Current Physiology Research

Topic 1: Muscles

1.1 - The brain's role in muscle fatigue

The chain of events that leads to muscle fatigue is complex, but can be split into impairment of normal functioning of muscles and nerves involved in muscle contraction, and changes in the brain signals that control the muscles, known as "peripheral" and "central" fatigue. A growing body of research suggests a significant part of the reason athletes slow down and/or stop is that the brain signals it is time to do so. Dr Emma Ross, of the Chelsea School, University of Brighton, has, for example, used electrical stimulation of leg muscles and magnetic stimulation (TMS) of parts of the brain on subjects before and after they ran marathons to demonstrate the important role played by the brain in reduced muscle performance during endurance running.

Reference: Ross EZ et al, Corticomotor excitability contributes to neuromuscular, fatigue following marathon running in man, *Exp Physiol.*, 92.2 pp 417–426 (http://ep.physoc.org/content/92/2/417.full.pdf)

1.2 - How free radicals tire you out

In the debate among researchers over what causes physical, "peripheral" muscle fatigue, a culprit that has been gaining ground is the accumulation of unstable free radicals and other reactive oxygen species (ROS) - the highly reactive by-products of metabolism. Exercise increases production of reactive oxygen species, and muscle cells contain antioxidants as defences against the oxidising injury these can cause. Some researchers suggest antioxidant deficiencies play an important role in undermining exercise performance and increasing susceptibility to exercise-induced injury. Shortage of vitamin E has been found to lead to muscle skeletal muscle degeneration in rats, while vitamin C deficiency in guinea pigs can reduce time to exhaustion on treadmills. Michael McKenna of Victory University, Melbourne, and colleagues, found giving cyclists an antioxidant solution allowed them to pedal for longer in tests. McKenna's team found the antioxidant in their tests improved the functioning of the sodium-potassium pump which allows nutrients to enter cells and maintains their membrane potential.

References: Scott K Powers, Dietary antioxidants and exercise, *Journal of Sports Sciences*, 2004, 22, 81–94 (http://www.sportsoracle.com/uploads/2600.pdf).
Carsten Juel, Muscle fatigue and reactive oxygen species, *J Physiol*. 2006 October 1; 576(Pt 1): 1 (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1995652/)
McKenna MJ et al, N-acetylcysteine attenuates the decline in muscle Na+,K+-pump activity and delays fatigue during prolonged exercise in humans, *J Physiol*, 2006 Oct 1;576(Pt 1):279-88

1.3 - Muscle memory

Pumping up one's muscles is easier for those who have done so previously. Muscle cells have more than one nucleus in order to provide the large amounts of protein that gives muscles their strength. Exercise triggers muscle cells to grow by merging with stem cells that sit between muscle fibre cells. In mouse studies, Kristian Gundersen, of the University of Oslo, generated extra nuclei in muscle cells through exercise, then severed a nerve leading to the muscles, and found that which the cells shrunk, the number of nuclei in the cells did not. Because the nuclei of muscle fibres are key to the generation of new muscle protein, this suggests that the potential to grow new muscle associated with training early in life stays even after an extended period of inactivity and muscle wastage.

Reference: K Gundersen et al, Myonuclei acquired by overload exercise precede hypertrophy and are not lost on detraining, PNAS, doi: 10.1073/pnas.0913935107

1.4 - How best to beef up

Scientists are re-thinking their advice to bodybuilders. The conventional view that the best results are achieved by using weights close to the maximum an individual to lift during training has been questioned by Stuart Phillips and his team at McMaster University in Hamilton, Ontario, Canada. Phillips analysed biopsies of leg muscles of men who lifted various proportions of the maximum they could lift. He found that new muscle protein generation was greatest when his subjects lifted around 30 per cent of their maximum until they tired out.

Reference: Burd NA, West DWD, Staples AW, Atherton PJ, Baker JM, et al. (2010) Low-Load High Volume Resistance Exercise Stimulates Muscle Protein Synthesis More Than High-Load Low Volume Resistance Exercise in Young Men. PLoS ONE 5(8): e12033. doi:10.1371/journal.pone.0012033 (http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012033)

1.5 - How fast can we go?

Usain Bolt's extraordinary shattering of his own previous 100m sprint world record in 9.58 seconds in 2009 was within 0.1 seconds of the absolute limit of human ability, according to Mark Denny and colleagues at Stanford University, California. They came to this conclusion after examining the historical record for top human speeds at various distances, as well as for horses and dogs. Denny believes the limit is set by power-to-weight ratio. Beyond a certain point, the benefits of longer legs and stronger muscles will be offset by the increased energy needed to move a greater load, he says.

Reference: Limits to running speed in dogs, horses and humans, Journal of Experimental Biology 211, 3836-3849

Topic 2: Respiration and Energy

2.1 - How energy drinks work

Endurance athletes are often advised to eat carbohydrate-rich foods such as pasta, especially before, during and after exercise. Many studies have demonstrated the beneficial effects on performance, which scientists say are primarily the result of maintaining levels of blood sugar and carbohydrate oxidation. Carbohydrate drinks have been popular, especially in endurance sports, since the 1980s. Research has also shown that consuming carbohydrates during high intensity exercise lasting less than an hour can also be beneficial. This suggests an alternative mechanism since the contribution of muscle glycogen to energy expenditure far exceeds that of blood glucose during high intensity physical activity, and muscle glycogen is not fully depleted in such sessions, and the amount of carbohydrate that can be absorbed in short periods is low. Prof Asker Jeukendrup and colleagues at the University of Birmingham asked cyclists to use a mouth rinse that either contained a carbohydrate solution or a placebo. They found the carbohydrate solution improved performance even though the subjects were asked to spit it out, suggesting carbohydrates trigger central nervous system messages that may stimulate reward and pleasure centres in the brain, and ultimately boost performance.

References: Asker Jeukendrup, Carbohydrate intake during exercise and performance, *Nutrition*, vol 20, issues 7-8, 2004, 669-677.
Carter J, Jeukendrup AE, Mann CH, Jones DA, The effect of glucose infusion on glucose kinetics during a 1h time trial, *Med Sci Sports Exerc*, 2004;36
[note: while the work quoted here is from 2004, I have checked that the above summary is still up-to-date, in terms of the likelihood of the brain's role in the mechanism of carbohydrate and performance in high intensity exercise]

2.2 - Lactate loses its bad guy reputation

For a long time, the role of lactate was seen as purely negative to athletic performance. Work by George Brooks, of University of California, Berkeley, showed that once the body has used up the available carbohydrates for fuel, it can then burn the lactic acid generated in the process, also for fuel. Brooks first showed lactate moves from muscles into the blood and travels to various organs to be burned with oxygen to generate fuel that muscle cells can also use lactate and that training triggers the growth of mitochondria, often called the powerhouse of the cell, and also the location where lactate is burned for energy. Interval training generates big lactate loads and the body adapts by building up mitochondria to clear these loads quickly. Dr Brooks describes his proposed cellular mechanism that allows muscles to use lactate as fuel as the "lactate shuttle" and that lactate is the link between oxidative metabolism and anaerobic metabolism.

Reference: Hashimoto T, Hussein R, Brook GA, Colocalization of MCT1, CD147, and LDH in mitochondrial inner membrane of L6 muscle cells: evidence of a

mitochondrial lactate oxidation complex, Am J Physiol Endocrinol Metab., 2006 Jun;290(6):E1237-44.

2.3 - Microbe metabolism

Trillions of microbes live in the human gut. They help break down otherwise indigestible food. Scientists found that obese and lean mice have different abundances of two types of bacteria in their guts, and that a mouse's ability to release calories from food during digestion can be changed by altering their gut microbiota. Ruth Ley of Cornell University and colleagues found obese people have a smaller proportion of beneficial bacteria called Bacteroidetes compared to lean people, and that when they were put on restricted fat and restricted carbohydrate low calorie diets, this proportion increased. The findings demonstrate the role of the microbial environment in the efficiency of metabolism, and indicate that manipulating it might be a way to treat obesity.

Reference: Ruth E Ley et al, Microbial ecology: Human gut microbes associated with obesity, *Nature,* 444, 1022-1023, 21 December 2006. (http://www.nature.com/nature/journal/v444/n7122/full/4441022a.html)

2.4 - Hunger hormones

Those seeking to lose weight can choose to focus on diet, exercise or a combination of the two. Some have suggested diet should be the main focus on the grounds that exercise might in fact stimulate hunger. David Stensel of Liverpool John Moores University carried out lab tests of hormone levels of individuals who on three separate days were given normal calorie breakfasts and lunches, or energy deficient meals caused by either low calorie content or normal calorie content but following a 90-minute run. Levels of ghrelin, the so-called "hunger hormone", stayed high in the low calorie meal state but were lower in the exercise state. Levels of peptide YY, a known hunger suppressor, stayed higher when the individuals did exercise but lower in the restricted calorie state. Participants were given an all-you-can-eat buffet at the end of each of their three days in the lab. They ate more when they had previously eaten low calorie breakfasts and lunches, than in the control and exercise states. Stensel concludes that, at least in the short-term, the notion that exercise stimulates hunger and is therefore somehow counter-productive or less useful for those seeking to lose weight is incorrect. He also says the research supports the idea that there may be merit in performing exercise soon after meals as a way to enhance the satiating effects of eating.

Reference: Stensel D, Exercise, Appetite and Appetite-Regulating Hormones: Implications for Food Intake and Weight Control, *Annals of Nutrition and Metabolism*, 2010;57(suppl 2):36–42

2.5 – Good Brown Fat

The white fat in our bodies mainly just stores energy. Brown fat, which actively burns calories for heat, was long thought of as only present in babies and children. However a study published two years ago showed it also exists in adults. Using PET and CT scan data, researchers at the Joslin Diabetes Centre in Boston also demonstrated differences in amounts of brown fat according to age, blood sugar levels and obesity levels. Brown fat is more active during cold weather due to its heat generating role. The scientists believe it plays an important role in glucose metabolism and potentially in determining body weight. They hope further work could lead to new ways to treat obesity and other metabolic disorders.

Reference: Cypess, Aaron M et al, Identification and Importance of Brown Adipose Tissue in Adult Humans, *N Engl J Med,* 2009 360: 1509-1517, Published online 9 April 2009.

Topic 3: Heart and Circulation

3.1 - Endothelium takes centre stage

The effect of exercise on the traditional risk factors for heart disease - raised cholesterol, blood pressure and blood sugar levels - have been shown in studies to account for only around half of the associated risk reduction. It was long thought the role of the endothelium, the thin layer of cells that lines the inside of blood vessels, was to stop blood from leaking out. It is now known, however, that healthy functioning of this lining allows it to produce hormones including nitric oxide, which relax muscles, allowing blood vessels to dilate and increasing the flow of blood, along with oxygen and nutrients. Exercise strengthens the endothelium, reducing heart disease risk and allowing for improved athletic performance. Researchers at the Research Institute for Sport and Exercise Science at Liverpool John Moores University are teasing out the detail of this phenomenon in greater detail. They have shown how exercise strengthens endothelial function in healthy humans through the repetitive shear stresses caused by increased blood flow. The group has also used ultrasound measurements of athletes and healthy controls to show how intensive training of one set of muscles, by squash players for example, has localized effects on the arterial size, but that arterial wall thickness, which is consistently lower in athletes, is affected by systemic, whole body factors.

References: Daniel J Green et al, Exercise and cardiovascular risk reduction: Time to update the rational for exercise?, Journal of Applied Physiology 105: 766-768, 2008.
Toni Tinken et al, Shear Stress Mediates Endothelial Adaptions to Exercise Training in Humans, Hypertension, 2010 Feb;55(2):312-8.
Exercise and arterial adaption in humans: uncoupling localized and systemic effects, Nicola J. Rowley et al, *Journal of Applied Physiology* 110: 1190-1195, 2011.

3.2 - Sudden cardiac deaths in athletes

Different forms of exercise can change the shape and size of the heart in different ways. Endurance training has been shown to thicken the walls of the left ventricle to allow it to pump and more blood. This is also a symptom used to diagnose hypertrophic cardiomyopathy (HCM), a genetic condition in which parts of the heart muscle can be thickened, and which is responsible for over a third of sudden cardiac deaths in athletes in the US. Footballer Marc-Vivien Foé collapsed and died during an international football match in 2003 as a result of having the condition. Researchers have been developing methods to distinguish between changes that result from exercise and those caused by HCM. Prof Greg Whyte, of Liverpool John Moores University, and colleagues have developed a system of diagnostic tools, including use of electrocardiograms, echo cardiography and heart-specific magnetic resonance imaging (MRI). He and a colleague have established a HCM screening programme for elite athletes in the UK

Reference: Papadakis, Whyte & Sharma, *British Medical Journal*, Preparticipation screening for cardiovascular abnormalities in young competitive athletes, BMJ 2008;337:a1596

3.3 - Cooling device boosts performance

All mammals including humans have regions of the body surface that dissipate excess heat from the body core. In humans these are the palms of the hands and soles of the feet. When we get hot during exercise, blood flow increases through these regions to get rid of heat through specialised blood vessels called arteriovenous anastomoses. This stops us becoming dangerously overheated. As a consequence however there is less blood available to carry oxygen to our muscles, and our ability to work as hard is reduced. Researchers have developed a device called the Rapid Thermal Exchange to cool the body's organs and improve endurance performance. It consists of a chamber containing a water-cooled steel plate. When an athlete puts their hand into the chamber, it is sealed and a pump creates a vacuum which increases blood flow to the hand while the steel plate draws heat from blood circulating through the hand. This flows back to the heart and is recirculated, cooling other organs by as much a 3°C. In tests, cyclists using the device could go faster during time trials and weight lifters could do more bench press repetitions. It has reportedly been used by a wide range of sports stars including San Francisco 49ers, Manchester United and Chelsea players.

Reference: Elliott JM et al, Medicine & Science in Sport & Exercise, Effects of the rapid thermal exchange (rtx) device on exercise in a heated environment, May 2003, Vol 35, issue 5, ps30 (http://www.avacore.com/works.html)

3.4 - The great altitude training mechanism debate

Endurance athletes have been using altitude training for around half a century. A key study carried out almost 20 years ago showed that living at an altitude of 2,500m for 20+ hours per day and raining at lower altitude of around 1,250m led to an increase in red blood cell production, in capacity to transport and use oxygen (VO2 max) and improved 5,000m performances in trained athletes compared to other athletes both training and living at either high or low altitude. At high altitude air is less dense, meaning we inhale less oxygen and nitrogen than at sea level. This triggers various physiological changes. The heart rate and respiratory rate increase in order to boost the amount of oxygen circulated around the body. There is greater red blood cell production in bone marrow. This means the blood contains more haemoglobin, the protein that binds oxygen to red blood cells. Breathing faster reduces carbon monoxide in the blood, making it less acidic. The kidneys release blood carbonate to try to balance the PH level. This helps athletes because bicarbonate protects muscles from the lactic acid which builds up in them during exercise, making them feel sore. Different scientists emphasize different elements of these changes to explain the performance improvements achievable through altitude training.

References: Levine BD, Stray-Gundersen J, Living high-training low": effect of moderate-altitude acclimatization with low-altitude training on performance, Journal of Applied Physiology July 1997 vol. 83 no. 1 102-112
Levine BD, Stray-Gundersen J (November 2005). Point: positive effects of intermittent hypoxia (live high: train low) on exercise performance are mediated primarily by augmented red cell volume, *Journal of Applied Physiology* 99 (5): 2053-5
Gore CJ, Hopkins WG (November 2005), Counterpoint: positive effects of intermittent hypoxia (live high: train low) on exercise performance are not mediated primarily by augmented red cell volume, *Journal of Applied Physiology* 99 (5): 2055-7
(http://www.chiefscientist.gov.au/2011/05/running-on-thin-air/)

3.5 - How free radicals can protect the heart

Free radicals, the chemically unstable molecules created as a result of metabolism, are generally thought of as harmful to the body. Health supplement companies advertise antioxidant supplements like vitamin C as being able to mop up free radicals and prevent a number of diseases as a result. However, while the apparent benefits of antioxidants have been easier to demonstrate in laboratory test tubes than in real human trials, and many tests of antioxidant therapies to protect against heart disease have failed to show beneficial results. A team led by Ajay Shah, at King's College London, last year made the surprise discovery that Nox4, an enzyme that produces free radicals and other reactive molecules in the heart, promotes the heart's natural defences. Mice engineered to over-produce the enzyme adapted better to stress, protecting the heart from becoming enlarged and allowing it to grow more blood vessels to improve blood supply than mice without Nox4. The research suggests some free radicals may have damaging effects while others may have a protective role.

Reference: Shah A et al, NADPH oxidase-4 mediates protection against chronic load-induced stress in mouse hearts by enhancing angiogenesis, *PNAS*, doi: 10.1073/pnas.1009700107

Topic 4: Brain

4.1 -Core body temperature rise undermines brain functioning

Exercising in heat is known to affect brain functioning. This has commonly been attributed to the effects of dehydration. Stephan Bandelow of Loughborough University and colleagues measured the cognitive functions of football players matches during July in Turkey in temperatures around 34°C.
Tests carried out on the players before, during and after found the effects of dehydration were inconsistent. However the elevation of core body temperature from normal levels to around 37°C to 39.5-40°C was associated with reduced performance in accurate movement, information and visual processing, memory scanning and visuo-spatial working memory tests. Changes in levels of the dopamine and serotonin neurotransmitters, blood-brain barrier permeability and brain blood flow were believed to be possible mechanisms.

Reference: S Bandelow et al, The effects of exercise, hear, cooling and rehydration strategies on cognitive function in football players, Scandinavian Journal of Medicine & Science in Sports, vol. 20, issue supplement s3, 148-160, October 2010.
Paper link: http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0838.2010.01220.x/full

4.2 - How exercise staves holds off brain ageing

Physical activity is considered important in staving off cognitive decline in old age, including dementia. This is partly an indirect effect resulting from the vascular benefits of reducing body fat mass and blood pressure. Exercise has direct protective effects on the brain through increasing blood flow, thereby boosting delivery of oxygen and glucose to the brain. Research also suggests exercise prolongs neurogenesis, particularly in the hippocampus, an area affected in Alzheimer's Disease, and helps in the production of neurotransmitters such as dopamine, serotonin and norepinephrine. Scientists say the protective benefits to the brain of regular exercise are particularly important in middle age, with two studies it cut the risk of Alzheimer's by 62% and 66%. Some research suggests the effects of these protective benefits are much stronger in women, however this may be because the types of exercise carried out by women is often more social in nature, and social activity has also been shown to protect against dementia.

Reference: Angela Clifford et al, Maintaining cognitive health in elderly women, *Aging Health* (2009) 5(5), 655-670.

4.3 - Why we choke under pressure

"The choke" occurs when individuals fail to perform to their normal level because of high levels of stress or pressure. There are many famous sporting examples, but the phenomenon occurs in many other areas. Sian Beilock, a psychologist at the University of Chicago, detailed the latest research on the physiology of "paralysis by analysis" in a book published last year. Tests in Beilock's lab have shown how golfers performed worse when asked to think about aspects of their putting, and how normal brain activity is disrupted in stressful situations. She says the brain contains a working memory system in the pre-frontal cortex that allows us to work with the information we have in our consciousness, and that this system can malfunction under stress. Brain scan studies have shown the prefrontal cortex to be the part of the brain most vulnerable to stress. Mild stress has been shown to cause rapid and dramatic loss of prefrontal cognitive abilities, while prolonged stress causes structural changes in prefrontal dendrites, the treelike extensions of brain cells which form connections with other nerve cells to allow nerve impulses to be transmitted.

Reference: Sian Beilock: *The Choke: What the secrets of the brain reveal about getting it right when you have to*; 2010; Free Press

4.4 - How 10,000 hours of practice alters the brain

The human body is remarkably adaptable. Increased loads and strains placed upon it trigger numerous physiological changes, including to the structure and functioning of the brain. Researchers have shown that, compared to novices, skilled athletes are quicker to pick up visual information prior to key events such as foot-to-ball or racket-to-ball contact, better at recognising and understanding patterns of play early in their development, display superior visual search tactics, make more accurate predictions of opponents' likely actions and make better appropriate strategic decisions based on memory structures called 'action plan profiles' and 'current event profiles'.
While there are various factors that influence level of achievement, there is little doubt that amount of time spent practicing is key. One study found that the very best violinists had accumulated 7,410 hours of practice over 10 years of playing, compared to 5,301 and 3,420 for good players and violin teachers respectively. International level wrestlers were found to train for 38.7 hours per week compared to 20.9 hours for club-level wrestlers. International footballers were found to have accumulated 9,332 hours of practice 18 years into their careers, compared to 7,449 and 5079 hours for national and provincial level footballers at the same points in their careers. The notion that expertise requires approximately 10 years or 10,000 hours of deliberate practice was summarised by Malcolm Gladwell in his 2008 book Outliers.

Reference: Williams A Mark and Ford Paul R (2008), Expertise and expert performance in sport, *International Review of Sport and Exercise Psychology*, 1: 1, 4-18
(http://uregina.academia.edu/RaquelPederciniMarinho/Papers/506570/Expertise_and_expert_performance_in_sport)

4.5 - Keeping a diary can speed recovery from injury

Various researchers have identified positive psychological and related health effects of "writing therapies". Elaine Duncan, of Glasgow Caledonian University, asked a group of students who competed in athletics, swimming, basketball and football, and who had injuries that prevented the training, to do three 20-minute weekly writing sessions, with half focusing on their injury, its emotional impact and lessons they had learnt, and the other half writing about their social lives. Those that wrote about their injuries saw greater improvements in peak muscle strength over the 5 weeks of the study. Another group found that elite athletes asked to write about their thoughts and feelings associated with long-term injuries felt less devastated, dispirited, cheated and restless. Neither of these studies looked at what might link writing with psychological changes and recovery, however Duncan speculates writing can provide relief from stress, thereby reducing inflammation and boosting immune responses. Links between levels of stress hormone cortisol and inflammatory responses have been shown by others.

References:
http://abstracts.bps.org.uk/abstracts/abstracts_home.cfm?&ResultsType=Abstracts&ResultSet_ID=3817&FormDisplayMode=view&frmShowSelected=true&localAction=details [publication pending]
Mankad A, Gordon S, Psycholinguistic changes in athletes' grief response to injury after written emotional disclosure, *J Sport Rehabil,* 2010 Aug;19(3):328-42.
Ronald Glaser & Janice K Kiecolt-Glaser, Stress-induced immune dysfunction: implications for health, *Nature Reviews Immunology* 5, 243-251 (March 2005) | doi:10.1038/nri1571

Topic 5: Breathing

5.1 - Role of lung in limiting athletic performance

Lung function has not traditionally been regarded as importance as a limiting factor to athletic performance because the respiratory system should be easily capable of transporting enough oxygen and CO2 around the body in healthy humans exercising at normal altitudes. However recent research has shown how the rapid blood flow that occurs during intensive exercise by elite endurance athletes can mean the blood that reaches muscles does not contain enough oxygen, leading to a lowering of energy production, and undermining performance. Fatigue in the diaphragm is caused by both the amount of work it is doing, and reduced blood and oxygen supply. The findings suggest patients with lung disease can be helped to increase exercise tolerance by breathing the low-density gas mixture Heliox, and that the training of respiratory muscles can be beneficial for athletes.

Reference: Exercise-induced respiratory muscle fatigue: implications for performance, Lee M Romer and Michael I Polkey, *Journal of Applied Physiology* 104: 879-888, 2008

5.2 - Breathing training

A growing body of evidence suggests that the performance of sports men and women including rowers, runners, cyclists and swimmers can be improved by increasing the strength, power and endurance of the inspiratory muscles through special training. One trial showed cyclists were able to improve their times over 40kms by 4.6%, or more than 2 minutes following 6 weeks of inspiratory muscle training. In another, oarswomen increased the distance they could cover by 1.9% in six minutes and reduced the time taken to cover 5,000m by 2.2%, both versus placebo, following 11 weeks of breathing training. Prof Alison McConnell of Brunel University has devised a device for breathing training which uses principles of resistance training. Work conducted in the 1990s by a group led by Jerry Dempsey at the University of Wisconsin revealed the existence of an inspiratory muscle metaboreflex which "steals" blood flow from locomotor muscles during exercise, thereby triggering fatigue and undermining performance. McConnell used an isolated human leg model to show that breathing training boosts performance by increasing the threshold at which this reflex kicks in, thereby extending the length of time individuals can work hard before blood flow is diverted from key muscles.

references: Lee Romer, Effects of inspiratory muscle training on time-trial performance in trained cyclists, Journal of Sports Sciences, 2002, 20, 547-562 (http://www.salveo.co.uk/fitness/youbreathe/pdf/inspiratory_muscle_training_in_cyclists.pdf) Kilding AE et al, Inspiratory muscle training improves 100 and 200 m swimming performance, *Eur J Appl Physiol*., 2010 Feb;108(3):505-11. Griffiths LA, The influence of inspiratory and expiratory muscle training upon rowing performance, *Eur J Appl Physiol*., 2007 Mar;99(5):457-66.

Alison K. McConnell and Michelle Lomax, The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue, *J. Physiol.,* 2006; 577;445-457 (http://www.fletchersportscience.co.uk/uploads/img45bb013a786fa1.pdf)

5.3 - Exercise-induced asthma

Asthma and related symptoms such as wheezing, chest tightness, abnormal breathlessness, coughing and sputum production are more common among elite athletes than the general population. One study found that 20 per cent of the athletes in Great Britain's Olympic team had asthma. Exercise can trigger what is known as exercise-induced asthma because cool, dry air that is breathed must be made warmer and more humid by the airways, creating greater stress and inducing inflammation. Research by John Dickinson of the English Institute of Sport found asthma to be almost three times more prevalent among elite athletes than in the general population. Dickinson found more than 40 per cent of swimmers have asthma. Chlorine has been suggested as being a potent trigger for EIA. Previous studies have shown winter sports participants are also at greater risk.

Reference: JW Dickinson et al, Impact of changes in the IOC-MC asthma criteria: a British perspective, Thorax, 2005;60:629-632. (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1747493/pdf/v060p00629.pdf)

5.4 - How coffee and fish helps combat exercise-induced asthma

Research over recent years has shown how various dietary changes can help treat exercise-induced asthma. A US-UK team found that drinking a high dose of caffeine taken one hour before an exercise session was as effective as using an albuterol inhaler, which is commonly used to treat exercise-induced asthma. Lower doses were also effective in reducing symptoms. The researchers say caffeine helps to dilate the airways. The same team has also found symptoms of exercise-induced asthma can be relieved with Omega 3 fish oil capsules (thanks to their anti-inflammatory effects), vitamin C and by cutting dietary salt.

References: VanHaitsma TA et al, Comparative effects of caffeine and albuterol on the bronchoconstrictor response to exercise in asthmatic athletes, *Int J Sports Med*, 2010 Apr;31(4):231-6 (http://www.ncbi.nlm.nih.gov/pubmed/20148372)
Timothy D Mickleborough at al, Fish oil supplementation reduces severity of exercise-induced bronchoconstriction in elite athletes, Am J of Respiratory and Critical Care Med Vol168, 11-81-1189 (2003)

5.5 - Competitive breath-holding could damage your health

French free diver Stephane Mifsud set a new word record for static breath-holding of 11 minutes and 35 seconds in June 2009. However researchers believe he and his rivals could be harming themselves. Johan Andersson of Lund University, Sweden, found that concentrations of S100B, a protein used as a marker of brain damage, increased by 37 per cent in trained breath-holders practising their discipline. He warns those who compete in breath-holding events could be accumulating long-term damage.

Reference: Journal of Applied Physiology September 2009 vol. 107 no.3 809-815. (http://jap.physiology.org/content/107/3/809.abstract)