maintain it. Complete 3 sets of 30 seconds, progressing to 3 x 60 seconds.

Plank



Side plank On your side, form a bridge with your body by supporting yourself on one elbow and the side of one foot. Lift your hips so your body is in a straight line, like a 'plank'. Make sure your top hip and shoulder are directly above the bottom hip and shoulder. Hold the straight line position. Complete 3 sets of 30 seconds each side, progressing to 3 x 60 seconds.

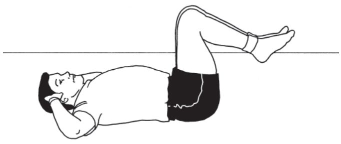
Gluteal bridge



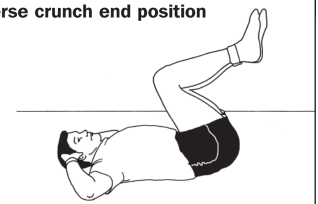
Gluteal bridge Place your feet on the floor and your neck and head on a Swiss ball. Squeezing your gluteal (buttocks) muscles, push your hips up until your back, hips and knees are in a straight line. Make sure your back is in neutral and focus on your gluteals to hold the position. Complete 3 sets of 30 seconds, double leg. Progress to one leg 3 x 30 seconds.

Reverse crunch Lie on your back with arms out to the side, then lift your legs off the floor with knees bent. Focusing on your abs, curl your pelvis and low back off the floor, crunching up. Don't kick or swing your legs to gain momentum – the slower you do the movement the more effective it is. Complete 3 sets of 20 reps. Progress by adding a dumbbell between the ankles to increase the load lifted by the abs.

Reverse crunch start position



Reverse crunch end position



Raphael Brandon

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Triathlon – breathe easy to conquer the cycle-run transition!

The cycle-run transition in triathlon represents a huge psychological barrier for most triathletes, but the perception that running is much harder after cycling is more than just the mind playing tricks. As Alison McConnell explains, the cycle phase presents some serious physiological challenges that triathletes have to overcome as they begin their run.

In triathlon, the cycle-run (CR) transition is associated with a number of changes, including an impairment in running economy; specifically, there is a 2-12% (1) decrease in running economy during the early part of the run phase (when compared to running economy in the 'fresh' state). The most obvious external cause for this deterioration is a change in running mechanics, which is often apparent as a slightly forward leaning posture. It is thought that this abnormal posture and the perception of poor coordination after the CR transition may be due to the inability of the neurosensory system to adjust quickly to the sudden change of posture from cycling to running. However there are also some less obvious and more fundamental physiological changes induced by the cycle phase. The fact that breathing discomfort also seems to be elevated during the early stages of the run phase provides some clues about the origin of these physiological changes.

During triathlon, the lungs are subjected to huge demands, and there have been repeated observations of reductions in post-event lung function (2). An important deficit is that of the lung diffusing capacity, which is impaired post-event (3) (and presumably also during the latter stages of the race). Other respiratory-related changes are also present; specifically, some breathing pump muscles exhibit evidence of fatigue during and after the event. However, the pattern of the changes is not as you might predict.

Inspiratory muscles fatigue

Research on swimmers has shown that front-crawl swimming is associated with the highest magnitude of inspiratory muscles fatigue (IMF) yet recorded; a 29% deficit in strength after a 200m swim at 90-95% of race pace [4]. In light of this, we might predict that IMF would be present after the swim phase of the triathlon and that it would become progressively more severe after the cycle and run phases.

However, the two studies that have examined the influence of triathlon upon respiratory muscle function have shown little or no IMF after the swim phase [2, 5]. In contrast, both of these studies observed IMF after the cycle and run phases (~25%), but there was no worsening of fatigue between the cycle and run phases. In other words, cycling induced fatigue that was not exacerbated by the subsequent run. In addition, there was no evidence of expiratory muscle fatigue [2].

‘Cycling presents the greatest challenge to the inspiratory muscles’

It is likely that the absence of IMF following the swim phase is due to triathletes' pacing strategy, and not to the fact that triathletes are more resistant to the IMF induced by swimming than swimmers are. There is some evidence to support this. For example, one study found that the slowest 50% of swimmers were significantly faster in the initial stages of the subsequent cycle phase [6]. Another found that athletes undertaking the swim phase at 80% of their maximal swim trial velocity completed a simulated event faster than when the swim was undertaken at 100% of maximal swim trial velocity. Thus, triathletes probably pace themselves during the swim in the knowledge that not pushing too hard during this phase results in a better overall performance.

It is clear from the data relating to inspiratory muscle fatigue that the cycle phase must represent a particular challenge to the inspiratory muscles, since this phase induces IMF that is not worsened by subsequent running. So what is known about the demands of cycling and the CR transition?

The cycle-run transition

The CR transition became a particular focus of respiratory research because for many years there was no satisfactory explanation for the increased perception of breathing discomfort that is present during the first minutes of the run phase. As mentioned previously, research has now shown that during the first minute of the run phase following the CR transition, the energetic cost of running is higher. Associated with this is an increase in the ventilatory requirement, and these changes have been ascribed, at least in part, to IMF[7,8].

A research group in France has attempted to tease out the independent and combined influences of cycling and running upon IMF and lung diffusing capacity. In one study[9] they compared the influence of a 20-minute cycle followed by a 20-minute run (CR), with that of a 20-minute run followed by a 20-minute cycle (RC) (all at 75% of maximal oxygen uptake). They found that the RC combination induced the greatest magnitude of IMF. The explanation for this is that cycling presents the greatest challenge to the inspiratory muscles and that when the run follows the cycle, the inspiratory muscles have time to recover. In contrast, when the cycle follows the run, the full magnitude of the cycle-induced IMF is apparent.

But why should cycling be more challenging for the inspiratory muscles than running? It probably relates to the influence of trunk posture upon breathing mechanics. The crouched body position associated with the use of 'aerobars' has some disadvantages when it comes to breathing. Research suggests that cyclists who are inexperienced in the use of aerobars experience detrimental effects on their breathing and mechanical efficiency compared to cycling in the upright position[10]. For example, compared with upright cycling, aerobars resulted in a lower maximal oxygen uptake and lower maximal ventilation. In addition, breathing appeared to be constrained, such that tidal volume was lower and breathing frequency was higher. This is a very inefficient breathing pattern; indeed, the study found that mechanical efficiency was lower when using aerobars, *ie* the same amount of cycling work required more energy.

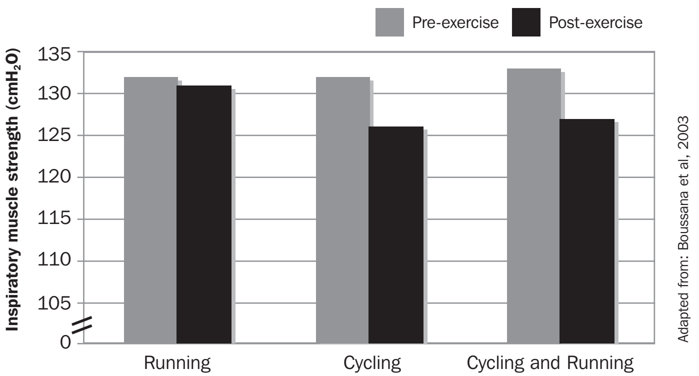
Cycling Position

The explanation for these findings resides in the influence of a crouched body position upon inspiratory muscle mechanics during cycling. Firstly, crouching forward forces the contents of the abdomen (stomach, liver and gut) upward against the diaphragm. This impedes the movement of the diaphragm during inhalation because the abdominal contents are pushed up against the diaphragm causing it to 'work harder' for each breath *(see figure 1)*. Secondly, the higher breathing frequency

Figure 1: Inspiratory muscle mechanics during cycling

The effects of crouching during cycling on respiratory muscle mechanics; the solid line represents the position of the diaphragm at the end of exhalation. During inhalation, the diaphragm moves downwards (the dotted line) encroaching on the abdominal cavity, which impedes the movement of the diaphragm, especially in the crouched position, for example when using aerobars.

Figure 2: Exercise modality and inspiratory muscle fatigue



In a study of the effect of exercise modality upon inspiratory muscle fatigue[11], researchers found that running for 20 min at 75% of maximal oxygen uptake induced no fatigue, while cycling at the same intensity induced significant inspiratory muscle fatigue (~5% fall in strength post-exercise). When 20 min cycling was followed by 20 min running, the magnitude of fatigue was the same as for just 20 min of cycling.

> *'Respiratory impairments induced by cycling carry over into the run'*

means that inspiratory flow rate must be higher, which means that the inspiratory muscles must work in a region of their force-velocity relationship where fatigue and effort sensations are greater.

In a follow-up to their RC/CR study, the French group tested their hypothesis that the crouched body position of cycling, and its negative impact upon respiratory muscle mechanics, might account for the differences between the effects of CR and RC transitions[11]. Subjects performed either 20 minutes of cycling, 20 minutes of running, or 20 minutes of cycling followed by 20 minutes of running (CR). Interestingly, they noted that cycling and CR induced almost identical IMF, whereas running induced none *(see figure 2)*. This suggests that cycling fatigues the inspiratory muscles in a unique way that is most likely related to the crouched body position.

As mentioned above, changes in lung diffusing capacity have also been noted after CR and RC transitions[12]. As was the case with IMF, the RC transition generated the greatest deficits in diffusing capacity. The authors speculated that this was due to a reduction in the volume of blood within the lung circulation during RC, which would reduce the proportion of the lung available for oxygen exchange between blood and air. Further, they speculated that the reduced lung blood volume was due to IMF, and secondary to alterations in breathing-induced pressure changes within the chest and thus to the amount of blood returning to the lungs.

Another potential explanation for the change in diffusing capacity relates to the influence of IMF upon blood flow distribution during exercise. During exercise that fatigues the inspiratory muscles, there is a narrowing of blood vessels, including those to working muscles [13], and possibly also those in the lungs.

A recent study into the influence of inspiratory muscle training (IMT) on exercise performance under conditions of simulated high altitude (low oxygen) using a PowerBreathe training device found that oxygen diffusing capacity and arterial oxygen saturation were increased during exercise after IMT, compared to before IMT. This may indicate that after IMT, a vasoconstrictor influence upon the blood circulation to the lungs has been removed, causing blood volume and diffusing

Summary comparison of high-intensity cycle interval training v IMT

	High-intensity cycle interval training[18]	IMT[15]
Performance enhancement	5 (%)	4.6 (%)
In 40km time trial	3 minutes	2.76 minutes
Duration of training	4 weeks	6 weeks
Type and intensity of training	VO2max on a cycle	50% of inspiratory muscle strength using an IMT device
Session regimen	8 intervals of 2.4 minutes	1 set of 30 breaths, twice daily
Session duration	53 minutes	2 minutes
Session frequency (per week)	2	14
Total training time (per week)	106 minutes	28 minutes

area to be increased. Thus, the impairment of diffusing capacity at the CR transition of the triathlon may be a manifestation of pulmonary vasoconstriction that has been induced by inspiratory muscle fatigue.

It seems likely therefore that the respiratory impairments induced by cycling carry over into the run, causing run performance to also be impaired. The greater IMF induced by the RC combination most likely occurs because in the CR combination, the inspiratory muscles can recover slightly from the impairments induced by the preceding cycle; whereas in the RC combination, there's no opportunity for recovery. It appears that the mechanical constraints of cycling, which restrict rib cage and diaphragm movement, induce impairments in both inspiratory muscle function and lung diffusing capacity, both of which can impair performance.

Overcoming IMF

The obvious question is what can be done to minimise these effects? Since studies appear to show that the aerobar position has fewer detrimental effects in cyclists who have used them for a prolonged period [(10)], it appears likely that the inspiratory muscles adapt to the increased demands imposed by aerobars. Clearly this adaptation doesn't appear to abolish the IMF, since there are numerous studies showing that even very highly trained triathletes and cyclists still experience IMF. However, an intervention that has been shown to abolish IMF is specific resistance training of the inspiratory muscles [(14)].

The benefits of IMT

The data described above creates a fairly compelling argument in favour of specific inspiratory muscle training in order to minimise the detrimental influence of the mechanical constraints to breathing that are imposed by cycling. Unfortunately, there are so far no published studies evaluating the benefits of IMT for triathlon performance. However, we can infer the likely benefits by considering the following facts, as well as data from studies of IMT in cyclists, all of which suggest that good breathing and avoiding IMF are central to success:

- All three disciplines of the triathlon elicit inspiratory muscle fatigue (IMF) when undertaken individually;
- IMT improves performance in both cycling[15] and running[16];
- The cycle-run component of the triathlon is associated with IMF, as in the event as a whole[2,5];
- Inexperienced cyclists using aerobars experience detrimental effects on their breathing and a decrease in mechanical efficiency compared to cycling in the upright position[10];
- Something that sets professional cyclists apart from mere mortals is the fact that their breathing remains deep and strong throughout intense exercise, maximising efficiency and minimising the metabolic cost of breathing[17].

Finally, in considering the merits of adding IMT to an already time-consuming training schedule, it's worth considering some facts regarding the time efficiency of IMT compared other training adjuncts. A typical IMT programme requires less, around 4 minutes per day, and can produce a 4.6% improvement in 40km cycling time trial performance[15]. So let's consider what else could be added to a training schedule in order to achieve a similar magnitude of benefit.

Very few studies have examined the influence of adding a different type of training to the endurance regimens of already highly trained endurance athletes. Fortunately, one of the few studies to have undertaken such an appraisal utilised a 40km cycling time trial as an outcome measure, making it possible to compare their data directly with those obtained using IMT.

The authors examined the effect of a number of interval training regimens, one of which produced an improvement in 40km time trial performance of ~5% over the 4-week period of their training intervention[18]. The intensity of training was very high, being set at the power output that elicited maximal oxygen uptake (VO2max) during an incremental exercise test. Athletes were required to undertake eight intervals of ~2.4 minutes duration interspersed with recovery periods of ~4.8 minutes. Athletes trained twice per week and the duration of each session was ~53mins.

Over the 4 weeks of the intervention, the total duration of high-intensity interval training required to elicit a 5% increase in 40km time trial performance was 7hrs. Compare this to the total time required to attain a 4.6% improvement in performance following 6 weeks of IMT, which is around 1.8hrs! Another salient point is the intensity and duration of each training session (53 minutes at VO2max v 2 minutes at moderate inspiratory muscle load), as well as the fact that IMT can be undertaken anywhere; there's no need for a bike, or even to break into a sweat! The choice is yours…

Summary

In this article we have considered the unique challenge to breathing posed by the triathlon, as well as the rationale for training the breathing pump muscles. Inspiratory muscle fatigue appears to contribute to the discomfort and physiological challenge of the run phase of triathlon. However, IMT reduces this fatigue and improves cycle time trial performance, indicating a strong likelihood that it will also ease the CR transition in triathlon, thereby enhancing performance. We've also considered what else could be added to a training programme to obtain the same performance improvement that has been demonstrated in response to IMT. The numbers speak for themselves and make the argument in favour of IMT a complete 'no brainer'. It's quick, it's easy, it's convenient, and you don't need to flog your guts out. Just add 4 minutes per day of relatively easy exercise to your normal training to achieve a 4.6% gain in your 40km time trial performance!

Alison McConnell

Jargon buster

Running economy – the energetic cost of running. A reduction in running economy equates to a reduction in efficiency and an increase in the energy requirement for a given pace

Lung diffusing capacity – the ability of the lung to transfer oxygen from the air into the blood

Tidal volume – The total volume of air inhaled/exhaled per breath

Force-velocity relationship –muscles are able to shorten faster when they are unloaded than when they are loaded and the heavier the load, the slower the maximal velocity of shortening. Every muscle has a maximal velocity of shortening for a given load, which means that every load can represent a maximal load if it is moved at the muscles' maximal velocity. Thus, moderately loaded movements undertaken as rapidly as possible can be more fatiguing than heavily loaded movements undertaken at slower than maximal velocity

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Don’t stress triathletes! – HRV data can help optimise all important rest and recovery

Review of heart rate variability and cardiovascular fatigue

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

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

Measurement of HRV for use in monitoring training and recovery involves analysis of the beat-to-beat variation. By accurately measuring the time interval between heartbeats, the detected variation can be used to measure the psychological and physiological stress and fatigue on the body during training. Generally speaking the more relaxed and unloaded (free from fatigue) the body is the more variable the time between heartbeats.

HRV data can indicate the impact of fatigue due to prior exercise sessions, hydration levels, stress and even the degree of performance anxiety, nervousness or other external stressful influences. Studies have shown that it varies within individuals according to size of left ventricle (inherited trait), fitness levels, exercise mode (endurance or static training) and skill (economy of exercise) [1]. Body position, temperature, humidity, altitude, state of mood, hormonal status, drugs and stimulants all have an effect on heart rate and HRV[1] as do gender and age.

Stress is associated with increased sympathetic tone of the ANS whereas recovery is associated with increased vagal tone of the ANS – *ie* a continuous low-level flow of impulses down vagal nerves that induces a maintained slowing of the heart under resting conditions. The vagal nerve is one of the many nerves that carry messages to and from the brain. One of the main functions of this nerve is to monitor and control the activity of internal organs such as the heart and stomach.

Cardiac autonomic modulation is diminished in an overtraining state[4] as well as after a hard training period[2] and a simultaneous shift in favour of sympathetic (increasing heart rate) over parasympathetic (reducing heart rate) dominance occurs in the autonomic balance. Overtraining and recovery analysis looks at the balance between low and high frequencies within the heartbeat.

Typically HRV measurements demonstrate a significant and progressive decrease in parasympathetic indices during long-term heavy training followed by a significant increase during resting. Then indices of sympathetic activity display the opposite trend. Sports-specific assessment prior to entering a long-term training plan using HRV has been demonstrated to be a useful tool [5, 6].

Why is it important to recover?

Overtraining is an imbalance between training/competition and recovery. Additional non-training stress factors and monotony of training may also contribute to overtraining syndrome. While short-term overtraining can be seen as a normal part of athletic training (HRV does not seem to be affected [7]) long-term overtraining can lead to a state described as burnout or overtraining syndrome [8].

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

This cardiac autonomic imbalance suggests that HRV is a useful parameter to detect overtraining and under recovery in athletes. During training, performance temporarily decreases but begins to rise during recovery. After a certain amount of time, performance rises above the pre-training level because the body is preparing to handle the next training load better than before.

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

The body needs time for recovery after a single high-intensity session, or a hard training period of several days, or even after a low-intensity but long training session. Without rest, adaptation to the training load will not occur.

The ‘overload’ principle is an important aspect of training and can be quantified by training load, duration, frequency and rest. However, application of excessive training stress or too many training sessions can result in exhaustion of the body’s physiological system. Numerous studies have demonstrated that overtraining from long-term stress or exhaustion is caused by a prolonged imbalance between training and other internal and external stressors and recovery.

How does HRV stress/recovery analysis work?

The ANS reacts quickly to changing conditions. Many changes in physiological functions and especially in the autonomic nervous system function are reflected in our heart. Heartbeat measurement and analysis of heart rate reactions and HRV can provide significant information on body processes.

Beat-by-beat heart rate data contains much more information than just actual heart rate. Different types of reactions and changes in the heart rate contain embedded physiological information. By analysing HRV it is possible to verify that athletes are able to recover during the working day, between training sessions and especially during the night. In this context, stress can be defined as a physiological state of a heightened level of ANS function that is not caused by immediate physical demands. Accordingly, the HRV method is not able to specifically identify individual stressors but rather indicates the cumulative effect of different sources of ANS stress (*eg* lack of sleep, poor recovery from physical training, medication etc).

Some heart rate monitors (*eg* models from Polar and Suunto) use HRV measurement as a feature to assess training load and overtraining based on individual heart rate response enabling the user to optimise their training load and recovery time (for a scientifically balanced view of HRV the reader is referred to an excellent review paper 'Heart Rate Variability in Athletes' (1)).

What are the benefits of measuring recovery?

There are a number of benefits of measuring how much recovery has taken place. These include:

- detecting early signs of overtraining or illness;
- optimising training load by finding the balance between training load and recovery;
- providing evidence-based support for critical coaching decisions;
- recording individual baseline values eg during off-season when the body is fully recovered;
- checking the recovery status during hard training periods;
- checking recovery status when subjective feelings and fitness levels indicates poor recovery;

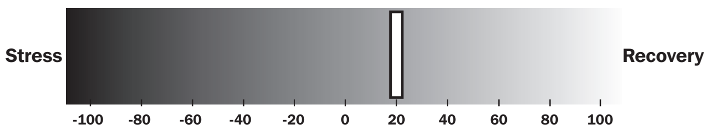
- making sure that the body is recovered sufficiently before a new hard training period.

Using software such as that from Firstbeat Technologies, a recovery test is usually done as an overnight measurement so that the effect of external stressors can be minimised. It is also advisable to do some daily stress measurements to look at overall lifestyle stress. The selected time interval should also be standardised so that the results of different measurements can be compared individually. The first sleeping hours are often the most sensitive for recovery analysis (*eg* if you go to bed at 10-11pm, analyse from midnight to 4.00am).

Stress and recovery index – some examples

Stress and recovery in the Firstbeat Technologies software are represented on a scale from -100 to +100 *(see figure 1)*. The stress and recovery index is the balance between stress and recovery. In the following diagrams 'dark' represents stress reactions whereas 'light' represents recovery reactions.

Figure 1: Stress/recovery index showing relative recovery (+20)



Stress and recovery index from the selected time period is 20

The intensities of the stress and recovery reactions are influenced by heart rate, heart rate variability and respiration rate, and can be considered as sensitive markers for detecting under-recovery and overtraining in sports.

Figure 3 shows when stress is present only during the first sleeping hours before the recovery reactions start to occur (therefore no risk for overtraining). Figure 4 shows stress reactions present during the whole night, indicating an increased risk of overtraining and that more rest is needed.

Figure 2: Interpretation of stress and recovery during the night (1)

No stress reactions detected during the night; athlete is well recovered

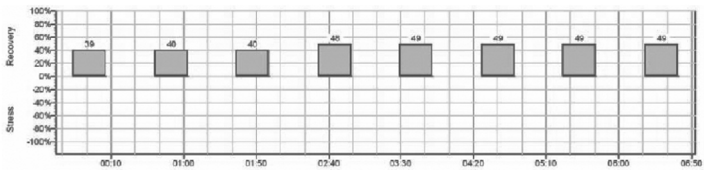


Figure 3: Interpretation of stress and recovery during the night (2)

Stress only present during first sleeping hours, after which good recovery

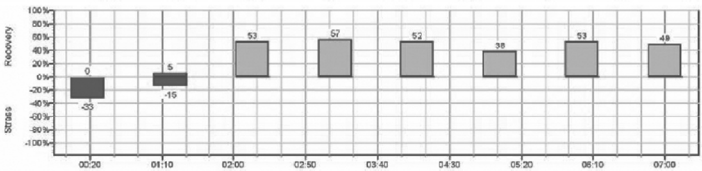
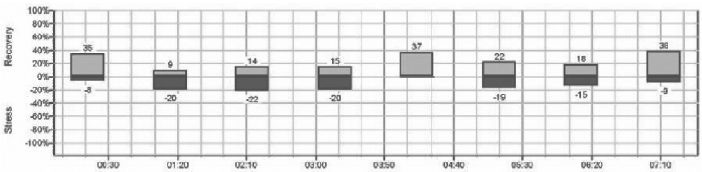


Figure 4: Interpretation of stress and recovery during the night (3)

Stress is present during whole night; an increased risk of overtraining – more rest needed



What are the benefits of measuring daily stress?

As with recovery, there are several benefits of measuring daily stress. In particular, daily stress monitoring can help athletes to:

- maximise recovery between training sessions;
- learn how different daily routines enable and limit recovery;
- observe the effects of training at high altitude;
- assess how travelling and jetlag affects recovery after competition/training;

- repeat the daily stress recordings and observe how changes in daily routines affect stress and recovery;
- check for social and psychological stressors that influence recovery and manipulate daily routines for arrangements to minimise stress during the day.

Figures 5 and 6 show the balance between stress and recovery during the daytime period after a morning workout and before an evening workout. Figure 5 shows that shopping did not enhance recovery between two training sessions because stress reactions were detected during the whole time period between training sessions! However, taking a nap and relaxing at home enhanced the recovery reactions, preparing the body for the next workout *(figure 6)*.

Figure 5: Shopping during the day – poor recovery

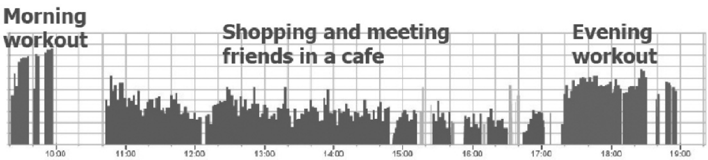
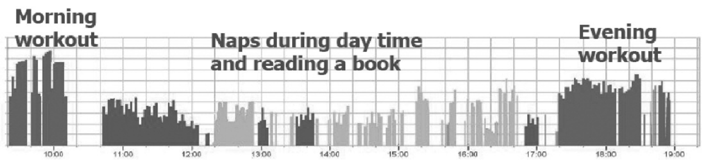


Figure 6: Napping and reading during the day – good recovery



Having carried out a large number of these tests, it is very clear that the largest influence on daily stress and recovery are work, family and emotional stressors with some individuals rarely recovering from normal daily activities. For example, figure 7 shows the full working day stress index for James, a busy professional, while figure 8 is the overnight log of the recovery stress index showing very little recovery.

Figure 7: Full working day stress index for James

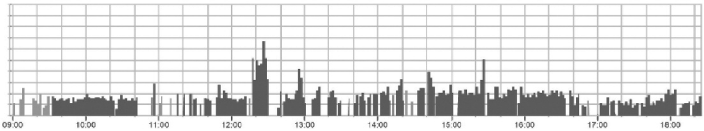
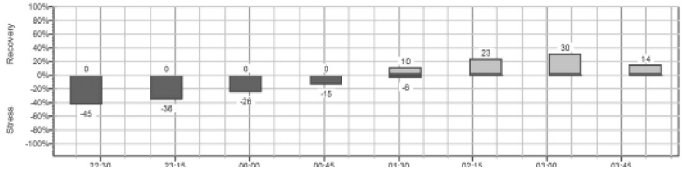
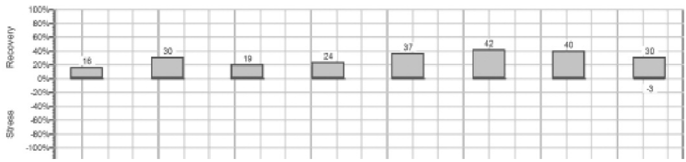


Figure 8: Overnight log of the recovery for James stress index showing poor recovery



Now compare this with figure 9, which shows James' overnight recovery log after a week away from work, but having climbed Mount Kilimanjaro just three days previously! His recovery stress index scored +100, which meant he was fully recovered.

Figure 9: Overnight recovery log after a week away from work – 100% recovery



Conclusion

HRV is a relatively simple, but effective, tool for regular checks of progress during endurance training programmes. Overtraining or under recovery are real issues that athletes and coaches alike need to consider. It is also evident that the stress of normal everyday activities exerts a larger influence on training and race performance. Seemingly relaxing activities such as shopping may impose more stress rather than help recovery. Taking a nap, reading a book or listening to music appear to be excellent de-stressors. Overload periods need to be used with caution and additional rest periods or reduced intensity training sessions introduced to ensure athletes are optimising their training and recovery time. Close to a competition, monitoring of taper activities can be undertaken to ensure that the athlete competes in a fully recovered state. Heart rate variability monitors and associated software are powerful tools for athletes and coaches, providing useful information which can be used to adjust training programmes to best effect.

Eddie Fletcher

Cardiovascular fatigue

- Physical training with incomplete recovery can produce significant fatigue. Studies of cardiovascular responses show that there is a sympathetic and a parasympathetic form of fatigue;
- In short there is a cardiovascular form of fatigue which HRV can detect [2];
- There is also evidence to suggest that when recorded overnight, HRV seems to be a better tool than resting heart rate to assess accumulated fatigue and that HRV may be a valuable tool for optimising individual training plans [2, 3].

Jargon buster

Parasympathetic activity – activity which slows down the heart beat

Cardiac autonomic modulation – regulation of the heart which occurs automatically

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Ultra-endurance psychology – training the mind to take control

Endurance performance is mentally tough; the best triathletes can push themselves to sustain physical fatigue and remain psychologically positive over long distances and durations. This doesn't happen by chance; endurance athletes can train the mind to develop emotional control.

Emotional control is a skill needed to cope with the stress of competition but the good news is that you can work to improve it. Focusing on emotional control can and will lead to improved performance. And while it can't transform the proverbial carthorse into a racehorse, it can make both go quicker.

Here we will outline the concept of mood profile and suggest ways in which athletes can use this knowledge to improve performance.

What research has been carried out?

At the University of Wolverhampton, we have done a great deal of research on psychological states in relation to endurance performance. We've studied anxiety and self-confidence in duathletes [1] and triathletes [2] and also studied emotional states before and after marathon races [3,4].

Our recent work has looked at emotional states before, during and after competition. We have looked at changes in emotions during four-hour and two-hour bouts of intense cycling [5,6]. We also looked at emotions before and at the worst point of the race during the London Marathon [7].

Our latest work has looked at changes in moods and emotions during the course of the Marathon of Britain, a foot race covering a route of approximately 175 miles held in set stages over six days [8]. We have also looked at mood state changes during a 44-day solo expedition to the South Pole [8]. These studies provide a large data set on which to draw and make recommendations for endurance athletes.

Trends

An analysis of the results of these studies shows several trends. First, it is normal to experience intense emotions before competition. Many athletes feel very anxious and most feel some degree of anxiety. Anxiety can be related to inadequate race preparation, setting a goal that is beyond your ability or perceiving the course to be overly difficult. Rarely do athletes get all of these things right and they should expect to feel anxious before each run.

However, they should try to interpret these feelings to mean that they are excited; sport performance is by its very nature uncertain, and even the most confident athletes still have a degree of anticipation regarding how things will turn out. It is possible to feel anxious but to interpret these feelings in a motivational way as being ready to perform. Anxiety can be a good thing.

The second trend is that athletes experience a mixture of emotional states during bouts of long, intense exercise. Runners should expect to feel fatigued. Athletes who cope successfully with endurance performance tend to feel fatigue and happiness simultaneously, whereas athletes who do not cope very well tend to feel fatigued, depressed and angry at the same time.

To illustrate these profiles, data from the 2004 London Marathon is depicted in Figure 1. It is noteworthy that there are no differences in fatigue between the two runners but that the successful runner reports feeling fatigued, vigorous and happy.

Figure 2 is a graph of a female explorer completing an expedition to the South Pole. This shows that vigour and fatigue fluctuate during repeated bouts of hard exercise; the key message is that endurance athletes should expect to feel intense fatigue and learn strategies to cope.

The third trend is that psychological toughness is built on a firm platform of physical fitness. To enjoy repeated bouts of

Fig 1: mood profiles of successful and unsuccessful runners at the 2004 London Marathon

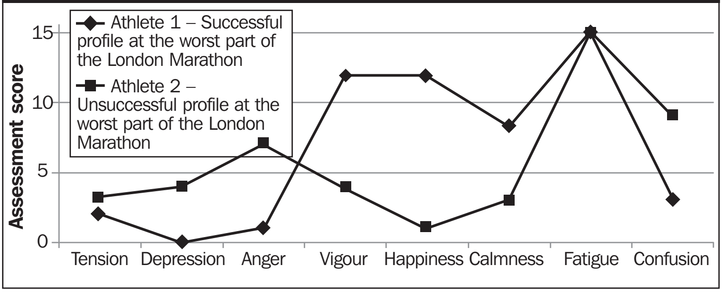


Fig 2: vigour and fatigue of female explorer during an expedition to the South Pole

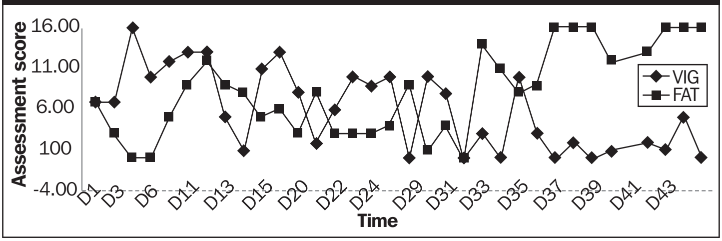
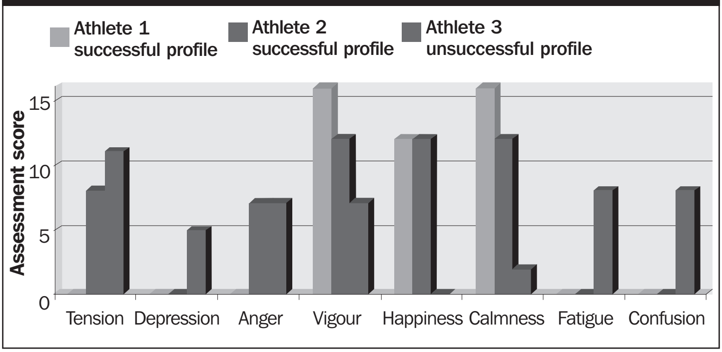


Fig 3: mood profiles of runners



hard exercise during competition you need to have experienced repeated bouts of fatigue that follow long-duration exercise in training. In the same way you train your body to cope with the demands of training, you also train your mind to think positively about the experience.

Developing emotional control

Task 1: Learning to recognise your emotional profile associated with success

We have all experienced intense emotions before important events. Some athletes can channel these feelings to enhance performance; some can regulate these feelings and reduce anxiety, while others become debilitated by anxiety.

We also know that we rarely experience one emotion on its own but rather groups of different emotions together. I have depicted these profiles graphically in Figure 3. Using this example, the first athlete feels excited and calm, the second feels anxious and excited, and the third feels anxious and downhearted. Athletes 1 and 2 should perform successfully whereas athlete 3 will probably perform poorly.

- Athlete 1 is an emotional profile typified by feeling vigorous, lively and alert, and in control. This athlete has regulated negative and unpleasant emotions. It is a profile often associated with supreme self-confidence and the perception that all challenges can be attained.
- Athlete 2 shows a different emotional profile associated with success. In contrast to athlete 1, athlete 2 has a profile depicted by feeling vigorous, tense and angry. Athlete 2 will use feelings of tension and anger to aid motivation. For athlete 2, feeling tense can be like a warning signal – 'I am about to try to achieve an important goal, and unless I work really hard, I will not achieve my goal'.
- Athlete 3 is a different story. This athlete feels anxious, angry, downhearted and depressed. These emotions are likely to interfere with performance. Feeling tense might make you want to try harder but when it is combined with feeling depressed, it can make you feel like giving up. Our research has found that feeling downhearted and depressed is possibly the most damaging emotion to experience before and during competition. When athletes

feel depressed, angry and fatigued at the same time they tend to turn anger inwards to self-blame and implode; poor performance is likely.

Task 2: Assessing your emotional profile

I ask athletes to complete self-report scales before training sessions and before competition. I also ask them to rate whether they achieved their goals. Emotional responses occur in all of these situations and knowing how emotions change can be extremely useful in understanding how behaviour can change. You should assess your emotional profile before a number of different performances; something that can be done by completing an emotion scale shortly before competition or a training session [(4)]. After competing, you should rate whether you performed to expectation or underperformed.

Performance should be rated in relation to your own expectations and your own goals. You will need around five successful and five unsuccessful performances before you can gather trends. Obviously, this is not always possible to do as you might be having a run of good form where most sessions/races are successful.

One way to get started is to think back to some of your recent performances and rate how you felt before a few races where you performed well (in relation to your own expectations) and a few races where you performed poorly (again in relation to your own expectations). Once you have a profile associated with successful and unsuccessful performance, a psychological skills programme can be tailored for your specific needs.

Assessment questionnaire

We assess emotions using self-report methods, typically a questionnaire. Of course, there are limitations with such an approach, as accuracy requires honesty. However, I would argue that there is not a better method available. A valid assessment of emotion necessarily requires access into thoughts and feelings.

It's true that we can make hormonal measurements (*eg* adrenaline) to infer emotions, and also that these hormones are detectable in emotions such as anxiety, anger and excitement. However, a limitation with this approach is that the physiology of emotional states such as vigour or excitement is similar to other high activation states such as anxiety and anger.

The only way to validate a physiological measure of anxiety or vigour is to compare it against a self-report measure; that is, to ask someone whether they were angry, anxious or excited. It's important to know your emotional states associated with success and failure. Once you've identified the factors linked with poor performance, you can begin to develop a strategy to combat these factors.

Task 3: visualising success

One strategy for developing emotional control is to use imagery. Imagery is effective because it can be used to replay situations. The emotions experienced during those situations can be changed from dysfunctional to functional. Imagery is a good way to do this as the situation can be replayed and aspects of it can be changed.

A good way of starting to learn imagery is to find a quiet place on your own. Sit down in a chair and make yourself comfortable, close your eyes, breathe deeply and evenly until you feel calm and relaxed. Picture yourself standing in your competitive environment and look around you taking care to notice as many details as possible. What can you hear?

What does your competitive environment smell like? How are you feeling? Immerse yourself in your competitive environment using all of your senses. Using 30-second blocks, you should relive the experience through your own eyes in real time. We encourage athletes to visualise in the first person and recall the emotional experiences before and during performance.

We also use imagery to help athletes cope with difficult situations. You should try to anticipate a difficult situation and see yourself coping with it successfully. An important part of this process is to imagine successfully tackling a number of the factors that make the task difficult; never underestimate the difficulty of the task as this can create a false sense of self-confidence.

For example, imagine yourself coping through the toughest part of the race, when your body feels exhausted. Imagine yourself coping successfully with this fatigue, feeling anger and depression starting to build up as you sense your physical fitness not being able to match the standard of performance you have set as a goal.

During imagery sessions you should rehearse the psyche-up strategies that would be used to raise vigour. For ultra-endurance events such as the longer triathlons or ironman events, you should imagine how you will feel at the start of a difficult stage. Imagine how you talk yourself into feeling ready, downplaying feelings of soreness. Imagine yourself on the course; focus on each step, on the small details, and go through how attainable each part is when broken down in to simple steps. What this can do is to develop effective coping strategies for successfully dealing with unpleasant emotions experienced in competition.

Task 4: use self-talk

Controlling emotions during an event is also about controlling that inner voice in your head. When you are feeling tired, this inner voice can be very negative. It can question what you are doing, talk you out of keeping going, and become a general nuisance. Positive self-talk is needed when feeling tired.

Endurance running involves coping with fatigue, which can be learned; you can turn the voice off and you can turn from negative to positive. First, think back to those runs when you felt tired. Think of what you said to yourself. Write it down. The next step is to change the negative self-statements into positive self-statements.

For example, consider the negative self-statement, ‘My legs have gone. I will have to stop’. This relationship between feeling tired and what to do about these feelings is clearly terminal for performance. We need to change both parts of this self-statement. Rather than saying ‘my legs have gone’ we need to change this to a transient statement such as ‘my legs are tired’. This is more likely to be true in any case. Tiredness tends to come in waves during endurance running and intense feelings of physical tiredness can pass.

It is also important to change the strategy for dealing with fatigue. I suggest that runners should focus on their technique when feeling tired. Focusing on technique is a good strategy as it is largely under the control of the athlete. If the runner focuses all of their attention on technique, this can detract attention from sensations of fatigue. The outcome is a much more positive self-statement: 'My legs are feeling tired, so I will concentrate on my technique to make it more efficient.'

A good way of using self-talk is to try to anticipate difficult moments in competition or in training. Develop self-talk scripts to change negative scenarios to positive ones. Use a combination of imagery and self-talk to create situations in which you experience unpleasant emotions, and see yourself deal successfully with these situations, using positive self-talk to control the inner voice in your head that can be negative.

Conclusion

Lets' draw together the main points outlined here. What should an triathletes know and expect before an event? Expect to feel fatigue and develop strategies to cope with this. Expect also to feel anxious before each run but try to interpret these feelings as excitement; sport performance is by its very nature uncertain, and even the most confident athletes still have a degree of anticipation regarding how things will turn out. Remember that psychological toughness is built on a firm platform of physical fitness. To enjoy an event such as this, athletes need to have experienced repeated bouts of fatigue that follows long-duration exercise. In the same way you train your body to cope with the demands of training, you also train your mind to think positively about the experience. Finally, prepare thoroughly for the specific demands of the event.

Andy Lane

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Carbohydrate drinks – can fructose enhance endurance?

Despite the numerous claims to the contrary by the sports nutrition industry, real advances in sports nutrition are comparatively rare. But recent research into carbohydrate absorption and utilisation could herald a new breed of carbohydrate drink, which promises genuinely enhanced endurance performance, promising news for all triathletes.

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

There are two main reasons for this. Firstly, carbohydrate is more oxygen-efficient than fat; each molecule of oxygen yields six molecules of ATP (adenosine triphosphate – the energy liberating molecule used in muscle contraction) compared with only 5.7 ATPs per oxygen molecule when fat is oxidised. That's important because the amount of oxygen available to working muscles isn't unlimited – it's determined by your maximum oxygen uptake (VO2max).

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

Carbohydrate storage

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

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

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

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

Later that decade, however, it became clear that carbohydrate ingested during exercise can indeed be oxidised at a rate of roughly 1g per minute [5-7] (supplying approximately

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

'When your muscle carbohydrate supplies run low, you feel as though you've hit a wall.'

Drink formulation

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

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

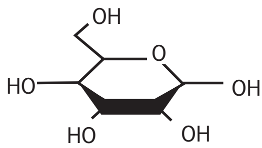
Carbohydrate type and performance

Many of the early studies on carbohydrate feeding during exercise used solutions of glucose, which produced demonstrable improvements in performance as discussed. In

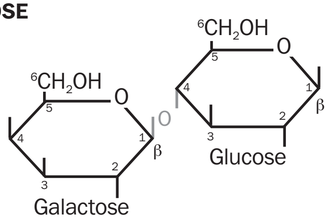
Carbohydrate building blocks

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.

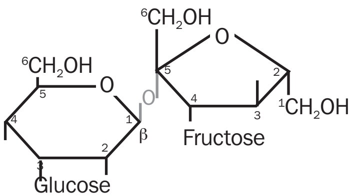
Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is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



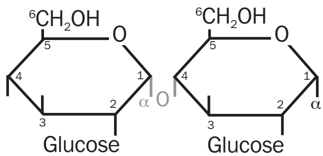
GLUCOSE



LACTOSE (MILK SUGAR)
= GLUCOSE + GALACTOSE



SUCROSE (TABLE SUGAR)
= GLUCOSE + FRUSTOSE



MALTOSE ('BREWERS SUGAR')
= GLUCOSE + GLUCOSE

the mid-1990s, some researchers experimented by varying the type of carbohydrate used in drinks, for example by using glucose polymers or sucrose (table sugar). However, it seemed that there was little evidence that these other types of carbohydrate offered any advantage [3].

But, at about the same time, a Canadian research team were experimenting with giving mixtures of two different sugars (glucose and fructose) to cyclists. In one experiment cyclists pedalled for two hours at 60% of VO2max while ingesting 500mls of one of five different drink mixtures [14]:

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

These sugars were radio-labelled with carbon-13 so the researchers could see how well they were absorbed and oxidised for energy by measuring the amount of carbon dioxide containing carbon-13 exhaled by the cyclists (as opposed to unlabelled carbon dioxide, which would indicate oxidation of stored carbohydrate). The key finding was that 100g of the 50/50 glucose fructose mix produced a 21% larger rate of oxidation than 100g of pure glucose alone and a 62% larger rate than 100g of pure fructose alone.

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

One of their early experiments compared the oxidation rates of ingested carbohydrate in nine cyclists during three-hour cycling sessions at 60% of VO2max [15]. During the rides, the cyclists drank 1,950mls of radio-labelled carbohydrate solution, which supplied one of the following:

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

The results showed that while the pure glucose and glucose/maltose drinks produced an oxidation rate of 1.06g of carbohydrate per minute, the glucose/sucrose combination drink produced a significantly higher rate of 1.25g per minute. This was an important finding because while both maltose and sucrose are disaccharides *(see box, p58)*, maltose is composed of just two chemically bonded glucose molecules, whereas sucrose combines a glucose with a fructose molecule. This suggested that it was the glucose/fructose combination that was being absorbed more rapidly and therefore producing higher rates of carbohydrate oxidation.

Fructose connection

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

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

There were two key findings; firstly, the carbohydrate oxidation rate when drinking high glucose drink was no higher than when medium glucose was consumed; secondly, the peak and average oxidation rates of ingested glucose/fructose solution were around 50% higher than both of the glucose-only drinks.

These findings point strongly to the fact that the maximum rate of glucose absorption into the body is around 1.2g per minute because feeding more produces no more glucose oxidation – probably because the absorption mechanism is already saturated. But because giving extra fructose does increase overall carbohydrate oxidation rates, they also indicate that fructose in the glucose/fructose drink was absorbed from the intestine via a different mechanism than glucose *(see box, below)*.

The studies above and others [17] had shown that glucose/fructose mixtures do result in higher oxidation rates of ingested carbohydrate, especially in the later stages of exercise. But what the team wanted to find out was whether this extra carbohydrate uptake could help with water uptake from the intestine, and also whether the increased oxidation of ingested carbohydrate had a sparing effect on muscle glycogen, or other sources of stored carbohydrate (*eg* in the liver).

To do this, they set up another study using a similar protocol to that above (eight trained cyclists pedalling at around 60% VO2max on three separate occasions, ingesting one of three

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.

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).

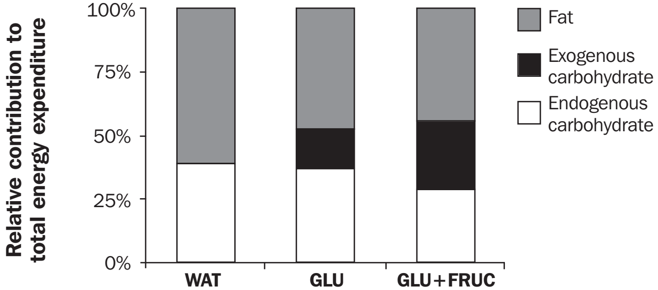
The water used in the drinks was also radio-labelled (to help determine uptake into the bloodstream) and the cycling trials were conducted in warm conditions (32oC) to add heat stress. Exercise in the heat results in a greater reliance on carbohydrate metabolism, which is thought to be due to increased 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.

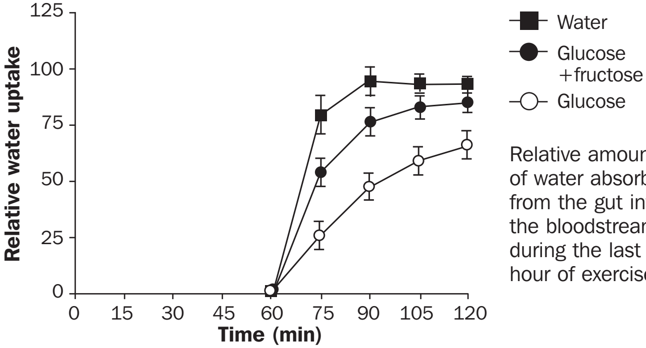
Although no direct muscle glycogen measurements were made, the kinetics of the rate of appearance and disappearance of glucose in the bloodstream from the drinks led the researchers to postulate that the extra carbohydrate oxidation observed could be as a result of increased liver oxidation, or the formation of non-glucose energy substrates during exercise, such as lactate, which is known to be an important fuel for exercising

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.

muscles. More research is needed to determine the exact mechanisms involved.

Implications for athletes

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

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

Recommendations for triathletes

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

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

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

Andrew Hamilton

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Jargon buster

Glycolysis – the partial but rapid breakdown of carbohydrate without oxygen

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

Radio-labelled – where a normal atom in a compound (*eg* glucose) is replaced by a chemically identical atom, but one carrying a different number of neutrons (isotope) making it possible to track the fate of the labelled 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 are designed to help maximise nutrient absorption

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Phosphatidylserine – a magic bullet for endurance?

Genuine advances in sports nutrition are rare, which is why the discovery back in the 90s that creatine supplementation really did improve anaerobic performance created such a stir. However, apart from caffeine use, there's been no equivalent 'magic bullet' supplement for aerobic athletes, such as triathletes. Although new research on a naturally occurring compound called phosphatidylserine is proving very intriguing indeed.

What is phosphatidylserine?

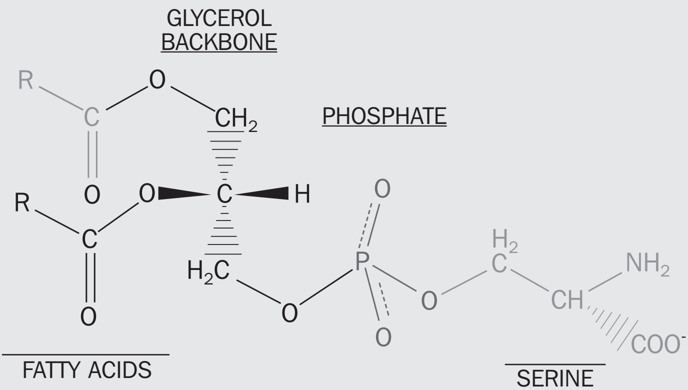
Phosphatidylserine (PS) is a naturally occurring compound found in a number of foods such as fish, rice, green leafy vegetables and soybeans. However, PS is also required for the functioning of all mammalian cells [1], and in humans it's found in particularly high concentrations in the membranes of cells with a high metabolic activity such as the brain, heart, liver and skeletal muscle [2].

Chemically, PS is a large 'phospholipid' molecule, consisting of an amino acid (serine) linked to a diglyceride (fat) via a phosphate bridge *(see figure 1)*.

Nature harnesses the unique physical and chemical properties of phospholipid molecules to form cell membranes, which as well as forming a boundary around the contents of the cell, are also needed to allow the movement of substances in and out of cells, such as nutrients and metabolic by-products.

Recent research suggests that PS is involved in a number of membrane-related functions in cells, including how cells communicate with each other, the regulation of the release of hormones such as acetylcholine, dopamine and noradrenaline

Figure 1: Molecular structure of phosphatidylserine



secreted by nerve cells, and the way in which tissues respond to processes involving inflammation.

Supplemental PS used for many of the early studies on PS and brain function (see later) was originally processed from cow brains. However, fears of possible prion contamination as a result of 'mad cow disease' led to a ban on this process and PS is now manufactured almost exclusively from soy.

Early PS research

The brain and nerve tissues contain very high levels of PS and, given its role in cell communication and regulation of nerve hormone secretion, many of the early studies conducted with PS understandably examined the effect on brain function, particularly the possibility that it could help prevent or even reverse cognitive decline.

Studies with rodents have shown that supplemental PS enhances cognitive function [2], improves learning/memory [3-6], and attenuates the effects of stress [7]. In humans, some studies have shown that supplemental PS exerts a significant therapeutic effect on the brain function of patients suffering cognitive decline [8,9], although some researchers have questioned just how effective this strategy is [10]. It's not clear how PS supplementation may exert these beneficial effects on brain function but, more recently, some researchers have postulated that increased PS concentrations may help support the functional capacity of the mitochondria in brain and nerve cells, particularly as imaging studies on brain activity frequently reveal energetic insufficiency and depleted energy reserves in brain tissue [11].

PS and athletic performance

Of more interest to athletes however is the recent research on PS and physical performance. The story began in the 90s when researchers noticed that PS supplementation seemed to enhance higher brain function even in healthy individuals with no signs of cognitive decline. Of particular interest was the effect of PS on the secretion of stress hormones such as cortisol following exercise. Chronically or excessively elevated levels of these stress hormones are known to be associated with immune suppression and tissue breakdown – not good news for athletes!

A 1990 study examined the effect of the administration of either 50 or 75mgs of PS on the subsequent release of stress hormones before a bout of cycling in eight healthy but untrained males [11]. The results showed a significant blunting of cortisol release following the cycling, but the degree of attenuation did not appear to be dose-related (*ie* the 75mg dose produced no more attenuation than the 50mg dose).

A couple of years later another study on the effects of PS supplementation examined a group of nine healthy but inactive males who took either a placebo, 400 or 800mgs of PS for a period of 10 days and then performed vigorous exercise [12]. In this case, the 800mg dose of PS blunted the release of cortisol without affecting the release of the anabolic 'growth hormone', whereas the 400mg dose showed no effect on cortisol.

The next step of the story came six years later when researchers looked at the effects of long-term PS supplementation on post-exercise cortisol production following strenuous resistance training [13]. They discovered that not only did PS appear to blunt the release of cortisol following training, but that it also led to lower perceived levels of post-exercise muscle soreness.

PS as an antioxidant?

Things then seemed to go quiet on the PS front for a few years until 2005, when a British research group led by Mike Kingsley at the University of Wales, interested in the role of antioxidant nutrients in controlling and reducing the inflammatory responses and post-exercise muscle soreness, wondered whether PS could be a likely candidate, especially as it was already known that PS can act as an antioxidant.

The group set up a study to investigate the effects of 750mgs per day of PS supplementation on exhaustive intermittent running in 16 football players [14]. The players were split into either PS supplement or placebo groups. Both groups were tested twice – once before supplementation and once again after 10 days of either PS or placebo supplementation. The test itself consisted of a 75-minute bout of high-intensity, intermittent exercise specifically designed to simulate match conditions. This was followed by a multi-stage shuttle run to fatigue.

‘There appears to be nothing to lose by experimenting with it.’

The scientists were particularly interested in the effects of PS supplementation on measures of blood antioxidants such as vitamins A and E, the post-exercise blood cortisol concentrations, perceived soreness and markers of oxidative muscle damage such as creatine kinase and hydroperoxides (these were expected to rise less following PS supplementation because of its antioxidant action).

What they discovered surprised them; there were absolutely no differences in any of the parameters above. But what was different was that the time to exhaustion in the PS group following the intermittent running increased by over 4%, while in the placebo group, it fell by just over 3%. However, while there was a measurable ergogenic effect, it was statistically not big enough for the group to draw firm conclusions, so a follow-up study specifically designed to investigate the effects of PS on endurance was set up [15].

PS and endurance cycling

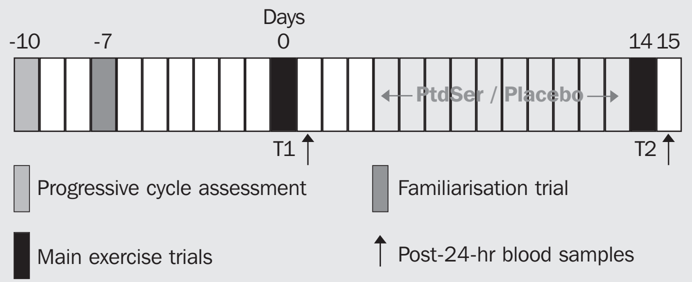
In this study, 14 fit and active males were recruited to undertake a cycling test. After some preliminary testing, all of the subjects completed a staged intermittent exercise protocol on three separate occasions, the first of these being simply to familiarise the subjects with the testing procedure. This procedure required subjects to complete three 10-min stages of cycling at work rates calculated (from initial tests) to elicit 45, 55, and 65% of each cyclist's VO2max, and this was then followed by a final exercise bout at 85% VO2max continued until exhaustion (an inability to maintain a cadence of 60rpm despite verbal encouragement).

A week after the familiarisation trial, the subjects repeated the exercise protocol, during which a number of physiological measurements were made including heart rates, oxygen uptake and kinetics (how rapidly oxygen delivery to the muscles changed to meet exercise needs), the blood concentrations of cortisol, how long each subject could continue before exhaustion set in and the perceived rate of exertion during the trial.

Five days after this initial testing (T1 in figure 2), the subjects were assigned in a randomised double-blind fashion to either receive 750mgs per day of PS or the same amount of glucose (placebo), which they took for 10 days after which the testing procedure was repeated again (T2).

When it came to analysing the data, the results showed that in many respects, there were no differences between the placebo and PS groups; oxygen uptake kinetics, heart rates, perceived rates of exertion and post-exercise cortisol levels showed no significant differences. However, there was one very significant

Figure 2: Experimental design scheme in PS and endurance cycling study



difference; those who had supplemented with PS between T1 and T2 increased their exercise time to exhaustion from an average of 7mins:51secs to 9mins:51secs – a staggering 29%! By contrast, the placebo group showed no improvement whatsoever.

The researchers concluded that their study had been the first to identify the ergogenic properties of PS but that further studies are needed to substantiate these initial findings and to investigate how these ergogenic effects might occur.

What's the future for PS use in sport?

One swallow doesn't make a summer, and while the initial findings on PS and endurance performance look very promising, more studies will be needed to ascertain just how effective it really is in different endurance events, the optimum doses and best time to use it etc. In order to answer these questions, scientists will also have to better understand the mode of action of PS; it doesn't seem to affect the dynamics of oxygen transport, neither did it appear to act as an antioxidant during this study.

One speculative theory is that supplemental PS can accumulate in the normal cell volume (*ie* not bound up in the cell membrane) and help to activate enzymes that are involved in moving sodium, potassium and calcium ions in and out of muscle cells. This could help to reduce the onset of fatigue that is thought to occur as a result of a build up of ionic imbalances within the cell. Another theory is that supplemental PS can accumulate in the membranes of heart cells, helping to enhance the contractibility of heart tissue (this has been shown to be the case in rat studies[16]) and so improve performance. There's also more research needed to unravel the mysteries of whether PS really can act as an antioxidant or reduce post-exercise muscle soreness and cortisol levels.

What's the advice for triathletes?

Numerous studies have concluded that PS is completely safe; indeed the only side effects seem to be beneficial (improved mental acuity, lower levels of circulating stress hormones etc), so while more evidence is needed, there appears to be nothing to lose by experimenting with it. A major drawback however is cost.

A tub of 60 x 500mg PS capsules purchased in the US typically costs in the region of $20-25, with UK prices significantly higher still, and athletes need to ask themselves whether that money could be better spent on improving dietary fundamentals or other aspects of training. Whether or not you choose to experiment, there's still much to learn about exactly what benefits PS may be able to offer, so triathletes and their coaches should keep their eyes peeled for new research in this exciting area.

Andrew Hamilton

Jargon buster

Phospholipids – fats containing a phosphate group in their structure

Hormones – molecules that act as 'chemical messengers' between one group of cells and another

Prion – a type of infectious agent made only of protein, which is thought to infect other proteins and propagate by abnormally refolding that protein structure

Mitochondria – the 'power plants' found in all cells, which convert food energy into the universal energy currency of the body (ATP) for use by the cell

Cortisol – a hormone released in response to physiological stress, which is associated with tissue breakdown and lowered immunityl

Antioxidant nutrients – molecules that help protect the body by deactivating potentially destructive free radicals produced during metabolism, which can damage DNA and other cell components

Oxidative muscle damage – chemical damage to muscles at the cellular level caused by free radicals produced as a consequence of (increased) oxygen metabolism during exercise

Randomised double blind – a method of selecting subjects for different trial groups (in this case PS or placebo) that is entirely random (eg using numbers picked from a hat) and which ensures that neither the subjects nor the researchers know who is taking PS and who is taking the placebo

Enzymes – protein molecules synthesised in the body that enable biochemical reactions to occur that would otherwise not occur, or occur too slowly for normal metabolism

Ions – Atoms carrying either positive (metals) or negative (non-metals) charge

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My heart-stopping race to be an Ironman

With two triathlon age-group world championships under my belt, I decided to mark 10 years of competing in triathlon by signing up for an Ironman in July 2006: 3.8km swim, 180km cycle and 42km run. It turned out to be a far more challenging day than I could ever have imagined.

The Race

The race took place outside Zurich, Switzerland. It was hot, reportedly 35-37C. The swim went quite well, given the difficulties of establishing the correct pace when surrounded, as I was, by 1,800 competitors. I finished in 60 minutes.

Next came the cycle: three laps, with three climbs per lap. I aimed to complete it in six hours, leaving some reserves for the marathon. Lap 1 went well, though a bit faster than I'd planned, at 1hr 52min. Then, halfway round Lap 2, at the foot of the main climb, I experienced stomach cramps. I tried to figure out the cause and what I should do:

- Are my extra-padded new shorts too tight at the waist? No.
- Have I been eating and drinking wrongly? No, I've followed my normal regime.
- Are the race conditions proving too much for my digestive system, what with the heat and the added psychological stress?

I know that cramps can happen if the stomach has too much concentrated energy/solids in it. So I thought I'd drink water for the next while to dilute the contents and see if I'd bounce back. The cramps persisted. I carried on riding, periodically altering my position on the seat, rubbing my stomach, pouring water on myself to try to stay cool, drinking a bit more water, and after a while trying to eat to top up my calories. I had to force down the food, sugary drinks and energy gels.

With about 40 minutes of the cycle ride to go, I stepped off to have a pee and spent a minute or so rubbing my stomach and stretching, with no improvement. I knew I was slowing – although less than I perceived at the time. I really wanted to clear this gastric discomfort before the run. Otherwise I might end up walking, and 26 miles wasn't a distance I wanted to walk!

As I started the run I decided to take it steady, find a pace that I could sustain and see what happened. My original plan had been to take fluids in at every water station (1.25km) and an electrolyte gel every 25-30 minutes. But now, feeling nauseous, I really didn't feel like taking in the gel.

The run was four laps and my goal was to finish in four hours. I completed lap 1 in 55min, including loo stop (where the sauna conditions added to my nausea). Concerned that my mind was becoming confused, I made a great effort to think strategically, calmly and with focus:

'Take it easy. Relax. Run economically. Is there any tightness in my body? Yes – OK, then stretch out as I run. That's fine. I expected niggles. It's been a long day. I've never done a marathon before. I can do it. Keep going. Try for the four-hour target, but keep it steady. I'm slowing. OK, do what you can. Follow the strategy. Run in the shade as much as possible. Relax. Keep going. Don't walk as you might not start running again. This is probably the only Ironman I'll do. You're doing well.'

On lap 2 I slowed to 65 minutes, and by lap 3 had dropped to 75 minutes. The final lap was a struggle, but I finished with a 4:28 marathon and an overall time of 11.41.

Breakdown

Once I'd crossed the finish line and stood still, I felt worse. My head was spinning and balance was difficult. I thought a drink might help and chose cola, believing the fluid, energy and caffeine would help. Within 30 seconds I vomited nine times, bent over double. Even in my hazy state, I was surprised at the volume that came out. I stayed bent over until someone offered help and walked me to the medical tent. There, they hooked me up to a drip. I was feeling so rough; I just wanted to lie down.

My memory of what happened next is less clear. I lay relaxed, mostly sleeping. After what was probably an hour, a medic asked how I was feeling and was I ready to leave? I replied that I was feeling very rough, my head was spinning and I was very tired. They gave me a second drip and took my blood pressure. At some point I got up, drip in arm and medic in tow, to use the loo. I felt truly dreadful and was becoming concerned.

Again, the drip finished and the medics asked how I felt. Again I repeated my symptoms and said I wasn't ready to leave. I was also cold by now. They gave me a blanket and a third drip.

Shortly after this, I recall a group of medics quizzing me sternly and insisting that I should make an effort to get up so that I might leave. I said I felt really bad, with everything spinning and light-headed. But I gave it a go, with a medic at each arm. As I straightened, everything went dark.

'As I straightened, everything went dark.'

The next thing I know, there's an object in my mouth. I drift in and out of sleep. Someone's rubbing my forearm. A clock shows 3:45, is that morning or afternoon? A nurse is telling me I'm in hospital. What is this in my throat? Can I be on a ventilator? The nurse tells me I'm on a ventilator. I'm an Ironman. She points to the drip stand with my finisher's medal on it. She points to a photo: do I know who it is? I nod, thinking it is me, but my eyes are fuzzy. It turns out it isn't me but my partner, also competing. The nurse says they will take me off the ventilator in a few hours to see if I can breathe on my own. She says I'm doing better. Better? How bad had things got? I'm told it is Tuesday morning. What's happened in the last 36 hours?

At 8am, a doctor arrived. They pulled the tube out of my throat; then removed the catheter. Apparently I had passed out after three hours in the medical tent. The hospital thought my heart had slowed to 5-10 beats per minute. Their main concern had been that my lungs were filling with fluid. For quite a while they didn't know what was happening. My sodium levels were very low, so my system started to fail and I had developed pulmonary oedema.

Off the ventilator, I was transferred to a lung ward, given some breathing apparatus and the goal of reaching 3.5 litres of inhaled air. My first four attempts reached 750ml. My lung function was so compromised that even turning in bed from my back to one side left me gasping. I had become so weak that even lifting the jug to pour water into a glass was impossible. I had to use both hands and lean the jug over. On the bright side, my appetite was good; at least my stomach seemed fine. I felt extremely bruised and sore around my shoulders. For the next five days I coughed blood, in steadily reducing amounts.

In the afternoon of day 5, I was let out, with a discharge letter listing my diagnoses:

1. Heat-stroke and dehydration after a triathlon:
   – generalised tonic-clonic epileptic seizure
   – with hemodynamic instability
   – with hemorrhagic pulmonary oedema (intubation and mechanic ventilation)
   – rhabdomyolysis
   – hyponatremia, anemia, low Quick
2. Asthma
3. Reduced ejection fraction of approximately 40%, cause unknown.

Some weeks later, a gastroenterologist suggested that I'd experienced exercise-induced gastric ischemia (reduced blood flow) that probably led to the valve below the stomach closing. This meant that little food or fluid made it through to the small intestine where it could be absorbed.

This meant I would have been sweating out more fluids and minerals than I was replacing. This would cause cramps, either as a product of the reduced blood flow or because of the stomach stretching with the food and drink I was forcing down, and my markedly reduced interest in taking in food or drink.

Recovery

My travel insurance company sent out a doctor from the UK and gave me oxygen for the flight home. Once back, I continued to use the breathing apparatus every hour or two. After a week I was hitting 3.5 litres regularly. From the first day home I settled into a daily routine of going for a mid-morning walk. In a week I built this up to a mile. I quickly learned that two-thirds of the way round I needed to stop and sit for 20-40 minutes to regain some energy. If I accidentally overdid things, I would feel a wave of fatigue that I could only liken to a very heavy flu, the cue for me to sit immediately to avoid collapsing. This was a feature of my recovery for the first month or so.

Within 10 days my lung function had recovered to normal. By the end of the first month I was walking for 1 -2.5 miles in the morning about four times a week. Some days I included hilly streets to work my body a bit harder. Once or twice a week I'd ride my mountain bike for 10-25 minutes.

After two and a half months I went to the hospital for an ECG and transthoracic echo (an ultrasound of the heart). My heart appeared normal. On hearing this news, I asked to be hooked up to a 24hr ECG and put myself through my own maximal exertion treadmill test – I needed to know that my heart really was sound. Having completed this with no ill-effects, I felt happier to push on my rehab to include some tougher work.

Lessons

Seven months have passed since my Ironman event and the start of my post-race recovery challenge. I've been back at work for three months.

Here are some learning points from my experience that might be useful for those who work with injured athletes:

- In endurance events, the warning signs that something dangerous or bad is happening to the body won't always be dramatic (*eg* fainting, severe pain). Sometimes they can be overridden by determination and doggedness. I accepted before and during the event that I might need to pull out, but because I was able to keep going, I just did.

- During my recovery I found I was often very poor at being able to interpret what my body was telling me. Was I feeling normal fatigue, sluggishness because I hadn't done much recently, tiredness due to illness, or idleness? At other times it was more obvious: when doing some exercise I would become sluggish and my mind dominated by thoughts of lying in bed. At these times, the best thing was to head for home within 10-15 minutes. I'm not sure how professionals can advise on this, as it makes it hard to prescribe a simple progression in rehab exercise.
- I went through a range of emotions after my near-death experience. For me, these were mainly anger and frustration about what had happened. There was some relief, of course, that I'd survived, but not joy. I was angry that the paramedics had, in my mind, either accelerated my deterioration or caused my system failure by giving only water and glucose, but no electrolytes. This diluted what little body salts I had, leading to heart failure and pulmonary oedema. I was angry that no one in the tent made the effort to ask me what had gone on in the race, what I had eaten, drunk or felt, or why I finished with plenty of unopened electrolyte gels on my belt. But then, these same medics had saved my life, too.
- I had to face further psychological trauma and challenges well after the hospital experience. For instance, three weeks after I returned home, I received an ambulance bill that also covered medical tent expenses. It itemised defibrillation pads, gel and charging; adrenaline injection; and 15 minutes of CPR. Up to that point I had thought that my heart had only slowed. I hadn't realised it had had to be jump-started or needed so much extra help. This news was difficult to absorb.
- Fear was another dominant emotion: What if something similar happens again? What if there is some lasting damage? What if there is a weakness in my heart? Are the sensations in my chest that I now notice something to worry about, or do I notice them only because I've become

hypervigilant? What if I'm out without my mobile or alone and something happens? For me, it was best to evaluate these thoughts rather than ignore them or become obsessed with them.

Looking ahead

My energy still varies throughout the week, though the dips are less low. I'm swimming, cycling, running and doing some gym-based strength work, probably at about 60% of the volume I'd expect at this time of year. In the past month, I've undertaken some swimming (400m) and running (5K) tests and my times are close to what they've been before, so this is encouraging. I have just been told my 24hr ECG seemed normal, but I've been referred for a further check-up with a cardiologist.

I hope to do some triathlons this year, and if training is consistent and things work out, I plan to try to qualify for the Triathlon Age-Group World Championships in 2008.

Components of my recovery

- **Rest:** sleep, taking it easy.
- **Fitness:** low intensity aerobic with some moderate bursts.
- **Strength**: resistance exercise in the gym, plus core work.
- **Stretching**.
- Mind: keeping brain active with reading, planning, industrious or work-like tasks, sudoku.
- **Social:** getting out to have coffee/cake in a café when 'home alone' during the day.
- **Psychological**: thinking about what had happened and talking about it (not all the time, though!).

Victor Thompson

Notes

WHAT THE SCIENTISTS SAY

Reports on recent rowing-related studies

Drafting for triathlon swimmers

Triathlon has become the most popular multidisciplinary athletic event over the last decade, with competitions performed over a variety of distances, ranging from the triathlon 'sprint' (750m swim, 20k cycle ride, 5k run) to the gruelling Ironman, culminating in a marathon run. Unsurprisingly, therefore, a significant amount of new research is being devoted to investigating the determinants of successful triathlon performance.

Most research to date has focused on the cycle-to-run transition, since significant correlations have been reported between cycling or running time and overall triathlon performance. The influence of swimming on subsequent cycling time has been relatively neglected.

However, a new study from France has demonstrated that swimming in drafting position can significantly improve subsequent cycling efficiency and might therefore be expected to improve triathlon performance in general.

The researchers had shown in a previous study that decreasing the metabolic load during a 750m swim by using a wet suit resulted in a 11% decrease in swimming heart rate and led to a 12% improvement in efficiency during a subsequent 10-minute cycling exercise when compared to swimming without a wet suit. The lower relative intensity when swimming with a wet suit is classically explained by a decrease in 'hydrodynamic drag' resulting from increased buoyancy.

Because hydrodynamic drag can also be reduced by drafting – ie swimming directly behind another swimmer – the researchers set out to investigate the effects of drafting on subsequent cycling in a group of eight male triathletes competing at regional or national level.

After laboratory tests designed to determine VO2max and maximal aerobic power (MAP), each triathlete underwent three submaximal sessions separated by at least 48 hours, as follows:

1. A 750m swim performed alone at a sprint triathlon competition pace to determine the swimming intensity for each subject;
2. A 750m swim at the pace adopted during the first session, followed by a 15-minute ride on a cycle ergometer at 75% of MAP and at a freely chosen cadence;
3. A 750m swim in drafting position at the same pace as before, followed by a 15-minute ride at the same intensity.

The triathletes wore neoprene wet suits for all the swim tests and, when drafting, swam in the wake of a highly trained swimmer competing at international level.

Although no significant differences in performance were observed between the two swimming trials, there were other clear benefits conferred by drafting:

- Drafting resulted in a significant mean decrease of 7% in heart rate values during the last 4 minutes of swimming by comparison with swimming alone, while post swim lactate values were significantly lower after drafting;
- RPE (rating of perceived exertion) values recorded immediately after swimming indicated that perception of effort was significantly lower after drafting;
- Cycling efficiency was significantly improved in the drafting trial, with VO2, heart rate and lactate values significantly lower after drafting;
- A significantly lower pedal rate was observed when cycling after drafting.

The researchers comment: 'The main result of the present study indicated a significant effect of swimming metabolic load on oxygen kinetics and efficiency during subsequent cycling at competition pace. Within this framework, a prior 750m swim performed alone resulted in faster oxygen kinetics and a significantly higher global energy expenditure during subsequent cycling in comparison with an identical swimming bout performed in a drafting position.'

They point out that further studies are needed to investigate the effects of this improved cycling efficiency on running and total triathlon performance and to validate the observed effects during a real triathlon event.

Med Sci Sports Exerc, vol 35, no 9, pp1612-1619, 2003

Ironman triathlon gender differences

High energy intakes during an Ironman Triathlon help males athletes to faster finishing times but have the opposite effect in females. That is the surprise finding of study investigating energy balance in 10 male and eight female participants in the 1997 New Zealand Ironman Triathlon, comprising a 3.8k swim, 180k cycle ride and 42.2k marathon run.

Few studies have described energy balance in these situations, and the researchers' aims were to examine gender differences in the following variables during the Ironman:

- Total energy, food and fluid, macronutrient and sodium intake;
- Energy expenditure for each stage of the event;
- Energy balance for the event;
- Relationships between energy and carbohydrate intake, energy balance and finishing times.

Their theory was that athletes would be in substantial negative energy balance (EB) after completing the Ironman and that carbohydrate ingestion would be related to improved performance in both male and female competitors.

They were certainly right in their first supposition: mean energy expenditure (EE) was significantly greater than mean energy intake (EI), with a substantial mean energy deficit after the event of 5,123 and5,973kcal for women and men respectively.

'These results reveal,' comment the researchers, 'that subjects obtained a high proportion (59%) of their energy from endogenous fuel stores.'

They also illustrate 'the importance of consuming a high [carbohydrate] diet prior to ultradistance events to maximise endogenous fuel stores'.

But the researchers were surprised to find themselves wrong in their second hypothesis – that energy intake would be positively correlated with performance for both men and women.

Energy intake during the Ironman was monitored by the athletes themselves and passed on to the research team during in-race interviews followed up by telephone interviews a few days later.

Mean total energy intake during the cycle and run portions of the event was 3,115 kcal for women and 3,940 for men, with all subjects consuming significantly more energy during the cycle section than the run. Women obtained significantly more energy from food than fluid during the cycle and run sections – a finding that did not apply to the men. However, the women consumed significantly more water than men and (non-significantly) less sports drink and Coca Cola.

But the most interesting differences between the sexes was this: for women, total energy intake and energy consumed during the cycle section showed significant positive relationship with finishing time: in other words, the more they ate, the slower their times.

For men, the opposite tended to be true, with a significant inverse relationship between relative carbohydrate intake during the run and finishing time: in other words, the more carbohydrate they ate while running, the faster their times.

Acknowledging that the finding about women is difficult to explain, the researchers offer the following possible explanations:

- The longer average finishing time for women in this study may have provided more opportunity for energy consumption: in other words the energy consumption was an effect rather than a cause of the slower times;
- Difficulties associated with digesting and absorbing large amounts of energy and carbs, particularly in the form of solid food, may have contributed to longer finishing times among the women;
- Females may be less reliant than men on energy from carbohydrates because of an enhanced ability to mobilise lipid stores.

The researchers conclude that increasing carbohydrate ingestion during the run portion may be a useful strategy for improving Ironman performance in male triathletes.

International Journal of Sport Nutrition and Exercise Metabolism, 2002, 12, 47-62

Swim slower for faster triathlon times

Most previous triathlon research has focused on the effect of the cycling leg on running performance but has not considered the effect that the initial swim may have on both subsequent disciplines. But new Australian research has concluded that completing the swim leg of a sprint triathlon at time trial intensity impairs subsequent cycling and overall triathlon performance.

In the study, nine highly trained male triathletes completed five separate sessions in the laboratory, including a graded exercise test, a swim time trial and three sprint distance triathlons. The swimming velocities of the three triathlons were 80-85% (S80) 90-95% (S90) and 98-102% (S100) of the time trial velocity, while subsequent cycling (on a cycle ergometer) and running (on a 250m grass track) were performed at a perceived maximal intensity.

The two most important findings were as follows:

- The S80 and S90 cycle times were faster than the S100 time;
- The overall triathlon time of S80 was faster than that of S100.

The overall mean time improvement of about 1 minute 45 seconds between S100 and S80 is clearly of huge significance to elite athletes when the difference between first and second place can be as little as one second. 'The findings of this study suggest that swimming intensity had a significant influence on subsequent cycling and overall triathlon performance during a simulated sprint distance triathlon,' conclude the researchers.

However, rather than recommending elite triathletes to swim slower, the researchers advise them to elevate their swim training to the same level as cycling and running. This should equip them to 'swim the initial discipline of an event at an intensity below maximum, without losing touch with the first pack of swimmers.'

Br J Sports Med 2005; 39:960-964

Why triathletes don't need extra sodium

People taking part in prolonged endurance exercise don't need supplements to maintain normal levels of sodium in the blood and prevent the life-threatening sodium deficiency condition known as hyponatraemia. That's the reassuring conclusion of a study of 413 triathletes who completed the 2001 Cape Town Ironman triathlon in South Africa.

This study set out to test the prevailing wisdom that athletes need to ingest 20-40mmol per litre of sodium during exercise to preserve their normal blood sodium concentration and prevent hyponatraemia, particularly during ultradistance events, when total losses of sodium in sweat might be as high as 400-650mmol.

A total of 145 triathletes were randomly assigned to either an experimental or control group for the event, which comprised a 3.8k swim, 180k cycle ride and 42.2k run. Subjects in each group were given 40 tablets to take ad lib during the race, with a suggested range of one to four per hour. The tablets given to those in the experimental group contained 620mg of table salt while those given to the controls were filled with starch (placebo). Food and fluid intake – water or sports drink – were also allowed on an ad lib basis.

After the race, the researchers compared the blood sodium levels and various other parameters of these two groups and of the remaining 299 triathletes who had taken neither supplements nor placebo during the race.

Subjects in the sodium group consumed a mean of 14.7 tablets during the race, giving them an additional 156mmol of sodium. The placebo group took 15.8 of their dummy tablets. Nevertheless, there were no significant differences between the three groups in the following measures:

- finishing time;
- sodium concentration before and after the race;
- weight before and after the race;
- temperature and blood pressure after the race;
- perceived effort, muscle soreness and mental wellbeing.

Only one athlete – in the placebo group – developed dangerous hyponatraemia during the race. He was the only athlete to show a substantial weight gain during the race and his problem was put down to drinking too much water.

'We can reasonably conclude,' say the researchers, '…that additional [sodium] supplementation is unnecessary during prolonged endurance exercise to maintain the serum [sodium] within the normal range.' According to the scientists, this may be because athletes may sweat less or lose less sodium in their sweat than is currently believed, or that during states of acute sodium loss, additional sodium may be released from body stores to compensate for these losses until sodium supplies can be replenished at the next meal.

Br J Sports Med 2006;40:255-259

Notes