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ROWING

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The research newsletter on stamina, strength and fitness

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Life at the top – how are elite rowers tested and monitored?

Elite rowers subject their bodies to incredibly high levels of physiological stress. So what kind of testing and monitoring is needed to maintain maximum condition without complete breakdown?

At a Glance

- The power demands of rowing are described;
- The impact of weight and gender effects on performance are discussed;
- Protocols for lab and field-testing elite rowers are outlined;
- Monitoring strategies for rowers in the field are also described.

Olympic rowing events are conducted over a 2,000m course. The event lasts about 320 seconds (s) to 460s, depending upon the number of rowers in the boat and upon competition classification *eg* heavyweight (now more commonly referred to as 'open weight'), lightweight, men or women, sculling or rowing. Furthermore, performance, as measured on the water, also depends on external factors including the environmental conditions *ie* water temperature, wind speed and direction, air temperature.

The advent of rowing ergometers has facilitated training, by providing a controllable and repeatable tool in the assessment of rowing performance. Performance over 2,000m on a rowing ergometer is dependent upon the functional capacity of both the **aerobic and anaerobic energy pathways** with the relative amount of energy derived from anaerobic metabolism being 21%-30%[1].

The study of physiological characteristics of rowers has revealed that power at VO_2max, VO_2 at **lactate threshold** (LT), maximum power production and power at a blood lactate of $4mmol{\cdot}L^{-1}$ are the most important predictors of 2,000m rowing ergometer performance in elite rowers (2). (The use of power output at $4mmol{\cdot}L^{-1}$ blood lactate level has been used by a number of coaches and is widely agreed to be important predictor of performance.) However, of the measures listed it is generally agreed that power at VO_2max is the strongest aerobic correlate of performance (a finding similar to that seen for endurance running).

Of the short-term maximal effort tests, maximum force and power production are the strongest correlates of rowing performance. Elite rowers sustain, on average, 77% of maximum power during a 2,000-m time trial (1). Thus, if all other determinants remain the same, the greater the maximum power, the greater the average power and resultant speed.

The results of 'off-water' ergometer studies indicate the importance of higher intensity parameters (power at VO_2max and maximum power) in rowing performance. Given this fact, it is perhaps surprising to note that most international teams utilise vast volumes of low intensity training for competition preparation (3). It must be remembered however that sub-maximal economy is important in underpinning power at VO_2max, and thus the importance of training that is focussed on improving economy and sub-maximal parameters should not be ignored. This type of training typically consists of a number of sessions per week dedicated to lactate threshold training, which has the dual advantage of improving **submaximal economy**, and improving the power output that can be sustained.

Weight and gender differences

There are significant performance differences between male and female and between heavyweight and lightweight rowers. On the ergometer, researchers have shown that male rowers were on average 7.7% faster than their female counterparts (2). Results from World Championships and World-Cup single scull events, suggest that this difference is increased to 10.9% on-water (there are subtle relationships between technique and power delivery which make on-water rowing harder than ergometer rowing, but why the difference is greater between ergometer and on-water rowing in women is not known).

The difference between heavyweight and lightweight rowers was 5.5% on-ergometer compared to 4% on-water. Whilst heavyweights are faster than lightweights research suggests that any increase in body mass should be primarily composed of functional (lean) mass to affect a change in ergometer/boat speed. This is particularly true for lightweight rowers. This requires the right combination of diet, rowing specific ergometer and on-water work, coupled with weight training, which ensures the development of an appropriate functional mass.

In describing the physiological components that are necessary for good rowing performance it must be remembered that anthropometric (*ie* height, limb length), technical (*ie* stroke length, stroke rate) and psychological factors are also crucial elements of that performance. Assessing the physiological aspects of performance is important in the profiling of athletes, as this allows the design of better training programmes, which in turn improves adaptation.

The physiological assessment of the rower should aim to test the range of physiological requirements of rowing performance, both aerobic and anaerobic. The following section outlines the range of tests employed by physiologists to assess elite rowers in laboratory and field (on-water or on ergometers in the boathouse or gym) settings.

‘The physiological assessment of the rower should aim to test the range of physiological requirements of rowing performance, both aerobic and anaerobic’

Laboratory testing for rowers

Rowing is a strength-endurance sport with a large aerobic component. A number of endurance sports have been proposed as the ‘most aerobic’, including cross-country skiing and running. But when scaling is used (that is a mathematical technique to allow individuals of different sizes and weights to be compared) then heavyweight rowers come out on top [4,5].

Heavyweight rowers (now more commonly referred to as 'open weight') are large individuals with an average height of 1.93m and average weight of 93kg. Although their body fat values tend to be slightly higher than their lightweight team-mates, they still carry considerable muscle mass.

Elite rowers require the ability to generate moderate to high forces and sustain efforts for six minutes (the average time to complete 2,000m in competition at World Championships or Olympic Games). Physiology support in the laboratory therefore is designed to examine the current conditioned state of the individual with respect to body composition, muscle power and force, aerobic power and sustainable percentage of maximal aerobic power.

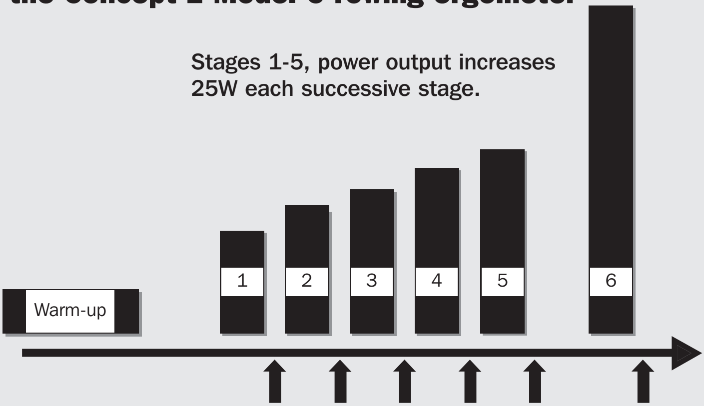
*'Body composition testing is particularly important for lightweight rowers because they cannot afford to be carrying excess 'nonfunctional' weight (*ie *body fat)'*

Body composition testing is particularly important for lightweight rowers because they cannot afford to be carrying excess 'non-functional' weight (*ie* body fat). The gold standard methodology for assessing body composition is DEXA (Dual Emission X-ray Absorpitometry). This involves whole body scanning technology using X-rays, which is expensive and time-consuming, and therefore used only occasionally with some elite rowers. More often, elite rowers continue to be tested for body composition by skinfold measurements, using a seven-site method recommended by the International Society for the Advancement of Kinanthropometry (ISAK).

As mentioned previously, it is important to measure maximal aerobic power (max) and the percentage of maximal aerobic power that can be sustained. To do this the discontinuous incremental protocol (commonly referred to as a 'step-test to max' and shown in figure 1) is the usual test used.

In the lab, testing occurs on a Concept II Model C rowing ergometer, the kind of rowing machine found in most health clubs. There is a difference however as (unlike the standard rowers) the lab ergometer is also fitted with a special force transducer at the handle, so that the force produced by the rower can be directly and very accurately measured.

Figure 1: Rowing exercise protocol used with the Concept 2 Model C rowing ergometer



Blocks 1-5 are work periods of 4 minutes with a 30s rest interval during which a capillary (earlobe) blood sample (red arrow) is taken. A 2.5-minute rest interval exists between stages 5 and 6. Stages 1-5 are submaximal; stage 6 is a maximal even-paced effort.

On this equipment a test is first carried out to examine strength and power. Before the test begins the rower performs a 10-minute warm-up followed by some light stretching. A specific warm-up is then completed using hard efforts of two, three, and four strokes prior to starting the test.

For the test itself, the rower is instructed to carry out seven strokes as hard as possible at a rate of 30 strokes per minute. From this test, work (in joules), mean force (in newtons), mean power (in watts), stroke rate (strokes per minute, spm) and stroke length (in metres) are reported from the last five strokes.

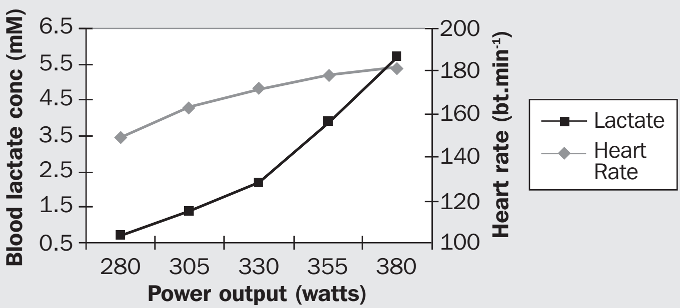
Elite rowers are often asked to perform 2,000m time trials on the ergometer in training, and so will have a recent 2,000m time. If a young rower visits the lab for the first time it can be difficult to know what intensity to start the step test at. However a means of determining this has been devised.

The time for 2,000m should be converted into a 500m split time. For heavyweight men and women add 15 seconds to this time and you have the split for the 3rd stage of the step-test. For the power output that equates to the time for stage 3, subtract

25 watts to get the power output (and split time) for stage 2 and subtract 50 watts for stage 1. For stage 4 add 25 watts and for stage 5 add 50 watts. For lightweight men and women, also add 15 seconds to the calculated 500m split time to find the split for the 3rd stage. However, it may be more appropriate to use 15-20 watt increments (rather than a 25 watt increment) to calculate subsequent stage workloads [5].

During the step test the rower wears a heart rate monitor and a mouthpiece for collection and analysis of expired air and every four minutes the rower stops to have an earlobe blood sample taken for blood lactate analysis. Figure 2 shows the typical heart rate and blood lactate profile for the sub-maximal portion of a rowing step test.

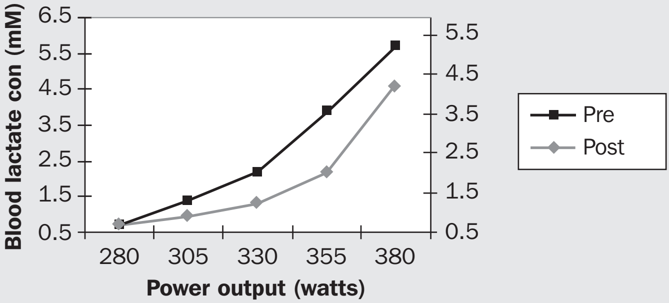
Figure 2: Heart rate and blood lactate response during a 'step-test' in an elite rower



The heart-rate associated with LT can be used to determine a number of heart rate zones which can be used for training, and after a few weeks improvements in endurance are detected as a rightward shift of the lactate curve as can be seen in Figure 3.

For the final stage of testing, the individual is asked to cover the furthest distance possible (at a relatively even pace) in four minutes. Traditionally, laboratory-based blood lactate measuring equipment such as Analox, Yellow Springs or Eppendorf lactate analysers have been preferred, as their

Figure 3: Changes in the blood lactate profile of an elite rower after 2-3 months of endurance training



validity and reliability has been tested and is well known. Although it is possible to use new 'palm top' lactate analysers, their validity and reliability continue to be questioned.

The data collected and calculated from the step test includes VO_2max, power at VO_2max, the percentage of maximum that can be sustained (*ie* at lactate threshold as a percentage of VO_2max), power at LT and power at reference blood lactate values of 2 and 4 $mmol \cdot L^{-1}$.

'Laboratory-based testing provides an objective set of data collected under standardised conditions; this level of standardisation and objectivity could never be achieved in the field'

Field-testing for rowers

Many elite sports routinely enjoy a physiology support programme and hence coaches and athletes have greater experience of sports science. As a result, coaches in many sports are increasingly demanding that field-based testing replace laboratory-based testing. However, coaches and athletes rarely have the training and experience of professional sports scientists and, while many physiologists are not averse to an increase in the use of field-testing, it is very difficult to justify the elimination of lab-based testing altogether.

Laboratory based testing provides an objective set of data collected under standardised conditions [5]. This level of standardisation and objectivity could never be achieved in the field. However, field based data has greater sports specificity, *'The primary purpose of altitude training is to capitalise on the adaptations associated with this increased physiological stress'*

something which is very difficult, or is impossible, to achieve in a laboratory based simulation of the sport. Accordingly, GB elite rowers are still lab tested two to three times per year with 4-5 field based (step-test) sessions. To supplement this, the coach also carries out some performance tests such as, 18km, 30 minute, 2km or 250m rows. On some occasions blood samples can be taken (by a physiologist) at the end of such rows, or the 18km row can be broken into 3 x 6km rows with a 30-60 second rest interval for blood samples to be taken.

At field camps overseas, early morning monitoring is routinely carried out prior to daily training. This involves the measurement of urine concentration to monitor hydration status, blood urea, body mass and resting heart rate to examine how the athlete is coping with the physical stress of exposure to a new, often extreme environment, coupled with normal training. All of these measures are viewed in combination with a psychological inventory and some discussion with the coach and athlete. As a result the coach decides on whether any modification of training is required for certain individuals as a consequence of this plus on-water and gym-based data.

Altitude camps

Originating in Eastern Europe, the use of altitude training camps in rowing has become commonplace. Elite rowers may ascend to altitude for training camps lasting up to three weeks on as many as three occasions per year. Altitude results in a lower availability of oxygen to the working muscles, due to lower barometric pressures, and this reduced availability of oxygen results in an increased physiological stress both at rest and during exercise

The primary purpose of altitude training is to capitalise on the adaptations associated with this increased physiological stress, which is suggested to increase red cell mass and haemoglobin concentration and hence increase oxygen carrying capacity.

Unfortunately, these adaptations come at a price; altitude has a number of deleterious effects that can affect health and performance of the rower including; sleep disturbance, dehydration, glycogen depletion, immune suppression and an increased incidence of illness including upper respiratory tract infections and gastrointestinal upsets. Altitude training can even lead to a reduction in performance due to a relative de-conditioning associated with an enforced lowering of training intensity [6].

It is for these reasons that monitoring rowers at altitude is crucial to optimise the beneficial effects and reduce the deleterious effects of low oxygen availability. Physiological monitoring of the rower at altitude is based upon assessing sleep quality, recovery, hydration and training intensities. Recent advances in the simulation of high altitude environments at sea level by reducing partial oxygen pressure (*ie* reduced O_2 concentration) in chambers, tents and face masks has led to new opportunities in the use of hypoxia (low oxygen) for training and competition [6].

Warm-weather camps

The purpose of warm-weather training is dependent upon the time of year and the focus of the camp. Warm-weather camps are often used to improve the training environment during the long winter months, but can also be used to acclimatise rowers to heat in preparation for competition in that environment.

Interestingly, it is unlikely that heat itself will affect a 2,000m rowing performance, as increased core body temperature is unlikely to be a limiting factor to performance. However, this assumes that the rower is fully hydrated at the start line with a near normal core temperature.

Unfortunately, the requirement for rowers to warm-up on water for extended periods of time prior to a race, and the multiple race schedule endured during competition means that rowers run the risk of becoming dehydrated prior to the start of racing, which can potentially have a deleterious effect on performance. Therefore, acclimatisation and experience of living, competing and training in the heat are crucial to optimise performance. Physiological monitoring of the rower in hot environments is less complex than altitude monitoring and is mainly focussed upon hydration status, recovery and training intensities.

In addition to the impact of environmental extremes on health and performance it is important to remember that travelling to foreign camps can also result in fatigue and jet lag that can subsequently affect training and competition performance. Careful physiological monitoring of travel fatigue and jet lag is important to reduce the negative impact of travel and optimise performance [6].

Summary

The functional capacities of the aerobic and anaerobic energy systems are important in 2,000m rowing, and performance and power at VO_2max, VO_2 at lactate threshold, power at a blood lactate of 4mmol·L-1 and maximum power production are the most important predictors of 2,000m rowing ergometer performance in elite rowers. Laboratory based testing is centred on step and maximum power tests and body composition assessment, while field-testing includes 'on-water' tests such as 18km, 30minute, 2km or 250m rows and lactate measurement following set pieces. In addition, careful monitoring takes place to assess the impact of the training/competition and environment on rowers' health and performance.

Richard Godfrey and **Greg Whyte**

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Jargon buster

Aerobic energy pathway – metabolism where energy is produced in conditions in which exercise intensity is relatively low and hence energy is produced using oxygen

Anaerobic energy pathway – where exercise intensity is relatively high and hence there is the requirement for energy to produced at a faster rate than can be achieved from aerobic pathways alone, leading to an accumulation of lactate

Lactate threshold – the point at which the linear rise in blood lactate with increasing exercise intensity becomes exponential – *ie* the point beyond which the rate of clearance of lactate from the blood is outstripped by production

Submaximal economy – the 'efficiency' of oxygen utilisation at a given (submaximal) intensity; when submaximal economy is improved, less oxygen consumption is required to maintain a given power output. In heavyweight rowers, oxygen consumption is often compared at a power output of 330 watts

Power to the people – maximising your 2,000m rowing performance

2,000 metre rowing is the ultimate test of power and endurance, imposing a unique set of demands on a athlete's body. Successful 2,000m rowers need an organised approach to their training if they are to succeed…

At a Glance

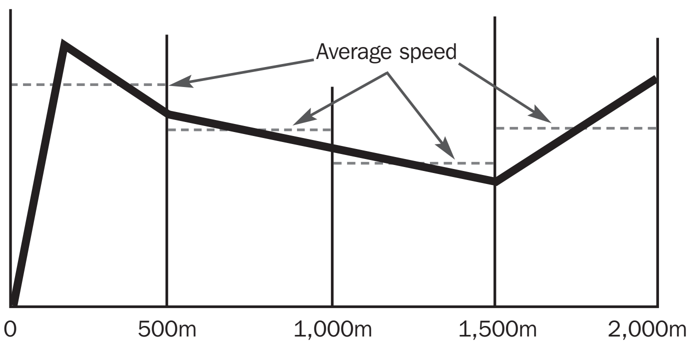
- The physiological and energy demands of 2,000m rowing are explained;
- A training band system is outlined, which can be tailored to train specific energy systems;
- A 4-stage testing procedure is described in order to help rowers and coaches design an appropriate training program.

As sports go, rowing is not high on skill. The reason for this is that it is a 'closed skill sport', which means the rower only has to learn one simple sequence of movements in order to master the technique. However, although the rowing sequence is relatively simple, repeating it 34-40 times per minute for 6 or more minutes in a 2,000m race challenges every aspect of an individual's strength and endurance. As well as being a closed skill sport, in a crew situation it is also a coactivity sport, where all the members of the crew have to do the same thing at the same time.

Rowing races are a test of power; crews start level and race over the same distance. The boats used are strictly controlled so crews have to do the same work, which is to get themselves, and their equipment from the start to the finish as quickly as possible. The crew that completes the course in the fastest time has therefore generated the highest power.

The standard international race distance for rowing is 2,000m and race tactics are pretty straightforward. In terms of duration rowing races are about the same duration as middle distance running. However, rowing differ because rowers travel facing backwards, so they can only see what is going on behind them. Also once a boat has reached race pace it is very difficult to make it accelerate further. In rowing, there is an advantage to be in front from start to finish so that you can see and cover any attack, whereas in running, the advantage is to be behind until the last moment. Rowing crews will therefore start as fast as they can and then try to settle at the highest sustainable pace through the middle and build up to the finish line *(see figure 1).* Usually, the first quarter of the race is the fastest followed by the final quarter, with the 2 middle quarters relatively slower.

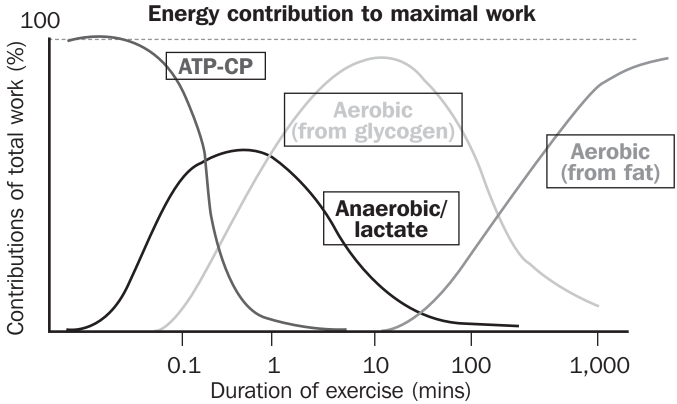
Figure. 1: Typical 2,000m race profile



Energy demands of 2,000m rowing

Rowers are able to apply the highest force on the first stroke where force in the region of 1,000 newtons has been measured [1] As the boat accelerates, the force that can be applied falls to around 250 newtons. The stroke rate typically climbs to around 48 stokes per minute in the first 45 seconds of the race before falling back to around 35 strokes per minute at around 90 seconds.

Figure 2: Relative contributions of energy systems during maximal exercise



The net result is that the local supplies of both **ATP** and **creatine phosphate (CP)** become drastically depleted in a very short time *(see figure 2)*. As energy demand greatly exceeds that which can be supplied via aerobic metabolism using oxygen, repeated muscle contraction can only continue as a result of **glycolysis**, which enables ATP to be generated in the absence of oxygen.

However, glycoysis results in the rapid accumulation of fatiguing lactate in the muscles, causing extreme fatigue. If the duration of the race were only about 1 minute, the amount of accumulated lactate wouldn't cause a problem; however, 2,000m rowers have to decide how much lactate they can tolerate and carry throughout the race, balancing the advantage of being ahead early on against the risk of complete fatigue due to excess lactate accumulation.

As the rowers slow down in the middle section of the race, they enter the aerobic phase where there is sufficient oxygen to metabolise the lactate produced and keep it at a managable level. Towards the race finish the rate of energy consumption increases again as do blood lactate levels. If you've timed it correctly, the last stroke of the race is the last stroke you are able to pull!

Physical demands of rowing

At the race start, the highest forces are generated, which require maximum strength. For the first 20 seconds, maximum power is required, which is supplied by CP stores in the muscle. From 20-45 seconds, the fuel for energy is supplied mainly by muscle glycogen broken down with insufficient oxygen, causing lactate acid accumulation. Energy supply is instantaneous but inefficient and unsustainable. From 45 seconds until the finish, energy is mainly supplied using aerobic metabolism; muscle glycogen remains the predominent fuel with some fat. Because sufficient oxygen is available, low levels of lactate acid are produced *(see figure 2)*.

To meet these physical demands training can be divided into the following training bands:

UT2: Endurance training

Total work time	Distance	Stroke rate	%Max boat speed	% Heart rate max	Lactate mmol/l
60-90mins	15-25kms	18-20	70-75%	70-75%	2 or less

The training aim of UT2 training is to develop a sound aerobic base by continuous exercise for the prescribed time or distance. The biomechanical aim is to drive as hard as possible, resting on the recovery so that you remain within the aerobic limit. UT2 can be carried out throughout the year and is compatible with all other types of training. It can also be used as active recovery, either from a very heavy training period or recovery from illness or injury. UT2 also offers the opportunity to develop technique.

UT1: Strength/Endurance training

Total work time	Distance	Stroke rate	%Max boat speed	% Heart rate max	Lactate mmol/l
30-60mins	15-20kms	20-24	75-80%	75-85%	2-3.5

UT1 training and biomechanical aims are the same as UT2. The training is carried out at a higher intensity and therefore is carried out in long intervals such as 2x20 minutes. The rest between the intervals should be long enough for the heart rate to drop to twice resting rate. UT1 can be carried out all year round, as it is compatible with most other types of training. However, it should not be mixed with high intensity training.

AT: Endurance training					
Total work time	**Distance**	**Stroke rate**	**%Max boat speed**	**% Heart rate max**	**Lactate mmol/l**
24-40mins	15kms	24-28	81-85%	>90%	3.5-4

AT is the highest sustainable training intensity that can be sustained before the onset of the debilitating effects of lactate accumulation. The session is broken up into medium length intervals such as 8-10 minutes segments. The rest periods should allow the heart rate to fall to twice resting. The biomechanical aim is to ensure that boat speed is proportional to the higher effort. AT training offer major benefits during the pre and competition periods, but can also be included in a limited form all year round.

TR: Development of the oxygen transport system					
Total work time	**Distance**	**Stroke rate**	**%Max boat speed**	**% Heart rate max**	**Lactate mmol/l**
12-20mins	15-20kms	28-36	86-90%	90-100%	4-6

TR is the transition point between the aerobic and anaerobic energy systems. Work at this intensity is carried out in intervals from 2–5 minutes, causing lactate to accumulate in the working muscles. Training in this band helps to develop a tolerance to high lactate levels and to increase enzyme activity, which acts as a buffer by metabolising some of the lactate in the working muscles. The biomechanical objective is to increase boat speed in proportion to the greater effort and to establish a good rhythm with a strong drive and relaxation on the recovery. TR is most effective in pre-competition and competition periods and should be interspersed with UT2.

AN: Anaerobic work – maximum physiological response					
Total work time	**Distance**	**Stroke rate**	**%Max boat speed**	**% Heart rate max**	**Lactate mmol/l**
12-15mins	12-16kms	Max	Max	Max	6+

Short intervals of 45secs to 2 minutes training in the AN band means that all energy systems are working flat out causing high levels of lactate accumulation. The biomechanical aim is to get the boats speed above race pace in proportion to maximum effort. Rowers should ensure they have completed a good warm up prior to commencement of AN work. AN work should be carried out with sessions of UT2 and is most effective during the competition period.

AL: Anaerobic alactate					
Duration	**Distance**	**Stroke rate**	**%Max boat speed**	**Heart rate**	**Lactate mmol/l**
10-12 sets of 7-15 strokes	8-12kms	–	Max	Max	–

AL training is carried out in very short bursts and uses stored CP for energy so that there is no lactate accumulation. It can be carried out twice a week throughout the year by adding to the end of UT1 and UT2 sessions.

Periodising your training

The traditional rowing plan is an annual plan divided into three phases; transition, preparation and specific. The transition phase lasts for four weeks, the specific phase for twenty-one weeks and the remainder is the preparation phase. The specific phase is usually divided into two – pre-competition and competition phases with durations of nine and twelve weeks respectively *(see table 1)*.

Training to perform

Rowing is an expression of power and endurance. To simplify matters you can consider four areas that determine rowing condition: maximum power, anaerobic capacity, specific aerobic capacity and endurance.

Table 1: Typical periodisation phases in rowing

Phase	Training Aim
Transition phase (4 weeks)	Situated between the final competition of the year and the beginning of the preparation for next; Some minimal level of activity should be maintained through cross training; Time to evaluate performance and set objectives for the coming season.
Preparation (27 weeks)	The two main aims of the preparation phase are to develop general physical capacity and to improve technically; Confidence for the coming season will grow with improvements in physical and technical ability.
Specific pre-competition (9 weeks	Training becomes more specific with increases in stroke rate and shorter intervals; Continue to develop good technique as work intensity increases; Mentally, the focus is on quality during every session.
Specific competition (12 weeks)	Training intensity continues to increase which can lead to break down in technique; This needs to be addressed during the low intensity sessions in the programme; This is the time to perfect the racing start and also to develop race tactics and strategy for competition as well as to stabilise competition performance.

1. **Maximum power** – can be determined by a 7-stroke standing start on the Concept 2 rowing ergometer. With the monitor set to display watts, record the average watts over the 7 strokes;
2. **Anaerobic capacity** – set the monitor on the Concept 2 to 1 minute and record the average power in watts rowed flat out;
3. **Specific aerobic capacity** – record the time taken to row 2,000m on the Concept 2 and the average power in watts;
4. **Endurance** – as above but over 5,000m.

The average maximum power of the 7-stroke test can be expressed as two values: the actual power and used as a '100% reference', against which the other values are measured. As a rough guide in a rowing crew:

- The average anaerobic power measured over 1 minute should be between 90% and 100% of average maximum power;

- Specific aerobic capacity measured over 2,000m should be between 55%-65% of average maximum power;
- Endurance measured over 5,000m should be between 45%-55% of average maximum power.

Table 2 shows an example of the test results from a club 8+:

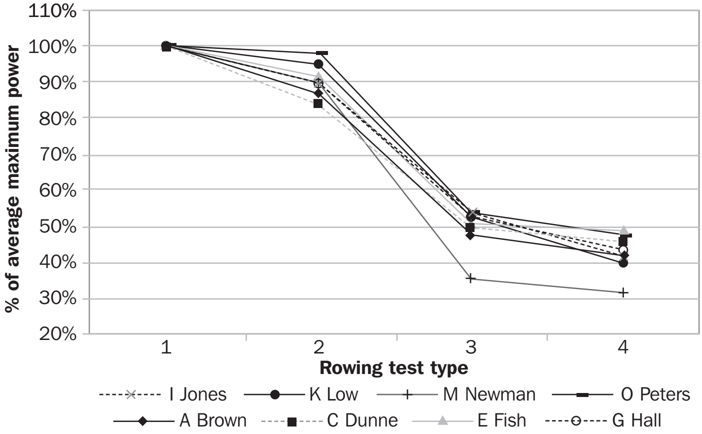
Table 2: Anaerobic and specific aerobic capacity and endurance in a crew of 8 referenced to the average maximum power output (figures in bold)

Name	Max Power (Watts)		Anaerobic capacity		Specific aerobic capacity		Endurance	
	Watt	% Ave Group	Mtrs	Watts	Time	Watts	Time	Watts
A Brown	815w	112%	380m	712w	6.25	392w	16.49 3	40w
	100%		**87%**		**48%**		**42%**	
C Dunne	750w	103%	365m	633w	6.31	375w	16.42	348w
	100%		**84%**		**50%**		**46%**	
E Fish	649w	89%	358m	596w	6.46	334w	17.10	320w
	100%		**92%**		**51%**		**49%**	
G Hall	764w	105%	376m	687w	6.20	408w	16.41	340w
	100%		**90%**		**53%**		**44%**	
I Jones	698w	96%	365m	630w	6.29	380w	16.49	293w
	100%		**90%**		**54%**		**42%**	
K Low	758w	104%	381m	719w	6.21	405w	17.31	301w
	100%		**95%**		**53%**		**40%**	
M Newman	764w	105%	376m	687w	7.15	272w	18.50	243w
	100%		**90%**		**36%**		**32%**	
O. Peters	623w	86%	361m	610w	6.45	337w	17.35	302w
	100%		**98%**		**54%**		**48%**	

This information can be expressed graphically by plotting relative power outputs (compared to average maximum power output for the crew as a whole) for each crewmember, which then allows you to compare athletes within your squad *(see figure 3)*.

Athletes whose power outputs are significantly below the rest of the crew in either the anaerobic, specific aerobic capacity or

Figure 3: Graphic representation of relative power outputs for crewmembers



endurance measures (*eg* M Newman – specific aerobic capacity and endurance in figure 3) can then undergo training to bring them up to strength (within 5% of the team average).

Using the test data in practice

When gathering this information there are a couple of points worth mentioning. It is quite common that with lightweight rowers, the average power level in the 1-minute test is higher than that in the 7-stroke peak power test. There are two reasons to explain this; heavyweight athletes who can generate high power levels tire at a faster rate than lightweight athletes who generate less power. The other reason is that most lightweight athletes do not have the outright strength to generate high power levels on the first few strokes and therefore with only seven strokes in the test the average is brought down.

Using the systematic approach training described above, athletes displaying anaerobic weakness will need to bias their training sessions towards those involving short intervals and lactate tolerance *ie* from the 'AN' and 'TR' training bands. For those displaying aerobic weakness, the emphasis should be placed on over-distance *ie* sessions from the 'UT1' and 'UT2' training bands, and intervals at race pace from the 'AT' band. Strength training is most effectively dealt with through weight training.

Terry O'Neill

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Jargon buster

ATP – a molecule containing high-energy phosphate bonds, which is used for a number of energy intensive tasks in the body including muscular contraction.

Creatine phosphate (CP) – a molecule that can donate its high-energy phosphate bond in order to temporarily regenerate ATP during extremely intense exercise.

Glycolysis – a metabolic pathway for the generation of ATP via the breakdown of carbohydrate without the presence of oxygen, which however leads to the accumulation of fatiguing lactate.

How thoracic spine flexibility can keep injuries at bay

Rowing can be the most demanding of sport: crawling out of bed at 4am for a two-hour session on a cold winter morning, putting in a full day's work, then returning to the fray in the afternoon for a hard session in the gym. When you put in that much hard work and make so many sacrifices, injury can be devastating – especially when it could have been avoided by doing some simple flexibility work.

Rowing consists of repeating the same cycle of body movements with a large output of force. It is for this reason that rowers suffer mostly from overuse injuries – usually of the spine. When dealing with such injuries, many aspects of the athlete must be considered and addressed.

In rowing, as in all sports that involve continually performing the same sequence of movements, technique plays a vital role in preventing injury. Poor technique will cause athletes to become tight in certain areas. If a rower is weak or has poor muscle endurance, then he/she will not be able to row with good technique. A rower must have good core stability and strength around his/her scapulas to hold the correct body position in the boat.

Technique and strength are areas where athletes should strive for continual improvement, but achieving excellence in these areas is a long process. In the meantime, rowers must still train hard to improve performance and, in consequence, parts of their body will become tight or stiff. The thoracic spine is one such area. The thoracic spine is the second most commonly-injured area in rowers, after the lumbar spine. It is considered the least mobile area of the vertebral column, due to the length of the transverse processes, the costovertebral joints and the decrease in disc height when compared with the lumbar spine and rib cage.

Movements that occur in the thoracic spine are mostly rotation and flexion/extension. But rowers tend to become limited in extension because of the amount of time they spend in a seated position and their tendency to fall into thoracic spine flexion, especially when fatigued.

‘Rowers tend to become limited in extension because of the amount of time they spend in a seated position’

Extension stiffness is often associated with limited movement into rotation. It is essential that rowers perform regular flexibility exercises to maintain their thoracic extension and rotation; otherwise, they place themselves at risk of rib stress fractures, facet and costovertebral joint irritation, which can often refer pain to the chest wall or muscle trigger points in the erector spinae, rhomboids, levator scapulae or upper trapezius. Stiffness in the thoracic spine can also place additional loads on other structures, such as the lumbar spine and shoulders.

The following case studies show how rowers can keep their thoracic spines flexible.

Case study 1: rower with right-sided upper chest pain

Fifty-year-old Barbara just loves to row and does so for up to 90 minutes at a time, five mornings a week, as well following a self-designed gym programme a couple of times a week, working full-time and looking after her family.

Barbara presented to physiotherapy two months before she was due to compete at a major event with a three-week history of worsening right-sided upper chest pain when rowing. She has twice suffered rib stress fractures anterolaterally on the left side, and says she always feels some pain around that area when she rows.

Barbara was understandably concerned that she might have stress fractures on the right side, but the area where she was feeling pain was not typical of stress fractures and she was not tender on palpation through that area. Examination revealed marked tenderness through the right costovertebral joints from T3-7, with limited thoracic extension and rotation to the right.

The diagnosis was facilitated by the fact that mobilising the costovertebral joints reproduced the right-sided chest pain. Barbara breathed a sigh of relief when I explained that I didn't think she had stress fractures on the right. In fact, she was suffering from a referral of pain from her costo-vertebral joints that related to her limitation of movement in the thoracic spine. Management from this point was relatively simple. Barbara rested for two days while we got in and loosened up the area with trigger points to the overlying muscle and joint mobilisations to the costovertebral and facet joints. She then reported a significant decrease in pain the next time she rowed.

Barbara was convinced that she needed to attain flexibility in her thoracic spine, and keep it that way, if she was to continue to enjoy rowing. We started her on regular stretches to improve her extension and rotation, and self-trigger pointing over a tennis ball to decrease the muscle tension over the joints.

Her new friend became the thoracic wedge, which is designed to increase extension range of movement. The wedge is a hard piece of moulded rubber that you place on the ground with a groove cut away for your spine to sit in. You lie on the ground with the wedge sitting between your shoulder blades and arch over it. The same can be achieved with two tennis balls taped together. It is a good idea to perform this exercise before stretching.

With treatment, Barbara also started to feel less pain in her ribs on the left side. We progressed her treatment to include mobilising all of the stiff areas in her thoracic spine and some remedial massage therapy to help speed up the process. Within three weeks, Barbara had ceased – for the first time in years – to feel pain anywhere in her thoracic spine or ribs when she rowed.

She was obviously determined to keep things that way, and her new training programme includes flexibility exercises for her thoracic spine, regular massage therapy and a new gym programme (devised by an experienced strength and conditioning specialist) that concentrates on her upper-back strength, scapula stability and core stability.

Case study 2: rower with right anterior shoulder pain

Kathy, another extremely fit-looking middle-aged woman, was a long-time friend and training partner of Barbara, and like Barbara she also worked full-time and followed a similar training schedule. Kathy complained of right anterior shoulder pain that had been present for a couple of months when she rowed and had also started to hurt when she performed any exercises that involved elevating her arm. Her left side was not painful at the time, but had given her problems in the past.

On assessment, Kathy showed all the positive signs of subacromial impingement. Her posture was poor, she was rounded through her thoracic spine, and her humeral head position was well forward. Impingement tests were positive and her posterior rotator cuff was very tight. I postulated that the impingement related mostly to the poor posture of her shoulder, caused by her stiff thoracic spine and tight posterior rotator cuff musculature.

This was an example of stiffness in the thoracic spine imposing excessive loads on other structures, and we immediately began addressing these two areas. Trigger points through infraspinatus and teres minor were performed in physiotherapy and at home, using a tennis ball, as described below. To do this, place the tennis ball between your shoulder blade and a wall, resting on any points that are tender. Remember not to roll over these points but to maintain the pressure on them until the pain starts to ease, then go on to another point.

Kathy had to stretch these muscles after the trigger points. This can be done by taking your arm across your body at shoulder height with a bent elbow and using your other hand to pull the elbow across. If you can't feel the stretch, try holding your shoulder blade back as you pull your elbow across.

We began to loosen Kathy’s thoracic spine through joint mobilisations in physio, through stretching, and using two tennis balls taped together.

Kathy's shoulder posture improved noticeably, and after two weeks of working on those two areas, she was rowing without any shoulder pain. Kathy was convinced that she needed to start addressing these areas with some regular flexibility exercises. Ironically, she had suffered from rib stress fractures in the past and had some ongoing pain in this area. Just as with Barbara, Kathy's rib symptoms also disappeared with the increase in thoracic spine flexibility.

Kathy then went to the same strength and conditioning specialist to work on the same areas as Barbara, as well as specific exercises to strengthen through her posterior rotator cuff.

We now had two very happy clients one week away from competing, both rowing without pain for the first time in years. Rowers, take note: keep that thoracic spine flexible. Don't let all your hard training be wasted because of an injury that could have been prevented.

Sean Fyfe

Pain and gain – how rowers can manage and overcome pain?

"Pain is inevitable, but suffering is optional." So goes a well-known but anonymous quote. For many rowers, pain is a normal everyday experience and success is often achieved in spite of pain. But what's the best strategy for coping with and overcoming pain and how can rowers distinguish between benign and potentially damaging pain?

At a Glance

- The popular theories of the mechanisms of pain are examined;
- The role of the nervous system in pain generation is explained;
- Strategies for assessing how to react to pain for minimal disruption to training are outlined.

Pain is synonymous with sport. Endurance athletes relish the challenge of 'pushing through pain' while boxers expect to fight on regardless of a jarring blow to the chin. Adulation is reserved not just for the star rugby player, but anyone who can play through pain and contribute to the team. Winners and heroes overcome pain. Losers don't.

But the price of pain can be high. Pain both demands attention and creates fear [1]. It can restrict the ability to concentrate on performance and take away the opportunity to compete. Pain can even end sporting careers. The relationship between pain and sport is filled with challenges for sportsmen and women as well as those who support them. However, although pain of some description is no stranger to most athletes, it's still a curious phenomenon in many ways. For example, consider the following questions:

- How are some people able to shrug off a painful injury?
- How can two rowers with the same injury experience different pain?
- Why do some pains seem to last 'forever'?
- Why can some people compete, seemingly regardless of pain, while others struggle to overcome even a minor niggle?

'an extensive network of nerves supplies the various tissues in your back, making them potential sources of pain when injured'

This article will explore these questions, offering practical advice about when it is appropriate to perform in the presence of pain, when you should consult a professional, and how to best approach pain in a sporting environment.

The diagnostic dilemma

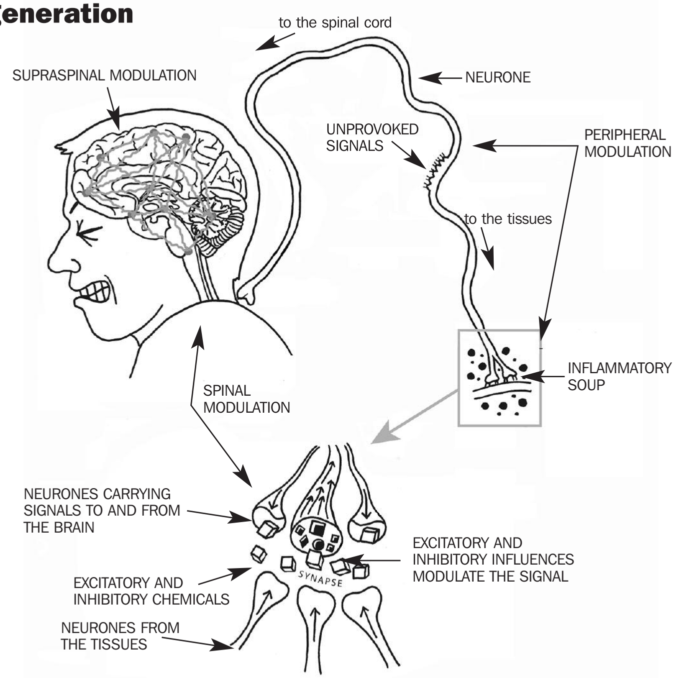
If you tear your hamstring muscle or sprain an ankle it hurts – obviously. Since the seventeenth century, the medical and scientific world has sought to diagnose pain by identifying the particular tissue that has been injured. For example, the philosopher Rene Descartes proposed that a pure pain sensation is transmitted from the damaged body to an entirely separate organ, the mind, just as… pulling on one end of a rope… makes to strike at the same instant a bell which hangs at the end [2,3]. Descartes separated the body from the brain, and even today it is usual for people to make a distinction between physical pain and mental pain [3,4]. This is especially the case in sport.

However, there are some problems with this classical view of diagnosis. For instance, an extensive network of nerves supplies the various tissues in your back, making them potential sources of pain when injured [5]. It follows that if you can identify the damaged spinal tissue, for instance using **Magnetic Resonance Imaging (MRI)**, it should be possible to explain the pain.

The problem is that while MRI findings of severe damage to the discs or nerves is associated with the experience of pain, studies have failed to demonstrate a clear relationship between the majority of tissue damage observed on MRI and the patient's pain [6]. What's more, almost 40% of people who have no history of back pain have abnormal, damaged spines at more than one spinal level when scanned using MRI [7]! Likewise, the damage shown by **ultrasound** investigations of athletes with painful patella tendons (jumper's knee) does not necessarily correspond directly to the degree of pain experienced by the athlete [8].

This doesn't mean that identifying the injured structure is not important or that it isn't crucially involved in your pain. But looking to tissue damage alone (which is both frequent and often quite subtle in sporting injuries) to explain the relationship between pain and sporting performance is probably not sufficient.

Figure 1: Nervous system processes in pain generation



Nervous system processes in pain generation

Peripheral modulation – a normal response following tissue injury. Pain receptors are stimulated, initially by tissues being stressed or strained, and then by the release of pain stimulating chemicals [10]. These chemicals are often referred to as 'inflammatory soup' and **sensitise** the pain receptors, so that for a period of time relatively gentle movements and pressures are enough to cause pain [10,13]. In certain circumstances, such as nerve injury, inflammatory soup and unprovoked signalling from the nerve can lead to long lasting sensitisation and pain [14,15].

Spinal modulation – primarily occurs at the junction between peripheral and spinal nerves. Rather than a signal passing straight to the spinal nerve (remember the telephone exchange model) for onward transmission to the brain, a range of signals from other peripheral and spinal nerves (some under the control of the brain) arrive at the junction at the same time, either increasing or decreasing the transfer of the signal [2,3].

Supraspinal modulation – takes place in the brain. While modern studies have confirmed that there are some areas of the brain consistently involved in painful experiences, they have also revealed that activity is spread throughout the brain, including areas not previously considered pain centres [1, 16-18]. What's more, brain activity is not the same for each painful experience. This widespread and variable activity helps explain how our attention, beliefs and experiences are involved in all pain and not just in mental pain [1,3,16].

A painful process

Another theory, first proposed in 1965, suggested that far from acting like an old fashioned telephone exchange, your brain and spinal cord can actually increase or inhibit the transmission of pain signals [9]. Gate Control Theory was revolutionary because it proposed a mechanism for the brain to have a modulating influence on the generation of all pains, and not just mental pain [10]. While the original theory has been modified and expanded, it has essentially stood the test of time and been supported by forty years of scientific research [11].

If you listen to the language people use to describe their pain, it soon becomes apparent that pain is quite simply pain, and is not separated into physical or mental compartments. All pain invokes not just a pure sensory response, but a range of thoughts and emotions also [3,12] and pain emerges from the integrated, combined action of the pain system [2,3]. Simplistically, this system can be viewed as three separate parts of the nervous system, all of which modulate pain (see box on nervous system opposite).

How do some people shrug off a painful injury?

Remember that following an acute injury, such as an ankle sprain, pain receptors are first stimulated by the mechanical stress and strain placed upon the tissue. 'Inflammatory soup' soon floods the tissue leading to peripheral sensitisation. Several hours later, similar chemicals will also lead to spinal modulation [19]. Pain and sensitivity to movement and pressure increase over a period of a few hours; the time between the transition from the original mechanical pain (which may pass) to the maximum sensitised state may provide athletes with a 'window of opportunity' to shrug off their pain and continue competing.

'In the cut and thrust of competition, the pain system can 'shut the gate', and athletes are able to continue in spite of injured tissue'

However, this mechanism is probably only the tip of the iceberg. When you are totally focussed on your opponent, or consumed by the contest, suprapsinal and spinal modulation may act to inhibit the transmission or limit the awareness of the pain signal [18]. We've all heard stories of sportsmen and women who have continued despite an injury which (theoretically) should have caused them to stop: a boxer with a broken hand, rugby players with torn ligaments, a long jumper with a strained hamstring etc. In the cut and thrust of competition, the pain system can 'shut the gate', and athletes are able to continue in spite of injured tissue [18]. However, once your attention is drawn back to the acute pain (particularly following competition), awareness of the pain becomes strong again, especially if this also coincides with an increase in peripheral and spinal modulation.

So, should you ignore pain and try to shrug off an injury? Acute sensitisation is a normal, helpful process to encourage you to stop using the injured tissue and avoid further damage [20]. It might be helpful to ask yourself the three questions in the box below.

The three 'C's'

- Can you cope with the pain?
- Are you able to contribute a meaningful performance?
- What are the consequences of continuing?

There are a few other questions, which are perhaps even more important. We'll get to these later. But remember, acute pain usually occurs for a good reason. It makes sense to seek professional advice as soon as you can. Sometimes people can overcome acute pain and continue to compete, but it doesn't necessarily make it a wise decision!

How can two rowers with the same injury experience different pain?

Studies have confirmed that people respond differently to similar levels of painful stimulation [19]. Differences exist not just in our individual sensitivity to a painful stimulus, but also in our perception of pain and how we display it. Pain is individual, even when the stimulus is not, but while we cannot know exactly what someone else is experiencing, our brains undergo quite similar activity when confronted with someone else's pain [21]. This is the basis for empathy and acknowledging someone's pain is normal and important.

Our individual sensitivity to pain is in part explained by our genetic makeup [22-24] while studies involving twins have shown that learned behaviours are also important [25]. Again, the division of pain into real and mental is unhelpful and the variation in pain between two athletes with the same injury lies at all levels of the pain system. Even for the same athlete, pain sensitivity varies under different circumstances, and perhaps not surprisingly, can become significantly less during competition [26].

It's also worth noting that different groups in society may have significantly different pain responses, and this applies within sport. A study performed forty years ago demonstrated that contact sport athletes could tolerate experimental acute pain for longer than non-contact athletes, while both groups could tolerate more acute pain than non-athletes [26].

Pain sensitivity may also be different in different people at different times; the way athletes display that they are in pain can vary, both between individuals and also between groups of athletes from different sports. It might be an extreme example, but imagine a footballer who could potentially be rewarded with a penalty responding to the pain from a kick in the shin. Now, assuming the tissue damage is equivalent, think about the same incident involving a Thai kick boxer who is in the middle of a title fight. Get the idea?!

'People who develop an exaggerated, negative mindset towards their ongoing pain have been shown to experience both increased pain and emotional distress'

Why do some pains seem to last forever?

During ongoing or chronic pain, adaptive changes at all levels of the pain system often outlast their usefulness in helping us protect injured tissues. Movements and pressures that would otherwise be normal continue to cause pain long after the risk of further injury has passed and often even once the tissue has essentially healed.

Examining possible tissue damage remains important when considering ongoing or recurrent pains, but a broader approach is required to address an athlete's fear and anxiety about their ongoing pain and help them return to their sport. Focussing too much attention on pain can actually increase pain [18]! It is probably more helpful to concentrate on working hard to strengthen the tissues at a sensible rate, regain normal fitness and aim to return to training.

Providing an appropriate environment for people to overcome ongoing pain is important and not always easy in sport. Coaches or team mates who are angry at or ignore athletes with ongoing pain may contribute further to those athletes avoiding the very things that will help them return to full activity (such as a rehabilitation program), and generate further anxiety that doesn't help either [27]. Getting this balance right and remaining positive is therefore important. People who develop an exaggerated, negative mind set towards their ongoing pain have been shown to experience both increased pain and emotional distress [28]. Pain is a normal part of sport but the right mental approach can prevent it from becoming a catastrophe!

Does this mean it is okay to ignore ongoing pain? Well, it's not quite that simple. Once again consider the Three 'C's'. Any pain that has been present for more than a week or so, or keeps returning periodically is worth getting checked out by a professional who can not only assess for tissue damage but can also understand your pain and hopefully point you in the right direction before the maladaptive changes to your nervous system become entrenched.

Why are some people able to compete, seemingly regardless of pain, while others struggle to overcome even a minor niggle?

Although pain (especially acute pain) is related to tissue damage, this damage alone is not sufficient to explain pain fully. Pain is not just a sensation but results from the interaction between sensory inputs and brain processes, such as emotion and conscious thought. And pain is individual, not just to you as an athlete, but also to the time, circumstance and environment you find yourself in. Within the mechanics of the pain system, individual variation and modulation occur subconsciously, which helps to answer this question.

To ultimately address the relationship between pain and sport however, it is necessary to consider one further aspect of pain: your own 'personal values'. We've already considered 'The Three C's' as a guide to considering how to act in the presence of pain; however, as anyone involved with sport knows, making decisions about athletes in pain is often a judgement call. The Three C questions only have meaning if we add a further, more personal line of questioning:

Adding value to three 'C's'

- Am I ***prepared*** to cope?
- How ***important*** is contributing a worthwhile performance to me?
- Am I ***prepared*** to suffer the consequences?

Having a pain killing injection two days before an Olympic final, regardless of the risks, would seem quite a reasonable thing to do for most elite athletes if it was the only way they were able to compete. Under similar circumstances, few casual joggers would agree to the same injection just days before a fun run. Entering a boxing ring, running 100 miles a week or crashing into a rugby scrum is not for everyone. Some people can continually and repeatedly overcome pain for the sake of their sport because they are prepared to. Sometimes they are rewarded with success, and sometimes, despite their desire to cope and contribute, their body succumbs to the consequences. Winners and heroes overcome pain sometimes. Losers often try and fail. Perhaps the most successful sports people are those who best understand the relationship between pain and performance: they are prepared to overcome pain, but make wise, informed decisions about when it is worthwhile trying to do.

Matt Lancaster

The dos and don'ts of pain and performance

As explained above, everyone responds different to pain stimuli, responses that may vary according to social and emotional environments and even expectation. However, here are a few tips that all athletes and coaches should bear in mind:

DO

- **Acknowledge pain** – Pain is pain. It is not 'physical or mental'. Coaches and other team members should understand that showing empathy is normal and helpful;
- **Seek professional advice** – Consult a sports doctor or physiotherapist for any acute, ongoing or recurrent pain;
- **Recover & rehabilitate** – Focus on allowing the tissue time to heal and work to become strong and fit again.

DON'T

- **Be too concerned** – Too much focus and attention on pain is counterproductive to sporting performance;
- **Fear pain** – Hearsay stories of similar pains ending careers are unhelpful. Pain is a normal part of sport; don't let it become a catastrophe;
- **Punish or reward** – Being angry at or ignoring athletes is as unhelpful as being over attentive. Remain positive, interested and constructive.

Jargon buster

Sensitise – conditioning tissue so that a particular stimulation produces a greater response than normal.

Magnetic Resonance Imaging (MRI) – A type of medical imaging technology that uses strong magnetic fields to make certain atoms in the body produce signals that can be detected by special radio equipment in an MRI machine.

Ultrasound – scanning technique using high-frequency sound waves bounced off internal tissues or organs to make echoes that are used to generate images.

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Masters rowing – don't fear the reaper!

As Mark Twain once said, "Age is an issue of mind over matter. If you don't mind, it doesn't matter." While older rowers can't completely escape the effects of age-related performance decline, the right kind of training can enable them to perform at the highest level…

At a Glance

- The evidence for age-related performance decline is presented;
- The physiological and physical requirements for successful masters rowing are discussed;
- The use of marathon rowing training programs to enhance rowing performance in older rowers is outlined and examples given.

The science of aging predicts a gradual decline in the body's ability to function as we get older. The precise mechanisms underlying the aging process are not fully understood, but the rate of decline in the general population of biological and physiological functions is known to be progressive and age related. The reduction in exercise capacity in older individuals stems from a decrease in muscle mass, cardiovascular function and respiratory function. One age-related alteration to respiratory function is decreased respiratory muscle strength and endurance and decline in respiratory muscle strength may lead to breathlessness during activities of daily living and exercise.

The following panel summarises the general and specific age related evidence for biological and physiological decline.

General evidence [1]

- Biological and physical peak is reached between ages 20-35;
- During middle age 35-45 physical activity usually declines with a 5-10kg accumulation of body fat;
- In later middle age (45-65) women reach menopause and men reduce substantially their output of sex hormones. The decline in physical condition continues and may accelerate;
- Early old age (65-75) modest increase in physical activity following retirement but by middle old age (75-85) many people have developed some physical disability and in very old age, (over 85) totally dependency may set in;
- Typical expectation is 8-10 years of partial disability and a year of total dependency.

Physiological evidence

- Maximum heart rate declines with age;
- Maximal oxygen uptake (VO_2max) decreases by 10% per decade in men and women regardless of age and exercise activity [2] although other studies have shown no decline in aerobic capacity during a 10 year period in people maintaining constant training [3,4] ;
- Factors other than physical activity are also crucial to the decline of maximal oxygen uptake – heredity, increase in fat, decrease in skeletal muscle mass.

However, it's not all bad news; several studies have shown that for athletes the decrease in maximum heart rate from age 50-70 is smaller than non-athletes [5] and exercise training for older people may increase aerobic capacity to the same relative extent (15-30%) as in younger adults [6-9]. Indeed, the endurance performance of older athletes provides good evidence of the benefits of maintaining regular exercise to preserve cardiovascular function and the overall conclusion is that exercise training improves physiologic response at any age and improvements often occur at a rate and magnitude independent of a person's age [10,11].

Age and indoor rowing

The specific sport of indoor rowing is well suited to older athletes. The sport is organised in 5 or 10-year age bands, male, female, heavyweight and lightweight (75kg for men, 61.5kg for women being the border between the two weight categories). Typically races are over 1609m (1 mile) or 2,000m. Age groupers tend to improve when they commence training and then quickly achieve peak performance. It may be possible to hold peak performance for a limited period before age related decline sets in [2].

Age groupers train consistently four to six times per week to maintain fitness, or in an attempt to reduce the decline in performance. High intensity exercise may reduce the age related decline in young and middle aged men by up to 50% (but not in older men) and for middle aged and older women it does not appear that the fitness loss rates can be reduced [2] although the author's work with older rowers supports an increase in aerobic capacity is possible with the correct training.

A 2,000m rowing race is a power/endurance event. There is evidence to suggest that the decline in power is characterised by early onset and rapid decline whilst endurance decline in rowing is not as rapid [12]. Muscle mass declines, particularly **fast twitch muscle**, which suggests there is an inherent loss of ability to produce powerful muscle contractions with increasing age. This loss of muscle mass is most severe during the 4th decade (30-40) where research has shown a decline in power of 3% per annum with 1% per annum every year thereafter for both men and women [12].

However, in a study of power lifting and rowing, the results suggest that from age 25 to 85, men's performance decreases by 29% with a gradual decline of just 4% from 25-55 and a more rapid decline after 55 of 0.83% per year [13]. For women aged 35-55 there is a gradual decline of 5% and after 55 the decline is more rapid at 0.80% a year. Men's performance peaks in their 20s while women's performance peaks in their 30s [12].

Despite persistent training, the effectiveness of training for development of muscle strength decreases progressively and rapidly with age

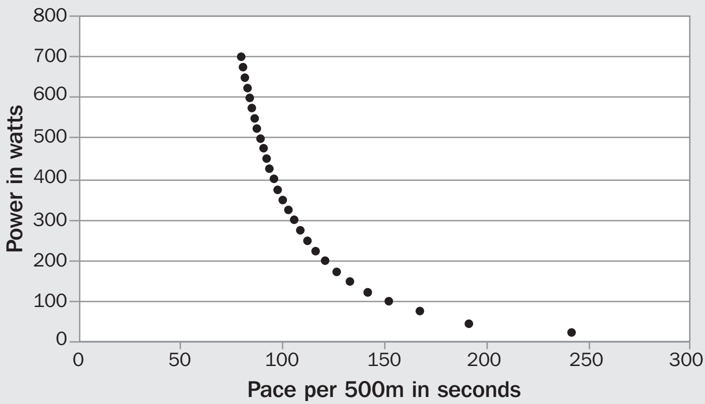
In an indoor rowing-specific study into the gender differences in rowing performance and power with aging, performance time (over 2,500m the standard race distance at the time of the study) to power output revealed that men and women lose absolute power at similar rates across the age span and that performance is only modestly correlated with age [13]. However, when the analysis was restricted to the best 5% of performers in 2-year age increments, age became the most powerful predictor of performance variance. For the top male rowers between ages 24-50, performance decline was only 3% per decade compared to 7% from age 50-74. The decline for women was essentially linear across a 50-year age span.

Physics of rowing and aging

Different starting positions on the power-velocity curve create differences in the pattern of performance decline between men and women. The maintenance of relative power between men and women suggests that differences in aging on performance are caused more by physics than physiology. For example, Figure 1 shows a plot of 25-watt intervals on the Concept II ergometer. As the graph reveals, the relationship between power (in watts) and pace is not linear but a curve.

Figure 1: Relationship between power output and 500m pace on Concept 2 ergometer

data from Concept 2



For instance, let's assume that rower 1 has a 2,000m performance of 8 minutes 24 seconds, which equates to 2:06 per 500m or 175 watts. Adding 25 watts would reduce the 2,000m time to 8 minutes 2 seconds giving a pace per 500m of 2:00.5 – a gain of 22 seconds. But suppose that rower 2 has a 6 minute 2,000m time (1min 30s per 500m or 480 watts). Increasing power in rower 2 by 25 watts would reduce the time over the 2,000m distance down to 5.51.2, giving a pace per 500m of 1:27.8 Rower 2 gains just 8.8 seconds for the 25 watt increase in power.

> ***In absolute terms the loss of power for both men and women is the same over a 50-year range at approximately 4 watts per year.***

2,000m rowing performance depends to a large extent on aerobic power as well as gender and a number of other physical and physiological characteristics. However, 2,000m rowing also requires power and older rowers may struggle to maintain performance. Therefore, with increasing age, there is more reliance on the aerobic capacity of the body to row a 2,000m race. This means that it is vital that every component of the aerobic system in older rowers is working as close to maximum efficiency as it is possible to achieve. And while older rowers can continue to perform effectively for endurance events, they may struggle in activities that require maximal effort and power.

> *'While older rowers can continue to perform effectively for endurance events, they may struggle in activities that require maximal effort and power'*

A study of 16 female rowers suggested that during a 2,000m-race simulation, the anaerobic and aerobic contribution for female rowers was 12.3% and 87.7% respectively[14]. In this study, the main body of the race was rowed at an intensity equivalent to 91% of the participants' maximal oxygen uptake. Additionally the participants used 72% of their anaerobic reserves by the end of the first 2 minutes, and had completely taxed their stores by the end of the race. Further studies estimate the energy requirement for a 2,000m indoor row to be 65%-75% aerobic and 25%-35% anaerobic[15,16] but there are significant gender differences. Some researchers suggest that anaerobic capacity explains only 10%-20% of the variance in performance[17].

'Elite rowers tend to be tall, have greater body mass, lower subcutaneous skinfold readings and long limbs not only in absolute terms, but also in relation to their height'

The strongest correlate of performance appears to be power at maximal oxygen uptake, which accounts for 72% of the variation in 2,000m rowing performance [18]. Other research is more precise in stating that velocity and maximal oxygen uptake at 4.0 mmol.L^{-1} can predict 2,000m performance [19]. Conversely a 2002 suggested that mean power during a 30s **Wingate sprint rowing test** accounted for 75.5% of the variance in 2,000m performance time with only 12.1% accounted for by maximal oxygen uptake and 8.2% by fatigue during the test [17].

In successful male rowers, strength and anaerobic power are comparatively high but current conditioning protocols recommend little strength training. Muscular strength has been suggested as an important determinant of rowing performance. However, the use of muscular strength as a predictive model only goes so far because further increases in strength are no longer beneficial to performance due to the large aerobic contribution needed for a successful 2,000m row.

It has been recognised that anthropometric characteristics have some influence on rowing performance. Elite rowers tend to be tall, have greater body mass, lower subcutaneous skinfold readings and long limbs not only in absolute terms, but also in relation to their height [20]. Lightweight rowers also tend to be taller, long limbed and lean. Lean body mass and therefore the need to maximise lean body mass has been suggested as a major predictor of indoor rowing performance.

The final piece of the jigsaw relates to the additional demands that indoor rowing places on the respiratory muscles, if respiratory muscle fatigue occurs during rowing, it may be of physiological significance with detrimental consequences for performance. Prevailing science suggests that this high respiratory demand 'steals' blood from the legs during exercise and therefore performance is reduced [21]. By strengthening the inspiratory muscles blood flow demand to the respiratory muscles is reduced, cardiac output to the leg muscles is increased and therefore performance should improve.

Putting it all together for masters rowers

As we've already mentioned, the key to success in older rowers is maximising the efficiency of the aerobic system. Performance is determined by how close to the maximum oxygen uptake level (VO_2max) a rower is able to maintain performance throughout a rowing session, and by the economy of the performance (how much of the oxygen consumed by the rower's body is actually converted into performance).

In my experience, the most effective way to boost aerobic capacity in older rowers is to concentrate on long duration work, at low to medium stroke rates at intensities, between 75%-85% of maximal oxygen uptake (determined from physiological tests). And one of the ways to do this is to follow a marathon rowing programme. To row a 'fast' indoor rowing marathon, rowers need to sustain 75%-85% of maximal oxygen uptake with average heart rate close to 90% of maximum and pace per 500m which is equivalent to 60-70% of 2,000m power in watts.

'The most effective way to boost aerobic capacity in older rowers is to concentrate on long duration work, at low to medium stroke rates intensities, between 75-85% of maximal oxygen uptake'

Anna Bailey (world record holder for the 2,000m 50-59 age category) provides a good example of how training can improve aerobic capacity and enhance performance. Anna followed a very specific indoor rowing marathon programme in 2002 and 2003 before breaking the British Indoor Rowing marathon record, twice. Between June 2002 and October 2003, Anna's absolute maximal oxygen uptake (absolute oxygen uptake – not calculated on a 'per kilo' basis) increased from 3.7 litres to 4.2 litres. Anna was aged 50/51 at this time and having continued to train in the same manner is till setting more age group records at the age of 55.

Another (more recent) example is Alex Brown who at 55 set an age group record over the marathon distance in May 2006 after following a marathon training programme. He switched back to a 2,000m programme shortly thereafter and, in October 2006 recorded a 2,000m time of 6.33.3 in the Maltese Indoor Rowing Championships, a time he last achieved some years before (*see table 1 overleaf*).

Marathon programme

Depending on the monitoring equipment available to the rowers, training sessions can be based on duration, stroke rate, heart rate, % of maximal oxygen uptake or cardio-vascular fatigue (heart rate variability [22]) and pace per 500m. The marathon programme calls for approximately 24 hours of rowing training every 4 weeks and the intensity sequence is light, medium, hard, light for each 4-week period, which is repeated 3 times to make 12 weeks in total.

Rowers should spend 50% of their training time at marathon pace, 10% at half-marathon pace, 25% at 10,000m pace and 15% at 5,000m pace. Average pace per 500m will be equivalent to 65% to 70% of their 2,000m power in watts, and over the 12-week period, they will row approximately 1,000kms! Rowing time is from 60-90 minutes per session over a 4-week cycle, varying between 80-92.5% of maximum heart rate. Obviously more specific work at higher stroke rates, pace per 500m and relative intensity is necessary to fully prepare any age group rower for an all-out 2,000m race, but time spent building the aerobic base will provide the greatest return.

So what would a typical marathon session look like – this session is taken from a light training week of Alex Brown in preparation for his marathon record attempt.

Table 1: A typical light training week for Alex Brown

Session 1	2	3	4	5
60’ (2 x 30’ with 3’ rest) Alternate 7.5’ @10,000m pace 1.49.0 7.5’ @ marathon pace 1.54.5 HR 80 – 90% max	60’ (4 x 15’ with 4’ rest) Alternate 6’ @ 5,000m pace 1.46.5 9’ @ marathon pace 1.54.5 HR 85 – 92.5% max	60’ (3 x 20’ with 2’ rest) 20’ each @ marathon pace 1.54.5, 10,000m pace 1.49.0, half marathon pace 1.51.5 HR 80 – 90% max	60’ (4 x 15’ with 90” rest) Alternate 6’ @ 5,000m pace 1.46.5 9’ @ marathon pace 1.54.5 HR 85 – 92.5% max	60’ (2 x 30’ with 3’ rest) Alternate 7.5’ @10,000m pace 1.49.0 7.5’ @ marathon pace 1.54.5 HR 80 – 90% max

Stroke rate guide (strokes per minute):
Marathon pace 18-22; half-marathon pace 22-24; 10,000m pace 24-26; 5,000m pace 26-28;
Rest days taken after sessions 3 and 5.

An important caveat to add is that many part time and older athletes have a lot of other family and work commitments; they therefore need to ensure adequate recovery between training sessions. One way to help ensure this takes place is to use heart rate variability data to monitor cardiovascular fatigue [22]. The cardiovascular fatigue identified from the data after each session determines whether the next session is reduced in intensity, or whether additional rest and recovery is needed. The body needs time for recovery after a single high intensity session, a hard training period of several days, or even after a low-intensity but long rowing session as without rest the body's adaptation to the training stimulus will not occur.

More generally, the priority order for utilisation of training time for older indoor rowers can be summarised thus:

- Five very specific rowing sessions per week;
- Inspiratory muscle training using a POWERbreathe device every other day;
- Core stability/flexibility work and at least one specific rowing weights session per week (time permitting);
- Two days of complete rest and recovery per week;
- Training weeks for a 'cycle' should follow the sequence of light, medium, hard and light;
- Training should cease completely if the rower is ill or injured until fully recovered.

Summary

Whilst age decline will eventually take its toll, it is possible to maintain a high level of performance with regular continuous training particularly aimed at developing aerobic capacity. If any inspiration is needed, just look at the performances of the Open Champion and the oldest competitor in the British Championships; 33-year old Graham Benton won the 2006 Open event in a time of 5.46.7 – an average power output of 538 watts. Another rower called John Hodgson appears every year, and in the most recent Championships, he rowed 11 minutes 6.2 seconds for the 2,000m – a power output of approximately 75 watts. John is 96 years of age!

Eddie Fletcher

Jargon buster

Fast twitch muscle – the type of muscle fibres that contract very rapidly and which are used for power, strength and explosive movements.

Wingate sprint rowing test – 30-second all out rowing ergometer sprint from a static start, which records stroke power and overall mean power in watts.

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Carbohydrate drinks – is fructose the new key to enhanced endurance performance?

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.

At a Glance

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

Understanding the carbohydrate conundrum

Even those with the most rudimentary knowledge of sports nutrition know that ensuring an adequate intake of carbohydrate is one of the most vital requirements for sportsmen and women, especially for endurance events where depletion can lead to a significant drop in performance. However, 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 can be broken down very rapidly without oxygen to provide large amounts of extra ATP via a process known as glycolysis during intense training (anaerobic training)'

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 6 molecules of ATP (adenosine triphosphate – the energy liberating molecule used in muscle contraction) compared to only 5.7 ATPs per oxygen molecule when fat is oxidised. That's important because the amount of oxygen available to working muscles isn't unlimited – it's determined by your maximum oxygen uptake (VO_2max).

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 training (anaerobic training). 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

Carbohydrate can be stored in muscles in the form of muscle glycogen – ready for use when contracting muscles need lot of ATP. The typical muscle concentration of glycogen in sedentary individuals is around 100-120mmols per kg of 'wet weight' muscle mass, which equates to around 300-400g in total.

Endurance training coupled with the right carbohydrate loading strategy can raise muscle glycogen concentrations further (to around 150-200mmols per kg ww), which can extend the duration of exercise before fatigue sets in by up to 20%[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. The problem of premature depletion can be an even bigger problem in longer events such as triathlon or endurance cycling events 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.

Carbohydrate on the move

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

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

Drink formulation

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

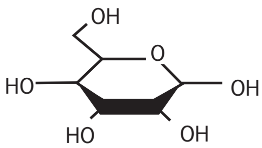
Many of the early studies on carbohydrate feeding during exercise used solutions of glucose, which produced demonstrable improvements in performance as discussed. In the mid-90s, some researchers experimented by varying the type of carbohydrate used in drinks, for example by using glucose polymers or 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 2 hours at 60% of VO_2 max while ingesting

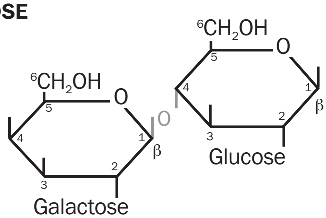
Carbohydrate building blocks

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.

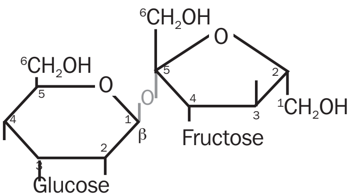
Sports drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is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



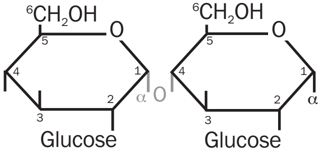
GLUCOSE



LACTOSE (MILK SUGAR)
= GLUCOSE + GALACTOSE



SUCROSE (TABLE SUGAR)
= GLUCOSE + FRUSTOSE



MALTOSE ('BREWERS SUGAR')
= GLUCOSE + GLUCOSE

500mls of different drink mixtures (14):
- 50g glucose
- 100g glucose
- 50g fructose
- 100g fructose
- 100g of 50g glucose + 50g fructose.

'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 – 1.25g per minute'

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 3-hour cycling sessions at 60% of VO_2max (15). During the rides, the cyclists drank 1,950mls of radio-labelled carbohydrate solution, which supplied one of the following:
- 1.8g per min of pure glucose
- 1.2g of glucose + 0.6g per minute of sucrose
- 1.2g of glucose + 0.6g per minute of maltose
- Water (control condition).

The results showed that while the pure glucose and glucose/maltose drinks produced an oxidation rate of 1.06g of carbohydrate per minute, the glucose/sucrose combination drink produced a significantly higher rate – 1.25g per minute. This was an important finding because while both maltose and sucrose are disaccharides (*see box on page 63*), maltose is composed of just two chemically bonded glucose molecules, whereas sucrose combines a glucose with a fructose molecule. This suggested was that it was the glucose/fructose combination that was being absorbed more rapidly and therefore producing higher rates of carbohydrate oxidation.

Fructose connection

The same team had also performed another carbohydrate ingestion study on eight cyclists pedalling at 63% of VO_2max 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:

- 1.2 g/min of glucose (medium glucose)
- 1.8 g/min of glucose (high glucose
- 1.2g of glucose + 0.6 g 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 on page 66*).

Intestinal absorption of glucose and fructose

Once the carbohydrate you ingest has been digested and broken down to its constituent sugar building blocks such as glucose and fructose, there's then the task of absorbing them. 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'. That's because that the cell walls of the digestive tract are electrically neutral, while sugar molecules, carry regions of positive and negative charge. Neutral and charged molecules don't like to mix – a good example is oil (neutral) and water (charged) – so the laws of chemistry make it difficult to get sugars across the gut wall into the bloodstream without these 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/min of glucose and 0.6g/min of fructose rather than 1.8g/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.

Glucose/fructose and hydration

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 as above (eight trained cyclists pedalling at around 60% VO_2max on three separate occasions, ingesting one of three drinks on each occasion[18]. However in this study, the duration of the trial was extended to five hours during which the subjects drank one of the following:

- 1.5g per minute of glucose
- 1.5g per minute of glucose/fructose mix (1.0g glucose/0.5g fructose)
- Water (control).

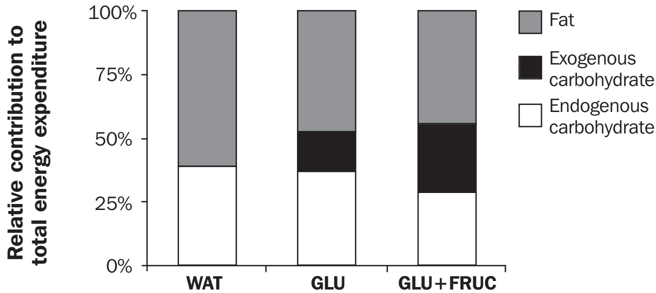
The water used in the drinks was also radio-labelled (to help determine uptake into the bloodstream) and the cycling trials were conducted in warm conditions (32°C) to add heat stress. Exercise in the heat results in a greater reliance on carbohydrate metabolism, which is thought to be due to increased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

There were a number of important findings from this study:

- During the last hour of exercise, the oxidation rate of ingested carbohydrate was 36% higher with glucose/fructose than with pure glucose (*figure 1, page 68*);
- During the same time period, the oxidation rate of endogenous (*ie* stored) carbohydrate was significant less with glucose/fructose than with pure glucose (*figure 1, page 68*);
- The rate of water uptake from the gut into the bloodstream was significantly higher with glucose/fructose than pure glucose (*figure 2, page 68*);
- The perception of stomach fullness was reduced with the glucose/fructose drink compared to pure glucose (*figure 3, page 68*);
- Perceived rates of exertion in the later stages of the trial were lower with glucose/fructose than with pure glucose.

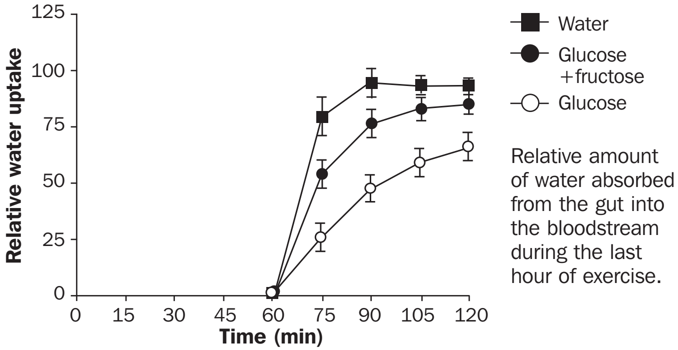
Although no direct muscle glycogen measurements were made, the kinetics of the rate of appearance and disappearance of glucose in the bloodstream from the drinks

Figure 1: Drink type and fuel usage



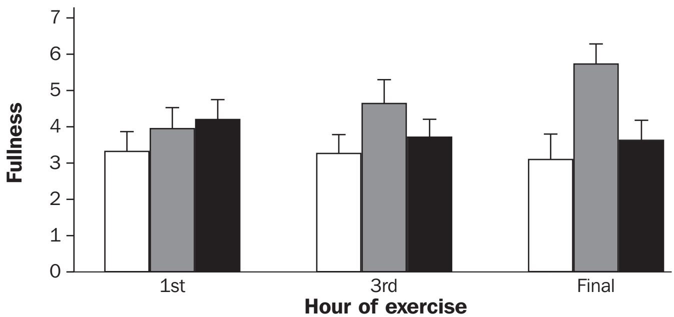
Relative contribution of fat, exogenous (ingested) and endogenous (stored) carbohydrate to energy expenditure during last hour of exercise

Figure 2: Drink type and water uptake



Relative amount of water absorbed from the gut into the bloodstream during the last hour of exercise.

Figure 3: Drink type and stomach fullness



Mean perceived stomach fullness in the 1st, 3rd and final hour of exercise. (Open bars = water; Grey bars = glucose; black bars = glucose/fructose) led the researchers to postulate that the extra carbohydrate oxidation observed could be as a result of increased liver oxidation, or the formation of non-glucose energy substrates during exercise such as lactate, which is known to be an important fuel for exercising muscles. More research is needed to determine the exact mechanisms involved.

Implications for athletes

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

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

The trials consist of two parts; an initial 2.5-hour steady state ride at 60% VO_2max to assess carbohydrate oxidation rates, water uptake, gastrointestinal distress and perceived rate of exertion followed 15 minutes later by a 60km performance time

'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'

	Glucose/glucose polymer drink	Glucose/fructose drink
Ingested carbohydrate oxidation rates (final 90mins)	1.07g per minute	1.32g per minute (23% higher)
Overall fluid uptake (compared to water)	78.18%	92.57% (18.4% higher)
60km time trial time	98.28mins	92.13mins (6.26% faster)

trial. The results of these trials are yet to be published, but the research team has made available to *Peak Performance* some of their initial findings, which are summarised below:

While these results are very promising, it's important to point out that these are initial findings, which have yet to undergo full statistical analysis, and that the team still need to collect more data. Also the 2:1 glucose/fructose drink contains small amounts of electrolytes, unlike the mainly glucose/glucose polymer product. However, should these early results be subsequently verified, they will provide some persuasive evidence that endurance athletes may benefit from this new breed of drink.

Recommendations for athletes

If you're an endurance athlete whose event typically exceeds 90 minutes, is it worth rushing out and trying to get hold of a glucose/fructose drink to use during training/competition? Despite the promising initial research, the cautious approach would be to hold back until scientists have confirmed beyond doubt that these drinks really do confer a performance advantage.

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

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

Andrew Hamilton

Jargon buster

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

Glycolysis – the partial but rapid breakdown of carbohydrate without oxygen.

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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WHAT THE SCIENTISTS SAY

Reports on recent rowing-related studies

Recipe for the perfect rower

As we've seen elsewhere in this issue, the anthropometric characteristics of a rower (*eg* limb lengths and girth, height etc.) can and do impact on their potential performance capabilities. But exactly what makes the perfect rower? That's the question that Australian scientists have been trying to answer in a newly published study.

In the study, rowers competing at the 2000 Olympic games were measured for 38 anthropometric dimensions, including body mass, sitting height, hip and arm girths, thigh length, chest, waist, and thigh dimensions, and skinfold thicknesses. The participants included 140 male open-class (heavyweight) rowers, 69 female open-class rowers, 50 male lightweight rowers, and 14 female lightweight rowers. In addition to the rowers, a group of healthy young adult 'non-rowers' (42 males, 71 females) were assessed for comparison. The researchers found the following:

- After scaling for stature, the open-class rowers remained proportionally heavier than the non-rowers, with greater proportional chest, waist, and thigh dimensions;
- Rowers across all weight and gender categories possessed a proportionally smaller hip girth than the non-rowers;
- Top-ranked male open-class rowers were significantly taller and heavier and had a greater sitting height than their lower-ranked counterparts. They were also more muscular in the upper body, as indicated by a larger relaxed arm girth and forearm girth;
- In male lightweight rowers, longer thigh lengths were associated with the best performers;
- In female open weight rowers, lower skinfold thicknesses were associated with better performance.

It was also observed that all rowers across all categories tended to have lower hip girths than non-rowers. However the scientists cautioned that

this might simply reflect the fact that the equipment demands of rowing disadvantages those with large hip girths, rather than lower hip girth actually conferring enhanced performance!
J Sports Sci. 2007 Jan;25(1):43-53

Power output and lean body mass – how do rowers compare with other athletes?

Olympic rowing is uniquely demanding; not only does it require superior cardiovascular endurance, high levels of power and strength are also essential. Because of this, many rowers train to increase lean body mass to raise power output. But how do the power outputs of rowers compare to other athletes, particularly in relation to lean body mass?

To try and understand this relationship, US scientists have carried out an extensive study to determine how power outputs vary across 32 different Olympic and World Championship events contested between 1976 and 2004, in male and in female athletes. Among the events were eight in running, four in speed skating, three in jumping, twelve in swimming and five in rowing. The researchers used laws of physics to derive simple equations relating to each event and then estimated relative power outputs of each sport.

What they discovered was that regardless of the event, the average power output of that event closely reflected the average lean body mass of participants in that event. In other words, higher lean body mass sports like rowing had proportionately higher average power outputs than low lean body mass events such as endurance running. Another way of expressing this is that on a 'per kilo of lean body mass basis', the power outputs across all the events and sports were remarkably similar!

They also found that between 1952 and 1972, there was a large difference in power outputs between female and males in running and swimming events, with the females lagging behind. However, in the period from 1976 to 2004, these differences were markedly reduced, reflecting the fact that women were more highly trained and carried higher levels of lean body mass compared to the earlier years.

The researchers conclude that 'It is noted that efforts in recent years

to provide equality of opportunity for female athletes coincide with equalization of estimated relative power output in competition with the relative lean body mass.'
J Sports Sci. 2006 Dec;24(12):1329-39

New methods of monitoring elite rowers

As Richard Godfrey and Greg Whyte have explained elsewhere in this issue, a crucial element of success in elite rowing is comprehensive and accurate monitoring of physiological status. However, continual monitoring is not always possible or desirable; most rowers prefer to train not in the lab, but in their own environment where (even with the best coach) physiological monitoring is much more difficult. However, Italian scientists have come up with a possible solution – 'remote power spectral analysis of heart rate variability'.

In the study, the researchers monitored a group of 18 rowers (average age 25.3 years) from the Italian national rowing team in the season preceding the 2004 Athens' Olympic games. The rowers were monitored while partially detrained, at the mid point of the training season and finally close to the games. As part of this monitoring, the athletes were fitted with a miniature 'trans-telephonic ECG recorder' – a device that measures the beat to beat interval of the heart during training, which can therefore be used to calculate the heart rate variability, giving information on how the athlete is adapting to and recovering from training sessions. Data was also collected on respiratory rates during training and the rowers additionally completed stress perception questionnaires and provided additional feedback about any physical symptoms related to training. The collected data was then downloaded via a modem to a referral centre, where the scientists were able to analyse the results. These were as follows:

- The system of collecting and transferring data was successful; all the ECG recordings were transmitted by phone to the referral centre without any problems;
- Surprisingly perhaps, no significant difference was detected in any marker of heart rate variability between athletes who subsequently won a medal at the Olympic games and those who did not;

- The average recorded respiratory rate was faster in subsequent medal winners compared to non-medal winners;
- Non-medal winners recorded significantly greater stress scores at the mid-point of the training season and close to the games compared to medal winners.

The scientists concluded that their system could be employed to provide early detection of psychosomatic symptoms resulting from long duration and elevated stress in athletes preparing for top-level competitions. More generally, they go on point out that 'This [remote monitoring system] shows the feasibility of remote monitoring of athletes' cardiac adaptations to strenuous training in the field, and that it could be used for improving individual training programs, allowing athletes evaluation in their natural environment.'
J Sports Med Phys Fitness. 2006 Dec;46(4):598-604

Why fluid is the key for pre-competition lightweight rowers

Unlike their heavyweight counterparts, lightweight rowers have to 'make their weight' in a pre-competition weigh-in, which often means undertaking short-term weight loss prior to the weigh-in and then replacing this lost weight with fluids, carbohydrates or other foods and drinks just before the race itself. But what's the most effective nutritional strategy for this period?

Australian researchers have spent some time examining different 'recovery' strategies in 2,000m rowers to try and find answers to this question. They looked at 12 competitive rowers completing four 2,000m ergometer trials, each separated by a 48-hour rest period. For the first trial, the rowers were not asked to reduce their weight, but for the second trial, they had to reduce body mass by 5.2% and then achieve this same body mass prior to the 3rd and 4th trials.

For each of the 3 body mass reduction trials, the rowers took one of the following pre-trial drinks or snacks following their weigh-in:

- Fluid only (containing zero carbohydrate, 0.6mg/kg of sodium and 28.5mg/kg of fluid);

- Carbohydrate and sodium (containing approx 10kcals/kg, 2.2g/kg of carbohydrate and 32.9mg/kg sodium plus 7.2ml/kg of fluid);
- A combination of water and carbohydrate/sodium (10kcals/kg, 2.3g/kg of carbohydrate, 33mg/kg of sodium and 28.5ml/kg fluid).

When the scientists measured their subsequent performances, they found that the carbohydrate and sodium snack produced significantly slower performances (averaging 4.13 seconds longer over 2,000m) than either the fluid only of fluid/carbohydrate/sodium combination. Moreover, while the combination of fluid plus carbohydrate and sodium snack produced the best performances, these were not significantly better than the fluid only drink.

The researchers concluded by stating '…that although carbohydrate and sodium intake may be important in the recovery period between weigh-in and 2,000m rowing ergometer performance, fluid intake has a greater influence on performance among lightweight male rowers who undertake short-term weight loss to achieve specified body-mass limits'. The message seems clear – rowers making weight should consider fluid replacement as their number one priority following weigh-in.

Med Sci Sports Exerc. 2007 Jan;39(1):184-19

Notes