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MAXIMISING OLYMPIC DISTANCE TRIATHLON PERFORMANCE: A multi-disculplinary pw3eapctive

Conenvors

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Table of contents

Page

Schedule of events

Day 1: Monday November 8th 1999

9.00-10.30

- Opening address - **Les MacDonald** - President ITU
- **Ron Clarke** - *Maximising Athletic Performance*
- **Dr John Hellemans** - *Maximising Olympic Distance Triathlon Performance - A Sports Medicine Perspective*

Morning tea

11.00-12.30

- **Dr Darren Smith -** - *Maximising Olympic Distance Triathlon Performance: A Sports Physiologist's perspective*
- **Ian Hellemans** - *Maximising Olympic Distance Triathlon Performance: A Sports Dietitians Perspective*
- **Brian McLean** - *Maximising Olympic Distance Performance –A Biomechanist's Perspective*

Lunch

1.30-2.30

- **Chris Hill** - *Maximising Olympic Distance Performance – The Athlete's Perspective*
- **Kieran Barry** - *Maximising Olympic Distance Triathlon Performance: A Coach's Perspective*

Afternoon tea

3.00- **Panel discussion**: *The above speakers will debate and discuss issues surrounding "Maximising Olympic Distance Triathlon Performance".*

Conference dinner - Informal setting - venue to be advised

Day 2: Tuesday November 9th 1999

National Park run and sea swim - meet in front of Surf Club 6.30 AM

Free papers

9.00-10.30

Special session on hypoxic training

- **Rod Cedaro -** *Using hypobaric oxygen techniques and hyperbaric intervention to level the playing field in olympic distance triathlon*
- **Sally A Clark,** Julie Dixon, Christopher J Gore, and Allan G Hahn - *14 Days of Intermittent Hypoxia Does Not Alter Haematological Parameters Amongst Endurance Trained Athletes*
- **John Hellemans** - *Intermittent Hypoxic Training: A pilot Study*

Morning tea

11.00-12.30

- **Dave Bishop -** *Reliability and validity of portable lactate analysers?*
- **Grant Landers -** *Kinanthropometric differences between World Championship senior and junior elite triathletes*
- **Bill Davoren** and J. Gregory - *The effects of three varied cycle leg protocols on self-paced run time trial performance.*
- **John Hellemans** - *Lactate Index and training load*

Lunch

1.30-3.00

Nutrition and fluids

- **Ian Hellemans -** *Fluid losses and voluntary fluid Intakes in New Zealand Age Group Triathletes During the 1998 ITU World Championship Triathlon*
- **Aaron Coutts, Peter Reaburn, and Kerry Mummery -** *Sweat loss, fluid intake and triathlon performance in hot and humid conditions*.
- **Asker Jeukendrup -** *Fat loading and Carbohydrate Loading in Endurance Athletes.*

Afternoon tea

3.30 Workshop - Bill Daveron and Cedaro - *Heart rate, lactate and power ouptput as training and monitoring tools.*

Maximising Athletic Performance….with air conditioning
Ron Clarke

The most important elements in any athletic or sporting performance are:

1. Skills
2. Muscular capabilities
3. Ability to absorb oxygen
4. Mental concentration and confidence

Skills and muscular capabilities are a matter of training sensibly, patiently and with a purpose, combined with generic characteristics and appropriate up-bringing.

Mental concentration should be practised as assiduously as the skill techniques.

Training, both for fitness and to enhance skills, is too often approached hap hazardly with no real purpose or concentration. A plan should be established for any workout prior to its start, which should fit into an overall program. And the plan should incorporate a goal – be it distance/time, number of hills or efforts, or the drills.

Whatever ….. fun runner or professional, it has always made sense to me that when you practice you do so for a reason.

And I have always found that real confidence comes from preparation. The better prepared you are the more confidence you will have to perform any task.

My favourite way of demonstrating this is with comnective circles:

> **The outer** is what your body is ultimately capable of – no one can tell you where these extremes are.
>
> **The middle** circle is what you believe your body is capable of in its present condition
>
> **The inner** circle is what you actually achieve.

As your fitness increases so do the two inner circles expand towards the outer with the ultimate, of course, having all three over-lapping.

The point being nobody can so control the mind as to free it of all inhibitions - have a look at someone having an epileptic fit, it takes three to four people to hold them down.

There are many examples of how sometimes performance exceeds expectations, especially when inhibitions are overcome either by fear, or adrenaline, or determination.

Examples: Ewry (Determination)
Beamon (Adrenaline)
Syme (Fear)

For this reason I actually believe the Para-Olympics produce the most amazing athletic performances of all.

Because they know all about pain, and suffering, and determination, and purpose. Interestingly they are also the fairest with the best displays of sportsmanship.

But I am here today to tell you about the third essential requirement for success in sport.

The use of oxygen has not been understood sufficiently as yet, its value has most certainly been underestimated, but I can assure you all that there is no more important element in training than to enhance the ability of the body to absorb oxygen.

Triathlon is the sport which has advanced most in recognising its value possibly because its participants need to be fitter than those for any other Olympic Sport.

In the main, these aerobic benefits which so improve performances, come from Hypobaric training, wherein the athlete is exposed to altitude, either natural or simulated, for extended periods of time so that their bodies adapt to overcome this lack of atmospheric oxygen by operating more efficiently. Normally the process is a stimulation of bone marrow by increased EPO (which occurs when the body is deprived of oxygen for a period) which results in more haemoglobin cells being produced so that more oxygen can then be collected from the lungs and distributed.

Consequently, in my day, athletes like Sebastian Coe spent months training and living at altitude (Coe's favourite location was St Moritz in Switzerland). More of this later.

The other major use of oxygen is in aiding recovery and circulation.

This technique is called Hyperbaric which means additional pressure. Ideally the pressure used should equate with 2 atmospheres and needs a special reinforced chamber (as this is twice the normal pressure).

Not only does this aid recovery from injury dramatically, it also relaxes and aids the brain and its function, amongst a host of other benefits.

I believe every athlete should, every day immediately after training, relax for 30 minutes in a Hyperbaric chamber. I have no proof but I project that this alone would improve performance by up to 5%. The profound effect of Hyperbaric treatment can be seen in this short video on some severely mentally debilitated children suffering from oxygen deprivation of the brain.

[Video to be shown}

Isn't that amazing. Imagine the effect on training recovery and athletic performance of fit and healthy athletes when it can have that sort of result with the mentally handicapped.

Now add that to the already enhanced performance the use of **Hypobaric** techniques, and I calculate we can artificially produce another Said Ouvita, Damien Komen, or Haile Gebrselasse.

In 1970, I predicted that for the next 5 decades world distance running records will be the exclusive domain of the mountain men.

Ever since 1980, every world record, except for Steve Cram's 1500 meters in 1985, has been set by them.

But the double whammy use of oxygen techniques in this way could level the playing fields.

Let me tell you more about the various ways we can tune up the haemoglobin via the use of Hypobaric techniques and what we are doing at the Runaway Bay Sports Super Centre to facilitate this.

We will be the only Sports Training Centre in the world to incorporate both techniques, that is have Hypo- and Hyperbaric chambers.

We will be the only Centre in the world where athletes can book in and sleep at altitude in normal hotel style accommodation.

And we cater for all sports, in particular, track (there is a 400 metre 8 lane international standard tartan track with pacing lights – again a world first), swimming (a 2 metre deep, 50 metre long, heated, 8 lane stainless steel Olympic pool as well as an indoor 25 metre 3 lane facility), road cycling (outside of the Gold Coast with hundreds of kilometres of roads), and many other sports. Our facilities include a 600 m^2 gymnasium incorporating free weights, Keiser resistance circuit, Nautilus, the whole range of aerobic equipment, and a Pilates "Gym within a Gym" (for stretching), spa, sauna, massage, hydrotherapy, and a fully equipped sports medicine clinic with physiotherapists, physiologists, sports medicine physicians, plus nutritionists, psychologists and chiropractors.

No Sports Training Centre anywhere in the world, matches us and we intend to continue to lead the way.

Two of our accommodation lodges will be fitted with special pump and monitoring equipment so that their occupants can sleep at altitude, up to 5,000 metres above sea level, 64 beds in all.

"Sleep High, Train Low" is a training program that has now been proven in many places throughout the world as the most effective way of building haemoglobin cells whilst retaining physical strength.

Add to this the effects from the Hyperbaric Chamber and, as I say, we're up with the Ethiopians, Kenyans, Moroccans, Algerians and Mexicans.

We have also incorporated a Hypobaric cubicle in the gymnasium to allow cyclists and runners to use ergonometers and treadmills at altitude (as well we can alter the humidity), so as to give the option of training at altitude if they so wish, without the expense and time needed to travel there.

In addition, we have the Hypoxicator, which is a further unit designed both to raise haemoglobin levels and enhance the capacity of muscle tissue to absorb oxygen. This is a 14 day course that has given us some spectacular results.

Lastly there is the Cat Hatch individual Hypobaric beds, and both Hypobaric and Hyperbaric tents that we can hire out.

Believe me, get onto the Internet and study the research. Call us if you need more literature. If you are ready to take the next step, and have the time, come down to Runaway Bay.

If you can't get down for an extended period, come and see us for a weekend, test out the theory, then work out how, in your particular circumstances, you can incorporate the use of oxygen into your programmes.

I have no doubt had I been able to use this stuff pre-1968, I would have won the two distance golds at the Mexico City Olympics instead of finishing flat on my back at the end of the 10K.

The fact I ran 6th in both races came about from the four weeks or so I was able to spend at Font Romeu in the Pyrenees. I broke the 2 miles world record, and ran the 2nd fastest ever 10,000m in gale conditions (the wind blew our numbers off our singlets it was so strong) en route to Mexico so the short time I spent there helped me no end.

There is no doubt about it … If you wish to reach the top, you have to incorporate both methods … or go live in Kenya.

Maximising Olympic Distance Triathlon Performance
A Sports Medicine Perspective

Dr John Hellemans*

*Dr John Hellemans is a Sports Medicine Practitioner in Christchurch New Zealand. He specialises in high performance endurance sport and exercise prescription. He is a six times New Zealand open and four times World Age Group Triathlon Champion.

Health Aspects of the Triathlon

It is well established that regular endurance exercise involving large muscle groups can produce many physical and psychological effects. Swimming, biking and running are often mentioned as examples of acquiring fitness for health [1 - 2].

Health-related physical fitness includes improvements in:

1. Cardio-respiratory endurance (linked directly to a reduced risk of cardiovascular disease).
2. Body composition (obesity is a well known risk factor).
3. Muscular strength, endurance and flexibility (eg. low back pain is often associated with fitness deficiencies and muscular imbalance in the lower back region).

In view of the relationship between health and exercise it makes sense that health-related fitness is relevant to all in today's industrialised society. The triathlon is a unique sport in that it encompasses all health related variables and therefore can be used as a prime example of health-related fitness. This is especially the case with respect to the short distance events (up to and including standard distance). In the longer distance events (½ Ironman and Ironman) the health advantages are possibly out-weighed by the stress created by prolonged exposure to environmental factors, combined with extreme fatigue.

The triathlon is an endurance activity which uses nearly all the muscles of the human body. Cardio-respiratory endurance is developed as well as strength and endurance in all muscle groups. Apart from the health-related quality of the triathlon, it is also fun and an achievable activity for many as most people can swim, bike and run. There are no complicated skill involved, as is the case in many team sports.

Just to finish a triathlon gives tremendous satisfaction and therefore also contributes to psychological development and self confidence.

Prevention

The individual triathlete will be more interested in preventing illness and injury than treating existing symptoms. The threat of over-training and injury is one of the limiting factors on how hard the triathlete can train. Months of careful preparation can be severely disrupted by injury or illness.

Training for triathlons means exposure to stress, both physical and mental, and it is likely most triathletes will have their training interrupted at least once a year through illness or injuries. Serious triathletes know that the harder they work, the fitter they become. At the same time, they are more likely to encounter ailments that destroy their fitness. The key for them is to find the right balance.

Educating triathletes about the value of closely monitoring signals from the body can greatly assist in preventing problems. Overwork - too much, too fast, too soon - is still the main cause of problems and injuries related to training [3 - 4].

Taking a detailed and specific sports history can give us an insight into the athlete's training habits, short and long - term goals and the equipment used. This information will form the basis on which to advise athletes when treating injuries or when dealing with potential problems.

Injuries

It has already been mentioned that many injuries are caused by errors in training. High mileage and intensity without allowing for a suitable recovery, and a sudden increase in training volume are the main culprits. Other causes are errors in technique, inflexibility of muscles, unyielding running surfaces and structural abnormalities (table I).

Surveys of triathletes show that the majority of their injuries are running related [5]. This is no surprise given the considerable stress on legs caused by pounding on the road, and most injuries, therefore, affect the lower extremities, especially the knee, lower leg and foot.

Common running related injuries are iliotibial band syndrome, stress fractures, compartment syndrome, tibial periostitis, Achilles tendinitis and plantar fasciitis [6].

In the treatment of those injuries, attention needs to be paid to the causes of the injuries listed in table I. Many minor injuries can be helped by proper footwear, possibly including orthotics, and by paying attention to technique. For established injuries, anti - inflammatory medication, physiotherapy, acupuncture and, as a last resort, cortisone injections, might be required. Stress fractures are one of the few injuries which require complete rest from running (for approximately six to eight weeks). Often, however, triathletes will still be able to swim and bike in this period.

Table I. Causes of overuse injuries:

Errors in training	'Too much, too fast, too soon' is a frequent cause of injury.
Errors in Technique	Toe running, for example, can lead to many lower leg ailments.
Faulty Equipment	Worn shoes, oversized bike etc.
Inflexibility of muscles	The main cause of 'swimmers shoulder' (supraspinatus endinitis). Muscle inflexibility also plays a major role in many running injuries.
Running Surfaces	Concrete and asphalt are hard on the legs.
Structural abnormalities	Pees planus (flat feet), pes cavus (high arched feet), rear foot valgum and varus, genu valgum (bow legs) and genu valgus (knock knees) can all contribute to running and cycling injuries.

Common cycling - related injuries, except for those sustained in crashes, are located in the knee, lower back and neck [7]. Chronic sprains and strains of the ligaments supporting the knees, together with patellofemoral dysfunction, are often caused by pushing too hard in high gears, excessive hill climbing, or a faulty placement of the feet on the pedals.

Back pain is a frequently encountered complaint in triathletes and cyclists. Most cases can be helped by adjusting body position on the bike, either by changing the seat position or the handle bar reach. If those measures fail or if there are neurological symptoms present, further investigations are necessary to exclude an underlying organic cause.

A whole new condition following the introduction of aerodynamic handlebars is the '*aeroneck*' [8]. This is neck pain and stiffness caused by sitting for long periods with the shoulders hunched, the arms tucked underneath the upper body and accompanying hyperextension of the neck. This unnatural position puts tremendous strain on the cervico-thoracic junction. Time will tell what the long term effects will be on this part of the spine. It looks at the moment as though conditioning improves the symptoms, at least in the short term. A forward seat position combined with widening of the elbow pads is still the most effective strategy for treatment and prevention.

Swimmer's shoulder (supraspinatus tendinitis) is one of the few injuries related to swimming. Swimmer's shoulder is a good example of an 'overuse' injury, where the repetitive movement is the main cause of the ailment. When the arm rotates - approximately 1500 times in a 3000m freestyle workout - the supraspinatus tendon can rub against the tip of the acromion, eventually resulting in tendinitis. There is a direct relationship between inflexibility of the shoulder and supraspinatus tendinitis [9]. The condition can be difficult to treat. Symptoms sometimes respond to an upper arm strap, icing after a work out, different stretching exercises and the avoidance of hand paddles (In more persistent cases, physiotherapy, anti - inflammatory medication, acupuncture or, as a last resort, cortisone injections can be tried.

Injuries always need to be distinguished from the normal aches and pains which are part of training. These are usually not severe enough to interfere with training. They appear early in the training session and improve as the session progresses. Alternatively, they can crop up at the end of a hard training session with quick recovery on cessation of training.

Overtraining

Overtraining, or staleness, is a combination of persistent physical and mental fatigue with a decline in training and racing performance. This is caused by too much training and/or not enough recovery. Outside stress (family, work, relationships) can also be a contributing factor, as well as not allowing enough recovery time during and following illness. The most common symptoms of overtraining which can accompany a decline in performance are loss of interest, insomnia, irritability, depression, loss of appetite and weight fluctuations, fatigue, increased muscle soreness, illness (frequent colds, sore throats, headaches, stomach ailments) and persistent increase (ten beats or more) in the resting pulse rate. It is thought that these symptoms are related to a dysfunction of the autonomic nervous system [4].

The precise mechanism involved in the development of staleness has yet to be established. One theory is that an increase in training does not allow glycogen stores to reload fully between training sessions, resulting in chronic glycogen depletion [10]. The answer to this is to increase the amount of carbohydrate in the diet. Dietary assessment of the overtrained athlete by a qualified dietitian or nutritionist is strongly recommended to check on carbohydrate intake and also to check on other possible nutritional deficiencies.

Nutritional deficiencies (eg. iron deficiency) and viral infections (eg. glandular fever) can mimic the symptoms of overtraining. The treatment for overtraining consists of decreasing the frequency, duration and intensity of training sessions for as long as it takes for the symptoms to disappear. Some athletes need to have a complete break from the sport to rekindle the desire to perform. Recently Intermittent Hypoxic Training (a method of altitude simulation) has shown promising results as a treatment for excessive fatigue and over training [11].

At present no sensitive or specific tests are available to prevent or diagnose overtraining [4].

The diagnosis is based on the medical history and clinical presentation. The best way for an athlete to monitor signs of overtraining is to monitor subjective well being [14]. In addition, it is worthwhile to record resting pulse rate and weight on a daily basis during periods of intense training. This is best done early in the morning, just after waking.

The fatigue associated with overtraining is only one of a range of symptoms and should not be confused with the tiredness which accompanies a solid build up towards a race.

Dehydration and Heat Illness

Dehydration is a well known condition associated with endurance events, especially in a hot environment. Heat illness (heat stroke, heat exhaustion, heat syndrome, hyperthermia) usually occurs in combination with dehydration. Although it is more common in long distance events it can also occur in standard distance events held in hot conditions. [12]

Thirst occurs when the body loses approximately 1% body weight. When athletes lose more than 2 to 3% of their body weight through perspiration, their performance will start to decline. When 5% of the body weight is lost, most athletes will show obvious signs of dehydration and heat illness. Dehydration levels of 7% or more are extremely dangerous.

Proper hydration before and during the event is the main means of preventing dehydration and heat illness. The risk of heat illness is significantly increased by high temperatures, high humidity, bright sunlight and lack of wind, all of which are factors on which the body’s ability to lose heat depends. Excessive sweating or possibly cessation of sweating, headache, nausea and vomiting, vertigo, and goose pimples are all early symptoms of heat injury.

The early stages of heat illness can sometimes be overcome by slowing down and taking fluids frequently. Advanced symptoms include impairment of consciousness with initial confusion, disorientation, and ultimately collapse. This stage requires urgent medical attention. The diagnosis is confirmed by taking a rectal temperature.

Treatment consists of cooling the athlete (using ice packs) along with hydration through intravenous fluids. Observation of vital signs and symptoms is essential.

If heat illness is not treated properly, serious complications can occur, such as renal failure, arrhythmia, coma and death. Research has shown that in well trained and acclimatised athletes, the heat dissipating mechanism becomes more efficient and, therefore, adequate conditioning, together with acclimatisation and paying attention to hydration, form the key to prevention. Some athletes can cope better with heat than others because of differences in heat generation and heat dissipation. Glycerol loading has been used to prevent dehydration but research has shown conflicting results and significant side effects can affect any potential benefits [13].

Hyponatraemia (water intoxication)

Hyponatraemia is now considered one of the more serious problems associated with endurance exercise. It has been reported to occur in athletes after long endurance events such as ultra - marathons and the Ironman Triathlon [18]. Although it may be asymptomatic, hyponatraemia has been associated with signs and symptoms such as altered mental status, seizures and pulmonary oedema. The most likely cause of hypotranaemia is a combination of loss of salt through sweat and retention of high volumes of hypotonic fluids that have been ingested. Sweat loss can be as great as 2.8*l* per hour.

The water intoxicated athlete is well hydrated and has a normal temperature (in contrast to the athlete with heat illness). Often the symptoms do no occur until a few hours after the athlete has finished the event. The delayed onset of symptoms may be due, in part, to continued hypotonic fluid ingestion following the race and increased absorption of hypotonic fluids from the gastrointestinal tract after the athlete has stopped running.

Treatment of hyponatraemia is primarily supportive and includes infusion of normal saline. The risk can be reduced by planning a replacement scheme that includes a combination of water and glucose electrolyte solutions.

References

1. Shephared RJ, What is the optimal type of physical activity to enhance health? Br J. Sports Med 1997; 31: 277-284
2. Hellemans J. Prescribing exercise in general practice. New Zealand Medical Journal 957: 98 (790) 1985
3. Kuipers H , Training and overtraining: an introduction Med. Sc. Sp.Ex 1998; 1137-1139
4. Kuipers H, Keizer HA. Overtraining in elite athletes. Review and directions for the future. Sports Medicine 79: 6, 1988
5. Maynard M, et al. Injuries amongst competitive triathletes. The New Zealand Journal of Sports Medicine 2: March 1988
6. James SL, Bates BT. Injuries to runners. American Journal of Sportsmedicine 40: 6, 1978
7. Mellion M.B. Common Cycling Injuries, Management and Prevention. Sports Medicine 11 (1):52-70, 1991
8. Hellemans J. Personal observation, January 1988
9. Greipp IF. Swimmers shoulder: the influence of flexibility and weight training. The Physician and Sportsmedicine 92: 13 (8), 1985
10. Costill DL, et al. Effects of repeated days of intensified training on muscle glycogen and swimming performance. Medicine an Science

in Sports and Exercise 249: 20 (4). 1989

11. Kolchinskaya, A Z. Hypoxia and Load Hypoxia: Destructive and Constructive effects. Hypoxia Med Journal 3/93
12. O'Toole M, Douglas P, Laird H L, Hiller D B. Fluid and Electrolyte status in Athletes Recovering Medical Care at an Ultra distance Triathlon. Clin J Sp med 5:116-122 1995.
13. Inder W J, Swanney P M, Donald R A, Pritchett T C R, Hellemans J. The effect of Glycerol and Desmopression on Exercise Performance and Hydration in Triathletes. Med Sci Sports Ex Sept 1998
14. Noakes TD, et al. Water intoxication: a possible complication during endurance exercise. Medicine and Science in Sports and Exercise 370: 17, 1985

Maximising Olympic Distance Triathlon Performance
A Sports Physiologist's Perspective.

Darren Smith, Ph.D
Manager, Queensland Academy of Sport Triathlon Program

This presentation will provide an overview of the following important physiological issues for maximising Olympic distance triathlon performance for the elite competitor:

1. Know the demands of the sport.

The sport has changed considerably in the past few years. Some believe that the swim leg is akin to a pool based 1500 m while others believe a successful triathlon swimmer has excellent starting speed, then a good threshold pace and strong endurance. The bike, while now a draft-legal event may still be similar to a time-trial event for some athletes, while very much a stochastic, skill based event for others. The run at the elite level is quite fast. Those athletes skilled enough to run at the fast baseline speed required to be in contention now have to be able to maintain contact during surges and also provide a fast (or sprint) finish.

2. Identify the physiological status of the athlete

After identifying the likely physiological demands placed on the athlete during competition, identifying the strengths/weaknesses and areas that need improvement is a key issue. Being able to identify these attributes can range from the high tech laboratory based physiological assessments such as gas analysis, blood biochemistry and the like, to field based testing of “test sets” or time-trials. Nevertheless, being able to monitor training adaptations by some reliable, and hopefully, valid measures are an important consideration to athlete development.

3. Plan training and racing schedules

The value of a business or operational plan to big and small businesses has always been crucial to their success. Equally, a plan for the development of elite athletes would also appear warranted. But despite this, many elite triathletes in the past have not had a systematic training or racing plan. It is acknowledged that triathlon training, which includes a number of disciplines, can be difficult to plan for in great detail for long periods of time. However, some general plan that clearly identifies short and long term goals, strategies for improving weaknesses etc. should clearly be a helpful addition to the “business” of being an elite triathlete.

4. Plan the sequence of sessions within the micro and macro cycle to optimise gains

Based on the fact that adaptation is enhanced by the appropriate balance between sport-specific training load and recovery, it is crucial in triathlon to get physical training, recovery, overall workload, sports-specific skill acquisition and other aspects of life into the right blend. Programming of discrete training blocks is often not a science, but perhaps should be. Identifying the length of recovery necessary from various key sessions and working out what combinations of sessions can be tolerated can provide great gains in triathlon performance. Increasing the intensity of some sessions can impact significantly on the training accomplished on the subsequent day, which in the overall scheme of training may not be ideal. Other sessions can be used for recovery, while still achieving an objective (e.g. skill based sessions).

5. Monitoring training

When to train harder and when to take a rest is a tough question for the coach and athlete to answer objectively. Some athletes rely heavily on being “in tune with their body” while others use more objective tools such as performance in a key session or psychological rating scale. Nevertheless, having an athlete-specific warning system is a crucial aspect of training and racing. Investigating the method(s) or signal(s) that work for each athlete makes the job of a coach much easier, reducing much of the guess work, and allowing for a more structured and efficient training program.

6. Tapering for competition

This is an extremely important aspect to overall elite athlete development since the race arena is the place where performance is examined, where national squads are selected and where sponsors notice athletes. However, the topic of tapering for competition is an extremely difficult concept for many coaches and athletes to get right. The balance between training volume and intensity, maintaining the “feel” for the skills of the discipline and getting your mind ready for a good performance is an individual thing, and must be practiced. The taper process can often be interrupted by travel, unfamiliar training environments and unexpected interruptions to the previous training block.

7. Coping with heat and cold

Much has been written about the adaptation to heat. It is well documented that athletes from colder climates can race well in hot conditions if appropriate heat acclimation routines (and hydration practices) have been observed in the few weeks leading up to competition. Less is known about cold adaptation, but as illustrated in a number of races during recent years, it may be just as important to our athletes performance at international competitions. Cold adaptation, which includes improvements in manual dexterity, the maintenance of core body temperature and the like, is also achievable if done in a systematic way leading up to competition.

8. Race day strategies

How many athletes do you know begin their swim warm-up for a race in the last 5 minutes before the start? If you asked these same athletes at what time (or distance) during a normal swim session did they start feeling good or started to get into the “groove”, I can guess the answer wouldn’t be 5 minutes or less, but instead perhaps 20-30 minutes or 1-1.5 km. Since the swim start of a race is not a leisurely activity these days, and maintaining contact with the swim pack is crucial to elite racing, I would regard an optimised swim warm-up to be a necessary part of the elite triathletes’ weaponry.

The start of the run leg is a flurry of activity. Athletes are generally excited about the run leg, to the extent that many appear to run out of transition with scant regard for the distance. It is well shown that running economy is depressed by between 7-10 % following a tough bike ride. Similarly, it is also demonstrated that athletes run the first kilometres of the triathlon run at an unsustainable pace. Considerable extra energy is therefore used to run very fast with an inherently inefficient running style. Run pacing, especially in races held in warm to hot environmental conditions, is therefore an avenue that I believe many triathletes can improve on their current race performances.

Maximising Olympic Distance Triathlon Performance: A Sports Dietitian's Perspective

Ien Hellemans, BDietetics, NZRD

Nutrition is a key factor in maximising Olympic Distance Triathlon performance. The role of nutrition is to maintain health, support training, maximise performance, enhance recovery and achieve optimum body composition and weight. Triathletes and their coaches are advised to develop nutrition plans for training and competitition based on current scientific information, adapted to individual needs and specific training and competition situations. It is important that supplement plans are an integral part of an overall dietary strategy, rather than being considered in isolation. Fad diets need to be avoided as they have no proven benefit and may have adverse effects.

Nutrition is one of many factors contributing to optimum triathlon performance. It plays a critical role in maintaining health, supporting training, maximising performance, enhancing rate of recovery and in achieving optimum body composition and weight. Furthermore, nutrition can be and therefore must be controlled for in order to prevent or minimise the risk of problems which potentially lead to reduced performance. It is imperative for triathletes and their coaches to be fully informed on current, science based nutrition issues and principles and to develop personal nutrition plans for training and competition.

Baseline nutrition

Prolonged, intense exercise exerts adverse effects on the immune system. The resulting impaired immune function may last between three and seventy two hours during which time viruses and bacteria may gain a foothold and increase the risk of subclinical or clinical infection. Meeting baseline nutritional needs through consuming adequate amounts of foods from the core food groups assists in maintaining optimum immune function as well as general health and wellbeing.

Training nutrition

The role of nutrition is a supportive one, that is, appropriate nutritional strategies enable triathletes to physically cope with heavy training schedules all year round. The key nutritional requirements can be summarised as follows.

Triathletes have increased energy requirements to compensate for an increased energy output.

A high carbohydrate intake will provide much of the extra energy and is crucial as muscle glycogen, derived from dietary carbohydrate is the preferred exercise fuel in high intensity exercise. Triathletes commonly train more than once a day and are at risk from glycogen depletion. As glycogen repletion takes time, it is difficult to restore energy levels between training sessions. Consuming adequate amounts of carbohydrates at frequent intervals is therefore an essential strategy. This can be achieved by consuming carbohydrate rich food at every main meal and snack as well as before, during prolonged and after training. Carbohydrate further appears to play a role in immune function. In a recent investigation researchers observed that a high carbohydrate intake reduces stress to the immune system in a group of triathletes. Recommended daily carbohydrate intake is 8-10g per kg body weight. Triathletes have increased protein requirements. Proteins have important functional and structural roles in the body. Protein catabolism may also contribute to total energy production, although this contribution is generally small. In endurance training protein is primarily associated with increasing and maintaining strength, recovery and immune function. Daily protein requirements for endurance athletes are 1.2 - 1.4 g and up to 1.6 g per kg body weight during high volume endurance training. Fat is an essential nutrient and needs to be included in the daily diet. Too much fat will displace carbohydrates and may contribute to an increase in body fat levels, however, too little fat can have a negative impact on health and performance. Recommended daily fat intake is 40-100g, depending on gender, energy requirements, training programmes and individual factors. The important issues are to consume the minimum required amount of fat for health and to obtain fat soluble vitamins and to consume mostly plant sources such as plant oils, margarines, nuts, seeds, avocados, and to make sure that fat does not displace carbohydrate. Once carbohydrate and protein needs are met, the balance of energy required can be obtained from carbohydrate or fat or a combination of both. The increased requirements for vitamins and minerals, particularly the B vitamins, vitamin C and E and the minerals Iron and Zinc are generally easily met through increased consumption of high quality carbohydrate and protein foods. Adequate fluid consumption is critical in the prevention of dehydration. A one litre sweat loss increases heart rate by 8 beats per minute and increases body temperature by 0.3°C. Scientists now believe that no level of dehydration is without physiological consequences. It is imperative that triathletes meet daily fluid needs by drinking at regular intervals right through the day as well as before, during and after training. Baseline fluid requirements are 4-5 litres a day and training increases daily requirements significantly. Fluid needs depend on training volumes, frequencies and intensities, environmental temperature and individual sweat rates. As there is considerable variation in sweat rates, triathletes are advised to take pre and post training body weight measurements to assess individual fluid needs.

Timing of food intake is another critical issue. Consuming carbohydrates and fluids pre training is important in topping up energy and fluid levels while consuming carbohydrates, protein and fluid within thirty to sixty minutes post training enhances rate of recovery. Consuming carbohydrates and fluids during training helps prevent glycogen depletion and dehydration. The following guidelines will assist in meeting daily training nutritional needs.

- Consume three main meals every day, designed as follows:

1. Base around a staple carbohydrate wholegrain breads and breakfast cereals, rice, noodles, pasta, potatoes, or kumara
2. Incorporate fruits and / or vegetables fresh is best, but can be supplemented with frozen or canned
3. Add a protein sourcelean red meat, fish, chicken, eggs, pulses, soy foods, or milk products
4. Include fluids drink water. Fruit juice or cordial optional

- Depending on total daily energy needs, snack on high carbohydrate foods between main meals
- Consume 50-100g carbohydrates in the two hours prior to training

- Consume 500 ml fluid in the hour before training
- Consume 500-1000 ml fluid per hour during training, depending on intensity of training, environmental temperature and individual requirements (pre and post training weight measurements show individual needs)
- During prolonged training sessions, consume 30-60g carbohydrate per hour. Using a sports drink is an effective and practical way to simultaneously meet fluid and carbohydrate requirements.
- Post training, consume one and a half times the amount of fluid lost in sweat (If weight loss is 1 kg, drink 1-2 litres fluid). Start drinking immediately post training and continue to drink at regular intervals until full rehydration is achieved.
- Consume 1*g* medium to high glycemic index carbohydrates within thirty minutes of finishing training and continue to consume carbohydrates at regular intervals to meet total daily needs.
- Consume protein within in hour of finishing training. Although post exercise protein requirements have not been quantified, it seems reasonable to recommend approx. 20g high quality protein.

The following protocol will assist in developing individual training nutrition plans.

1. Estimate total daily energy, carbohydrate and protein requirements based on training programmes, body weight and experimentation.
2. Calculate pre-, during- and post training carbohydrate, fluid and protein needs
3. Subtract total training needs (2) from total daily requirements (1).
4. Divide the amount of carbohydrate, protein and fluids in 3 over three main meals and further snacks.

For instance, an estimated nutrient requirement for a 75 kg male triathlete is 675g carbohydrate (9 g / kg) and 113g protein (1.5g / kg) per day. Assuming he swims early morning and runs at 4 pm, his requirements are 50g carbohydrate prior to and 75g carbohydrate and 20g protein immediately after both sessions, adding up to a total of 250g carbohydrate and 40g protein. If his swim session is particularly hard and long, he may consume a further 60g carbohydrate during the session. Total training related requirements are 310g carbohydrate and 40g protein. His main meals need to provide a total of 675 - 310 = 375g carbohydrate and 113 - 40 = 73g protein which can be divided evenly over breakfast, lunch and dinner. Similar calculations can be made for varying training schedules.

A further goal of training nutrition is to experiment with planned race nutrition strategies and to achieve optimum body composition.

Competition nutrition

Pre competition nutrition goals include maximising muscle glycogen levels, topping up liver glycogen and blood sugar levels and optimising hydration. Nutrition goals during competition are to prevent energy depletion, dehydration, gastro intestinal problems and disturbances in electrolyte balance, while the objective of post race nutrition is to enhance rate of recovery. The latter is particularly important when racing frequently. The race nutrition plan is dictated by nutritional requirements as well as by practical issues such as where the race is held, accommodation, access to suitable foods and availability of fluids at aid stations, and is therefore personal and may need to be adapted to different race situations. Nevertheless, the following general recommendations can be used in designing a personal plan.

Pre race

As glycogen depletion has been shown to occur in endurance races of over one hour, carbohydrate loading may be of benefit. Carbohydrate loading simply means increasing usual daily carbohydrate intake in the three or four days prior to a race without increasing total energy intake, and this is achieved by reducing fat intake. The increased carbohydrate will result in 'superloading' muscles with glycogen, thus increasing the body's available energy reserves. Carbo loading can be viewed as an extension or exaggeration of the normal diet and to what degree and how often a triathlete loads will be determined by racing schedules and previous experience.

The pre race meal is best consumed between two and four hours prior to the start, depending on personal preference and race starting time. An intake of 200 g of carbohydrate is recommended in the four hours pre race. Fat consumption should be limited while protein may be added in moderate amounts, depending on personal preference. It is unclear whether low glycemic index carbohydrates are beneficial and the choice of carbohydrate food is therefore a personal one. Those triathletes who experience hunger during a race could potentially benefit from consuming low glycemic index carbohydrates such as oats or mixed grain breads. Some athletes have difficulty tolerating solid foods because of pre race nervousness or when race start is very early, and a liquid meal such as Sustagen™ and sports drink or fruit juice in amounts to meet carbohydrate needs are an alternative option.

During the race

As glycogen depletion can occur in an Olympic Distance Triathlon, consuming a sports drink is beneficial. Volumes depend on on environmental temperature and individual needs. Suitable sports drinks have a carbohydrate concentration of 4-8%, contain a mixture of carbohydrates with only small amounts of fructose and provide 500 - 700 mg sodium per litre. Recommended carbohydrate and fluid intakes are 30-60g carbohydrate (or 1g / kg) in 600 - 1200 ml fluid per hour. It is best to start drinking in the swim - bike transition and to drink at regular intervals during the bike and run sections. In practice, most triathletes find it easiest to consume fluids on the bike. During the run section, when it is not possible to carry one's own bottles, the options are to have personal drinks at aid stations, to use gels and water or to use the available race drink in which case it is important to try the product prior to the race.

Post race

Especially when racing frequently, appropriate nutrition strategies are vital. Within 30 minutes post race, consume 1-1.5 g high glycemic index carbohydrates and 1.5 times the amount of weight lost as sweat. A sodium containing beverage promotes rehydration. A mixed meal, containing protein as well as carbohydrate should be consumed as soon as is practical with regular carbohydrate consumption in the 24 hour post race period to achieve a total of 600g carbohydrate or 10g / kg.

Body composition

A triathletes physical characteristics are determined by genetic factors, the environment, and past and present training and nutrition status. Elite triathletes are generally tall, of average to light weight with low levels of body fat. Such a physique provides the advantages of large leverage and an optimal power to weight ratio. It is expected that body fat levels vary to some degree between the training and competition season. Typically, elite male triathletes have body fat levels of 6-10% while female body fat levels range from 11-18% . The New Zealand Triathlon Academy uses skinfold ranges rather than percent body fat and current criteria for sum of 8 skinfolds for Academy triathletes are 35 - 75 mm for males and 45 - 100 mm for females. The range acknowledges the considerable individual genetic variation in body fat.

Supplements

In addition to a nutrition plan, triathletes need to have a supplement plan. Supplements are as the name suggests supplemental to the diet and the need for supplements viewed as part of an overall dietary strategy, rather than in isolation. The potential role of supplements as part of a triathletes nutritional plan is fourfold:

1. To supplement the diet in meeting total daily nutritional needs. For instance, a liquid meal supplement may be used to help meet high total daily energy needs.
2. To meet a particular nutritional need in a triathlon specific setting. The use of a sports drink during training or in a race is effective in the prevention of energy depletion and dehydration. Another example is the use of an iron and vitamin C supplement when training at altitude.
3. To manage or treat a specific nutrient deficiency. When suffering an iron deficiency, using a high dose iron supplement in conjunction with a high dietary iron intake, may be beneficial.
4. To exert a direct and specific performance enhancing effect. A multitude of substances are used for this purpose, yet very few have a proven benefit. The only nutritional ergogenic aid which has been shown to enhance endurance performance is caffeine. However, as caffeine is a restricted substance, it's use as a beneficial aid to performance has to be carefully planned

Other dietary regimens.

Although such dietary programmes as the 'Zone', the 'PR' programme and high fat diets are popular with athletes, there is no actual evidence these diets enhance triathlon performance. On the other hand, there is a large and increasing body of evidence showing the benefit of a high carbohydrate diet. It could be argued that the claimed benefit of these programmes merely results from the fact that any plan is better than no plan.

References

Henson, D. A., Nieman, D. C., et al. (1999) Influence of exercise mode and carbohydrate on the immune response to prolonged exercise. IJSN. 9:213-228.

Burke, L., Deakin, V. Clinical Sports Nutrition 1994 McGraw-Hill Book Company Australia Pty Ltd

Sleivert, G.G., Rowlands, D.S. (1996) Physical and physiological factors associated with success in the triathlon. Sports Med. 1:8-18

Frentsos, J.A., Baer, J. T. (1997) Increased energy and nutrient intake during training and competition improves elite triathletes' endurance performance. IJSN. 7:61-71

Jacobs, K.A., Sherman, W.M. (1999) The efficacy of carbohydrate supplementation and chronic high carbohydrate diets for improving endurance performance. IJSN 9:92-115

Applegate, E. (1999) Effective nutritional ergogenic aids. IJSN. 9:229-239

Optimising Olympic Distance Triathlon Performance – A Biomechanist's Perspective.

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Optimum competition performance is directly related to maximising the average velocity achieved during the race. From a biomechanical perspective maximising velocity involves optimising technique to increase propulsive force production, optimising technique and equipment to minimise the resisting forces that limit velocity and making tactical and technique decisions which conserve energy or limit reductions in velocity. Biomechanics can contribute to optimising ODT performance in these ways. However, given that there is a direct relationship between the ability to train and the competitive performance, and that failure to achieve optimal training loads is primarily due to injury, biomechanics plays a secondary role in optimising competition performance by helping to keep an athlete injury free.

Since triathlon is an endurance sport, high numbers of running strides, swimming strokes and pedal cycles are undertaken on a routine basis. A small biomechanical inefficiency can soon lead to injury once many thousands of repetitions are encountered in heavy training. Similarly, anatomical anomalies, technique faults, inappropriate equipment and equipment adjustment can lead to injury without large numbers of repetitions if any of these factors introduce large forces to the body. Specific training techniques can also apply high loads to the body. Inappropriate use of these techniques or incorrect management of their frequency and duration can lead to injury. Biomechanics can play a significant role in preventing injury, which can lead directly to enhanced competition performance.

Mechanisms Of Injury In Swimming.

The shoulder is the most common site of injury in swimmers. Impingement of the long head of the biceps and/or the supraspinatus tendons in the shoulder joint is a common mechanism underlying shoulder injury. Flexibility and strength issues and how these relate to movement patterns are primarily associated with impingement injury. Swimmers with reduced flexibility or with strength imbalances, either avoid the shoulder positions and movement patterns which promote a technically efficient stroke, or they achieve the correct stroke pattern by compensating with undesirable movement of the shoulder joint, putting it in a position that may cause impingement. In general, injury prevention occurs if an athlete has the efficient movement which is associated with performance enhancement. Routine assessment of flexibility, the strength of individual muscle groups and stroke technique can identify problems that lead to swimming injury.

Performance Enhancement In Swimming.

Swimming Velocity = Stroke Length X Stroke Frequency

Stroke length is the distance the swimmer moves through the water from right hand entry to right hand entry. The longer the stroke length the more propulsive force produced during the stroke. A swimmer is more efficient if he optimises the force produced throughout the stroke, producing a longer stroke length, than by increasing the stroke frequency as a way of compensating for reduced stroke length. The complete stroke of the swimmer needs to be periodically analysed, to ensure that inefficiencies in technique are not reducing the stroke length.

As well as increasing the forward propulsive forces, swimming speed can be increased by reduction in the resistive forces. Reducing resistive forces is an effective way of improving performance because it requires no extra energy expenditure from the swimmer. The main component of resistive force to the swimmer is due to the shape exposed to the oncoming flow of water. It can be reduced by utilising better technique during propulsive actions and better streamlining during recovery. Another potential areas where biomechanics can improve performance is in optimising the technique and strategy of slipstreaming in the wake of other swimmers to conserve energy.

Mechanisms Of Injury In Cycling.

Cycling is a unique component of triathlon because it involves the interaction of man and machine. The way the athlete interacts with the bicycle is influenced by its dimensions and this influences the loads applied to the body. The gearing system of the bicycle promotes high pedal rates compared with swimming and running and hence large numbers of flexion/extension and pedal loading cycles occur. An athlete undertaking bike training of 10hrs/week will undergo over 50,000 pedal cycles in the week. Any adverse loads placed on the musculoskeletal system even if small can soon manifest as an injury.

The most common site of injury from cycling is the knee joint. However the mechanism that underlies knee joint injury is rarely located at the knee. Bicycle seat height, incorrect gear usage, biomechanical or anatomical anomalies originating in the ankle or the hip are primary causes of knee injury in cycling. The other common site of injury from cycling is the lower back. Contributing factors to this injury include seat height, inappropriate crank length, leg length discrepancy and asymmetry of the riding posture.

Optimising the dimensions of the bicycle for an athlete’s individual limb segment lengths, flexibility and pedalling technique is a fundamental aspect of reducing injury from cycling. Similarly, routine biomechanical screening of the riding posture and pedalling technique will identify biomechanical inefficiencies which could lead to injury.

Performance Enhancement In Cycling.

The movement of the lower limbs during cycling is defined and restricted by the bicycle dimensions. Consequently, the development of propulsive forces in cycling is fundamentally linked to the geometry and adjustment of the bicycle.

The riding position and posture affects the lower limb muscle length characteristics, the knee joint mechanics and the pedalling technique. These parameters have to be considered to maximise force production. Unfortunately, they interact such that the optimisation of one parameter may have a negative effect on another. Hence, the biomechanical optimisation of cycling to maximise force production is not about optimising individual components but about balancing conflicting mechanisms to produce the most effective outcome.

As with swimming, reducing the forces that resist forward motion can have as great effect on performance as increasing propulsive forces. The main component of resistive force is that due to the size and shape of the body as it encounters the oncoming air. Because the posture on the bike is influenced by the athlete's flexibility and is defined by the points of contact with the bicycle, bicycle dimensions and adjustment is also the main factor involving the resistive forces. Since it effects both the propulsive and resistive forces, the optimisation of the riding position is a fundamental component of optimising cycling performance.

In addition to optimising force production, technical and tactical aspects also play a significant role in optimising cycling performance. The bicycle is essentially an unstable machine and it is the rider that keeps the forces in balance to keep it stable. The bicycle is potentially most unstable when the additional forces present during braking and cornering act on the bike. Because the forces of gravity and deceleration act on the Centre of Gravity (C of G) of the bike and rider, the position of the C of G has a large influence on performance during braking and cornering. The position of the C of G is influenced by the bicycle dimensions, the riding position and the technique of the rider. Optimising the position of the C of G will result in higher speeds through corners and less energy expended on keeping the bicycle stable.

Recent rule changes allowing drafting in elite level ODT have fundamentally changed triathlon. Because the resistive forces encountered when riding can drop by as much as 40% when drafting the dynamics of bunch riding greatly change the physical and tactical demands of the bike leg. Power output profiles associated with criterium style riding c.f. time trial riding indicate significantly different physiological and technical demands. This has implication for the optimisation of the riding position, the riding technique and tactical strategy. From an optimisation perspective, bunch riding and the dynamics of drafting have changed triathlon from an individual sport to a team sport. The optimisation of ODT performance now lies in the optimum use of team resources to maximise the performance of a selected individual.

Mechanisms of Injury and Performance Enhancement in Running.

The forces acting on the body during running are higher than those encountered in swimming and cycling. Runners experiencing high impact loads are more likely to get injured than those with lower impacts.
Consequently the attenuation and management of the loads that accompany running play an important role in remaining injury free.

Running shoe construction has a large influence on the foot and ankle movement patterns and the magnitude of the loads transmitted to the lower limb during ground contact. Control of the amount of dorsiflexion and pronation with footwear appropriate for an individual athlete can lessen the likelihood of injury. Similarly, the occurrence of injury is reduced by shoes with midsole construction and pressure distribution characteristics that lessen the transmission of impact forces. Training parameters also influences impact loads. Increased running speed causes a linear increase in impact loads. Running downhill dramatically increases impact as well as moving the point of force application on the foot, enhancing the risk of injury. Contrary to common belief, running on grass increases impact shocks up to 30% above running on asphalt or a polyurethane track surface.

Routine biomechanical assessment of running mechanics, appropriate footwear to control the movement patterns and reduce impact loads as well as informed training decisions that limit the magnitude and frequency of impact loading will help the athlete achieve their training goals by staying injury free.

The relationship between technique and performance is not as strong in running as it is in swimming and cycling. Running techniques that reduce braking forces during initial foot-ground contact have not been clearly shown to improve running efficiency. However runners with large vertical movement of the body's C of G have a higher energy cost and care should be taken to limit these vertical movements.
Potential areas where biomechanics may help optimise running performance is with investigation of the pacing and tactical strategy of the bike leg and its influence on the subsequent run performance. Investigation of power output records associated with the cycle leg may lead to the evolution of an individualised riding strategy that optimises running performance.

References

Kyle C.R. Reduction of wind resistance and power output of racing cyclists and runners travelling in groups. *Ergonomics 22*, 387-397, 1979

Lafortune M.A, Valiant G.A. and McLean B.D. The biomechanics of running. In: *Running*, Hawley J.A. (ed) Blackwell Science Publishing, 2000 (in press)

Mason B.R. Where races are won and lost. *Proceedings of the 19th Annual International Symposium of Biomechanics in Sport*. Perth, July 1999.

McLean B.D. Anatomical and *Biomechanical correlates of performance in cycling*. PhD thesis, University of Queensland 1990.

McLean B.D. and Blanch P. Bicycle seat height: A biomechanical consideration when assessing and treating knee pain in cyclists*. Sport Health Vol. 11:1*, 12-15, 1993.

Maximising Olympic Distance Performance – The Athlete's Perspective

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Preparation is not just the physical training in the months leading up to the event. There are psychological, emotional, dietry, health and circumstantial components that are critical to performance. A balance must be kept between these. An obvious but important factor is the sporting career of the athlete. Most elite athletes have dedicated themselves to sport from a very young age. With this span of time comes wins and lossess and constant competitive experience. Understanding how an elite triathlete maximises Olyimpic Distance Triathlon Performance is as complicated as it is personal. This paper will discuss these themes in the context of my career as an elite triahtlete since 1991.

1. Background

My triathlon career began in October 1991, shortly after my sixteenth birthday. I competed in a Brisbane Milo event over a distance of 300/12/3. I finished eighth after coming out of the water second. I had been swim training since I was four so this was no real surprise to me. I had spent what seemed like forever in transition; my bike was too big and the distance of the run was too short. I knew my best run distances were 6km and above. This became clear following my years in primary school as I had been beaten over distances up to 4km. There was great room for improvement but I was hooked and I knew I would be more suited as the distances became longer. I later represented Queensland in the National Schools Cross Country Championships over 8km and was placed in a 5km State Schools Athletics Championship but although I had achieved a satisfactory level in running races needed to be much longer which Olympic Distance Triathlon offered.

In the eight years since, I have competed in 51 Olympic Distance Triathlons - four of which I did not finish due to injury, sickness, or mechanical failure. I competed in:

- 4 triathlons when I was 18 years of age
- 7 when I was 19 years of age
- 4 when I was 20 years of age
- 12 when I was 21 years of age
- 15 when I was 22 years of age
- 7 when I was 23 years of age, and
- 2 so far at 24 years of age

My introduction to olympic distance triathlon was slow. I had competed in five olympic distance triathlons prior to racing in my first Olympic Distance Junior World Championships and thirteen when I won the 1995 World Junior Championships.

My early sporting career started with swimming. Apart from the long and regular eleven weekly sessions, I learned the finer points in stroke technique and learned to swim fast at an early age.

Whilst I never had a regular running coach I was advised to run long and slow. Rhythm was achieved by good head position and flowing arm movement. I was also advised to position the ball of the foot under the knee to get the necessary lift.

In my formative years, I had no specialist training cycling but I was given simple advice to spin on small gears to learn how to pedal. In each of the disciplines I practised these and other self learned techniques. Every second of every session I concentrated on technique, following the adage "practice makes perfect".

I trained hard and often but I did not push myself into olympic distance racing. Race days were sacred. Mentally and physically, I was ready to explode on race days. But the theory was that I should not suffer the Olympic Distance until I was 100% ready unless it might have an adverse mental and physical effect on my performance in future.

I competed in another 16 triathlons in the first two years of my triathlon career. It was not until December 1993, at eighteen, that I raced in my first olympic distance triathlon. I competed in the Cadbury National Junior Selection race at Port Stephens. I won after taking the lead for the first time in the run leg. Until this time, my training mainly revolved around the particular sport on the school sports calendar (swimming September to March, cross country running April to June, and athletics July to August) but I had some introduction to triathlon training with a triathlon coach. My two year preparation for olympic distance triathlon had paid dividends.

A question I ask now is would I be a better triathlete had I been trained as a triathlete rather than specifically training in each discipline with specialist coaching? For me, the answer is that specific uninterrupted training, especially in swimming, taught me to repetitively practice technique in each discipline – which I still rely on today.

Also, I ask how much does my performance now, over the olympic distance, at 24 years of age, depend on the platform laid in those years where I was protected from the arduousness of racing often in extreme conditions for 1hour 50 minutes. It takes not much more time to run a marathon. I think my slow introduction was the right foundation.

2. The Coach

I have had four triathlon coaches (probably there aren't many more in Australia!) and there was a period when I coached myself. I engaged a swim coach and did my running, cycling and transition training myself. Managed in a disciplined manner, this approach has appeal as one can get very specialised training in each of the disciplines and for me it meant I could live at home with appropriate meals and support. However, my racing performances during this period were mediocre. Swim sessions were unnecessarily long, as were designed for swimmers. Running and cycling lacked the required quality and intensity although I race regularly in cycle races. This approach to training is used by some of our elite athletes and highlights the infancy of our sport as it has not progressed to the stage where there are enough elite coaches with the appropriate credentials and experience to provide training at the required level.

A coach is important to me as I will train more effectively and as a result maximise performance in racing. Each of the coaches I have had has been very skilful and used different training methods. From an athlete's point of view, some of the requirements for effective coaching are:

- the coach's team is strong in elite athletes creating a competitive environment
- good programs and advice
- general agreement with coaching philosophies
- training with minimum of injury

3. Training, Preparation and Racing

Triathlon offers a great challenge to athletes, coaches, high performance managers and others involved. It not only has three distinct disciplines but it is connected by two others - "swim-bike" and "bike-run". This adds complexity for those trying to maximise performance. The "do's and don't's" are not set in concrete and opinions in maximisng performance vary greatly. Maximising performances of course may mean different things to coaches and athletes. To some it will mean maximising performance in one critical race, or a series of races. It will often depend on what are critical national selection races. Training through races may be necessary to be at a peak for a particular race.

My preparation involves careful training and racing at least eight weeks from the race where my performance is to be maximised. This involves selecting lead up races preferably spaced at two weekly intervals. In the final few days I will rest and make sure I am adequately hydrated.

3.1 Swim

My triathlon performance is underpinned by my swim and it has become such an important element since the drafting rule was applied to World Cup racing. I am now pleased about my early education in swimming as it is essential to make the first bike pack out of transition to put oneself in the right position. I train about 28km per week which is enough for me to be in the first group out of the water after a 1500m swim.

My swim stroke is a great asset. I now believe that had I not trained as a swimmer from a young age, I would be facing a difficult task to maximise my performance at the elite level. I often compare the swim stroke to the golf stroke as it must be rhythmically and mechanically perfect to gain optimum effectiveness. However, the open water, turning buoys and the proximity of other competitors can wreak havoc with your stroke. Open water swim practice is required so that breathing, headlift and stroke can be refined for race circumstances. Also a good start is imperative to avoid the trouble in the back of the field. Finding a competitor's feet is a natural tactic unless leading.

3.2 Swim Bike

This transition seems to have less importance than its counterpart as the muscles used are wholly different. However, maintaining the continuity of the race is critical. A good transition is essential to gain as many seconds as possible.

3.3 Bike

I cycle about 400km per week with a variety of speed work, rolling hills, time trials and strength work using the hinterland. The aim is to get the miles in the legs. The triathlon distance is always 40km - not a great distance for a cycle race, but the shorter the race the greater the speed and the higher the level of skill required in taking turns and sitting on a wheel. The technical nature of the courses has meant that I do drill practice to improve the technical aspects of my bike handling.

Now drafting brings higher levels of danger, faster racing, but with some opportunity for physical relief when taking a wheel. In the future, when the pack is racing and it becomes even more "cut throat", I think we will see more cycling surges and counter-surges, especially from those with weaker run legs. There is now little opportunity for a sole cyclist to stay in front of the pack since triathletes are becoming proficient racing cyclists. It is that part of the race which now carries with it the most tactics.

3.4 Bike Run

This is critical as the legs are the centre of attention in both the bike and the run but used in entirely conflicting ways. I train for this transition each week which is imperitave to my overall performance. It is difficult to achieve this having coaches for each discipline.

3.5 Run

One will argue this is the most critical and it seems this is the discipline where there can be the greatest diversity of opinion in training. Some will work on the basis of the more you do, the better you get. If this is the case I can get a lot better. I generally run about up to 70km per week when other successful athletes will train up to 100km to 140km per week. Perhaps as the sport evolves maximising performance will be in the latter range.

The 10km run leg comes after 75minutes of swimming and cycling at high intensity. I instinctively run into rhythm, adopt the right posture and try to keep my leg speed up and just run fast. This is something that I concentrate on during training. There is little time to think – maximising performance is a reflection of adequate training. If I get in a position to finish high in the field my mental attitude will naturally increase. There is often not much time for tactics. It is a case of running as fast as you can, reaching into the bank of training miles cumulated from the years before.

3.6 Weights and resistance training and stretching

My personal view is that weight training would be advantageous in maximising performance. But there is some debate about whether the performance would be maximised from an additional session of weights. Perhaps the time would be better spent doing another swim/bike/run session. My regular programs do not include weight training, with the development of strength coming from general training sessions through mountain and hill climbing work. My only experience with weight training was prior to winning the Queensland Schools Championships. This was over the sprint distance which gave me the edge I needed for that day. I had been doing weight training under a coach for eight weeks prior.

I currently do strength exercises on a regular basis and stretch to prevent injury. These aspects of my training are largely unstructured, but as I get older I expect there will be a greater demand for me to use weights more regularly to maximise performance.

3.7 Drafting

I have witnessed first hand the transition between non-drafting and drafting. From my own point of view this has not made too much difference to my performances as a strong swim leg will put you into the race be it drafting or non-drafting.. Disc wheels have disappeared and aero bars have been shortened as they do not have the effect they used to.

The paramount importance of the swim leg has not yet been wholly realised as there are not yet enough brilliant 1500m swimmers to form a bike pack to always form a bike pack of their own to take advantage of the swim lead. Generally, the good swimmer will be left to labour on the bike by him/herself or with perhaps only one other competitor until the pack is ready to hunt them down. They are then left totally vulnerable in the run leg. But when bike packs come together the race becomes a runners race as some will be are inclined to do less work on the bike whilst the non runners will do more. Drafting has made the race faster and a far more tactical affair.

Training must now be directed to the requirements of drafting races.

3.8 The Course

The Olympic Distance Courses are now often technical. The swim can be in laps so good positioning at the turning buoys is essential. The bike courses are technical around many laps which demands superior bike skills. Apart from triathlons I have often race in cycling criteriums to learn the skills required. The run courses are also lap courses but this has a lesser effect on performance. The courses can include hills and or be totally flat so that preparation may have to be specific to the course to get a satisfactory result.

This brings me to the question of what is the adequate amount of training to maximise performance at the Olympic Distance. I have never raced at a triathlon distance longer than this. I have never trained or raced over the marathon running distance and only trained over a running distance beyond half marathon distance in recent times. I have relied on my technical and aerobic ability to consistently maximise my performances. This is complemented simply by my getting older and physically more mature. As a smaller person I have always found it has taken me a little longer for my body to “catch up” so I can maximise my expected performance. I have been conscious of training to extreme where the onset of injuries could put me at risk or shorten my career. I have not yet reached physical maturity.

4. Olympic Distance versus Grand Prix/F1 Distances

One of the great dilemmas for the professional triathlete is to balance the necessities to earn a living and still achieve the lofty ambitions of national selection for World Championships, Commonwealth Games and Olympics. In 1996, directly after winning the World Junior Olympic Distance Championships I raced in the International Triathlon Grand Prix Series. At that stage in my career it was a significant decision to make. I had earned little prizemoney or sponsorships even after winning the Worlds. The shorter, intense distances of the Grand Prix style of racing do not wholly suit my strengths as an athlete. Yet at that time I had to reconcile being a professional against my olympic distance aspirations. During that year I raced in five olympic distance events. After four years in triathlon, I had competed in only 19 olympic distance events. In retrospect, it took another year for my olympic distance form to return to some level of consistency which reflected the way I trained for these events and my first year out of juniors, as well a the different style of racing.

The professional events such as the Grand Prix/F1 and Tri Tour events may not wholly accord with preparation for the institutional olympic distance events. This can be a dilemma for the athlete and coach as it may be impossible to maximise performance in both in the one season. Triathletes do not have the luxury of training with a taper for one specific event in each year. Decisions such as whether to train through the Grand Prix/F1 Series, train for greater speed, taper for each race, or only some, are difficult. All become significant decisions when World rankings and national selection hinge on soon to be contested olympic distance races. You will notice some athletes do the F1 Series, others do not. It is often not clear to the triathlete which is the better option or if both types of racing can complement each other. I have often compared the two to be like squash and tennis the games are alike, but nothing alike.

I suppose my current view having raced in five Australian Grand Prix/F1 Series, one International Grand Prix Series and two Australian Tri Tours is that they do not necessarily in themselves prepare you for olympic distance triathlon racing despite the greater intensity. Although it provides the opportunity to hone your skills, gives you greater experience and you learn to deliver under great physical and mental pressure.

5. Racing Frequency

It is difficult for me to say what the optimum number of races an athlete can race in to maximise performance without risking injury and suffering serious staleness. The frequency of racing to maximise performance is something I believe will depend on many factors for me. Having eight years of triathlon racing in 51 races is mainly as a result of the influence of my mentors in my early years of my career. As I have grown older I have raced more. In 1998 I raced 13 times and this was my most consistent year in olympic distance triathlon. I certainly thought I could manage that number of races at that time, and I did. I finished third in the ITU World Cup Series and at the end of the year I was ranked sixth in ITU World Rankings. I raced more and my performances improved. But I believe there comes a time when you have to stop racing, rest and build base again.

In the Tour de France, the athletes race every day for three weeks over massive distances and mountainous terrain. Compare this to an elite marathon runner who would only run two marathons a year. An acceptable number of races in triathlon to maximise performance and remain free of injury is not clear to me. This may be an individual thing but more likely sports scientists, coaches and triathletes themselves should know better as the sport progresses further.

6. The Other Session – Rest/Recovery

Recovery between sessions is vital to maximising training performance and I have no difficulty doing this after each session. Recovery is the session where it is most difficult to measure its value. I am currently allowed one day off per week. My performances have been better having the day off and my injury rate has been much lower. Prior to this I would not have a day off but my training was not as high in intensity. Prior to winning the Junior World Championships I was having one morning rest/recovery per week.

Often it can be difficult to reconcile whether you should be getting a few more "miles" in the legs rather than resting. I am sure some coaches would define resting as under-achieving. I suppose the effect of additional training compared to resting can only be measured in the longer term.

7. Injury

To maximise performance I have tended on the safe side with injury unless my coach has insisted I train through. Prior to the World Juniors in 1995, I had an ITB problem which lasted for four weeks. I trained during this time. This injury came after an all day session at a much higher increment than the usual training miles. It was one of the few times I trained through an injury.
Early in my career I would rest for 48 hours after an injury and this fixed most problems. I have relied on physiotherapy for all my serious injuries from the best physios. I now use massage on a regular basis as a precaution against injury.

I have had three a major bike falls in training which unfortunately goes with the territory. Each time I have received immediate medical attention and concentrated physiotherapy. Coaches have different approaches to recognising and treating injuries. The long term effects of injury should not be discounted. Obviously maximising performance in Olympic Distance racing can only be achieved when injury free.

8. The Ideal Body Shape for Olympic Distance Triathlon

For me, the signs were clear early in my sporting life that I never had abundant speed. My body size, weight and genes meant that I was probably more suited to longer distances. This makes me wonder what the essential aerobic and physical characteristics are for maximising performance over the Olympic Distance. I believe a triathlete should not be too big in the pecs and shoulders nor too big in the quads or gluts. This is just extra weight to be carried during the run. Yet swimming and cycling develops these parts. Body shape is something over which one has little control. Just as a result of training you naturally develop in the quads or the shoulders.

Perhaps the best body shape is to look as much like a runner as possible - narrow in the shoulders, not overly developed in the quads, and very lean all over. However, this has to be achieved without losing strength in the upper body and legs required for the run and the bike. But, without a good run leg in Olympic Distance triathlon in a well balanced field of elite triathletes, you cannot win. Therefore I think some emphasis needs to be placed in the ideal shape of a runner to maximise performance. Perhaps triathlon training, in the long run produces the ideal triathlon body naturally.

9. Diet and Supplements

My diet is fairly basic with pasta and fruit and vegetables as common elements. I take little in the way of dietary supplementation probably through a lack of reliable professional advice rather than anything else. This may need greater consideration when considering performance maximisation.

10. Travel

Travelling is part and parcel of being a professional triathlete and in some ways hinders performance. The dilemma of the triathlete is that he/she must travel to races to earn money and/or world ranking points. One has to decide which races to target which hopefully fall nicely into training programs but as the races set down in countries around the world they will only coincidentally match up with an athlete trying to maximise performance.

11. Conclusion

Olympic distance triathlon comprises a set of events the technical aspects of which are extraordinarily complex when taken as a whole. I believe it offers more challenges than any other sport, not just because of the separate disciplines, but as a young sport the norms in respect of training, preparation, racing and recovery are still being established. The current triathletes in some respects are pioneers, as are the coaches, sports scientists and administrators each of whom has a role in contributing to the maximisation of performance of triathletes.

I have outlined my introduction to the sport and my subsequent journey to date and hope that this will contribute to the general education one might undertake in becoming an elite olympic distance triathlete. I hope that the outline of the historical record of my olympic distance races provides some insight into the training and race management for triathletes, particularly those progressing through the junior ranks, and the subsequent progression towards high performance at the elite level of olympic distance triathlon competition.

My performances have been founded on a good technique in each discipline which I believe to be the most significant factor, apart from having the aerobic ability, that has sustained my performances.

Guidance from high performance triathlon coaches is essential in maximising performance as well as specialist coaching in each of the disciplines in the formative years.

Now that triathlon is an Olympic sport significantly more pressures have been imposed upon all parties involved. From a triathletes perspective this has meant that making the right decisions to maximise performance is much more imperative especially given the limited timeframe in the life cycle of the triathlete. I hope the comments in this paper may contribute in a positive way in helping triathletes maximise performances over the olympic distance.

Maximising Olympic Distance Triathlon Performance
A Coach's Perspective.

Kieran Barry
Elite Triathlon Coach

Using hypobaric oxygen techniques and hyperbaric intervention to level the playing field in olympic distance triathlon: Literature review and study proposal

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1998 saw the cycling world rocked to its very foundations by the well publicised exposure of the widespread use of performance enhancing drugs during the Tour de France of that same year.

Since then athlete after athlete in a myriad of different sports around the world have "gone positive" as Sports Drug Agencies, and indeed law enforcement agencies, worldwide crack down on the use and traffic of performance enhancing drugs in sport.

The UCI, in what could only be described as a "knee jerk" reaction to the scandal surrounding its show-piece event, Tour de France, introduced "blood testing" as a means of determining the "potential" illicit use of erythropoitin (EPO) as an ergogenic agent. By setting an arbitrary figure of 50% as a haematocrit "competition cut off" (i.e. When an cyclist records a Hct greater than 50% they are not allowed to compete for "health reasons"), the UCI opened a Pandora's box of potential "false positive" disqualifications from competition being called against "clean" athletes.

In a recent paper by Browne et al (1999), the authors concluded that blood testing as a means of detecting the illicit use of performance enhancing substances such as EPO is "not yet justifiable in sport" (Browne et al, 501, 1999).

While not exposed to the sort of scandal and resultant media pressure of the UCI, the ITU has been able to adopt a more conservative, mainstream approach to drug control within the sport of triathlon. It would however be naive to believe for one moment that a sport such as triathlon, which has its training basis in aerobic strength/endurance, requires voluminous repetitive training and offers the elite of the sport a lucrative lifestyle, is immune to drug abuse.

While various researchers and academics have offered a myriad of "natural alternatives" to drug use for various athletes (e.g. Report of the Ross Symposium on Muscle Development: Nutritional Alternatives to Anabolic Steroids. 1988), the last few years have seen major advancements in sports science and bio-technical instrumentation that provide startling new possibilities in leveling the playing field between those athletes who chose to avail themselves to illicit, and currently largely undetectable, performance enhancing drugs, and those that wish to compete “clean”.

Without doubt, the areas of "hypobaric" or altitude training and "hyperbaric" therapy are the two areas that warrant further investigation as methods of improving athletic. While both practices are thwart with much conjecture and supposition, particularly in Western Society, Eastern Bloc countries such as the then Soviet Union, have been using such techniques with resounding success for more than a decade (Latushkevich et al 1993, Vorob’ev et al 1994).

It is the purpose of this discussion to briefly review some of the more recent scientific research, pilot and case studies in these areas to ascertain their potential worth as legal performance enhancing practices as we head towards the new millenium. This presentation will also outline an applied research study to be conducted at the Runaway Bay Sports Super Centre (Gold Coast, Queensland) within the next 6-12 months, to ascertain the practical, tangible, measurable performance and physiological benefits and responses to these practices.

Hyperbaric Therapy:

Hyperbaric medicine is not a new area of interest for the medical fraternity, indeed human physiological responses to increased pressure gradients have been something that has interested the medical profession for hundreds of years - ever since man started descending to the depths of the ocean floors for commerce and recreational reasons (Mader, 1989). The use of hyperbaric intervention however in the treatment of various ailments (e.g. Burns, slow healing wounds, etc.), crush and compartment syndrome type injury (personal communication with Dr. Ian Millar, Biophysical Journal (71): 1997) has a relatively short history (Hunt and Pai, 1972).

A considerable body of scientific evidence now exists that illustrates significant improvements in the speed of recovery from a variety of ailments including; burns (personal communications with Drs: Millar and Larkins), wound healing (Hunt and Pai, 1972; Anderson et al, 1992; Storch and Talley, 1988) as well as a number of commonly experienced sporting injuries involving; ligament, tendon, muscle and bone (Vujuovic, 1983; Wilcox and Koloding, 1976; Abbot et al, 1994; Ashley L. 1994; Favalli et al. 1990.)

When one considers that many of the injuries athletes experience at a cellular level, particularly in those activities which have a large eccentric muscular contraction component - such as running - are as a direct consequence of "hypoxia" (i.e. A lack of oxygen supply), it stands to reason that practices which augment oxygen supply to muscles that have been worked in an anaerobic environment, may indeed speed the rate of recovery from one exercise bout to another. It then follows, if an athletes' rate of recovery between exercise bouts can be significantly improved, the athlete will then be able to absorb greater volumes and intensities of training which would potentially translate to improved physical performances (Nb. This is one of the rationales for the use of anabolic steroids such as nandrolone by endurance athletes – an improved recovery rate.).

Studies of both animal (Staples et al 1995) and human models (Staples,

1996) suggest treatment with hyperbaric oxygen may decrease the inflammatory process and actually modulate tissue injury as a consequence of augmented eccentric exercise (i.e. downhill running).

Additionally, "interesting evidence suggests that adjunctive treatment with hyperbaric oxygen therapy enhances recovery from soft tissue injuries, specially the type of injury seen most often in sports medicine. The most impressive results appear to be generated by prompt treatment. When hyperbaric oxygen is initiated within the first 8 hours post trauma, the effects seem to be the most dramatic." (Staples and Clement, 1996). When one considers that much of the post training response encountered by athletes after a hard training session mimic soft tissue injuries (e.g. Microscopic tears of muscle fibres and the resultant edema, leading to increased diffusion distances between the cell and blood supply, as a normal result of training). Hyperbaric oxygen, the effects of which are often referred to as “internal icing”, may well have a role to play in speeding recuperation and decreasing the instance of injury in hard training athletes.

There are however some situations in which hyperbaric oxygen therapy may have complications and adverse side effects, particularly at higher atmospheric pressures (i.e. 3 atmospheres): Grand mal seizures (Clark and Fisher, 1977; Clark et al, 1991; Lambertsen et al, 1953) and even at lower atmospheres (i.e. 2 atmospheres) (Adameic, 1977; Clark and Fisher, 1977; Stevens et al, 1991). Apart from these potential neurological based problems there is also the risk of nausea, tooth and sinus pain and blurred vision (Jain, 1990). Those people suffering upper respiratory tract infections, fever, etc. should be excluded from hyperbaric therapy until they overcome such ailments. One group of people that should be excluded entirely from hyperbaric oxygen treatments are those suffering from pneumothorax (chest trauma) (Foster, 1992).

As yet there have been no controlled, scientifically based investigations looking directly at the proposition that hyperbaric oxygen therapy speeds the rate of recovery from one exercise bout to the next for hard training athletes, although the indications are (from related areas of investigation) that such treatment may well have a role to play in speeding athlete recuperation from training.

Hypobaric Training:

It has long been recognised that for athletes to perform to their optimal capabilities at elevations of 1400 metres or greater such athletes must either be born and trained in these environments, or spend a significant period of time (3-4 weeks) "acclimatizing" to these rarefied atmospheric environments if they are to perform to their potential. The physiological reasoning behind this phenomena is quite simple, and related to red blood cell concentrations and the decreased partial pressure of oxygen and has been well documented in a number of classic scientific investigations (Buskirk et al 1969; Raynaud et al 1986; Terrados et al 1990; Terrados et al 1988).

VARIABLE	Pre IHT exposure	Post IHT exposure
* Resting heart rate (bpm)	35	28
* Body weight (kilograms)	68.7	67.9
* Skinfolds (sum of eight sites – mm)	32.3	29.3
* Hematocrit	44%	51%
* Performance time for for 4km track time trial at fixed aerobic heart rate of 152bpm (mins/seconds)	15.25	14.56

There is less decisive scientific evidence available as to the benefits of training at altitude for a period of time, to gain the various physiological adaptations associated with such environments, and then competing, at sea level, at a later date. Those investigations that have been conducted have returned a host of conflicting results (Levine and Stray-Gunderson 1992; Mizuno et al 1990; Wolski et al 1996). One of the principal reasons often cited as a cause of this conjecture is the lack of including control groups in these studies. In recent times some investigators (e.g. Mac Dougall, Gamow - personal communications, Levine and Stray-Gundersen, 1990 and 1997.) have proposed the "sleep high, train low" theory of athletic training. The only published investigations in which such a practice has been investigated are by Levine and Stray-Gunderson (1990 and 1997). In these studies they found a group living at 2500 metres and training at 1250 metres (hardly sea level) improved VO2 max, 5000 metre run time (by 30 and 13.4 seconds in their 1990 and 1997 investigations respectively) and increased blood volume by 500ml (1990 investigation) and red cell mass (Hct) by 9% (1997 investigation). The control groups, living and training at 1250 metres, showed no changes in these aforementioned parameters. Unfortunately this study (1990) was thwart with a host of shortcomings and as such the results must be viewed with a degree of skepticism.

Reviewing the current literature reveals a scarcity of information pertaining to this aforementioned area of investigation. When one considers that many of the negative concerns often cited as being counterproductive to athletes remaining for extended sojourns, particularly at higher altitudes, are as a direct result of modifications in body composition. Namely a loss of lean muscle mass, and/or changes in neuromuscular innervation patterns, as a consequence of not being able to train at a high enough intensity, due to a lack of oxygen, to fully innervate type two, fast twitch muscle fibres (Wolski et al 1996). It stands to reason that if the positive aspects of prolonged hypoxic exposure can be maintained (i.e. Increases in RBC (Sutton et al, 1988; Mairbauri et al 1990), improved sub-maximal aerobic function (Vallier et al 1996)), whilst those negative aspects can be removed (e.g. Dehydration, loss of muscle mass, lower maximal oxygen uptake etc.), then athletic performance may well be augmented.

It has been theorised that by "sleeping high and training low" athletes may well be able to gain the positive EPO release, which will produce the desired increases in RBC populations that will improve oxygen delivery to working muscles, whilst avoiding the negative changes in body composition and counterproductive neural innervation patterns that comes with extended stays at altitudes above 3000 metres.

Until relatively recent times such a practice as detailed above would have proven extremely impractical (i.e. Having to transport athletes from high altitude accommodation to appropriate low lying training facilities.). This however is no longer the case. The advent of various, relatively inexpensive, portable hypoxic chambers such as the "Gamow bed" (Patented by Professor Igor Gamow of the University of Colorado at Boulder, USA), as well as purging sleeping quarters (bedrooms and tents) with 12-15% oxygen/nitrogen atmospheres, all allow athletes to sleep at the simulated altitudes necessary to stimulate increased EPO releases, invoke the positive skeletal muscular adaptations to enhance endurance performance, whilst still training at sea level and hence maintaining the intensity of exercise necessary to maintain appropriate neuromuscular patterning.

Intermittent hypoxic training (iht): the next frontier in altitude training.

Introduction:
Intermittent Hypoxic Training or "IHT" which has its origins in the Russian military and space programs heralds the new frontier in "altitude" training. Approximately 18 months ago this form of altitude simulation was introduced to New Zealand sports by Dr. Alexei Korolev.

This method of "altitude training" – which is claimed to be equivalent and even superior to conventional altitude training by being able to control the altitude "dose" – is achieved by exposing athletes to hypoxic air containing 9-16% oxygen (equating to an altitude exposure of 2,000 to 6,500 metres above sea level) intermittently at 4-6 minute intervals interspersed with breathing normoxic air for the same periods, for 60-90 minutes per session, once or twice a day.

Exposing the athlete to such hypoxic gases in the aforementioned manner, via a machine called an "hypoxicator", is thought to stimulate EPO release and hence red blood cell production resulting in increased oxygen carrying capacity within the blood.

Preliminary Research and Case Studies:
In a pilot study of a group of 10 elite endurance athletes (swimmers, triathletes and runners), Dr. John Hellemans (1998) found:

1. Endurance performance over a series of performance tests (swimming, cycling and running) improved on average by 3.1%.
2. Hemoglobin concentration increased on average by 4.4%.
3. Hematocrit increased on average by 4.8%.
4. Reticulocyte count increased on average by 28.7%

Dr. Hellemans summarised the findings of this investigation as follows:

Ten endurance athletes were tested with the method of Intermittent Hypoxic Training (IHT) in relation to hematological factors and performance over a period of three weeks. Results show an overall improvement in hematological factors related to oxygen transport and performance. The results indicate that IHT is an effective method to simulate altitude training. On the basis of the results it is recommended that further research and testing is done in the area of maximising outcome for individual athletes. However in general the method of IHT can be strongly recommended for any serious athlete as part of their training and preparation.

A further case study was recently (August-September 1999) undertaken at the Runaway Bay Sports Super Centre on Queensland's Gold Coast. The results of this case study are indicated below and occurred over a ten to fourteen (10-14) day period during which time the training of the athlete remained constant.

The athlete involved in this case study was an elite ultra-distance triathlete (Nb. Training performances prior to IHT exposure suggested that he has the potential to record in the vicinity of 8 hours for an Ironman distance triathlon) training 30+ hours per week. His weekly training comprises 25-30km per week or swimming, 400-600km per week of cycling, 100-120km per week of running and two to three weight training sessions per week. This athlete's training was not altered in any other way during the IHT exposure. All factors listed above show tendencies to improved aerobic function as a consequence of a greater red cell mass – this is conclusively supported by a 7.25 second per kilometre improvement in performance time for the fixed heart rate aerobic track run (Cedaro, Unpublished observations, 1999).

Conclusions:
On the strength of these findings of the above mentioned case study, and those of Dr. Hellemans, the Sports Science Medicine Department of the Runaway Bay Sports Super Centre purchased two hypoxicator machines (one four station and one two station) for use by RBSSC Triathlon Squad members and visiting athletes to the facility.

Study Proposal:

Since these interventions (i.e. Hyperbaric therapy and "sleep high, train low" and IHT) are still relatively new areas of investigation in relation to optimising athletic performance, the following investigation will be undertaken at the RBSSC within the next 6-12 months:

Study Design:
30 well trained, triathletes are pre-screened and tested for:

* Performance tests (e.g. 1km. swim for time, 30km. time trial, 6km track run)
* VO2 max: Standard test protocols (bike/run)
* Key strength/power indicators (e.g. Knee extension)
* Anthropometric data (i.e. Height, weight, skin-folds, etc.)
* Various blood parameters (e.g. Uric acid, Hct, RBCM, blood viscosity, plasma volume)

They will then be divided into five evenly matched groups of 6 and trained equally, as a squad for five weeks by the same accredited multi-sport coach, in the same manner with the following interventions:

(a) Group one acts as the control group, lives in close proximity to the other study groups and trains under the guidance of the study coach. This group receives the same coaching advice, nutrition, medical/physiotherapy support, etc. as the other three study groups.

(b) Group two, is treated in precisely the same manner as group one, the only difference being that once a day, for 60-90 minutes they are placed into a hyperbaric chamber and breath pure oxygen under two atmospheres of pressure.

(c) Group three, is treated in the same manner as group one, but unlike group two, this group sleeps in a hypobaric chamber/nitrogen house for 8 hours per night at a simulated elevation of 2500 metres.

(d) Group four, is once again treated in the same manner as the other three groups in relation to the training provision, nutrition, massage, etc. provided. The interventions provided for this test group are: (i) Sleeping for 8 hours in the hypoxic environment (as per group three) and (ii) 60-90 minutes per day of hyperbaric exposure (as per group two).

(e) Group five will be provided with the same interventions as group four, however the eight hours of sleeping at 2,500 metres will be replaced by IHT exposure for 60 minutes per day as per the exposure protocols manual provided with the hypoxicator device.

Throughout this intervention period the athletes will on a weekly basis:

(a) Keep detailed training logs in relation to:

(i) Work completed (Volume and intensity - heart rate readings, etc.).

(ii) Monitors of overtraining (as per Hooper et al, 1995) and illness log.

(b) Be assessed for changes in blood chemistry:

(i) RBC populations (MCHb, MCV, RBCM, Reticulocytes).

(ii) Blood viscosity.

(iii) Indicators of recovery (CPK, urea).

(iv) EPO concentrations.

(v) Iron status.

(c) Assessed for changes in body composition via standard anthropometrical practices (e.g. skin-folds, body mass index).

After a common taper, at the end of the five week intervention period the triathletes will be reassessed for the initial performance indicators recorded at the commencement of the investigation for statistical comparison within and across all five groups in an attempt to ascertain whether or not the interventions and protocols (and/or combinations thereof) discussed above have any significant effects on endurance performance.

References:

Abbot NC., Beck JS., Carnocham EH., et al. Effect of hyperbaric oxygen at 1 and 2 ATA on hypoxia and hypercapnia in human skin during experimental inflammation. J. App. Physiol. 1994: 77(2): 767-773.

Adameic L. Effects of hyperbaric oxygen therapy in some basic vital functions. Acta Physiol. Pol. 1977: 28: 215-224.

Anderson LH., Watson B., Herring ER., et al. Influence of intermittent hyperoxia on hypoxic fibroblasts. J. of Hyperbaric Med. 1992: 7(2): 103-114.

Ashley L. Hyperbaric Oxygen Therapy with the Vancouver Canucks, 1993-

1994 season. Vancouver Canucks report, 1994.

Browne A., Lachance, V. and Pipe A.: The ethics of blood testing as an element of doping control in sport. Med. Sci Sports Exerc. 31(4): 497-501, 1999.

Buskirk ER., Kollias J., Akers RF., et al. Maximal performance at altitude and on return from altitude in conditioned runners. J. Appl. Physiol. 1967: 23(2): 259-266.

Cedaro R.: IHT: A case study (unpublished observations, August 1999).

Clark JM., Fisher AB. Oxygen toxicity and extension of tolerance in oxygen therapy. In: Davis JC. Hunt TK. editors. Hyperbaric oxygen therapy. Bethesda (MD): Undersea Medical Society, 1977: 61-77.

Clark JM., Gelfand R., Stevens WI., et al. Pulmonary function in men after oxygen breathing at 3.0 ATA for 3.5 hours. J. Appl. Physiol. 1991: 71(3): 878-885.

Favalli A., Zottola V., Lovisetti G., Lovisetti L.: External Fixation and Hyperbaric Oxygen Therapy in the Treatment of Open Fractures of the Tibial Shaft. In: Bakker DJ., Cramer FS., v.d.Kley AJ., Van Merkesteyn JPR. (eds.). Proceedings of the 10th international conference on hyperbaric medicine, 1990; 171-174.

Foster JH. Hyperbaric oxygenation treatment - contraindications and complications. J. Oral Maxillfac Surg. 1992: 50(10): 1081-1086.

Hellemans J.: Intermittent Hypoxic Training. Pilot Trial (unpublished, August-September 1998).

Jain KK. Textbook of hyperbaric oxygen. Toronto: Hogrefe and Huber, 1990.

Latushkevich LA, Zakusilo MP, Shaklina LH.: The Efficiency Of Interval Hypoxic Training in Volleyball. Hypoxia Medical J.: 1993: 2: 33-35.

Lambertsen CJ., Kough RH., Cooper KY., et al. Oxygen toxicity; effects in human inhalation at 1 and 3.5 atm upon blood gas transport, cerebral circulation, and cerebral metabolism. J. Appl. Physiol. 1953: 5: 471-486.

Levine BD., Engfred K., Friedman D., et al. High altitude endurance training: effect on aerobic capacity and work performance. Med. Sci. Sport and Exerc. 1990: 22 Suppl.: S35.

Levine BD., Stray-Gunderson J. A practical approach to altitude training: where to live and train for optimal performance enhancement. Int. J. Sports Med. 1992: 13: S209-S212.

Levine BD., Stray-Gunderson J. Living High-Training Low: Effect of Moderate Altitude Acclimatization with Low Altitude Training on Performance. J. Appl. Physiol.: 83(1): 102-112, 1997.

Mader JT. editor. Hyperbaric oxygen therapy: a committee report. Bethesda (MD): Undersea and Hyperbaric Medical Society. 1989: 1-90.

Mairbauri H., Schobersberger W., Oelz O., Bartsch P., Eckardt KU., Bauer C. Unchanged in vivo P50 at high altitude despite decreased erythrocyte age and elevated 2,3-diphosphoglycerate. J. Appl. Physiol. 1990: 68: 1186-1194.

Mizuno M., Juel C., Gro-Rasmussen T., et al. Limb skeletal muscle adaptation in athletes after training at altitude. J. Appl. Physiol. 1990: 68 (2): 496-502.

Raynaud J., Douget D., Legros P., et al. Time course of muscular blood metabolites during forearm rhythmic exercise in hypoxia. J. Appl. Physiol. 1986: 60: 1203-1208.

Ross Laboratories. Muscle Development: Nutritional Alternatives to Anabolic Steroids. Ross Laboratories, 1988.

Staples JR., Clement DB. Hyperbaric oxygen chambers and the treatment of sports injuries. Sports Med. 1996 22(4): 219-227.

Staples JR., Clement DB., McKenzie DC., et al. The effects of intermittent hyperbaric oxygen on biochemical muscle metabolites of eccentrically exercised rats. (abstract). Can. J. Appl. Physiol. 1995: 20: Suppl: 49.

Staples JR. Effects of intermittent hyperbaric oxygen on pain perception and eccentric strength in a human model injury (dissertation). Vancouver: University of British Columbia, 1996.

Stevens WC., Clark JM., Paolone AM., et al. Interacting effects of 2.0 ATA PO2 and exercise on cardio-pulmonary parameters (abstract). Undersea Biomed Res. 1991: 18 Suppl.: 86.

Storch TG., Talley GD. Oxygen concentration regulates the proliferative response of human fibroblasts to serum and growth factors. Exp. Cell. Res. 1988: 175: 317-325.

Terrados N., Jansson E., Sylven C., et al. Is hypoxia a stimulus for synthesis of oxidative enzymes and myoglobin? J. Appl. Physiol. 1990: 68 (6): 2369-2372.

Terrados N. Melichna J., Sylven C., et al. Effects of training at simulated altitude on performance and muscle metabolite capacity in competitive road cyclists. Eur. J. Appl. Physiol. 1988: 57: 203-209.

Vallier JM., Chateau P., Guezennec CY. Effects of physical training in a hypobaric chamber on the physical performance of competitive triathletes. Eur. J. Appl. Physiol. 1996: 73(5): 471-478.

Vorob'ev LP., Chizhov Ala, Potievskaia VI: The Possibilities of Using Intermittent Normobaric Hypoxia for Treating Hypertension Patients. Ter Arkh: 1994: 66(8): 5-12 (In Russian).

Vujouvic D. The influence of oxygen on fracture healing. In: Dekleva N. editor. Symposium on Hyperbaric Medicine: 1983: Sep 7-9: Belgrad: 1983: 57-61.

Wilcox JW., Koloding SC. Acceleration of healing of maxillary and mandibular osteomies by use of hyperbaric oxygen: a preliminary report. J. Oral Maxillolac Surg. 1976: 34: 370-375.

Wolski LA., McKenzie DC., Wenger HA. Altitude training for improvements in sea level performance. Is there scientific evidence of benefit? Sports Med. 1996: 22(4) 251-263.

14 Days of Intermittent Hypoxia Does Not Alter Haematological Parameters Amongst Endurance Trained Athletes

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The aim of this study was to determine the efficacy of intermittent hypoxic therapy on red cell production amongst a group of well trained athletes. Eight rowers underwent preliminary testing and were pair matched for VO_{2max} and performance on a rowing ergometer. In a single blind design, with both groups sitting quietly at rest, the treatment group (TRE) inhaled 12.20% O_2 while the control group (CON) inhaled 20.93% O_2. The groups inhaled gas for 5 min and then room air for 5 min alternately for a total of 90 $min.d^{-1}$ for 14d. The performance test was conducted twice before and twice after 14d of IHT. A venous blood sample was taken at rest before and immediately after IHT.

During IHT there was a decrease in SpO_2 ($p<0.05$) and increase in HR ($p=0.06$) in the TRE compared with the CON. There was no change in resting values for RBC, [Hb], Hct and reticulocytes between pre and post measurements for either the TRE or CON group. During the performance test there were no differences for HR, submaximal VO_2, VO_{2max}, total metres, La and respiratory exchange ratio.

In conclusion, IHT of 90 $min.d^{-1}$ for 14 d had no effect on any haematological parameters which would reflect an increase in total haemoglobin mass and accordingly there was no effect on VO_{2max} or ergometer performance.

Altitude training to enhance sea level performance has been of interest to scientists for more than 30 years. Altitude training is thought to enhance sea level performance as a direct result of increasing red blood cell (RBC) mass and haemoglobin [Hb] concentration (Wolfel et al, 1991). Very few of those that incorporated control groups have shown improved performance and it is recognised that there is a reduction in the ability to train at the appropriate intensity when at altitude. Scientists have been investigating other methods of altitude exposure which potentially offer the physiological benefits of altitude whilst minimising the disturbance to training.

Living at moderate altitude (2200-3000m) but training at sea level (Live High:Train Low) has been reported to increase RBC mass, increase VO_{2max} and improve performance (Levine and Stray-Gundersen, 1997). Because this approach is not always practical methods for simulating altitude have been developed (eg. “altitude houses”). The introduction of simulated altitude houses has enabled more extensive research and rigorous blood analysis. A series of studies at the Australian Institute of Sport which investigated the effect of Live High: Train Low have reported no change in haematological parameters. (Ashenden et al, 1999a, Ashenden et al, 1999b).

Intermittent Hypoxic Training (IHT) is another method of using simulated altitude. IHT was developed in Russia for its use in aviation and clinical medicine but recently has been investigated for possible application to sports performance. IHT involves breathing alternately a hypoxic gas mixture (equivalent to 5000-5500m altitude) and ambient (normoxic) air at rest. Each session consists of 4-6 series of 5-min inhalations of a 10-12% hypoxic mixture with normoxic intervals of the same duration. An IHT course consists of 14-24 sessions with gradually decreasing oxygen concentration. The advantages of such a method include the following: the possibility to control pO_2 in the inhaled hypoxic mixture across a range; the possibility to combine the hypoxic training with sport training at sea level (therefore not compromising training intensity); the absence of organisational and methodical problems connected with the removal to mountains, changes in the usual mode of life, weather and climate. In addition IHT is simple to operate, does not require the expense of building special altitude houses and is portable. IHT allows exposure to quite severe hypoxic conditions without great risk of altitude sickness.

The amount of literature on IHT and sports performance is limited and mostly unavailable in English. There are also very few studies which measured haematological parameters after IHT. A study by Latyshkevich et al. (1993) reported that twenty-four days of IHT decreased submaximal oxygen consumption, ventilation and heartrate during exercise to exhaustion. In addition they reported that athletes were able to produce more work after IHT, but did not indicate how long after the treatment period the subjects were re-tested. More recently Hellemans (1998) reported on the use of IHT for two, one hour periods per day for a duration of eighteen days. He observed an increase in post values for RBC, [Hb], Hct and number of reticulocytes compared with pre values. However, there was no control group making the results difficult to interpret.

The purpose of the following study was to investigate the efficacy of IHT in evoking a change in RBC, [Hb], Hct and reticulocytes amongst a group of well trained athletes.

Methods

Subjects

Eight rowers (6 females, 2 males) from the ACT Academy of Sport Rowing squad gave written consent to participate in this study which was approved by the Australian Institute of Sport Ethics Committee. The characteristics of the group were age = 21.5± 5.6yr, VO_{2max} = 3.88 ± 0.91L.min^{-1}. Subjects were pair matched based on training history and laboratory indicators of aerobic and anaerobic fitness and their coaches' evaluation of their competitive ability. One group was randomly selected to be the treatment group (TRE, n=4) and the other became the control group (CON, n=4). Each subject kept a daily training log of mode, frequency, intensity and duration. The two males trained together in a pair and the six females all trained in single sculls in the same squad.

Experimental Design

In a single blinded design subjects came into the laboratory for 14 consecutive days. On each occasion they rested in a seated position for 90 minutes and alternated every five minutes between breathing from the room and breathing from a 2000L Douglas bag (Scholle Industries, Elizabeth, South Australia). For the treatment group, the Douglas bag contained 12.2% O_2 (simulated altitude = 5000m) while for the control group it contained 20.93% O_2. The O_2 concentration inside the bag was measured every fifteen minutes with an Ametek (Pittsburgh, Pennsylvania) O_2 gas analyser (model S-3A) which had been calibrated against alpha grade gases (BOC Gases Australia Ltd) that spanned the physiological range. Throughout the 90 minutes, heartrate (HR) and oxyhaemoglobin (SpO_2) were recorded via finger-tip pulse oximetry (Criticare, Waukesha, Wisconsin) every five minutes.

A resting venous blood sample was collected prior to, and immediately after the 14 days of IHT to measure haematological parameters. Each subject underwent a performance test on the rowing ergometer (Concept II) twice before and twice after IHT to ensure reliability.

Haematological Parameters

A venous blood sample was collected via a winged infusion set (21-G, Terumo, Elkton, USA) into a 4ml K3EDTA vacuette tube (Greiner Labortecnik, Kremsmunster). Red blood cell (RBC) count, [Hb] and % reticulocytes were analysed using flow cytometric measurements on a Bayer H*3 Haematology analyser (Bayer Diagnostics, Tarrytown NY, USA). The directly measured percentage of reticulocytes per 20,000 red blood cells and RBC count was used to calculate reticulocyte number.

Absolute reticulocyte count = RBC count x % reticulocytes (x $10^9.L^{-1}$)

Ergometer Testing

The performance test consisted of three 4-minute submaximal workloads, four minutes of rest and a final four minutes, of which the first two minutes was held constant and the final two minutes was an “all out” effort to complete as much work (measured in distance) as possible. The submaximal loads were determined for each rower based on their own personal best time for 2000m ergometer test. This was a modified version of a national test protocol that had been regularly performed by all subjects. A finger tip blood sample was taken after each workload and was analysed for lactate using the Radiometer ABL 625 Analyser (Radiometer, Copenhagen, Denmark). The ABL System 625 was calibrated daily against standards of known lactate concentration.

Oxygen Consumption

During the performance test the metabolic variables of oxygen, carbon dioxide production, minute ventilation and respiratory exchange ratio were measured using an open-circuit indirect calorimetry system every thirty seconds. The O_2 and CO_2 gas analysers were calibrated using three alpha grade gases (BOC Gases Australia Ltd) immediately before each test. Heartrate (HR) was assessed every 5 seconds with a telemetry system (Polar Vantage, Polar Electro OY, Kempele, Finland).

Statistical Analyses

For each dependent variable a delta score was calculated (post treatment minus pre-treatment) at each workload. The delta scores were statistically analysed using non parametric test (Mann-Whitney U) to determine whether IHT produced a physiological response.

Results

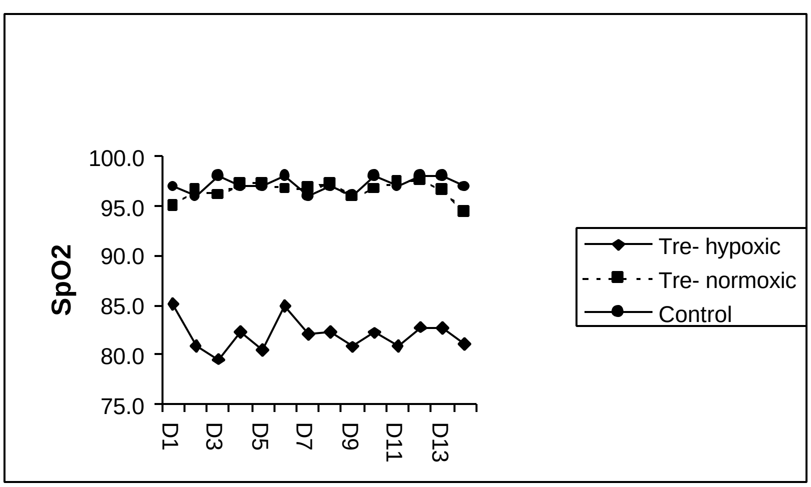
As expected in the time periods where hypoxic gas was breathed there was a decrease in SpO_2 ($p<0.05$, Figure 1) and an increase in HR ($p=0.06$, Figure 2) in the TRE group compared with the CON. There was no change in resting values for RBC, [Hb], Hct and reticulocytes between pre and post measurements for either the TRE or CON group (Table 1).

During the performance test no differences were observed between the groups for HR, submaximal VO_2, VO_{2max}, total metres, La and respiratory exchange ratio (Fig 3 a-e).

TABLE 1. Haematological parameters pre and post 14 days of IHT amongst TRE and CON groups. Values are mean ± SD

	T-PRE	T-POST	C-PRE	C-POST
RBC	4.94±0.61	4.91±0.6	4.83±0.65	4.80±0.75
Hb	14±1.5	13.8±1.4	13.6±1.2	13.5±1.4
Hct	0.42±0.04	0.42±0.04	0.41±0.04	0.41±0.04
# Retics	42±18.2	35.8±15.0	41.5±20.2	46.0±12.5
% Retics	0.85±0.34	0.75±0.35	0.85±0.37	0.95±0.24

Figure 1. Oxygen saturation (SpO_2) during the 14 days of IHT comparing TRE to CON groups.



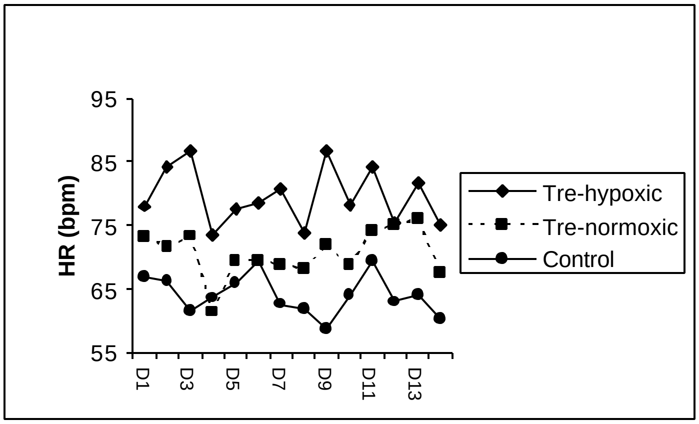


Figure 2. Heartrate response during 14 days of IHT comparing TRE and CON groups.

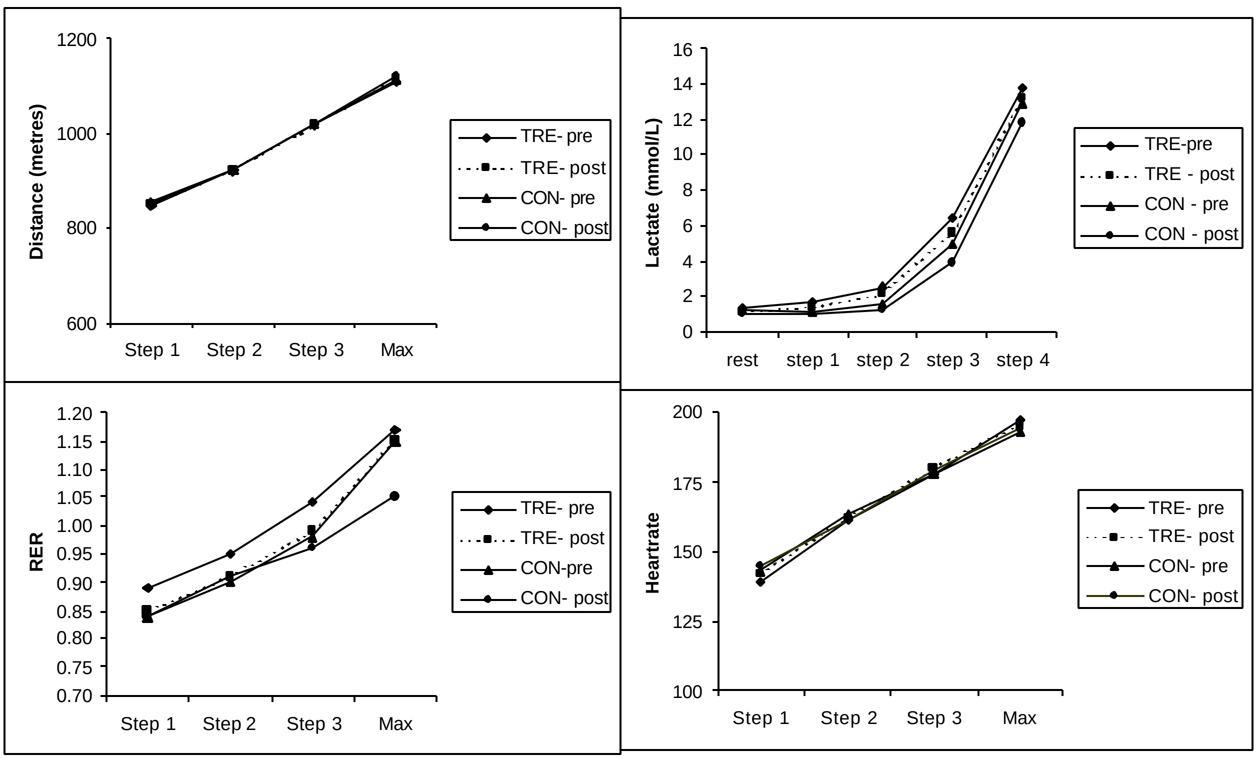


Figure 3 (a-e) Change in (a) distance (m), (b) heartrate (HR), (c) oxygen uptake (VO2), (d) Lactate and (e) respiratory exchange ratio (RER) during exercise after 14 days of IHT, comparing TRE and CON groups.

Discussion

This study did not find any increase in RBC, [Hb], Hct and total number of reticulocytes after 14 days of IHT. Our results differ from others (Hellemans 1998, Radezievsky et al, 1993, and Rodriguez et al 1999), however the present study was the only one to use a control group. It is unlikely that the difference between our results an those of the other researchers can be explained by the total amount of hypoxic exposure to which the athletes were subject. While both the daily duration (45 min vs 60 minutes) and the number of days (14 vs 18) was less than that of Hellemans (1998), he reported the greatest change in the haematological profile and physical performance occurred in a subject who reduced IHT to one session per day. This would be less than the daily exposure in the current study. Furthermore, Radzievsky et al. (1993) used a protocol of hypoxic exposure (15 days, one session per day) similar to ours and yet reported an increased [Hb].

Rodriguez et al. (1999) reported a significant increase in RBC and [Hb] after nine days of hypobaric hypoxia. The subjects in this study were not exposed to classic IHT but to a continuous hypoxic stimulus (equivalent to 4000-5500m altitude) for 3-5 hours per day. Mean RBC increased from 5.16 to $5.79 \times 10^{12} L^{-1}$ and [Hb] from 14.2 to $16.7 g.dL^{-1}$. It seems unlikely that these changes could have resulted from an increase in red blood cell production, since even daily administration of 50 $U.kg^{-1}$ recombiant erythropietin does not produce changes of such a magnitude within ten days (Audran et al, 1999). In addition the subjects of Rodriguez et al. (1999) showed no increase in VO_{2max}. An increase would have been expected if red blood cell numbers were augmented (Audran et al, 1999.

There is a substantial day to day variation in [Hb] (Martin et al, 1997) and reticulocytes (Schmidt et al, 1988), and changes also occur across the training cycle. Schmidt et al. (1988) reported that a single bout of exercise doubled the number of reticulocytes one to two days later. An examination of blood reticulocyte number across a group of rowers showed that the values increased on average by 22% as the rowers moved from an endurance phase to an intensive phase of training (Parisotto, personal communication). This fast response of reticulocytes points to a washout effect releasing premature reticulocytes from the bone marrow rather than a stimulation of RBC Mairbaurl, (1994). It is possible that the reported changes observed by others may reflect a temporary effect of training and not a real increase in RBC production.

Conclusion

It is well recognised that living at high altitude (4000m or higher) is a strong stimulus for an increase in RBC mass (Wolfel et al, 1991). Using the method of IHT in the present study does expose the athlete to high levels of hypoxia however the interval approach and the short duration of exposure was not enough to evoke a change in haematological parameters and accordingly there was no effect on VO_{2max} or ergometer performance.

References

Audran M, Gareau R, Matecki S, Durand F, Chenard C, Sicart M, Marion B, Bressolle F (1999) Effects of erythropoietin administration in training athletes and possible indirect detection in doping control. Med Sci in Sports and Exer, Vol. 31, No. 5, pp 639-645

Ashenden M, Gore C, Martin D, Dobson G, Hahn A (1999a) Effects of a 12-day 'live high, train low' camp on reticulocyte production and haemoglobin mass in elite female road cyclists. Eur J Appl Physiol, Vol 80, pp 472-478

Ashenden M, Gore C, Dobson G, Han A (1999b) "Live high, train low" does not change the total haemoglobin mass of male endurance athletes sleeping at a simulated altitude of 3000m for 23 nights. Eur J Appl Physiol Vol 80, pp 479-484

Hellemans J (1998) Intermittent hypoxic training: pilot trial. Sports MedQE11, New Zealand

Latyshkevich L, Zakusylo M, Shakhlina L (1993) The efficiency of interval hypoxic training in volleyball. Hyp Med J, No 2, pp 33-35

Levine B, Stray-Gundersen J (1997) Living high-training low: effect of moderate-altitude acclimatization with low altitude training on performance. J Appl Physiol. Vol 83, No 1, pp 102-112

Mairbaurl H (1994) Red blood cell function in hypoxia at altitude and exercise. Int J Sports Med, Vol 15, No 2, pp 51-63

Martin D, Lee H, Victor J, Boston T, Parisotto R, Putland K, Anson J, Hahn A (1997) Biochemical and haematological response to a 3-day stage race in female national team road cyclists. Proceedings of Australian Conference of Science and Medicine in Sport, Canberra, Australia, pp 234-235

Radzievsky P, Shpak T, Polyshtchuk N, Bakanichev A (1993) The changes of functional state and working capacity of kayak-paddlers after interval hypoxic training with traditional sports training as a background. Hyp Med J, No.2 pp 30-33

Rodriguez F, Casas H, Casas M, Pages T, Rama R, Ricart A, Ventura J, Ibanez J, Viscor G (1999) Intermittent hypobaric hypoxia stimulates erythropoiesis and improves aerobic capacity. Med Sci Exerc, Vol 31, No 2, pp 264-268

Rusko H, Tikkanen H, Paavolainen L, Hamalainen I, Kalliokoski K, Puranen A (1999) Effect of living in hypoxia and training normoxia on sea level VO_{2max} and red cell mass. Med Sci Sport and Exer, S86:277

Schmidt W, Maassen N, Trost F, Boning D (1988) Training induced effects on blood volume, erythrocyte turnover and haemoglobin oxygen binding properties. Eur J Appl Physiol, Vol 57, pp 490-498

Wolfel E, Groves M, Broks G, Butterfield G, Mazzeo R, Moore L, Sutton J, Bender P, Dahms E, McCullocugh R, McCullough G, Huang S, Sun S, Grover R, Hultgren H, Reeves J (1991) Oxygen transport during steady-state submaximal exercise in chronic hypoxia. J Appl Physiol, Vol 70, No 3, pp 1129-1136

Intermittent Hypoxic Training: A Review

***Dr John Hellemans**

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Intermittent Hypoxic Training (IHT) consists of exposure to alternating periods of hypoxia (9 - 14% O2 inhaled through a mask) and reoxygenation with atmospheric air. [1, 2]

The method originates in Russia where it has been studied extensively in the areas of aviation and clinical medicine. [1]

Recently it has been applied in the field of athletic performance as an alternative to altitude training. [3]

For the purpose of performance enhancement IHT sessions consist of six 5 minute periods of hypoxic air (9-10%) alternated with 5 minutes of exposure to atmospheric air. A full course consists of 1 or 2 sessions a day for 15 - 20 days.

Adaptations to IHT do not only include improvements in oxygen uptake, transport and utilisation but also in neuroendocrine regulation and immunity. [4,7]

Kolchinskaye and others have done studies on rowers, swimmers, cyclists, kayakers, skiers, track and field athletes and volleyball players. [3]

A course of IHT showed improvements in performance, VO_2 max, haematological values as well as decreased heart rates and pulmonary ventilation, compared to a placebo group. Athletes involved in the studies also showed a lesser increase in arterial O_2 saturation during exercise and an improved lactate response.

Of interest is that volleyball players showed a significant improvement in the Vertical Jump test following IHT. One study showed a significant increase in resistance to high physical training loads measured by products related to activation of lipid peroxidation. [5]

It is acknowledged that the adaptation process to IHT is not necessarily exactly the same as those obtained during altitude hypoxia and that additional adaptive processes might be responsible for some of the more pronounced effects of IHT. [6,7]

Meerson describes the following advantages of IHT in comparison with continuous hypoxic exposure. [7]:

1. Avoidance of chronic stress associated with continuous exposure to hypoxic air.2. Control of the dose.
3. The absence of the disadaptation syndrome which athletes experience when returning to sea level following altitude training.
4. Increased activities of antioxidant enzymes in the brain, liver, heart and other organs. (In

contrast to suppression of antioxidant processes under chronic hypoxic stress)

To have an optimal effect IHT needs to be done in conjunction with physical training. Both types of training will expose the body to hypoxic stress. The adaptive responses to hypoxic hypoxia (via IHT) and load hypoxia (via training) have a different mechanism but are complimentary. 8. Adaptive effects of training are enhanced by the adaptation to IHT. 9.

Intermittent Hypoxic Training, A Pilot Study

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Intermittent Hypoxic Training (I.H.T) is a method of altitude simulation which originates in Russia. It has been studied extensively for the purpose of aviation and clinical medicine for many years and more recently also in the area of performance enhancement in sport. Recently the method of IHT was presented to New Zealand sport by Dr Alexei Korolev, currently from Auckland. The results of IHT are claimed to be similar or superior to those obtained when doing conventional altitude training. The method of IHT consists of exposing athletes to hypoxic air (9 - 11%) intermittently for five minute intervals, alternated by normoxic air, also for five minutes for a total of one hour for one or two sessions a day for a total of 15 - 20 days.

The effect of exposure to altitude air on endurance performance is thought to be related to an increased production of red blood cells, resulting in an increased oxygen carrying capacity of the blood

IHT is done with help of an hypoxicator which is a machine which can extract oxygen from the air to any desired level, between 9 and 16%. This is comparable to an altitude of 2000 to 6,500 metres. Normoxic (athmospheric) air has an oxygen concentration of 20.9%. Recently an hypoxicator was installed in QEII Sports Stadium in Christchurch. This paper reports on the results of the first pilot project on the effects of IHT on performance and haematological factors.

Methods

Ten athletes, consisting of four elite swimmers, two elite triathletes, three age-group triathletes and one runner were invited to take part in the study. All were well trained athletes in the final preparations for major events. The group consisted of four woman and seven men ranging from 16 to 45 in age. The athletes were exposed to 10% (first 10 days) and 9% (second 10 days) intermittently for five minute intervals, alternated by normoxic air also for 5 minutes for one hour twice a day for a total of 18 days. Athletes were instructed to have a minimum of one hour between IHT and their physical training sessions. All athletes underwent performance testing in the form of specific field time trials in their sport, decided by the athletes and their coach and haematological testing (Haemoglobin, Haematocrit, Reticulocytes and Erythropoetin) before, and after the period of IHT.During the period athletes kept a record of subjective perception in regard to muscle soreness, fatigue, sleep and performance.

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Results and Discussion

Results are summarised in Table 1. Performance improved by 2.9%, haemoglobin by 4.3%, haematocrit by 5% and reticulocytes by 30.3%. Overall improvements for the group are expressed in percentages compared to the baseline. Only one athlete did worse on the performance test. The athlete who improved most (CP) also had the most marked haematological response. Of interest is that this athlete did only I hour of IHT per day due to time constraints. The general increase in haemoglobin, haematocrit and reticulocytes are known to support improvements in endurance performance, making it less likely that the performance results are solely due to a placebo effect. Haematological and performance improvements observed with IHT are similar or superior to those observed in other methods of altitude training.

The findings suggest a significant stimulation in red blood cell production as indicated by a strong reticulocyte response. The accompanying performance improvement can be linked to the haematological changes although other factors will play a role, including motivation, mood, conditions etc.

No significant side effects were experienced by the athletes. All experienced transient light headedness during the first one or two sessions, to the extent that two athletes had to remove their mask temporarily during the first hypoxic phase. All athletes reported a significant improvement in subjective well being soon after starting IHT. Two of the athletes reported excessive fatigue during the second half of the programme. However they were also in a high intensity phase of their training programme. One of the athletes reduced IHT to one session a day for a period of four days before returning to two. Not all athletes observed the rule to have a minimum of one hour break between sessions of IHT and physical training sessions. This could have resulted in an accumulative effect of both types of training, contributing to excessive fatigue. Two athletes, who were known asthmatics, noticed that they did not require to take their usual medication during the three weeks of IHT.

Summary

Ten endurance athletes were tested with the method of intermittent hypoxic training (IHT) in relation to haematological factors and performance over a period of three weeks. Results show an overall improvement in haematological factors related to oxygen transport and performance. The results indicate that IHT is an effective method to simulate altitude training. On the basis of the results it is recommended that further research and testing is done in the area of maximising outcome for individual athletes. However, in general the method of IHT can be strongly recommended for any serious athlete as part of their training and preparation.

Conclusions

1. IHT is an effective alternative to altitude training.
2. Side effects are minimal or absent.

3. IHR is often accompanied by a general improvement in health and wellbeing (confirming its use in the medical field).
4. There is likely to be an optimal dose for any individual athlete. This needs to be established.
5 Results compare favourably with other studies done on altitude training, in particular the live high-train low model.
6 Hypoxic training can be considered as additional training. There is potential for overload if the athlete does not adhere to the guidelines, especially in relation to recovery.
7 Some athletes will respond more than others, comparable with any form of training.
8 IHT is user friendly and easily accessable. It can be used by 4 athletes at any one time.
9 Current cost of a course of IHR is $385.00 per athlete, which is considerable cheaper than other forms of altitude training and simulation.
10 Of relevance are the significant health benefits obtained through IHT, which are unique for this particular method.

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References

Meerson, F.Z. Common Mechanisms of Adaption and Prophylaxis. Mowcow Meditzina 1973.

Tkatchouk, E.N. Repeated Reoxygenation as the Main Factor of Interval Hypoxic Training. “Hypoxic Medical” Clinical Research Laboratory, Russia.

Kolchinskaya, A.Z. HIT Combined with Traditional Training Schemes is an Effective Method in Professional Sports.Hypoxia Medical Journal 1993, no. 2 pp29-30 Hypoxia Medical Journal 1994, no. 3 pp 8-14

Knaupp, W, et alErythropoëtin Response to Acute Normobaric Hypoxia in Humans. J.Appl. Physiol 1992 Sep; 73(3) 837-40

Nickonorov Adaption to Intermittent Hypoxia Enhances the Resistance of Athletes to Competitive Loads

Tsvetkova, A.M, Tkatchouk, E.NThe Justification of Interval Hypoxic Training Protoco lProceedings 3th International conference on Hypoxic Medicine, 1998, Moscow . 93-94

Meerson, F.Z. Adaption to Intermittent Hypoxia : Mechanisms and Protective Effects Hypoxia Medical J. 3/93

Kolchinskaya, A.Z.Hypoxia and Load Hypoxia : Destructive and Constructive Effects Hypoxic Medical J. 3/93

Pshennikova, M.G. Similarity and Differences of Adaptions to Hypoxic Hypoxia to Physical Loads and their

Reliability and validity of portable lactate analysers?

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Purpose: It has been suggested that lactate concentrations may provide a guide to an optimal training intensity. However, lactate concentrations established during incremental exercise in the laboratory are not always indicative of what is occurring during constant-load exercise at the same intensity. Ideally, lactate concentrations should be measured during a training session and immediately reported to the athlete to ensure that the athlete is working at the desired intensity. The purpose of this investigation was, therefore, to determine the reliability and validity of a compact, portable lactate analyser (ACCUSPORT; Boeringer Mannheim, Castle Hill, Australia). **Methods:** A total of 224 capillary blood samples were taken from 25 athletes who took part in routine laboratory testing. Seventy-three of these capillary blood samples were analysed in duplicate with the Accusport for determination of intraclass, single-trial reliability. Day-to-day reliability of the Accusport was assessed by measuring known concentrations of aqueous lactate solutions every day for seven days. The validity of the Accusport analyser was assessed by comparing the 224 capillary blood lactate concentrations determined on the Accusport with the lactate concentration obtained using a MICRO STAT LM3 (Analox Instruments Ltd., London, GB). In addition, lactate parameters derived from the lactate concentrations obtained with the two analysers were compared. **Results:** The Accusport showed high single-trial reliability (R=0.992; Standard Error of Measurement (SE_M) = 0.2 $mmol \cdot l^{-1}$; n = 73) and high day-to-day reliability (R=0.997; SE_M = 0.2 $mmol \cdot l^{-1}$; n=42). Despite a strong correlation between blood lactate concentrations obtained on the two analysers (r=0.96; n=224) the limits of agreement were $^{+}$1.9 to $^{-}$2.2 $mmol \cdot l^{-1}$. Although the mean values for power output, HR and lactate concentration associated with the lactate parameters were not significantly different when determined on the Accusport or Micro Stat, some individuals did record large differences between analysis methods. **Conclusion:** In summary, the results of this investigation have shown that lactate concentrations can be reliably determined within a single trial and from day-to-day using the Accusport analyser. It is not valid to compare lactate concentrations determined on the Accusport with lactate concentrations determined using the Micro Stat LM3 lactate analyser. Due to differences between the analysers, it is recommended that to more precisely control training intensity in the field that a threshold should first be determined in the laboratory using an established laboratory analyser (eg. Micro Stat). Blood samples taken at two to three workloads around the expected threshold power output should also be analysed on the Accusport. This would allow the user to determine an Accusport lactate value at the threshold power output determined using the laboratory analyser. As the Accusport has been shown to reliably measure lactate concentration, this Accusport lactate value could then be used in the field to monitor training intensity.

To obtain optimal training effects, and to prevent overtraining, it is important to monitor and control the intensity of training. While many athletes use a heart rate monitor, there are a number of limitations that need to be taken into account when using heart rate to control training intensity. For example, a rider's position on the bicycle may change heart rate at a constant intensity.

A more important limitation is the increase in heart rate over time, a phenomenon known as 'cardiac drift'.

An alternative marker of training intensity is the lactic acid concentration in the blood. Until recently however, lactic acid measurements have only been available within the laboratory environment. In order to be most applicable, blood lactate information should be made available to the athlete as soon as possible, preferably during the training session. The recent development of compact, portable, lactate analysers (e.g., Accusport and Lactate Pro) now allows coaches, athletes and physiologists to gain immediate measurement of lactate concentrations in the field. It is common practice for results obtained in the field to be compared with lactate concentrations determined in the laboratory. Therefore, it is crucial that the two methods produce similar results.

The purpose of this investigation was to determine the validity and reliability of the Accusport analyser. Blood lactate concentrations were determined on the Accusport and then compared with the blood lactate concentration obtained using a common laboratory lactate analyser (Micro Stat LM3). Blood samples were analysed in duplicate to assess the reliability of lactate measurements obtained with the Accusport. Lactate threshold (LT) estimates obtained from the Accusport and Micro Stat were also compared to determine whether the Accusport could be used to determine the LT in the field.

Results

Validity of lactate measurements.
There was a strong correlation (r = 0.96; $P<0.05$) between blood lactate concentrations obtained with the two methods of measurement. Despite the strong correlation, 95% of the lactate concentrations obtained with the Accusport ranged from 1.9 $mmol{\cdot}l^{-1}$ above to 2.2 $mmol{\cdot}l^{-1}$ below the lactate concentrations obtained with the Micro Stat (Figure 1).

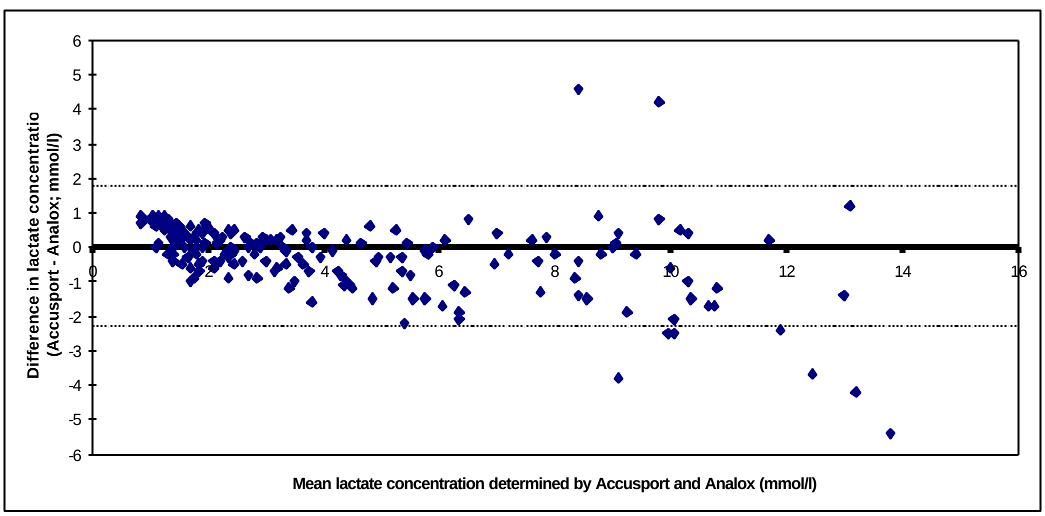

Figure 1. Bland-Altman plot showing relationship between mean lactate concentration determined by both analysers (x-axis) and the difference in concentration between analysers (y-axis).

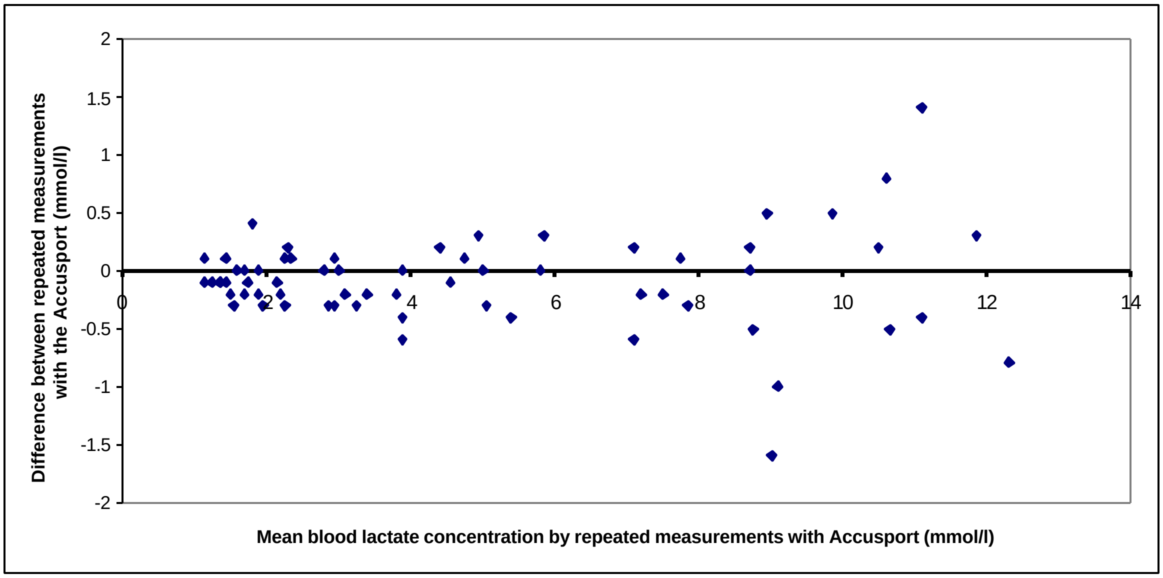

Figure 2. Variation in blood lactate concentrations determined on the Accusport as a function of mean blood lactate concentration

Single-trial reliability.

The Accusport was found to have very high single-trial reliability (R=0.99; SE_M = 0.2 mmol·l^{-1}). In addition, 95% of repeated measurements on the Accusport were within 0.4 mmol·l^{-1} of the initial measurement (Figure 2).

Day-to-day reliability.
The Accusport was found to have very high day-to-day reliability when using the same standard lactate solutions each day for seven days (R=0.99; SE_M = 0.2 mmol·l^{-1}).

Validity of lactate threshold determination.
The exercise intensity, heart rate and lactate concentration corresponding to the LT (first rise in lactate concentration above resting value), was significantly higher when determined with the Accusport than when determined with the Micro Stat (Table 1).

Table 1. Means ($\pm$ SD) for the power output, heart rate and lactate concentration associated with the LT for both analysers. Also reported is the mean difference and difference range between the two analysers. *P< 0.05

	Power output (watts)	Heart rate (beats·min^{-1})	Lactate concentration (mmol·l^{-1})
Analox	105.5 $\pm$ 39.2	144 $\pm$ 13	1.3 $\pm$ 0.3
Accusport	120.1 $\pm$ 48.1*	150 $\pm$ 10*	1.9 $\pm$ 0.2*
Mean Difference	17.4 $\pm$ 16.6	7 $\pm$ 7	0.6 $\pm$ 0.3
Difference Range	-53.7 - 22.7	-18 - 5	-1.2 - 0.1

Discussion

Consistent with previous studies (2,5), there was a strong correlation (r=0.96) between blood lactate concentrations obtained using the Micro Stat and the Accusport analyser. While these results suggest that the two methods are strongly associated, a strong correlation is not a valid measure of how closely lactate concentrations determined with the two analysers agree. To overcome this limitation, a Bland-Altman plot was used to quantify the level of agreement between the two analysers. This revealed that despite the strong correlation, 95% of lactate concentrations obtained with the Accusport ranged from 1.9 $mmol.l^{-1}$ above to 2.2 $mmol.l^{-1}$ below the lactate concentration obtained with the Micro Stat. This is similar to the limits of agreement ($^{+}2.1$ to $^{-}2.6$ $mmol.l^{-1}$) reported in a previous study comparing the Accusport analyser with a YSI 2300 Stat analyser (1).

The Accusport can therefore result in under or overestimations of the blood lactate concentration (see Figure 1) and hence training intensity in some athletes. While an optimal training intensity is yet to be established, it has been suggested that for continued improvements in endurance capacity, some training must be above LT (4). Furthermore, it has been reported that athletes who performed their aerobic training at too intense a level exhibited decrements in performance (3). Caution therefore needs to be exercised if using the Accusport to control training intensity.

Repeated measurements of lactate concentration with the Accusport on two samples drawn at the same time showed high reliability (R=0.996) and a low SE_M (0.2 $mmol·l^{-1}$). While the Accusport does show high single-trial reliability, its reliability appears to decrease as the lactate concentration increases. The Accusport was also found to have very high day-to-day reliability when using the same standard lactate solutions each day for seven days (R=0.998; SE_M = 0.2 $mmol·l^{-1}$; n = 42). Thus, the Accusport analyser is able to reliably measure lactate concentration within one day and from day to day.

In addition to monitoring training intensity, Accusport analysers are also be used to determine LT in the field. The results of this study indicate that the power output, HR and lactate concentration associated with LT is overestimated when the lactate concentration is determined on an Accusport analyser. This can probably be attributed to an overestimation of low lactate concentrations (i.e., < 2 $mmol·l^{-1}$) by the Accusport (Figure 1). Thus, it does not appear valid to determine LT with the Accusport analyser.

Conclusions

1) Lactate concentrations can be reliably determined within a single trial and from day to day using the Accusport analyser.
2) While there is a strong association between blood lactate concentrations obtained using the Accusport and Micro Stat analysers, 95% of lactate concentrations obtained with the Accusport range from 1.9 $mmol·l^{-1}$ above to 2.2 $mmol·l^{-1}$ below those obtained with the Micro Stat. It is not valid to compare lactate concentrations determined on the Accusport with those determined using the Micro

Stat LM3 lactate analyser

3) It is also not valid to determine the LT with the Accusport analyser. It is recommended that to more precisely control training intensity in the field that LT should first be determined in the laboratory. Blood samples taken at two to three workloads around the expected threshold should also be analysed on the Accusport. This would allow the user to determine an Accusport lactate value at the threshold determined using the laboratory analyser. As the Accusport has been shown to reliably measure lactate concentration, this Accusport lactate value could then be used in the field to monitor training intensity.

References

1. Clough, M., D. T. Martin, D. Pyne, et al. Interpretation of accusport blood lactate results - how do they compare with YSI2300 stat values? *The Australian Conference of Science and Medicine in Sport*. :82-83, 1997.

2. Fell, J. W., J. M. Rayfield, J. P. Gulbin, and P. T. Gaffney. Evaluation of the Accusport Lactate Analyser. *International Journal of Sports Medicine. 19*:199-204, 1998.

3. Mikesell, K. A. and G. A. Dudley. Influence of intense endurance training on aerobic power of competitive distance runners. *Med. Sci. Sports Exerc. 16(4):*371-375, 1984.

4. Weltman, A., R. L. Seip, D. Snead, et al. Exercise training at and above the lactate threshold in previously untrained women. Int. *J. Sports Med. 13(3):*257-263, 1992.

5. Wigglesworth, J. K., V. J. LaMere, N. D. Rowland, and L. Miller. Examination of the reliability of a new blood lactate analyser. *Med. Sci. Sports Exerc. 28(5)*:S59, 1996.

Kinanthropometric differences between World Championship senior and junior elite triathletes

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Eighty-seven triathletes who competed in the senior or junior elite categories at the 1997 Triathlon World Championships were measured on a battery of 30 anthropometric dimensions. Analyses sought to clarify what physical differences existed between these competitors at the highest level.

Generally, the senior triathletes were older, faster, heavier and had broader shoulders than their junior counterparts. The junior females recorded a greater sum of 8 skinfolds, endomorphy rating and had less muscle mass than their senior triathlete counterparts. The senior males revealed significantly greater segmental lengths, girths and breadths than the junior males. However, most of these differences were removed when applying dimensional scaling to the raw scores.

These results suggest that, while the junior males have not fully matured, they already have many of the proportional physical characteristics of the senior male triathletes. Hence, after full development, they could possess similar morphology. In contrast, the junior female triathletes are closer to the senior females in physical maturity, except for a greater sum of skinfolds and less muscle mass. A higher level of training may therefore alter these characteristics and possibly improve their performance.

Development in a sport at the elite level can be improved by knowing the physical, physiological and psychological characteristics of current elite athletes and to isolate those factors that contribute to high levels of performance. Then, coaches benefit by planning better training programs when preparing their athletes for competition. It also assists the junior athletes who have self-selected themselves and who will one day be the elite representatives of the sport.

During its relatively brief existence, the physiological characteristics of triathlon's participants have been investigated, but the physical morphology has not yet been subject to vigorous inquiry. Laurenson et al. (1993), Leake and Carter (1991) and Travill et al. (1994) all have examined small samples of classic distance triathletes in terms of physique and body composition through comparisons with individual sport athletes, or between different ability level triathletes. Ackland et al. (1998) reported complete anthropometric data for senior and junior elite triathletes at the 1997 Triathlon World Championships (TWC). This research was expanded to study into the relationship of these anthropometric dimensions with the performance outcomes in this event (Ackland et al., 1999; Landers et al., 1999).

This paper aims to examine further the age-related kinanthropometric differences of male and female elite level competitors at the 1997 TWC. It is envisaged that these data could help to improve training practices, possibly form the basis of talent identification or allow a clearer understanding of the self selection in the sport of triathlon, and improve the interpretation of the body shape of triathletes.

Methods

Eighty-seven senior and junior elite, male and female triathletes from 11 nations who participated in the 1997 TWC were measured. The sample consisted of 20 senior male triathletes, eight of whom finished in the top 20; and 29 junior male triathletes, three of whom finished in the top 20. The female sample comprised 18 seniors, six of whom were placed in the top 20; and 20 juniors, of whom eight placed in the top 10.

Only volunteers participated in the research. All testing was carried out one week prior to competition to minimise disruption to their final championship preparation.

Testing protocol

The Human Rights Committee of the University of Western Australia granted approval for the study and all participants signed a consent form after being informed of the study requirements. Data were collected at the Department of Human Movement and Exercise Science, or at other suitable accommodation sites using a mobile testing unit. All equipment other than electronic scales and stadiometer could be transported. For these occasions a mobile stadiometer and beam balance scale were used.

Personal details and demographic data were obtained at the first test station and anatomical landmarking of the subject by a criterion anthropometrist (ISAK level-4) took place. The triathletes then moved through five measurement stations. Separate stations recorded seven skinfold thickness, height, weight and five segmental lengths; two stations were available for four girth measurements each and another for five segment breadths. To allow continuous testing by the anthropometrist, a scribe was posted at each measurement station to record the scores. The data were then entered into a computer on an SPSS spreadsheet (SPSS Inc.) for subsequent analysis.

Standard measurements were undertaken in accordance with those approved by the International Society for the Advancement of Kinanthropometry (ISAK) and reported in Bloomfield et al. (1994) and Norton and Olds (1996).

The same investigator was posted at each station for the entire testing program. This strategy was adopted to limit inter-observer variability and to maximise the reliability of results. The technical error of measurement (TEM) was calculated on a sample of 20 subjects randomly chosen. The TEM for all variables was within the standards set by ISAK for level-2 anthropometrists (Norton and Olds, 1996).

Data analysis

Data were entered onto a spreadsheet from which descriptive statistics for each characteristic were calculated. Standard formulae were employed to derive brachial and crural indices (BI & CI) (equation 1 & 2), relative sitting height (RSH) and relative lower limb length (RLLL) (equation 3 & 4). Somatotype was calculated using the Carter and Heath (1990) somatotype formulae, while proportionality variables were computed via the phantom stratagem for all measurements (Ross and Ward, 1986). Body composition was also determined using the five compartment fractionation model (Ross & Kerr, 1991). The Phantom stratagem is a technique used to analyse proportionality by removing size and gender differences, and permits analysis of results in parametric statistics.

$$BI = \frac{\text{radiale-stylion} \times 100}{\text{acromiale-radiale}} \quad (1)$$

$$CI = \frac{\text{trochanterion-tibiale laterale} \times 100}{\text{tibiale laterale height}} \quad (2)$$

$$RSH = \frac{\text{sitting height} \times 100}{\text{height}} \quad (3)$$

$$RLLL = \frac{\text{trochanterion height} \times 100}{\text{Height}} \quad (4)$$

Data were initially split by gender and analysis was by one-way ANOVA of each variable comparing the senior and junior elite competitors. Tables containing all of the measures and derived variables were constructed for males and females separately, as well as senior and junior groups. Due to the large number of ANOVA conducted, the possibility of type one and two errors exist. All results were significant at $p<0.05$ level. For those variables that showed significant differences the effect size was calculated and reported to clarify differences.

Results

Table 1 includes the means and standard deviations for body type and composition parameters of the triathletes.

Senior males were significantly taller and heavier than the junior males. The senior males also had greater compartment masses for muscle, residual, skin and bone. Differences in absolute size were accounted for by applying the phantom stratagem to obtain proportional scores. As a result, there were no significant differences in proportional masses between the senior and junior male triathletes. After converting the fractional masses to a percentage of total body mass, the senior and junior male triathletes differed significantly in residual mass only.

No significant differences were noted between the senior and junior males in endomorphy, mesomorphy or ectomorphy ratings (1.9 - 4.2 - 3.0 Vs 2.2 - 4.2 - 3.1), sum of skinfolds or sitting heights.

Senior and junior female triathletes differed significantly in muscle mass and body fatness. The senior female triathletes had significantly greater muscle mass, yet smaller sum of eight skinfolds and endomorphy (2.8 Vs 3.5) ratings than those of the junior females. The mean somatotype rating for all females was 3.2-3.6-2.9. Junior female triathletes had a significantly greater percentage of adipose tissue than the senior females when the five way fraction results were compared with total mass of the triathletes.

Senior male triathletes recorded significantly greater bone breadths for the humerus, biacromial, chest and biiliocristale sites, as well as the anterior-posterior chest depth, compared with their junior counterparts (Table 2). There were no significant differences in femur breadth. Mean chest breadth of the junior male triathletes was also

Table 1 Body type: descriptive data & comparisons via ANOVA of senior Vs junior male and senior Vs junior female triathletes

Male Triathletes		**Senior**		**Junior**		**sig**	**Effect**
		n = 20		n = 29			**Size**
variable	unit	mean	sd	mean	sd		
age	y	27.5	3.9	19.1	1.1	***	1.7
height	cm	179.8	6.2	175.7	5.6	*	0.7
sitting height	cm	92.8	2.4	92.1	2.9	ns	
phantom sitting height	z	-0.5	0.5	-0.1	0.6	ns	
height, weight ratio	z	43.2	1.0	43.3	1.2	ns	
mass	kg	72.3	6.0	67.0	6.3	**	0.79
phantom mass	z	-0.4	0.5	-0.4	0.6	ns	
skin mass	kg	4.0	0.2	3.8	0.2	**	0.83
adipose mass	kg	14.6	2.1	14.3	2.6	ns	
muscle mass	kg	37.2	3.3	33.6	4.0	***	0.88
bone mass	kg	9.0	0.7	8.5	0.8	*	0.64
residual mass	kg	9.4	1.0	8.1	1.1	***	1.05
skin mass / total mass	%	5.5	0.2	5.7	0.3	ns	
adipose mass / total mass	%	20.1	2.1	21.3	2.8	ns	
muscle mass / total mass	%	51.5	1.7	50.1	3.5	ns	
bone mass / total mass	%	12.5	0.9	12.6	0.9	ns	
residual mass / total mass	%	13.0	0.2	12.0	1.1	**	0.9
sum of 8 skinfolds	mm	47.4	10.4	51.5	14.8	ns	
endomorphy		1.9	0.6	2.3	1.0	ns	
mesomorphy		4.2	0.8	4.2	0.9	ns	
ectomorphy		3.0	0.7	3.1	0.9	ns	

Female Triathletes		**Senior**		**Junior**		**sig**	**Effect**
		n = 18		n = 20			**Size**
variable	unit	mean	sd	mean	sd		
age	y	29.3	3.1	19.0	1.5	***	1.8
height	cm	168.3	4.6	164.9	7.2	ns	
sitting height	cm	88.7	2.2	87.0	3.4	ns	
phantom sitting height	z	-0.1	0.4	0.0	0.4	ns	
height, weight ratio	z	43.2	0.9	43.0	1.2	ns	
mass	kg	59.5	4.8	56.7	5.4	ns	
phantom mass	z	-0.4	0.4	-0.3	0.6	ns	
skin mass	kg	3.5	0.2	3.4	0.2	ns	
adipose mass	kg	14.5	2.1	15.3	3.0	ns	
muscle mass	kg	28.4	2.7	26.4	2.9	*	0.7

bone mass	kg	6.9	0.8	6.7	0.5	ns	
residual mass	kg	6.6	0.6	6.2	0.7	ns	
skin mass / total mass	%	5.9	0.2	6.0	0.2	ns	
adipose mass / total mass	%	24.5	3.0	27.0	3.8	*	0.7
muscle mass / total mass	%	48.0	2.2	46.8	6.1	ns	
bone mass / total mass	%	11.6	1.1	11.9	1.0	ns	
residual mass / total mass	%	11.2	1.0	11.0	1.1	ns	
sum of 8 skinfolds	mm	62.6	13.8	73.1	17.2	*	0.64
endomorphy		2.8	0.9	3.5	0.9	*	0.7
mesomorphy		3.6	0.9	3.6	1.0	ns	
ectomorphy		3.0	0.6	2.9	0.8	ns	

Note: * = p<0.05, ** = p< 0.01, ***p<0.001

Table 2 Breadths: descriptive data & comparisons via ANOVA of senior Vs junior male and senior Vs junior female triathletes

Male Triathletes		**Senior** n = 20		**Junior** n = 29		**sig**	**Effect Size**
variable	unit	mean	sd	mean	sd		
humerus	cm	7.2	0.3	7.0	0.4	*	0.56
biacromial	cm	41.5	1.9	40.5	1.4	*	0.61
chest	cm	30.1	1.4	28.6	1.0	***	1.1
a-p chest depth	cm	21.9	1.9	20.6	1.8	*	0.68
biiliocristale	cm	28.2	1.2	27.3	1.4	*	0.65
femur	cm	9.8	0.4	9.8	0.4	ns	
phantom humerus	z	0.9	0.8	0.7	0.8	ns	
phantom biacromial	z	0.7	1.1	0.6	0.7	ns	
phantom chest	z	0.3	0.6	-0.1	0.5	**	0.68
phantom a-p chest depth	z	2.3	1.3	1.8	1.1	ns	
phantom biiliocristale	z	-1.2	0.5	-1.4	0.8	ns	
phantom femur	z	-0.5	0.8	-0.1	0.8	ns	

Female Triathletes		**Senior** n = 18		**Junior** n = 20		**sig**	**Effect Size**
variable	unit	mean	sd	mean	sd		
humerus	cm	6.3	0.3	6.2	0.3	ns	
biacromial	cm	37.0	1.1	36.9	1.2	ns	
chest	cm	26.9	0.9	26.6	1.1	ns	
a-p chest depth	cm	18.6	1.2	18.4	1.8	ns	
biiliocristale	cm	27.7	1.1	26.7	1.2	**	1.7
femur	cm	9.0	0.8	9.1	0.3	ns	
phantom humerus	z	-0.4	0.9	-0.4	0.8	ns	
phantom biacromial	z	-0.3	0.7	0.0	0.9	ns	
phantom chest	z	-0.4	0.5	-0.2	1.0	ns	
phantom a-p chest depth	z	0.9	0.8	1.1	1.3	ns	
phantom biiliocristale	z	-0.5	0.6	-0.8	0.5	ns	
phantom femur	z	-0.9	1.6	-0.4	0.8	ns	

Note: * = p<0.05, ** = p< 0.01, *** = p<0.001
a-p = anterior-posterior

Table 3 Girths: descriptive data & comparisons via ANOVA of senior Vs junior male and senior Vs junior female triathletes

Male Triathletes		Senior n = 20		Junior n = 29		sig	Effect Size
variable	unit	mean	sd	mean	sd		
forearm	cm	26.8	1.0	26.2	1.1	ns	
arm	cm	29.1	1.3	28.2	1.8	ns	
arm flex	cm	31.7	1.6	31.0	1.9	ns	
chest	cm	99.6	3.5	94.6	4.6	***	1.03
waist	cm	77.9	2.5	74.9	3.8	**	0.83
hip	cm	92.9	3.0	91.0	3.6	ns	
thigh	cm	55.4	3.2	53.2	2.8	*	0.62
calf	cm	36.8	1.8	35.8	2.0	ns	
phantom forearm	z	0.2	0.8	0.2	0.8	ns	
phantom arm	z	0.3	0.5	0.2	0.8	ns	
phantom arm flex	z	0.3	0.6	0.3	0.8	ns	
phantom chest	z	1.3	0.6	0.7	0.9	*	0.75
phantom waist	z	0.4	0.5	0.2	0.7	ns	
phantom hip	z	-1.2	0.5	-1.2	0.5	ns	
phantom thigh	z	-0.8	0.7	-1.0	0.7	ns	
phantom calf	z	-0.2	0.6	-0.2	0.9	ns	

Female Triathletes		Senior n = 18		Junior n = 20		sig	Effect Size
variable	unit	mean	sd	mean	sd		
forearm	cm	23.8	1.0	23.6	1.1	ns	
arm	cm	26.3	1.7	25.8	1.4	ns	
arm flex	cm	28.2	1.3	27.7	1.5	ns	
chest	cm	88.3	2.5	86.4	2.9	ns	
waist	cm	68.2	3.5	67.6	2.7	ns	
hip	cm	90.9	3.4	89.9	3.0	ns	
thigh	cm	54.0	3.7	53.8	2.1	ns	
calf	cm	35.5	1.9	33.6	3.2	*	0.68
phantom forearm	z	-0.7	0.7	-0.6	0.8	ns	
phantom arm	z	-0.1	0.7	-0.1	0.8	ns	
phantom arm flex	z	-0.4	0.5	-0.3	0.8	ns	
phantom chest	z	0.3	0.5	0.3	0.9	ns	
phantom waist	z	-0.7	0.7	-0.5	0.6	ns	
phantom hip	z	-0.5	0.6	-0.3	0.7	ns	
phantom thigh	z	-0.3	0.8	-0.1	0.7	ns	
phantom calf	z	0.3	0.8	-0.2	1.6	ns	

Note: * = p<0.05, ** = p< 0.01, *** = p<0.001

Table 4 Lengths and Indices: descriptive data & comparisons via ANOVA of senior Vs junior male and senior Vs junior female triathletes

Male Triathletes	Senior n = 20	Junior n = 29	sig	Effect Size

variable	unit	mean	sd	mean	sd		
armspan	cm	186.2	6.7	181.1	8.3	*	0.64
radiale-stylion	cm	26.6	1.1	26.4	1.9	ns	
acromiale-radiale	cm	34.3	1.4	33.3	1.6	*	0.68
trochanterion-tibiale	cm	46.7	1.9	44.5	2.1	***	0.87
tibiale-laterale	cm	47.7	2.1	46.3	2.7	ns	
phantom armspan	z	0.5	0.6	0.4	0.5	ns	
phantom radiale-stylion	z	0.4	0.6	0.8	1.3	ns	
phantom acromiale-radiale	z	0.0	0.6	-0.2	0.6	ns	
phantom trochanterion-tibiale	z	1.2	0.5	0.7	0.5	**	0.85
phantom tibiale-laterale	z	3.5	0.5	3.3	0.7	ns	
Brachial Index		77.4	1.7	79.6	6.0	ns	
Crural Index		102.0	2.8	104.2	4.9	ns	
Relative Lower Limb Length	%	52.5	1.1	51.7	1.2	*	0.69
Relative Sitting Height	%	51.7	1.4	52.5	1.5	ns	

Female Triathletes		**Senior** n = 18		**Junior** n = 20		**sig**	**Effect Size**
variable	unit	mean	sd	mean	sd		
armspan	cm	170.8	4.3	166.8	7.4	ns	
radiale-stylion	cm	24.2	1.2	23.9	1.5	ns	
acromiale-radiale	cm	31.8	1.3	31.1	1.6	ns	
trochanterion-tibiale	cm	43.6	2.7	43.7	2.9	ns	
tibiale-laterale	cm	43.8	1.9	43.0	2.6	ns	
phantom armspan	z	0.1	0.4	0.0	0.6	ns	
phantom radiale-stylion	z	0.0	0.9	0.0	0.7	ns	
phantom acromiale-radiale	z	-0.2	0.5	-0.3	0.6	ns	
phantom trochanterion-tibiale	z	1.1	0.8	1.5	0.8	ns	
phantom tibiale-laterale	z	3.0	0.5	3.1	0.6	ns	
Brachial Index		76.3	3.7	76.8	3.0	ns	
Crural Index		100.7	5.0	98.6	4.5	ns	
Relative Lower Limb Length	%	51.9	1.5	52.6	1.5	ns	
Relative Sitting Height	%	52.7	1.2	52.8	1.0	ns	

Note: * = p<0.05, ** = p< 0.01, *** = p<0.001

significantly smaller than that of the senior males when comparing phantom scores. Table 2 also reveals that the senior and junior female triathletes differed significantly only in the biiliocristale breadth.

Girths of the juniors (Table 3), revealed significantly smaller chest, waist and thigh girths in comparison with the senior male triathletes. A strong correlation was recorded for all male triathletes existed between residual mass and chest girth (0.960), chest girth and chest breadth (0.740), and residual mass and waist girth (0.595). The senior males also recorded significantly larger, proportional chest girths than did the junior male triathletes.

Senior females recorded significantly larger calf girths when compared with their junior counterparts (Table 3). Paired t-tests of all female triathletes showed hip girth was significantly greater than chest girth (t= -5.20, p< 0.0001), and chest girth was significantly larger than waist girth (t= 39.15, p< 0.001). Significant correlations were also recorded between girth variables of chest and waist (0.573); chest and hip (0.341); and waist and hip (0.360).

Segmental length and index scores demonstrated that senior male triathletes reported significantly greater arm spans, acromiale-radiale lengths and trochanterion-tibiale lengths than the junior male triathletes (Table 4). A significant correlation (r = 0.486) was recorded between humerus breadth and acromiale-radiale length. Senior male triathletes recorded significantly higher relative lower limb length (RLLL) scores than the junior males. The senior male triathletes possessed proportionally longer thighs (phantom trochanterion-tibiale length) than the junior male competitors.

There were no significant segmental length differences between the senior and junior females (Table 4).

Discussion

Male Triathletes

The senior male triathletes were significantly taller and heavier than the junior males. A comparison of the senior male triathletes of this study (179.75 cm & 72.33 kg) with elite triathletes of other sudies (Hue et al., 1998, 180.4 cm & 69.7 kg; Rowbottom et al., 1997, 179 cm & 73.1 kg; Schneider et al., 1990, 178.8 cm & 70.2 kg) revealed similarities in both height and mass.

The senior males also recorded significantly greater values for skin, muscle, bone and residual mass compartments than the junior males, but there was no significant difference in adipose mass scores. Most of the greater mass could be accounted for by the greater height of the senior triathletes because height is proportional to mass. This is supported by the proportional masses not showing any significant differences. That is, after height is accounted for there are no noticeable differences between the masses of the senior and junior male triathletes. But, all compartment masses were not greater, which suggested that the senior and junior male triathletes were not geometrically similar. Hence, there is more than just a scaling factor involved in the variations of the make-up of a triathlete.

The larger, senior triathletes have an increased skin mass that is a direct result of an increased body surface area. Being taller and heavier leads to an increased surface area (Tittle & Wutscherk, 1988). This, in turn, means that there is more skin and also more skin mass. This is supported by there being no difference in skin mass, as a percentage of total mass, between the two groups.

The difference in total body mass was largely accounted for by the differences in the muscle mass compartment. An increase in the mass of muscle follows growth or extended endurance training. This is because Type 1 muscle fibres hypertrophy and can lead to an increased skeletal structure mass, which also was significantly greater in the senior male triathletes. This variation in muscle and bone mass could be a direct result of greater levels of training in the senior triathletes or different levels of maturity. No differences could be recorded for muscle or skeletal percentage of total mass, which suggested geometrical similarity of these variables.

Increased bone mass is related to increased muscle mass and total mass. The skeletal system is the framework for the body during movement. With greater muscle action and weight bearing exercise there is an increase in both muscle mass and bone mass. This is summarised by Wolff's bone law (1884) which states that an increased training effect will lead to increased stress on the skeletal system and cause bone remodeling.

Residual mass indirectly measures the mass of internal organs, such as those involved in endurance performance. Organs such as the cardiopulmonary system are enlarged and become heavier with training (Douglas et al., 1986). However, a bigger body also needs a larger cardiopulmonary system. That is, bigger people have larger lungs and greater blood volume. The question remains as to whether the increased residual mass is a result of greater training, greater size, genetics (phenotype), a precursor for high performance, or a combination of these. Douglas et al. (1986) showed that higher level triathletes had a significantly greater thickness of the left ventricular wall of the heart than those triathletes who did not participate at such a high level. Residual mass was also shown to account for a greater percentage of the total mass of a senior male triathlete when compared with a junior male. This difference in percent residual mass indicates where the senior and junior triathletes are not geometrically similar. It may suggest that greater loads and greater exposure to training lead to heart hypertrophy, increased capillarisation and increased total blood volume. This shows also that the variation in the two scores is important in developing a senior triathlete. Various studies (Sleivert & Rowlands, 1996; Rowbottom et al., 1997; Laurenson et al., 1993) have demonstrated that physiological characteristics such as a superior VO_{2max} play an important part of determining success in a triathlon. Therefore, the variation in residual mass could be linked more closely with training rather than body size.

No significant differences were noted between the senior and junior males in endomorphy, mesomorphy or ectomorphy ratings, or the sum of 8 skinfolds. Carter and Heath (1990) through the summation of others (Alonso, 1986; Chovanova & Pataki, 1982; Guimaraes & De Rose, 1980; Hayley, 1974; Thorland et al., 1981), have stated that young athletes showed similar somatotype patterns at the time of adolescence to those of adults, but are less mesomorphic. The similarities show a homogeneous group and emphasises self-selection for the event in terms of body type.

There were no significant differences between the mean sitting height of the male senior and junior triathletes. However, there was a significant difference in mean height between these two groups. Therefore, the difference was in lower limb length and these long bones of the limbs fuse last in growth. These results suggest that the upper body or trunk has developed to maturity because of similarity, but the limbs have not. This could reflect the incomplete maturation of the junior males.

The male triathletes showed no significant differences between senior and junior competitors in the scores of adipose mass or sum of 8 skinfolds. It could be expected that, with an increase in height, there would be an increase in other variables such as mass, adiposity or skinfolds. With no increase in skinfolds or adipose mass of the larger triathlete, it could be interpreted that the senior male triathletes carried less subcutaneous tissue than their junior counterparts. However, this was not supported by the finding that there was no significant difference in percentage adiposity between the two groups.

Senior male triathletes recorded greater bone breadths for humerus, biacromial, chest and biiliocristale, and anterior-posterior chest depths, than their junior counterparts. This relates to the significantly greater bone mass recorded by the senior triathletes. No significant differences were found in femur breadths. That significant differences were found in bone breadths between the senior and junior male triathletes, suggested a lower level of maturity or development of the junior triathlete. All the breadth differences, except chest breadth, were removed by applying the phantom stratagem, and revealed that, proportionately, there was no difference between senior and junior male competitors. The proportionately smaller chest breadth of the junior male triathletes also suggested a lack of maturity. Hence, there could be scope for more development via training as well as biologically.

The senior males recorded significantly greater chest, waist and thigh girths when compared with the junior males. The senior males also recorded a proportionately larger chest girth. The raw and proportional chest girth differences can be related to the greater raw and proportional chest breadths recorded by the senior males, with significant correlation between chest girth and chest breadth ($r = 0.740$), and that there is development still to come for the junior male triathletes. The relationship between the residual mass and space for internal endurance organs was apparent via strong correlations between residual mass and chest girth, and residual mass and waist girth.

Senior male triathletes displayed significantly greater arm span, acromiale-radiale length, trochanterion-tibiale raw lengths, and proportional lengths of trochanterion-tibiale than junior male triathletes. As the arm span consists of two components of arm length and one of biacromial breadth, significantly different arm spans could be expected. As reported earlier, the mean humerus breadth in the junior male triathletes was significantly smaller than in the senior triathletes. This was also the case when comparing femur lengths. The junior male triathletes recorded absolute and proportionally shorter thighs, and thus, overall leg length, than the senior males. As noted previously, sitting heights were equal but significantly different standing heights were recorded. With these variables together, height, sitting height and thigh length, it could be assumed that the junior triathletes were still not fully matured.

Senior male triathletes recorded significantly higher RLLL scores, which showed greater maturity. There was no significant difference in sitting height or tibiale-laterale length, but significant differences were found in standing height and femur length. Further support that the RLLL score for the junior males would be smaller can be noted when the proportional (phantom) trochanterion-tibiale scores were found to be significantly smaller.

Female Triathletes

The body types of senior and junior elite female triathletes differed in muscle mass, sum of skinfolds, and the percentage of adipose mass in relation to total mass. The heights and masses of the triathletes in this study (168.27cm & 59.47kg) were similar to those of previous studies of highly trained (Leake & Carter, 1991, 162.1cn & 55.2kg; Laurenson et al., 1993, 168.8cm & 59.5kg) and elite (Laurenson et al., 1993, 167cm & 56.4kg) female triathletes. A comparison with the only somatotype data found for classic distance triathletes (Leake & Carter, 1991), demonstrated that the female triathletes measured in this study were similar in endomorphy, and recorded greater ectomorphy and less mesomorphy. That is, the female triathletes of this study were slightly more linear and less robust. This suggests a changing shape over time. Possibly, the run leg is taking on a more dominant role than the swim leg in the final outcome of the race than previously. With the runner tending to be more linear as a result of introducing drafting, mesomorphy has declined, possibly due to the decreased need for consistent power output during the cycle. The female senior and junior triathletes showed no differences in mesomorphy or ectomorphy but the seniors scored significantly lower on endomorphy. However, the difference in these scores was less than one unit. For junior competitors, this is considered acceptable in preparation for transition into the senior ranks (Carter & Heath, 1990).

The senior female triathletes recorded significantly greater muscle mass and a significantly smaller sum of 8 skinfolds than the junior females. Hence, the junior female triathletes could be nearly mature but require a higher level of training as evidenced by a greater sum of 8 skinfolds and less muscle mass. High levels of endurance training lead to hypertrophy of type-1 muscle fibers and decreased fat stored (Wilmore and Brown, 1974). In weight bearing endurance events, a lower level of body fat is associated with higher level performances. Hence, the greater percentage of adipose mass to total body mass recorded by the junior female triathletes could be one of the reasons why their performances were not equal to those of the senior females.

Biiliocristale was the only significantly different breadth measures between the two categories of female triathletes. It should be noted that the general growth trends of males and females are different. Females tend to mature at a younger age than males. Generally females have matured or are close to full maturity at the age of 18 years. The average age of the junior female triathletes in this study was 19.0 years, which is greater than the age of average female maturity (18.0 y). Full maturity for the male general population is 21.0 years or greater and the junior male triathletes were of mean age 19.1 years. It must also be noted that the senior triathletes, both male and female, reported mean ages greater than the accepted age of maturity and were assumed to have fully matured (Table 1).

Senior females were found to have significantly larger calf girths when compared with their junior counterparts. This variation could contribute to the significant difference in muscle mass between the two categories and suggested that junior females retained some scope for increasing muscle mass. This could be achieved through an increase in muscle development in the lower limb with training and/or maturity.

No significant differences were recorded for any of the indices or segmental lengths between the senior and junior female triathletes. Again, this demonstrates homogeneity in the female triathletes and could indicate some degree of self selection.

Summary

Eighty-seven triathletes were measured before competing in the Triathlon World Championships in Perth, 1997. A series of anthropometric, demographic and performance variables were measured. Subjects were senior and junior elite, males and females.

Analysis of these data indicated that the senior male triathletes were more developed and recorded larger values for most variables than the junior males. The junior female triathletes appeared to have reached maturity and recorded less morphological differences between the senior and junior females when compared with junior and senior males.

A comparison of the male senior and junior elite groups revealed that senior triathletes were older, taller and heavier; recorded greater skin, muscle, bone and residual masses. Raw scores of biacromial width, chest breadth, anterior-posterior chest depth, biiliocristale and humerus breadth were also significantly greater in the elite competitors. Larger values were recorded for acromiale-radiale and trochanterion-tibiale, as well as chest waist and thigh girths. When male variables were converted to proportional scores, most differences were removed and accounted for by growth and development. Hence, junior male triathletes could be "on target" to attain an optimum morphology. Those variables not affected by scaling, were residual mass, proportional chest girth and breadth, and can be changed through increased training.

Senior female triathletes also recorded significantly larger measurements than their junior counterparts for muscle mass, biiliocristale breadth and calf girth. The junior female triathletes recorded greater sum of skinfolds and higher endomorphy which can be altered with increased training. Junior females had neared full maturity and more closely resembled the morphology of the senior females.

Thus it seems apparent that the junior athletes of both genders, through very similar morphological characteristics to those of the senior competitors, and have successfully self-selected themselves for the sport of triathlon.

References

Ackland, T.R., Blanksby, B.A., Landers, G. and Smith D. (1998) Anthropometric profiles of elite triathletes. *Journal of Science and Medicine in Sport, 1*(1), 53-56.

Ackland, T.R., Blanksby, B.A., Landers, G. and Smith D. (1999) Anthropometric correlates with performance among world championship triathletes. *Kinanthopometry VI Proceedings ,* (in press)

Bloomfield, J., Ackland, T.R. and Elliot, B.C. (1994). *Applied Anatomy and Biomechanics in Sport*. Melbourne, Australia: Blackwell Scientific Publications, pp 40-92, 267-109.

Carter, J.E.L. and Ackland, T.R. (Eds). (1994) *Kinanthropometry in Aquatic Sports; a study of world class athletes.* USA: Human Kinetics Publications Inc.

Carter, J. and Heath, B. (1990). *Somatotyping – Development and Applications*. Cambridge: Cambridge University Press.

Douglas, P.S., O'Toole, M.L., Hiller, W.D.B. and Reuchek, N. (1986). Left ventricular structure and function by echocardiography in ultra endurance athletes. *American Journal of Cardiology, 58*, 805-809.

Hue, O., LeGallais, D., Chollet, D., Boussana, A. and Prefaut, C. (1998). The influence of prior cycling on the biomechanical and cardiorespiratory response profiles during running in triathletes. *European Journal of Applied Physiology, 77*, 98-105.

Landers, G.J., Blanksby, B.A., Ackland, T.R. and Smith, D. (1999) Morphology and performance of world championship triathletes. *Annals of Human Biology*, (in press)

Laurenson, N.M., Fulcher, K.Y and Korkin, P. (1993). Physiological characteristics of elite and club level female triathletes during running. *International Journal of Sports Medicine, 14(8)*, 455-459.

Leake, C.N. and Carter, J.E.L. (1991). Comparisons of body compositions and somatotypes of trained female triathletes. *Journal of Sports Sciences, 9*, 125-135.

Norton, K. and Olds, T. (1996) *Anthropometrica*. Sydney, Australia: University of New South Wales Press, pp 27 - 75, 409.

Ross, W.D. and Kerr, D.A. (1991) Fraccionament de la massa corporal: un nou methode per utilitzar en nutricio clinica i medicina esportiva. *APUNTS, 18*, 175-187.

Ross, W.D. and Ward, R. (1986). Scaling anthropometric data for size and proportionality. In; T. Reilly, J. Watkins & R. Borms (Eds). *Kinanthropometry III, Proceedings of the VIII Commonwealth and International Conference on Sport, Physical Education, Dance, Recreation and Health*. New York: E. & F.N. Spon. pp 85-91.

Rowbottom, D.G., Keast, D., Garcia-Webb, P. and Morton, A.R. (1997).

Training adaptation and biological changes among well-trained male triathletes. *Medicine and Science in Sports and Exercise, 29*(9), 1233-1239.

Schneider, D.A., Lacroix, K.A., Atkinson, G.R., Troped, P.J. and Pollack, J. (1990). Ventilatory threshold and maximal oxygen uptake during cycling and running in triathletes. *Medicine and Science in Sports and Exercise, 22*(2), 257-264.

Sleivert, G.G. and Rowlands, D.S. (1996). Physical and physiological factors associated with success in triathlon. *Sports Medicine, 22*(1), 8-18.

SPSS for Windows Release 8.0.0 (1997), SPSS Inc.

Tittle, K. and Wutscherk, H. (1988). Anatomical and anthropometric fundamentals of endurance. In; R.J. Shephard & P.O. Astrand (Eds). *Endurance in Sport, the encyclopedia of sports medicine*. Blackwell Scientific Publications.

Travill, A.L., Carter, J.E.L. and Dolan, K.P. (1994) Anthropometric characteristics of elite male triathletes. In, F.I. Bell and G.H. Van Gyn (eds.) *Proceedings for the 10th Commonwealth and International Scientific Congress: access to active living*. University of Victoria, Victoria, 340-343.

Wilmore, J. and Brown, C. (1974). Physiological profiles of women distance runners. *Medicine and Science in Sport, 6*(3), 178-181.

The effects of three varied cycle leg protocols on self-paced run time trial performance.

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In the past, the cycling portion of an Olympic Distance Triathlon (ODT) was typically performed at steady state power outputs. However, with the advent of drafting and the inclusion of smaller spectator friendly bike courses, the demands of the cycle leg have changed. The purpose of this research was to investigate the effect of three varied cycle leg protocols on self-paced run time trial performance. Subjects (n=4) completed an initial phase of testing to determine baseline information. A 7.5 km run time trial on the treadmill (RTT) was followed by progressive maximal run (RT) and cycle tests (CT) 72 hours later. The best run performance was established using the RTT, whilst the individual anaerobic threshold (IAT), maximal power and VO_{2max} was recorded from the maximal tests. The subjects then completed three cycle leg protocols each of 45 minutes in duration, followed immediately by another 7.5km run time trial, with a minimum of 72 hours recovery between testing protocols. This bike-run combination is referred to as a BRICK. The three protocols were conducted in a randomised counter-balanced manner and included: a simulated draft time trial ($BRICK^{DRT}$), a self paced steady state time trial ($BRICK^{ITT}$) and a variable power output time trial ($BRICK^{ITU}$). Compared to the control RTT, the results demonstrated for all BRICK running protocols significantly lower ($p<0.005$) mid and end oxygen consumption (VO_2) values, $BRICK^{ITT}$ (3.61 ± .15, 3.73 ± .24), $BRICK^{DRT}$ (3.67 ± .24, 3.70 ± .24) and $BRICK^{ITU}$ (3.54 ± .22, 3.66 ± .15) v's RT (3.90 ± .39, 3.95 ± .28). No significant differences were recorded between the RTT and the BRICK protocols for the measures of heart rate (HR), bicarbonate ion concentration (HCO3), lactate (HLa), pH, perceived exertion (RPE) and 7.5km run times. This research demonstrated a decrease in VO_2 during the run leg of all BRICK protocols and indicated limitations in run pacing and velocity of competitive triathletes.

Of significant importance to coaches in the development of effective training programmes, is an understanding of the primary physiological and psychological characteristics that contribute to successful sporting performance (Craig *et al*., 1993). With respect to physiological characteristics, coaches and sports scientists commonly seek an understanding of the various metabolic components and their respective contributions to success in that sport or event.

The Olympic Distance Triathlon (ODT) involves swimming (1.5 km), cycling (40 km), running (10 km) and transition skills. In the past, the cycling portion of the ODT was typically performed at steady state power outputs. However, with the advent of draft legal events and the inclusion of smaller spectator friendly bike courses, the demands of the cycle leg have changed.

Recent data suggests that power output and the energy systems utilised during draft legal and tight street circuits are vastly different to the steady state time trial (Smith *et al*., 1997; Hausswirth *et al*., 1999). Hence, the effects of these changes on subsequent run performance are still not fully understood.

The cycle leg, represents the largest proportion of the total race duration of the ODT (>50%). With regard to draft legal events, anecdotally the effect appears to have reduced the importance of the cycle leg in the outcome. The draft legal ODT has been described as a 'wet run,' de-emphasising the place of the cycle leg. The inclusion of tight street circuits has also changed the nature of the conventional cycle leg. Recent data collected from the International Triathlon Union race over the proposed Sydney 2000 Olympic course, reveals large variations in power output, more in line with criterium massed start cycle events (Smith et al. 1997).

In contrast, the traditional 40 km individual time trial (ITT) event requires a steady state power output. Power at anaerobic threshold (AT) and maximum power, obtained from an incremental cycle test, are positively correlated to 40 km ITT time (Coyle *et al*., 1991; Hawley and Noakes, 1997).

The effect of drafting on cycling performance has been assessed by Palmer *et al*., (1997). They compared the time to ride a 20 km ITT following a 150 minute ride which was either at a constant load (58% of peak power output), representing a draft ride, or a variable power output ride (mean power of 58% of peak power varying by $\pm$ 12%). Despite similar total work and heart rates, the 20 km ITT time following the steady state draft ride was significantly faster than the variable power output protocol. In a study on the effect of drafting during a triathlon bike leg, Hausswirth *et al*. (1999) reported a rise in cadence by approximately 6.3%, a 47% decrease in blood lactate response (BLC) and a reduction in VO_2 of 14%. This effect is not surprising given the reduction in energy expenditure of 26% when behind a single rider and up to 39 % sitting in a group of riders (McCole *et al*., 1990). According to Hausswirth *et al*. (1999) the effect of the draft bike leg improved 5 km running speed compared with the no draft mode (17.8 vs 17.1 $km \cdot hr^{-1}$) and furthermore, increased the physiological values of VO_2, HR and BLC during the draft run leg.

The decision towards a 'draft-legal' and criterium styled cycle leg has placed a greater importance upon the assessment of the triathlete's physiological and psychological responses towards running. It appears that a draft cycle leg may provide for a psychological readiness and reduced physiological fatigue which may allow the triathlete to run at a higher intensity in comparison to that which can be attained after a variable power output cycle leg. This is an important consideration given that it has already been well established that the running portion of the ODT is the most difficult of the three segments to complete.

Given the support that a non draft cycle triathlon is more demanding than a draft triathlon, the principal purpose of this study was to investigate the effects of differing cycle leg protocols (variable power output, steady state ITT and simulated draft cycle protocols) on self-paced treadmill run time trial performance.

Methods

Subjects

Four (n=4) male triathletes (ODT = 2hrs) participated in this research study (See Table 1). Each triathlete completed a pre-test medical questionnaire and signed an informed consent statement. Testing was conducted just prior to the commencement of the triathlon season. All subjects had been engaged in at least eight weeks of training in all three disciplines of the triathlon when assessed as a part of this study.

Experiment Design

All subjects took part in five testing sessions at the Human Performance Laboratory of the Tasmanian Institute of Sport. The test sessions were completed over a 14 day period. Subjects were asked to refrain from training for 48 hours leading into the testing sessions.

All subjects completed an isolated self-paced 7.5 km run time trial test (RTT) on day one. Seventy two hours later the subjects completed progressive maximal bike and run tests with 4 hours separating the tests. The subjects then completed three bike/run tests (BRICK TEST) in a random counter balanced manner. Each BRICK test consisted of a cycle leg protocol lasting 45 minutes immediately followed by a 7.5 km self-paced run time trial. A minimum of 72 hours recovery was given between testing protocols. The three cycle protocols were:

- a simulated draft time trial (TT^{DRT});
- a self paced individual time trial (TT^{ITT});
- a variable power output bike time trial (TT^{ITU}).

Progressive maximal cycling test (CT)

The CT was conducted on a Lode Excalibur Sport (v 1.5; Groningen, Netherlands) cycle ergometer which interfaced with a Lode BV Work Load Programmer (WLP). Subjects warmed up on the ergometer for 10 min at a power output of 75 Watts (W). The progressive VO_2max and lactate test consisted of 5 min stages commencing at 100W and increased 50W until volitional exhaustion (cadence < 80 revolutions.min^{-1}). All subjects performed the test at a cadence between 85-95 revolutions.min^{-1}. Maximum power output was determined by using the formula:

$$P@VO_{2Max} = P_p + (t_f \times (V_f - V_p / 5 \text{ min})$$

where P_p is the power output of previous stage, V_f is the power output of the final stage and t_f is the time (in min) at final power.

Expired gas was collected continuously during the CT and analysed with a Quinton Metabolic Cart (QMC: Quinton ® Instruments Co, Seattle, U.S.A).

At the completion of each 5 min interval, a blood sample was taken from the finger to determine blood lactate, pH and bicarbonate ion concentration. Lactate analysis was conducted using a Yellow Springs Instruments (YSI, Ohio, U.S.A.) 1500L Lactate Analyser and pH and bicarbonate ion concentration was assessed using a AVL Omni (Graz, Austria) blood gas analyser.

Heart rate (beats.min^{-1}) was recorded by telemetry (Polar Advantage NV, Polar, Finland) during the last 15 seconds of each 5 min interval, and the maximum heart rate reached by each subject was recorded.

Following completion of the test, all subjects completed a 10 min warm down at 50-75W. Data attained during this test is represented in Table 1.

Progressive maximal run test (RT)

The RT was conducted on a calibrated Quinton treadmill (Model Q-65: Quinton ® Instruments Co, Seattle, U.S.A). Subjects warmed up on the treadmill for 10 min at a speed between 8-10 $km.hr^{-1}$. The RT consisted of 4 min stages commencing at $10km.hr^{-1}$ and increasing $2km.hr^{-1}$ until $18km.hr^{-1}$, thereafter the velocity increased $1km{\cdot}hr^{-1}$ each minute until volitional exhaustion. Velocity at VO_{2max} ($V@VO_{2max}$) and oxygen consumption variables: VO_2 ($mL.kg^{-1}.min^{-1}$), ventilation ($L.min^{-1}$) and respiratory exchange ratio (RER) were recorded. VO_{2max}, maximal ventilation and RER were determined as the average of the highest two consecutive values obtained during the last increment.

At the end of each 4 min interval, the treadmill was stopped for 1 min and a blood sample was collected from the finger in a heparinsied capillary tube to determine blood lactate, pH and bicarbonate ion concentration. Heart rate was recorded during the last 15 s of each 4 min interval during the incremental test and maximum heart rate was also recorded.

Velocity, VO_2, heart rate, blood lactate, pH, and bicarbonate concentrations at AT was determined using the log-log transformation method (Beaver *et al*., 1985) from the progressive maximum test.

Run Time Trial Testing (RTT)

The RTT was conducted on a single day, with the same treadmill, gas and blood analysis equipment described above. The subjects completed a ten min warm up at $10km{\cdot}hr^{-1}$. They then selected a starting velocity (10-$14km{\cdot}hr^{-1}$) and proceeded to cover 7.5km as quickly as possible, being permitted to self-select velocity at the completion of every minute. VO_2 was recorded between 1-3 (start), 14-17 (mid) and 24-27 (end) min of RTT. At the 10 and 20 min blood samples were taken from the finger, whilst the subject continued to run and analysed for blood lactate, pH and bicarbonate ion concentration. The same procedure was repeated immediately at the completion of RTT. Heart rate was recorded continuously throughout RTT. RPE was recorded at each 5 minute period during the RTT and at the end of the trial. The changes in run velocity were recorded throughout RTT. The same procedure and distance of RTT was employed for the run portions of all BRICK protocols.

BRICK Testing

The BRICK protocols were conducted using the same cycle ergometer and treadmill equipment described above. Every 8 min during the 45 min cycle test a blood sample was taken from the finger and analysed for blood lactate, pH and bicarbonate ion concentration. RPE was also recorded at this time. Heart rate was monitored continuously for the 45 min protocol.

At the completion of the cycle protocol the subjects changed into running shoes and commenced the self-paced run time trial as outlined in RTT.

BRICK Protocols

$BRICK^{DRT}$ (TT^{DRT} + run) consisted of a series of intermittent sprints combined with a draft simulated effort. The sprints involved 2 sets of 24 efforts with each sprint lasting 10 s and ranging in intensity from 80 –183 % peak power. The sets were separated by a 20 min draft simulated effort of variable power (mean 67 ± 10% peak power). $BRICK^{ITU}$ (TT^{ITU} + run) required the subjects to repeat intermittent 10 s sprints (80 – 183 % peak power) and recover (150 watts) in a stochastic manner with open cadence. The subjects then completed 3 sets of 30 sprints continuously for 45 min. Sprints were randomised and the sprint power had to be reached and held to be valid. $BRICK^{ITT}$ (TT^{ITT} + run) required the subject to maintain the highest power output for 45 min. The linear factor for the Lode Excalibur cycle ergometer was calculated based on a cadence of 90 rpm and factored by the subject's power at individual anaerobic threshold as determined by Beaver *et al*., 1985.

LF X = IAT watts/90 rpm/90rpm

Where: IAT = Individual anaerobic threshold (W)
X = linear factor for each individual

All values are reported as mean ± standard deviation and significance was set at p = 0.05.

Results

Table 1 outlines the descriptive statistics for the subjects. The mean ± SD for lactate, heart rate and VO_2 can be found in Table 2 for each of the BRICK cycle protocols. Table 3 outlines the mean time taken to complete the 7.5 km time trial following each cycle protocol and RTT.

Maximal physiological measures and significance of ANOVA between the RTT and $BRICK^{DRT}$, $BRICK^{ITU}$ and $BRICK^{ITT}$ are presented in Table 4. No significant differences were found between RTT and $BRICK^{DRT,\ ITU}$ or ^{ITT} for run time, mean run velocity, blood lactate, bicarbonate ion concentration, perceived exertion and average heart rate. Significant differences were observed for mid (p = .0102) and end (p = .0024) oxygen consumption (VO_2) values between $BRICK^{DRT,\ ITU,\ ITT}$ and RTT. Similarly, significant differences were recorded for % VO_{2max} for mid (p = .0083) and end (p = .0015) between $BRICK^{DRT,\ ITU,\ ITT}$ and RTT.

Table 1. Subject characteristics

Test Parameters	Mean	SD ±
Mass (kg)	69.6	8.8
Height (cm)	178.9	5.7
Maximum Power (watts)	365	32.4
V @VO_{2max} (km · hr^{-1})	19.5	0.40
Bike VO_{2max} (L·min^{-1})	4.42	0.26
Run VO_{2max} (L·min^{-1})	4.60	0.46

Table 2. Bike Brick Summary

Brick	Parameter	Mean	SD ±
ITT	Lactate (mmol·l^{-1})	3.9	.09
DRT		3.3	.86
ITU		4.4	.58
ITT	Heart rate(b · min^{-1})	160	6
DRT		147	4
ITU		150	9
ITT	VO_2 (L·min^{-1})	3.603	.213
DRT		3.145	.064
ITU		3.349	0.38

Table 3: Mean times for 7.5 km run time trial

Run Protocol	Mean Time (min)	SD
RTT	28.34	1.52
$BRICK^{ITT}$	28.41	1.34
$BRICK^{DRT}$	28.43	1.41
$BRICK^{ITU}$	28.42	1.16

Table 4: Comparisons between physiological variables for each run time trial

	VO2 ($L.min^{-1}$)			**Lactate ($mmol.L^{-1}$)**			**pH**			**Bicarbonate ion ($mmol.L^{-1}$)**			**Heart Rate ($beats.min^{-1}$)**			**RPE**	
	Start	**Mid**	**End**	**Start**	**Mid**	**End**	**Start**	**Mid**	**End**	**Start**	**Mid**	**End**	**Start**	**Mid**	**End**	**Start**	**Mid**
RTT	3.37 (0.32)	**3.91 (3.39)**	**3.99 (0.28)**	4.3 (0.9)	4.4 (1.7)	5.3 (3.1)	7.396 (0.022)	7.387 (0.056)	7.373 (0.063)	20.8 (2.7)	20.3 (2.8)	18.7 (3.6)	167 (5)	176 (5)	180 (6)	14 (1)	16 (1)
BRICK^{ITT}	3.33 (0.17)	**3.62 (0.16)**	**3.74 (0.24)**	4.5 (0.7)	4.6 (1.2)	5.1 (1.3)	7.397 (0.030)	7.404 (0.033)	7.392 (0.032)	20.3 (1.4)	20.4 (1.4)	19.4 (1.9)	167 (3)	174 (6)	179 (3)	15 (1)	16 (1)
BRICK^{DRT}	3.24 (0.08)	**3.68 (0.25)**	**3.70 (0.23)**	4.4 (2)	4.9 (2.4)	5.7 (2.7)	7.398 (0.016)	7.393 (0.039)	7.382 (0.055)	20.3 (2.4)	19.4 (2.9)	18.3 (3.0)	168 (7)	175 (5)	178 (5)	15 (2)	17 (2)
BRICK^{ITU}	3.19 (0.26)	**3.55 (0.30)**	**3.67 (0.16)**	4.1 (1.6)	4.2 (1.9)	5.7 (2.4)	7.394 (0.026)	7.393 (0.034)	7.363 (0.047)	21.0 (2.2)	20.2 (2.0)	18.6 (2.6)	167 (8)	173 (6)	179 (7)	16 (1)	17 (1)

Bold values represent significant differences (p = 0.05)

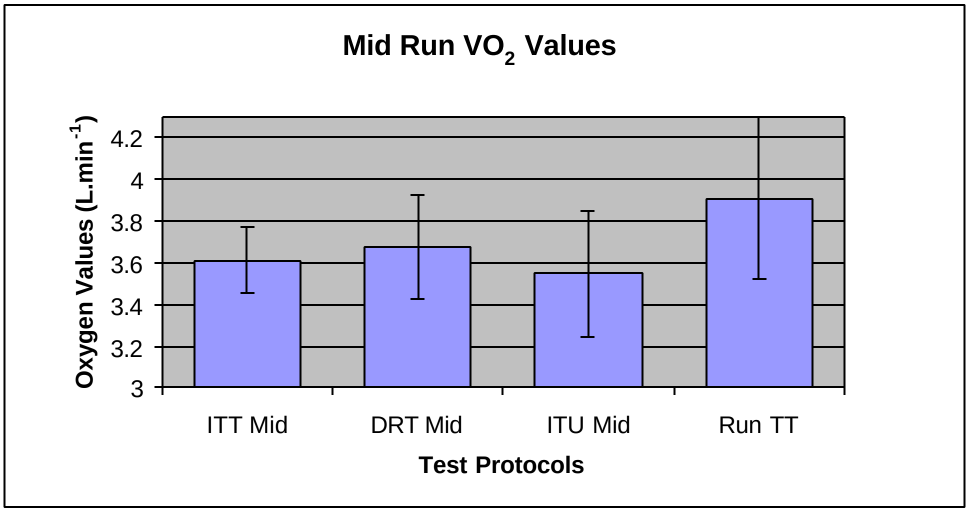

Figure 1: Mid run mean and SD for VO_2 values for all BRICK protocols and RTT.

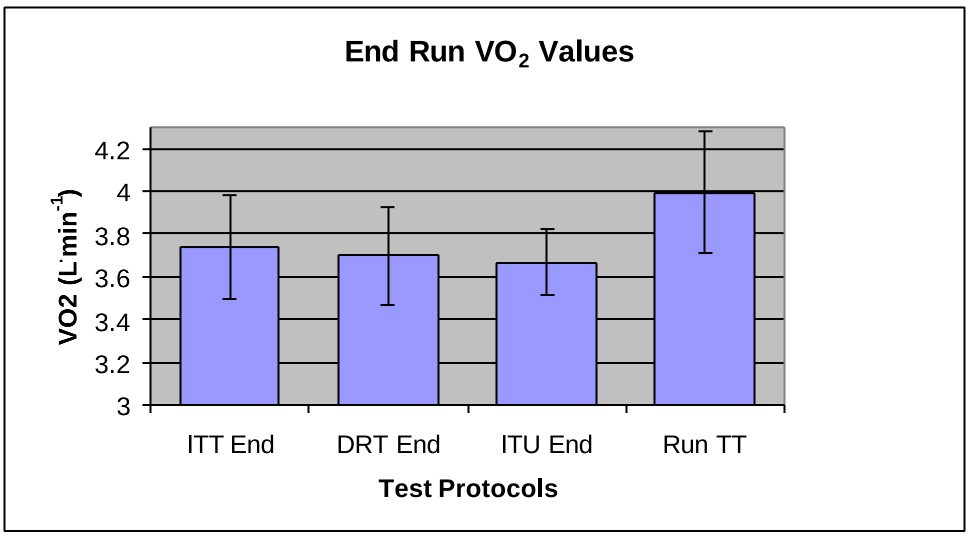

Figure 2: End run mean and SD for VO_2 values for all BRICK protocols and RTT.

Discussion

The principle finding of this research was the reduction in VO_2 during the run portion of all three BRICK protocols. De Vito *et al*. (1994) conducted an isolated incremental run test and one week later another incremental run test following a 1.5 km swim and 40 km cycle leg and found a 12% and 7.2% decrease in VO_2 at AT and VO_{2max}, respectively. This would equate to the same VO_{2max} being achieved at a lower velocity due to the physiological responses characterising decreased running economy. De Vito *et al*. (1994) made the assumption that a reduction in economy would result in a reduced run performance; however, this was not tested directly. In the present study a reduction of 6.2 % in mid and end VO_2 values was found, without any differences between all BRICK run and RTT 7.5km time. Thus, despite reductions in VO_2 during the BRICK run, performance time and average velocity did not decrease. This suggests a transitory improvement in economy.

Studies conducted by Kreider *et al*. (1988), Hue *et al*. (1998) and Guezennec *et al*. (1996) analysed triathlon pace over a 10 km run distance and in addition investigated changes in oxygen consumption where they found a mean increase of 0.44 $L.min^{-1}$ (6.0 $mL.kg^{-1}.min^{-1}$), 0.24 $L.min^{-1}$ (3.4 $mL.kg^{-1}.min^{-1}$) and 0.25 $L.min^{-1}$ (3.5 $mL.kg^{-1}.min^{-1}$), respectively. The increase in VO_2 may be explained by changes in running mechanics whereby there is a decrease in stride length and increase in stride rate possibly resulting in greater energy expenditure (Hue *et al*. 1998).

It is thought that fatigue processes may cause decreases in VO_2 during the run portion. Hausswirth *et al*. (1999) conducted a study on the effect of a draft legal cycle leg on physiological and performance parameters using elite male triathletes. It was found that VO_2 was higher and run velocity greater (17.1 v's 17.8 km.hr-1) during the run leg, following the draft legal triathlon (Hausswirth *et al*., 1999). This indicates that the athletes were more fatigued during the run after riding the non-draft format and thus were not able to fully utilise their metabolic systems. It is claimed that glycogen depletion may explain the feelings of heaviness and be related to reduced muscle fibre recruitment (Wilmore and Costill, 1994). With glycogen depletion, slow twitch (ST) fibres fail to develop maximum tension and recruitment of fast twitch (FTa and FTb) fibres becomes reduced, decreasing muscle tension and ultimately run velocity. It is also claimed that hyperthermia may explain the reductions in VO_2 and run performance (Cade *et al*., 1992). The additive effects of glycogen depletion, hyperthermia and psychological trauma can affect fibre recruitment and hence VO_2. To achieve peak performance, athletes must learn to improve pacing, which may explain similar run performance, despite physiological fatigue in the subjects of this study.

Significant differences were expected between RTT and $BRICK^{ITT}$ and $BRICK^{ITU}$, with similar run times expected between $BRICK^{DRT}$ and RTT. This; however, was not the case as there were no significant differences reported for run time between RTT and $BRICK^{ITT,}$ ^{ITU} and ^{DRT}. According to Palmer *et al*. (1997), 20 km bike time trial performance was faster following a 150 minute pre-ride at steady state power output (58% peak power) versus a variable power output pre- ride (58± 12 % peak power) (26:32 ± 1:30 min v's 28:08 ± 1:47). These results indicate for cycling, that improved time trial performance is expected following a steady state pre-ride at 58% of peak power. This effect may be explained in part by the recruitment of FTa and FTb fibres during the variable power output protocol, in turn causing more physiological fatigue.

In this research, the similar run times between all protocols, despite significant variations in power output, may be explained by the subject group. The subjects may have had limitations in their ability to increase running pace, despite varied pre-run physiological cost. Thus the subjects may have employed the same run pace strategy for all run conditions. Biomechanical limitations in stride rate and frequency, as well as a lack of run speed, may explain the similar run times. Further analysis of the study by Hausswirth *et al*. (1999) reveals that performers with established running backgrounds gained the greatest time improvements in run time after a draft cycle protocol. Thus, better runners appear to be able to profit from reduced bike efforts and increase run pace as a result. The similar run times in this research may be related to limitations in running and pacing ability but also the small sample size. The implications for the competitive triathlete may be that drafting may not improve run times and individual bike efforts could produce faster overall times. It also appears that the competitive triathlete could benefit from speed specific run training and pacing.

This research on the effect of cycle leg intensity on self-paced run performance showed no differences in run times, despite findings to the opposite in the literature. The results indicate the subject group may have running velocity and pacing limitations. Research comparing the effect of BRICK protocols on run pacing between competitive and elite triathletes is recommended. Furthermore, investigations are needed with a larger sample size to measure the effect of cycle leg intensity on run time.

References

Beaver, W.L., Wasserman, K. & Whipp, B.J.: Improved detection of lactate threshold during exercise using a log-log transformation. J. Appl. Phys., 59, 1936-1940, 1985.

Cade, R., Packer, D., Zauner, C.,Kaufmann, D., Peterson, J., Mars, D., Privette, M., Hommen, N. and Rogers, M.J. Marathon Running: physiological and chemical changes accompanying late race functional deterioration. Eur. J Appl Physiol Vol 65: pp 485-491, 1992.

Coyle, E.F., Feltner, M.E., Kautz, S.A., Hamilton, M.T., Montain, S.J., Baylor, A.M., Abrahams, L.D. and Petrek, G.W. Physiological and biomechanical determinants of of elite endurance cycling performance. Med Sci Sports and Exerc, Vol 23, pp 93-107, 1991.

Craig, N.P., Norton, K.I., Bourdon, P.C., Woolford, S.M., Stanef, T., Squires, B., Olds, T.S., Conyers, R.A.J. & Walsh, C.B.V.: Aerobic and anaerobic indices contributing to track endurance cycling performance. Eur J Appl Physiol 67:150-158, 1993.

De Vito, G., Bernardi, M., Sproviero, E. & Figura, F.: Decrease of endurance performance during Olympic triathlon. Int J Sports Med 16(1): 24-28, 1995.

Geuzennec, C.Y., Vallier, J.M., Bigard, A.X. & Durey, A.: Increase in energy cost of running at the end of a triathlon. Eur J Appl Physiol 73: 440-445, 1996.

Hausswirth, C., Lehenaff, D., Dreano, P. and Savonen, K.: Effects of cycling alone or in a sheltered position on subsequent running performance during a triathlon. Med. Sci.Sports Exerc., Vol.31, No4, pp. 599-604, 1999.

Hue, O., Gallais, D.L., Chollet, D., Boussana, A. & Préfaut, C.: The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes. Eur J Appl Physiol 77: 98-105, 1998.

Kreider, R., Boone, T., Thompson, W., Burkes, S. & Cortes, C.: Cardiovascular and thermal responses of triathlon performance. Med Sci Sports Exerc 20: 385-390, 1988.

Palmer, G.S., Noakes, T.D. and Hawley, J.A. Effects of steady state versus stochastic exercise on subsequent cycling performance. Med. Sci. Sports Exerc. Vol 29: pp 684-687, 1997.

McCole, S.D., Claney, K., Conte, J.C., Anderson, R. and Hagberg, J.M. Energy Expenditure during bicycling. Journal of Applied Physiology, Vol 47, pp 201-206, 1991.

Hawley. J.A. and Noakes T.D. Peak power predicts maximal oxygen uptake and performance time in trained cyclists, European Journal of Applied Physiology, Vol 65, pp 79-83

Smith, D., Lee, H., Pickard, R., Sutton, B. and Hunter, E. Monitoring of the cycle leg within the 1997 Sydney ITU Triathlon. Unpublished report, (1997).

Wilmore, J,H. and Costill, D.L. Physiology of Sport and Exercise (1994) Human Kinetics, Champaign Hill, Illinois, USA.

The Lactate Index: Classification of Training Intensity Based on Lactate, Heart Rate and Perceived Exertion.

John Hellemans

Dr John Hellemans is a Sports Medicine Practitioner and Coach based at QEII Sports Stadium in Christchurch. He has a special interest in high performance endurance sports and altitude training. He is the founder of the New Zealand Triathlon Academy and the author of the book "Triathlon, A Complete Guide for Training and Racing". John has extensive practical experience in altitude training as an athlete and coach.

Current terminology regarding training intensity, based on energy systems, the relative percentage concept and ratings of perceived exertion reflect confusion which exists amongst scientists and coaches when it comes to establishing desired training intensity zones.

The first part of this presentation clarifies relevant factors regarding the metabolic, cardio-vascular and psychological response to increasing workloads.

The second part introduces the simple and reliable system called the lactate index, to establish training intensity zones for endurance athletes.

Based on the lactate and heart rate testing, combined with subjective perception, five intensity zones are recognised: easy, steady, moderately hard, hard and very hard. It is proposed that identified zones and related terminology will be easily adopted by sports scientists and coaches when prescribing exercise intensity for endurance sports. This does not only apply to competitive athletes but also to the general public who exercise for fitness and general health.

Fluid losses and Voluntary Fluid Intakes in New Zealand Age Group Triathletes During the 1998 ITU World Championship Triathlon

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The adverse effects of dehydration on sporting performance are one of the most thoroughly investigated areas in sports science. It is well established that athletes can lose sweat in excess of one to two litres per hour during intense exercise in the heat. A one litre fluid loss causes core temperature to rise by 0.3°C during exercise in the heat, heart rate to be elevated by 8 beats per minute and cardiac output to decline by 1 litre per minute. It has been found that sweat rates are highly individual and that athletes do not voluntarily replace more than 50% of the fluid loss incurred during exercise. Most of the research in the area of dehydration is conducted within a laboratory setting which may not accurately reflect field conditions. Considering all of this, it is clearly important that athletes assess their sweat induced fluid losses and fluid requirements in the field and that they develop appropriate individual fluid plans in order to maximise performance and prevent problems resulting from dehydration.

The aim of this field study was to first estimate sweat induced fluid losses in New Zealand age group triathletes during an Olympic Distance Triathlon race and to secondly provide feedback on fluid losses and fluid needs to individual athletes to assist them in developing appropriate individual fluid plans for use during competition.

Methods

Subjects
Six female and 15 male New Zealand age group triathletes volunteered to participate in a field study in which sweat induced weight loss was measured during the 1998 ITU World Triathlon Championships in Lausanne, Switzerland. Recruitment took place at a team meeting two days prior to the race and the aims and procedures of the study were explained at this meeting.

At the World Triathlon Championships each age group spans five years, except for the junior age group which is from 16-19 years. The women's races preceded the men's and the higher age groups took place before the lower age groups. The first race in which subjects participating in this study competed started at 7 am with subsequent starts at 10 minute intervals. The last start for subjects in this study was at 9.30 am for the 20-24 year old males. Table one shows the age groups in which subjects participating in this study competed.

Study design
Subjects reported to the New Zealand tent which was situated close to the starting line for a weigh in approx. 30 minutes prior to the start of their individual race and again as soon as was practical, but within half an hour of, finishing. Subjects were weighed in their racing togs and were dried off thoroughly with a towel before the post race weight measurement. A Wedderburn Tanita 1609 N set of weighing scales was used. Outside

temperature at 6.40 am was 12.5°C and had increased to 16.6°C by 11.40 am

Table 1. Age groups in which New Zealand triathletes raced at the 1998 ITU World Triathlon Championships.

Age group	Females	Males
65 - 69	-	1
50 - 54	2	1
45 - 49	2	4
35 - 39	1	2
30 - 34	-	1
25 - 29	1	4
20 - 24	-	2

Subjects were instructed to estimate and report on the amount and type of fluid consumed between the pre and post race weight measurements. Fluid intake for each athlete was reported on and recorded at the post race weight check.

Subjects were further asked to report on urine output and bowel motions between the pre and post race weight checks. They were instructed to report on the frequency of passing urine and to indicate if they passed a small, medium or large amount. A small volume was estimated to be 100 ml urine, medium 200 ml and large 300 ml.

Fluid loss (g) was estimated using the following equation:

Fluid loss = reduction in body weight (g) + fluid intake (g) - urine output (g).

Percent dehydration is defined as the body weight loss which occurred during the race and was calculated as follows:

Percent dehydration = (body weight reduction - urine output) / initial body weight x 100

Results

All subjects lost weight during the race and mean weight loss was 1200 g (range 200 - 2600 g). Mean total fluid intake between pre and post race weight measurements was 1120 g (range 500 - 2500 g). Mean estimated urine output was 120 g. Total mean fluid loss (reduction in body weight + fluid intake - urine output) was thus 1200 plus 1120 - 120 = 2200 g. Mean percent dehydration (body weight loss - urine output / initial body weight x 100) was 1.4%.

Discussion

A limitation of this study was that due to it's nature, fluid intakes and urine output could not be accurately measured and had to be estimated by subjects. However, as this study was conducted during an important international race it does provide valuable information on fluid losses and intakes during such an event and under specific climatic conditions. The results indicate that despite the perceived cool temperatures during the first part of the morning during which the age group World Championship race took place, the triathletes in this study did become dehydrated and had not judged their fluid requirements accurately. As scientists now believe that there is no critical amount of dehydration which can be tolerated without physiological consequence, these triathletes would have benefited from larger fluid intakes during the race. As sweat rates are highly individual and because athletes do not voluntarily meet their fluid requirements, assessing fluid losses in both training and racing is of significant benefit in developing appropriate fluid intake plans for individual athletes.

References

Coyle, E.F., Montain, S.J. (1992a) Carbohydrate and fluid ingestion during exercise: Are there trade-offs? *Medicine and Science in Sport and Exercise , 24*, 671-678

Noakes, T.D. (1993) Fluid replacement during exercise. *Exercise and Sports Science.Review, 21*:297-330

Broad, E.M., Burke, L.M., Cox, G.R., Heeley, P., Riley, M. (1996) Body weight changes and voluntary fluid intakes during training and competition sessions in team sports. *International Journal of Sports Nutrition, 6*,:307-320

The effect of fluid loss on Olympic distance triathlon performance in high thermoregulatory stress.

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The purpose of this study was to measure the effect of ad-libitum fluid intakes and sweat losses on Olympic distance triathlon (ODT) performance. Ten (3 female and 7 male) trained triathletes ($\dot{V}O_{2max}$ = 58.4 ± 7.7 mL•kg^{-1}•min^{-1}; Best ODT time = 131.5 ± 13.3 minutes) completed two ODT's (1.5-km swim, 40-km bicycle, 10-km run), two weeks apart. The average wet-bulb globe temperature outdoors ($WBGT_{out}$) was 28.0 ± 2.8 ^{o}C. ODT relative body mass change, sweat loss, sweat rate and fluid intake were found to be 3.86 ± 0.76 %BM, 4370 ± 937 mL, 1886 ± 503 mL•hr^{-1} and 1551 ± 550 mL, respectively. Run time was significantly influenced by ad-libitum fluid consumption during and the relative body mass change during that leg. Similarly, high sweat rate, high sweat loss but decreased relative body mass losses were all significantly correlated with increased bicycle leg performance. Although swim leg time was significantly related to ODT time, no measures of sweat or fluid intake correlated with swim performance.

The ODT requires participants to swim 1.5 kilometres, bicycle 40 kilometres and run 10 kilometres. With the introduction of the ODT as an official Olympic sport, it has become the major focus of competition for many triathletes. The competitive triathlon season in Australia extends through the summer months where typically the ambient air temperature and humidity are high. Additionally, the event requires participants to exercise aerobically at high percentage of their maximal aerobic capacity for approximately two hours for most well-trained triathletes. Consequently, the risk of hypohydration during ODT is high. Hypohydration causes greater heat storage and reduces the athlete's ability to tolerate heat strain. Sawka (1992) suggests that heat storage is mediated by reduced evaporative heat loss through sweating and reduced skin flow. Furthermore, hypovolemia is also associated with reduced performance in endurance events in hot and humid conditions.

Previous laboratory research has shown that triathletes lose between 1.7 and 4.1% of body mass during an ODT in hot and humid conditions (Millard-Stafford et al. 1990; Broad et al. 1997). These findings indicate that fluid replacement is critical for triathlon performance as endurance performance has been shown to decrease with hypohydration levels greater than 1.8% BM (Walsh et al. 1994). Therefore, the aim of this paper is to report on fluid loss during ODT. Furthermore, the results of the study will be used to present a predictive model for fluid balance measures and ODT performance. This will be done by constructing a path analysis of the effects of fluid intake and sweat loss on ODT performance.

Methods

Subjects

Ten acclimatised triathletes (3 female and 7 male) voluntarily participated in the study. The participants mean age body mass, maximal oxygen uptake, sum of nine skinfold sites and best ODT time were 33.3 ± 6.7 (SD) yr, 70.9 ± 9.7 kg, 58.4 ± 7.7 $mL \cdot kg^{-1} \cdot min^{-1}$ 84.3 ± 31.7 mm and 2:11:30 ± 0:13:20 (hr:min:sec), respectively.

Participants were requested to maintain normal training volume and intensity during the testing period and to abstain from physical training in the 24 hours prior to each test. Similarly, participants were instructed to abstain from alcohol, coffee and products containing caffeine during the 24-hour period prior to testing. During the 24 hours prior to each test, participants were requested to drink two litres of a six-percent carbohydrate solution (Gatorade®) to ensure that they were adequately hydrated and had adequate glycogen levels.

Prior to participation, each volunteer completed a medical history questionnaire and a written informed consent document. The experimental protocol was approved by the Central Queensland University (CQU) Human Ethics Research Review Panel.

Procedures

Preliminary measurements

In the week prior to the exercise-testing period, each subject was familiarised with the exercise testing protocols that were employed in the study. To ensure that all subjects were familiar with the exercise environment, each subject was transported around the ODT course.

Anthropometric measures

Prior to the initial $\dot{V}O_{2max}$ test, body mass, height and the sum of nine skinfolds (tricep, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh, calf and mid-axilla) of each participant were measured by a Level 1 Anthropometrist certified by the International Society for the Advancement of Kinanthropometry (ISAK).

Maximal aerobic power testing

In the week prior to initial testing, maximal oxygen uptake ($\dot{V}O_{2max}$) was determined using an incremental treadmill test to exhaustion. The test was conducted on a motorised treadmill (Precor, USA). Maximal oxygen uptake was measured using a Medgraphics® Gas Analysis System (Medgraphics®, Parkway, USA).

The participants arrived at the Human Performance Laboratory at least two hours post-prandial. Following a ten-minute warm-up at 70% of age predicted maximal heart rate, the exercise protocol commenced at a workload of 10 $km \cdot hr^{-1}$. The workload was increased by one $km \cdot hr^{-1}$ every five minutes until volitional fatigue. Maximal oxygen uptake was considered the highest oxygen volume recorded during the last minute of exercise. Heart rate was recorded throughout the protocol via Polar® Vantage NV™(Polar OY, Finland).

Following $\dot{V}O_{2max}$ testing, each participant was provided with a training diary and dietary guidelines to complete over the three-day period before each ODT. These guidelines were to ensure that all participants had similar glycogen and hydration status at the time of testing.

Experimental design

Prior to the warm up, a measure of nude, towel dry, body mass was taken post-micturition. This was repeated at each transition and then after both ODT's using electronically calibrated scales (Mercury, Australia) accurate to 50g.

Participants were required to complete an ODT in an uncontrolled environment on two separate days, seven days apart. The 1.5-km swim was completed in a 25-metre swimming pool, the 40-km bicycle leg was completed on an accurately measured 10-km road loop, and a 2.5-km road loop was used for the 10-km run. Performance time was taken as the total ODT time minus experimental intervention time.

Environmental conditions

$WBGT_{out}$ was measured at 30-minute intervals during each trial using a heat stress monitor (QUESTEMP°10, Oconomowoc, WI, USA).

Fluid Intake and Sweat loss

During each test, participants were provided with half-strength Gatorade® for ad-libitum intake. Individual fluid intakes were calculated as the difference in the volume of fluid in each subject's water bottle at the beginning and end of each test. Urinary fluid loss was measured using a volumetric cylinder accurate to 10 ml. Sweat loss (SL) was assessed using the method of Noakes and co-workers (1988).

Statistical analysis

Means and standard deviations were calculated for each variable. A hierarchical multiple regression was used to determine if swim time, bicycle leg time and run leg time, and the sweat loss, sweat rate, relative body mass change and fluid intake were significantly related ODT time. A multiple regression was also performed to measure correlations between sweat loss, sweat rate, relative body mass change and fluid intake for each leg with performance time for each leg. Finally, a partial correlation was completed correlating total race fluid consumption to ODT time while controlling for sweat loss. An alpha level of 0.05 was accepted as showing statistical significance. All statistical analyses were completed using SPSS statistical software package (SPSS Inc., Chicago, Illinois).

Results

Table 1. Mean environmental conditions (°C), ODT performance time (hr:min:sec)

	Mean ± SD
$WBGT_{out}$ (°C)	28.0 ± 2.8
$WBGT_{in}$ (°C)	29.8 ± 2.6
Relative humidity (RH)	49.9 ± 7.2
Performance time (hr:min:sec)	2:20:47 ± 0:10:15

Table 2. Mean relative changes in body mass (%BM), gross sweat loss (mL), sweat rate $mL \cdot hr^{-1}$ and ad-libitum fluid intake (mL) during each ODT ($\bar{X}$ ± SD).

ODT Leg	Relative Body Mass Change (%BM)	Gross Sweat Loss (mL)	Sweat Rate ($mL \cdot hr^{-1}$)	Ad-libitum Fluid Intake (mL)
Swim	-1.07 ± 0.36	783 ± 321	1975 ± 789	0 ± 0
Bicycle	-1.99 ± 0.72	2351 ± 602	2052 ± 621	899 ± 413
Run	-0.80 ± 0.85	1236 ± 435	1587 ± 621	651 ± 297
ODT	3.86 ± 0.76	4370 ± 937	1886 ± 503	1551 ± 550

Table 1 shows the environmental conditions and performance times for the two testing days. Table 2 shows the changes in markers of fluid balance during ODT

The hierarchical multiple regression revealed that swim-leg time, bicycle-leg time and run-leg time all significantly correlated with ODT time. No other variables significantly correlated with ODT time. Multiple regression failed to show any fluid balance marker as a predictor of swim-leg performance time. However, increased bicycle sweat rate, increased bicycle sweat loss and decreased relative body mass change were shown to be significantly correlated to bicycle leg time**.** Furthermore, increased fluid intake and decreased relative body mass change on the run leg were also shown to be significantly correlated with run leg performance. A simple model was constructed to demonstrate the effects of changes in fluid balance and ODT performance. Figure 1 shows a path analysis for the prediction of ODT performance time from the fluid balance markers monitored in the present study.

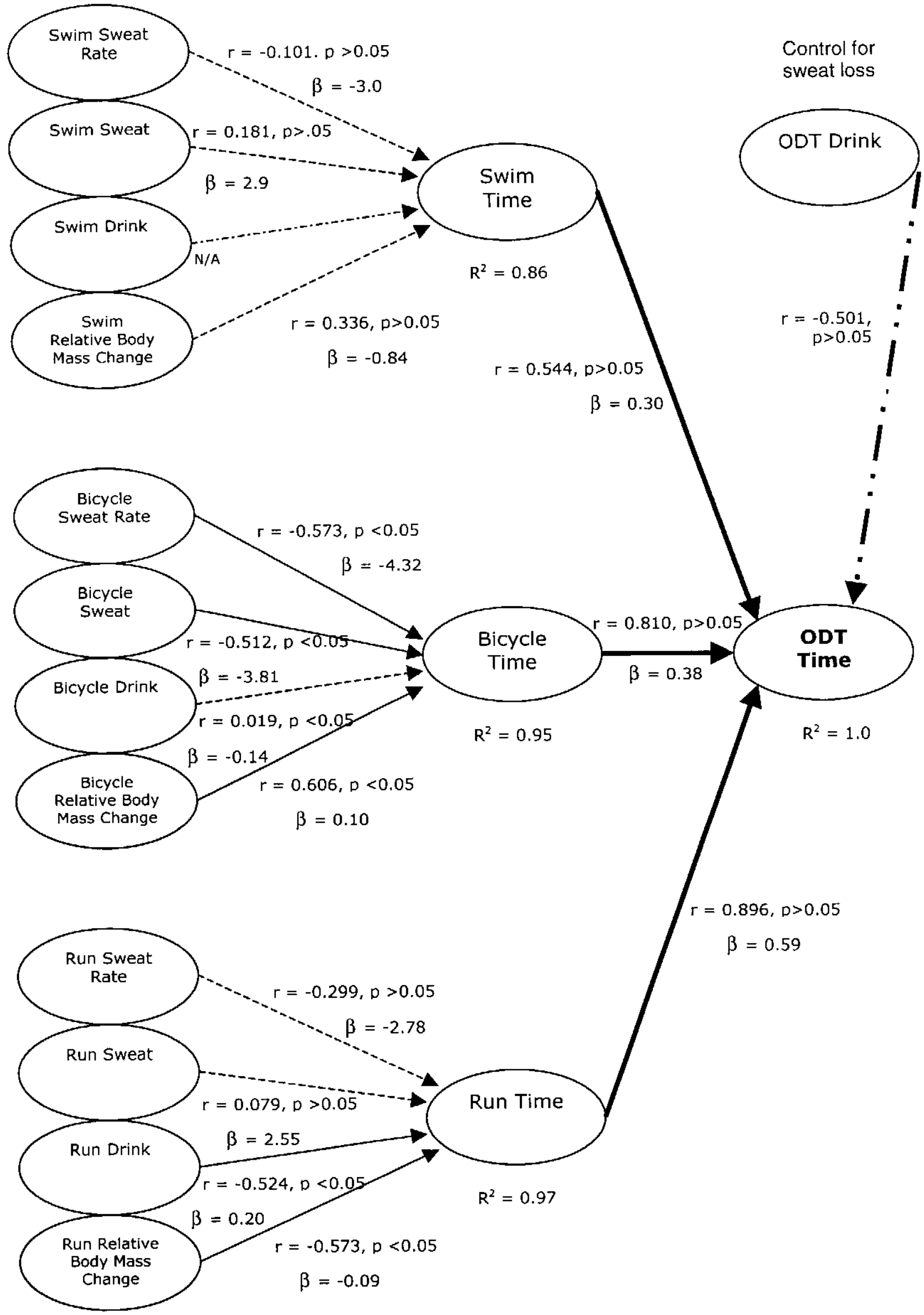

Figure 1: Path analysis of the significant correlations between measures of fluid balance and ODT performance.

Figure 1 shows that path analysis of the significant correlations between measures of fluid balance and each triathlon leg time and ODT performance. As expected swim times, cycle times and run times predict 100% of ODT time (Y = 0.3 (swim time) + 0.38 (bicycle time) + 0.59 (run time) + 4.787×10^{-13}). Change in run performance times was predicted from run leg sweat loss, run sweat rate and run drink intake. This model accounted for 97% of the variance (Y = 2.545 (run sweat loss) – 2.776 (run sweat rate) + 0.203 (run drink) + 2625.738). Similarly, bicycle leg performance time was predicted using bicycle leg sweat loss and sweat rate. This model predicted 96% of the variance (Y = 3.81 (bicycle sweat loss) – 4.315 (bicycle sweat rate) + 4145.948). Furthermore, a similar prediction equation was developed for swim performance time. This model accounted for 86% of the variance (Y = 2.988 (swim sweat loss) – 3.003 (swim sweat rate) + 1429.502)

Finally these prediction equations were combined to provide a predictive model for ODT performance using markers of fluid balance (Y = 0.3 (2.988 (swim sweat loss) – 3.003 (swim sweat rate) + 1429.502) + (0.38 (3.81 (bicycle sweat loss) – 4.315 (bicycle sweat rate) + 4145.948) + 0.59 (2.545 (run sweat loss) – 2.776 (run sweat rate) + 0.203 (run drink) + 2625.738) + 4.787×10^{-13}).

A partial correlations showed that ad libitum fluid intake during the ODT is significantly correlated with performance time when sweat loss was controlled for ($r = -0.501$, $p < 0.05$) (see figure 1).

Discussion

The purpose of the current study was to examine the relationships between fluid intake, sweat loss, body mass changes and sweat rates on ODT performance. Results show that changes in sweat loss, sweat rates, fluid intakes and relative body mass changes were effective predictors of performance in the bicycle leg and run legs of ODT. However, these measures of total body water deficit do not effectively predict 1500-m swim time in ODT.

The relative body mass changes in the present research are in agreement with previous findings (Millard-Stafford et al. 1990; Broad et al. 1997). In the present investigation a reduction in mean body mass from the start to the finish of the ODT of between 2.3 %BM and 5.2 %BM of pre-ODT body weight was observed. Other laboratory-based research investigating fluid losses during ODT in hot and humid conditions, noted a mean body mass change of approximately three kilograms (approximately 4.0 %BM) (Millard-Stafford et al. 1990).

Present results show that the greatest body mass changes in the ODT occurred during the 40-kilometre bicycle leg. In contrast, Broad and colleagues (1997) observed the greatest body mass losses during the run leg. The differences in these results may be attributed to a greater availability of fluids during the run leg in the current study. Broad and colleagues (1997) made one cup of fluid available very 2.5-kilometres during the run leg. The current study had drink stations positioned every 1.25-km on the run leg. Previous research has shown that fluid consumption is increased when athletes are presented with fluids more frequently (Burke and Hawley 1997).

The findings in the present study show that although the athletes lost approximately 1% of their body mass during the 1500-m swim leg that measures of fluid balance cannot reliably be used to predict swim performance time. Sweat loss, sweat rate, relative body mass change and fluid intake did not significantly correlate with performance time. The absence of a correlation with performance in the swim leg may be due to its brief nature. Although the swim leg lasted approximately 24 minutes, the thermoregulatory demand was quite high. Body mass changes of 1.07 ± 0.36 percent and sweat rates of approximately two litres per hour suggest that there was high thermoregulatory load. This finding is converse to the research of Broad and colleagues (1997) who reported that approximately 0.1% BM was lost during a 20-minute swim in hot and humid conditions. The abnormally large sweat losses calculated during the swim leg in this study may have been due to the subjects urinating in the pool during the swim, which would have compromised sweat loss calculations.

On average, the triathletes lost approximately 2% of body mass at the completion of the 40-km bicycle leg. These body mass losses have previously been shown to decrease endurance performance capacity in endurance athletes (Sawka 1992; Walsh et al. 1994). Furthermore, the present results demonstrate that bicycle leg performance time can be reliably predicted from measures of bicycle leg sweat loss, sweat rate and relative body mass change. In particular, triathletes who completed the bicycle leg with the least body mass change had fastest ODT time. This finding highlights the importance of drinking during the 40-km bicycle leg. Additionally, triathletes with the greatest sweat rate and sweat loss also significantly correlated with faster ODT time. This suggests that fluid balance is critical for performance on the cycle leg. Therefore, it seems reasonable to suggest that performance is increased in athletes who can best prevent the deleterious effects of hypohydration on endurance performance through maintaining the best possible fluid balance. This may be achieved through greater heat acclimatisation. Research has shown that heat acclimatisation is associated with increased blood volume, enhanced ability to sweat, earlier onset of sweating and an increase in sweat rate (Maughan and Sherriffs 1997). These physiological adaptations may reduce the thermal load during ODT in hot conditions.

The present results show that run leg performance time to be the strongest predictor of overall race time. This is particularly interesting as the race examined was non-drafting, which often allows athletes to enter the run leg in a group. Therefore, in drafting-legal races, the fastest finisher is often the best pre-fatigued 10 km runner. However, in non-drafting events such as the present study, the run leg performance is a significant predictor of ODT time because the faster athletes have entered the run leg with greater total body water which allows them to exercise at a higher intensity. This is supported by the relative body mass change results on the bicycle leg where the best performers maintain a body weight closer to their euhydrated state than the slower triathletes.

Therefore, importance must be placed on preventing negative fluid balance during ODT in order to maintain intensity. This is highlighted by the finding that bicycle sweat loss was also significantly correlated with run leg time. Fluid intake on the bicycle is difficult during the first 25 minutes of the race. The present findings suggest that if hypohydration is to be delayed in ODT then fluid consumption in the early stages of the bicycle leg are important.

Similar to the bicycle leg results, a strong correlation was observed between relative body mass changes and run leg time. Triathletes who had maintained their body mass during the run leg were faster, however, greater fluid consumption during the run leg also correlated significantly with run leg time. Relative body mass change is reflective of total hydration state and is the net product of fluid intake and loss. In the present study, triathletes entered the run leg hypohydrated by approximately two percent of their body mass. Sawka (1992) suggests that once body water deficit exceeds 2% BM, there becomes a disproportionate larger decrease in maximal aerobic power with an increased magnitude of body water deficit. Therefore, the athletes who enter the run leg with the least body water deficit are better equipped to complete the run leg in a faster time. This may explain that athletes who have a decreased body water deficit are better able to exercise at higher intensities and therefore complete the 10-km leg faster. Hence, the present results further support the need for protection of body water during ODT in hot conditions. Furthermore, ad-libitum fluid consumption during the run strongly correlated with faster ODT. This result also suggests that faster triathletes maintain total body water for longer than their slower counterparts during ODT. This is supported by the current results that indicate that when controlling for individual sweat fluid loss, that the triathletes who consumed the most fluid during the ODT was faster.

Taken together these results would suggest that the best triathletes competing in ODT have greater sweat capacity, however are also trained in fluid intake. Therefore, strategies for delaying hypohydration are critical for increasing ODT performance in hot and humid conditions. The predictive model presented can be used to highlight the importance of correct hydration methods during ODT.

Coaching Implications

The present study highlighted the deleterious effects of hypohydration on ODT performance. These results would suggest that athletes competing ODT in hot and humid conditions should take measures to prevent body water loss. Acclimatisation periods for longer than 14 days should be undertaken to best prepare the athlete for exercise in hot and humid conditions (see Maughan and Sherriffs (1997) for appropriate strategies).

Furthermore, triathletes should be trained to consume as much fluid as possible during the early stages of the bicycle leg to the completion of the ODT in order to prevent the deleterious effect of hypohydration. These strategies should be reinforced at training. Finally, pre-event hyperhydration with solutions such as glycerol should be considered to assist in the preservation of total body water during ODT (Coutts et al. 1999). These strategies will aid the athlete in increasing ODT performance when competing in hot and humid conditions.

References

Broad, E., D. Smith, G. Van Ewyk, S. Beasley and A. Roberts (1997). Sweat losses during an Olympic distance triathlon. Sports Medicine Australia (SMA), Canberra, Sports Medicine Australia (SMA).

Burke, L. M. and J. A. Hawley (1997). “Fluid balance in team sports: Guidelines for optimal practices.” Sports Medicine 24(1): 38-54.

Coutts, A. J., P. R. J. Reaburn , W. K. Mummery and M. Holmes (1999). “The effect of glycerol hyperhydration on Olympic distance triathlon in hot and humid conditions.” Journal of Science and Medicine in Sport In Review.

Maughan, R. J. and S. M. Sherriffs (1997). “Preparing athletes for competition in the heat: developing an effective acclimitization strategy.” Sports Science Exchange 10(2).

Millard-Stafford, M., P. B. Sparling, L. B. Rosskopf, B. T. Hinson and L. J. DiCarlo (1990). “Carbohydrate-electrolyte replacement during a simulated triathlon in the heat.” Medicine and Science in Sports and Exercise 22(5): 621-628.

Sawka, M. N. (1992). “Physiological consequences of hypohydration: Exercise performance and thermoregulation.” Medicine and Science in Sports and Exercise 24(6): 657-670.

Walsh, R. M., T. D. Noakes, J. A. Hawley and S. C. Dennis (1994). “Impaired high-intensity cycling performance time at low levels of dehydration.” International Journal of Sports Medicine 15: 393-398.

Carbohydrate versus fat ingestion during exercise

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Although it is known that carbohydrate (CHO) feedings during exercise improve endurance performance, relatively little is known about the underlying mechanisms. One of the proposed mechanisms is based on the observation that CHO ingestion during exercise maintains blood glucose levels and high rates of CHO oxidation. Studies using (stable) isotope methodology have shown that not all CHO are oxidized at similar rates and hence they may not be equally effective. Glucose, sucrose, maltose, maltodextrins and amylopectin are oxidized at high rates. Fructose, galactose and amylose have been shown to be oxidized at 25-50% lower rates. Combinations of multiple transportable CHO may increase the total CHO absorption and total exogenous carbohydrate oxidation. Increasing the CHO intake will increase the oxidation up to about 1.0-1.1 g/min. A further increase in CHO intake, however, will not further increase the oxidation rates (Jeukendrup et al 1999a). There is convincing evidence that this limitation is not at the muscular level but most likely located in the intestine or the liver (Jeukendrup et al 1999ab). Intestinal perfusion studies seem to suggest that the capacity to absorb glucose is slightly in excess of the observed entrance of glucose into the blood and is thus a factor contributing to the limitation. The liver, however, seems to play an additional important role, in that it provides glucose to the bloodstream at a rate of only ~1 g/min by balancing the glucose delivery from the gut and from endogenous glycogenolysis/gluconeogenesis into the systemic circulation (Jeukendrup et al 1999ab).

In the last few years several studies have attempted to increase fat oxidation during exercise by dietary means in order to “spare” CHO. This could theoretically enhance physical performance. Ingestion of long-chain triglycerides (LCT) pre-exercise may result in small alterations in fat substrate availability, but no effects on substrate oxidation or performance were observed. Medium chain triglyceride (MCT) ingestion during exercise has been suggested as an alternative way to increase plasma fatty acid levels. However, the contribution of MCT to energy expenditure is only small because generally the gastrointestinal tract can tolerate only small amounts (Jeukendrup et al 1995). Although one study showed decreased glycogen utilization and improved performance with CHO+MCT feedings (Van Zeijl et al 1996) when larger amounts of MCT were ingested, this could not be confirmed by follow-up studies (Jeukendrup et al 1998, Goedecke et al 1999).

References

1 Goedecke, J. H., R. Elmer-English, S. C. Dennis, I. Schloss, T. D. Noakes, and E. V. Lambert. Effects of medium chain triacylglycerol ingested with carbohydrate on metabolism and exercise performance. Int J Sports Nutr , 1999; 9: 35-47

2 Jeukendrup, A. E., W. H. M. Saris, P. Schrauwen, F. Brouns, and A. J. M. Wagenmakers. Metabolic availability of medium chain triglycerides co-ingested with carbohydrates during prolonged exercise. J Appl Physiol , 1995; 79: 756-762

3 Jeukendrup, A. E., J. J. H. C. Thielen, A. J. M. Wagenmakers, F. Brouns, and W. H. M. Saris. Effect of MCT and carbohydrate ingestion on substrate utilization and cycling performance. Am J Clin Nutr, 1998; 67: 397-404

4 Jeukendrup, A. E., J. H. J. C. Stegen, A. Gijsen, F. Brouns, W. H. M. Saris, and A. J. M. Wagenmakers. Carbohydrate ingestion can completely suppress endogenous glucose production during exercise. Am J Physiol , 1999a; 276: E672-E683

5 Jeukendrup, A. E., A. Raben, A. Gijsen, J. C. H. C. Stegen, F. Brouns, W. H. M. Saris, and A. J. M. Wagenmakers. Glucose kinetics during prolonged exercise in highly trained subjects. Effect of glucose ingestion. J Physiol , 1999b; 515.2: 579-589

6 Van Zeyl, C. G., E. V. Lambert, J. A. Hawley, T. D. Noakes, and S. C. Dennis. Effects of medium-chain triglyceride ingestion on carbohydrate metabolism and cycling performance. J Appl Physiol , 1996; 80: 2217-2225

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