submissions

From: Ken Harvey [redacted]
Sent: Tuesday, 30 September 2014 1:37 PM
To: submissions
Subject: Re: FSANZ Proposal P1030 - Health Claims - Formulated Supplementary Sports Foods & Electrolyte Drinks
Attachments: Mythbusting sports and exercise products.pdf; The truth about sports drinks.pdf; Forty years of sports performance research and little insight gained.pdf

Dear Madam / Sir,

Submission on FSANZ Proposal P1030 - Health Claims - Formulated Supplementary Sports Foods & Electrolyte Drinks

I oppose this proposal which appears to be more about increasing the sales of largely unnecessary products rather than improving the public health.

I have attached three relevant references:

1. “Mythbusting sports and exercise products” BMJ 2012;345:e4848 doi: 10.1136/bmj.e4848 (Published 18 July 2012).

2. “The truth about sports drinks” BMJ 2012;345:e4737 doi: 10.1136/bmj.e4737 (Published 18 July 2012).

3. "Forty years of sports performance research and little insight gained" BMJ 2012;345:e4797 doi: 10.1136/bmj.e4797.

In summary, there is no evidence that these drinks are required by anyone doing less than 2 hours of endurance activity. For most people engaging in moderate exercise, water (drunk according to thirst) is the best option for rehydration.

Although originally designed for athletes, sports drinks are now promoted and consumed outside of strenuous exercise or sporting events, commonly by people who are not athletes. Sports drinks are flavoursome because they contain lots of sugar. Drinking them regularly in the absence of strenuous exercise while eating a normal diet will lead to weight gain and obesity. In addition, the high levels of sugar contained has potentially serious long-term consequences for dental health; both for athletes and non-athletes alike.

These drinks should only be used by athletes actively involved in training for competitive endurance sports. Adding claims to labels about their health benefits will mislead the public and be to the detriment of public health.

Dr Ken Harvey
Adjunct Associate Professor
School of Public Health and Preventive Medicine
Monash University
http://www.medreach.com.au

BMJ

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FEATURE

Mythbusting sports and exercise products

Carl Heneghan and colleagues examine the evidence behind the claims made for sports and exercise products

Carl Heneghan *clinical reader in evidence based medicine*, Peter Gill *DPhil candidate*, Braden O'Neill *DPhil candidate* , Dan Lasserson *clinical lecturer* , Miriam Thake *visiting research assistant*, Matthew Thompson *clinical reader* , Jeremy Howick *research fellow*

Centre for Evidence Based Medicine Department of Primary Care Hea th Sciences University of Oxford Oxford OX1 2ET UK

There is no doubt that sport and exercise are beneficial for health and wellbeing. Yet, one might be fooled into thinking it is more important to heed correct nutrition and hydration advice than to actually exercise. In our analysis of the evidence of sports products[1] there were six claims that were so pertinent in terms of performance that we wanted to answer them with evidence. To find the evidence we searched PubMed Clinical Queries using systematic reviews and randomised controlled trial filters.

In terms of hydration we wanted to know if the colour of urine accurately reflects hydration and whether you should hydrate before exercise or just when you feel thirsty? For nutrition, we wanted to know whether carbohydrate protein combinations and branched chain amino acids improve performance or recovery after exercise. Finally, we wanted to determine the benefits of caffeine ingestion and analyse whether wearing compression garments helps improve overall performance?

The colour of urine accurately reflects hydration

The qualitative measure of urine colour is viewed as a simple way to assess hydration status. Athletes are advised to "observe urine output over the course of a day and notice changes in urine flow and colour. Output volume and frequency should be consistent and the colour should be getting lighter towards the end of the day, aiming for the last outputs of the day being close to clear."[2] But recommendations from the American College of Sports Medicine state that urine colour is often subjective and might be confounded. Many companies also provide a "urine colour chart" allowing athletes to quantify their level of hydration.[4 5]

Science behind the claim

Antidiuretic hormone is secreted by the posterior pituitary gland as a result of dehydration, resulting in increased water absorption in the collecting ducts of the kidneys. This decreases urine output and concentrates the solutes (including urea, uric acid, creatinine), leading to a darker colour of urine. After fluid ingestion less water needs to be reabsorbed to maintain homeostasis so larger quantities of pale urine are produced.

What the evidence says

We found eight low quality studies published with no systematic reviews. As there is no objective measure of hydration, all of these studies compared urine colour to surrogate markers: none directly investigated the correlation between urine colour and performance or the correlation between urine colour and thirst. The results are divided. Three studies recommend urine colour as a tool to roughly estimate hydration status, albeit when accurate results are not required or other assessment tools are not available,[5 7] while three conclude urine colour is too inaccurate to be useful.[8 10] Two further studies suggest urine colour can be useful but only in specific situations (such as first morning void) or in combination with other measures of hydration such as body mass.[11 12]

The three studies that support the use of urine colour include several caveats: vitamins and medicines interfere with the results by making urine darker,[1] variations in diet and dietary supplements affect accuracy, and, if large volumes of hypotonic drink are consumed following exercise,[10 14] copious volumes of dilute urine will be produced before normal hydration is achieved.[15] Despite this, no study has looked at the correlation of urine colour with hydration when different fluids are used for rehydration.

None of the eight studies looked at the correlation between urine colour and overhydration. This important oversight makes it difficult to recommend urine colour as a safe hydration assessment tool: attempts to produce pale or straw coloured urine may go too far, potentially leading to overhydration and hyponatraemia.[16] Many of the studies recommend a stopping point, often using the 8 point scale to assess urine colour described by Armstrong and colleagues.[5] but this seems to be based on speculation rather than research.

Finally, one study showed that 66 people were less reliable at distinguishing their urine colour than trained investigators.[16]

Correspondence to: C Heneghan carl.heneghan@phc.ox.ac.uk

However, all eight trials used trained investigators to interpret urine colour but they were unblinded to the results of other measurements of hydration status. This alone seriously undermines the use of urine colour for assessing hydration. In the practical sports setting it is likely to be misleading.

You should drink before you feel thirsty

The website for sports drink Gatorade says “Your brain may know a lot, but it doesn’t know when your body is thirsty. You need to drink during exercise before you feel thirsty in order to get enough fluids in your body to maintain your performance level” (wardmulroy.com/gatorade/DOCS/4/content(13).html). Powerade advises customers that “To avoid dehydration … you should drink before, during, and after sport” and that, “You may be able to train your gut to tolerate more fluid if you build your fluid intake gradually” (www.powerade.com.au/Sports Hydration/Using Powerade for Training and Competition.html).

Science behind the claim

When the body loses fluid due to sweat, the extracellular concentration of sodium rises leading to a subsequent increase in osmotic pressure and intracellular dehydration. Osmoreceptors in the hypothalamus detect dehydration and signal other parts of the brain to stimulate the sensation of thirst.[17] In extreme conditions such as malnutrition[18] or when children are left in hot cars[19] failure to react to thirst sensations by consuming fluid can have fatal consequences.

Drinking too much leads to other potential problems. If the body takes in more water than the kidneys can excrete, body solutes become diluted. Hyponatraemia occurs when the sodium concentration in the blood drops below 136 mmol/L.[20] The effects of hyponatraemia range from mild (asymptomatic) to fatal.[21]

What the evidence says

One systematic review of the effects of glycerol induced hyperhydration on fluid retention and endurance performance in long cycling time trials found performance was maintained provided loss of body water is kept between 1.8% and 3.2% of body weight (roughly 1.5 L of sweat for a 60 kg human).[21]

A more recent systematic review of the effects of exercise induced dehydration on performance in long cycling time trials suggested that drinking according to thirst sensations (as opposed to drinking more or less frequently) was associated with better sports outcomes.[22] One of the studies in the review found that exercise induced dehydration of up to 2.3% of body weight significantly improved performance.[2] The explanation for how exercise induced dehydration might improve performance is straightforward: you carry less weight, and you don’t have to interrupt your exercise.

Although we could not find a report in the medical literature of dehydration being a direct cause of death in marathon runners, we did find overhydration was responsible for several deaths.[24,25] By following advice to “drink before thirst,” many athletes are drinking too much, which does not help performance and puts them at risk. A recent study of 88 participants in the London marathon found that 11 (12.5%) developed asymptomatic hyponatraemia.[26]

Energy drinks with caffeine and other compounds improve sports performance

Drinks manufacturers claim that “Stimulants such as caffeine, guarana and taurine with energising fast and slow release carbohydrates produces a scientifically proven range designed to enhance your overall performance (www.maxifuel.com/maxifuelranges/focus). Red Bull says “In extensive studies it has been repeatedly proven that Red Bull increases performance” (www.redbull.co.uk/cs/Satellite/en UK/Red Bull Energy Drink/001243026254412).

Science behind the claims

Caffeine has long been used to enhance sports performance,[27] and energy supplements containing caffeine, in addition to other compounds, are purported to be uniquely performance enhancing when taken together. These include taurine, a sulphonic amino acid that is thought to increase skeletal muscle contractility while decreasing systemic vascular resistance[28,29]; and guarana, which contains caffeine and related xanthines. [0] Caffeine acts as a competitive inhibitor of adenosine on central nervous system receptors, [1] and an inhibitor of phosphodiesterase. [2] It increases heart rate and induces glycogen sparing, and is believed to enhance available energy stores.

What the evidence says

One systematic review of adding caffeine to carbohydrate [4] and several other reviews of caffeine alone [5,8] suggest that it enhances endurance performance, with these effects being most marked after at least seven days’ abstinance from caffeine.

We found nine randomised controlled trials investigating the effects of caffeine energy drinks. [9,47] Four trials recruited the general public [9,46] and five trained athletes.[40,47] Seven tested a caffeine energy drink in addition to guarana and/or taurine. [9,47]

Four studies reported positive effects: a study of 15 “healthy young adults” reported an energy drink increased mean bench press repetitions, but not anaerobic peak or average power during a cycling test.[4] Aerobic and anaerobic endurance was increased in 14 habitual caffeine users [9] and two trials demonstrated improved endurance in trained athletes.[45,47]

Three studies found energy drinks did not improve sports performance: for running time to exhaustion among physically active university students,[41] mean sprint time among female collegiate soccer players engaged in repeated running trials,[40] and sprint performance or anaerobic power in American college football players.[44]

Two studies tested the effect of a caffeine only energy drink and did not include other supposedly performance enhancing compounds.[46,47] One study of a caffeine taurine energy drink reported its effect on echocardiographic findings and did not report sports outcomes.[48]

We did not find any research comparing the effectiveness of energy drinks versus caffeine alone on sports performance.

On the negative side, effects of caffeine consumption can include insomnia, headache, and gastrointestinal bleeding.[27] The harms of energy supplements include nausea and vomiting, tachycardia, tremors, seizures, and sleep disturbances, particularly in adolescents.[49,51] There are several reports of cardiac arrhythmia and death,[50] as well as reports of adolescents requiring hospital admission as a result of consuming energy drinks.[52]

We could not identify any research that assesses the additional benefit energy drinks provide in addition to moderate caffeine

Bottom line: urine colour as a measure of hydration

General public Evidence is lacking o sugges ha urine colour is a useful safe or accura e marker of hydra ion

Professional athletes Limi ed evidence o show ha firs morning urine colour can be reliably used o assess dehydra ion and rehydra ion

Required research A high quali y s udy evalua ing he use of urine colour in de ec ing hydra ion wi h blinding of par icipan s and researchers o o her assessmen ools when measuring urine colour deally his should look a he rela ion be ween urine colour and o her markers of hydra ion including hirs and body mass

Bottom line: drinking ahead of thirst

General public Drinking ahead of hirs may worsen performance in endurance exercise and carries a rare bu serious risk of hypona raemia The body's in ernal mechanism for s aying hydra ed is cheaper easier and seems o be he bes way o op imise performance

Professional athletes Eli e endurance a hle es perform bes when hey drink o hirs some s udies sugges exercise induced dehydra ion can improve performance

Required research A high quali y randomised rial measuring he performance effec s of differen hydra ion regimes during shor er exercise (sprin ype) would de ermine whe her he resul s of sys ema ic reviews are generalisable beyond endurance a hle es

doses, and we found no systematic reviews of these products and sports performance.

Carbohydrate and protein combinations improve post-workout performance and recovery

"The combination of protein and carbohydrates has been shown to stimulate increased uptake of glucose by the cells, resulting in faster glycogen storage compared to carbohydrates or proteins alone (www.myprotein.com/uk/products/recovery evo)."

Science behind the claims

After exercise, 24 hours of rest are usually sufficient to replenish glycogen stores alongside a regular diet.[5 54] Ingesting carbohydrate during recovery from exercise may improve subsequent sports performance by increasing the rate of glycogen synthesis.[55 56] However, combined ingestion of both protein and carbohydrate has been shown to synergistically influence the release of insulin,[57 58] increase the rate of muscle glycogen storage,[59] and reduce markers of exercise induced muscle damage.[56]

What the evidence says

We identified 21 trials (15 randomised with 322 participants), of which fewer than half reported an overall benefit of combined protein and carbohydrate compared with carbohydrate alone. One systematic review concluded that the available evidence fails to show a relation between increased muscle glycogen synthesis and improved sports performance.[54]

Studies varied considerably in the outcomes and the ratio of carbohydrate to protein used: from 2:1 up to 6:1. Four studies that evaluated the effects of a 2:1 ratio on cycling performance were inconclusive.[60 6] A 2006 study reported no difference in total distance cycled with supplementation, but two years later the same group reported the effect was significant.[60 61] Similarly, another group found added protein improved sprint cycling performance in men 60 hours after exercise but not at 15 hours after exercise.[62 6]

The five studies evaluating a 4:1 protein to carbohydrate ratio had contrasting results.[64 68] Only one study evaluated performance in a competition and reported no change in cross country race times.[66]

Four of six studies[69 74] evaluating a 3:1 ratio, used an isocaloric control, enabling comparison between two products of the same caloric content.[69 7] Two reported improved cycling performance[69 71] while the other two reported no change in running time to exhaustion or performance tests for football players.[70 71] The improvement reported in the most recent study was trivial: a small increase in mean sprint cycling power of 2.5% with overlapping confidence intervals.[69]

One study evaluated a 6:1 ratio and found no change in running time to exhaustion in 16 recreationally active men.[75]

Experts have suggested there is little additional benefit of protein in supplements when carbohydrate is ingested in adequate quantities (≥1 g/kg/hour).[57] If carbohydrate content reduces to below 1 g/kg/hour, then adding protein will produce similar results to carbohydrate alone.[57] We found little consistent evidence across all included studies to support this claim.

Six studies looked at whether carbohydrate and protein improved muscle recovery.[72 80] Only one found that carbohydrate and protein after exercise induced muscle damage resulted in smaller decreases in muscle performance (such as. knee flexion repetitions) compared with carbohydrate alone.[80] However, the main findings were post hoc analyses, and two follow up studies failed to definitively replicate the findings.[78 79] Three further studies looking at similar measures found no effects on muscle recovery.[72 77]

The lack of benefit from protein supplements on performance or muscle is probably due to the fact that most athletes consume adequate amounts of protein in their diets.[81]

Branched chain amino acids improve performance or recovery after exercise

Pure branch chain amino acids are claimed to help hard training athletes recover faster after intense exercise, combat muscle damage during exercise, and support peak endurance performance (www.maxifuel.com/bcaas). Manufacturers also maintain that they can "help to sustain a healthy immune system during periods of intense training and play an important role in fatigue and performance" (www.maximuscle.com/viper).

Science behind the claims

Branched chain amino acids (leucine, isoleucine and valine) are termed essential amino acids because they cannot be synthesised by humans and therefore have to obtained from the diet. They are incorporated into all protein structures and are an essential precursor for muscle protein.[82] Muscle fibres are disrupted during exercise and essential amino acids are therefore required for repair, remodelling, and synthesis.[8] Ingesting excess branch

Bottom line: energy drinks containing caffeine and other stimulants

General public Low quali y evidence suppor s he use of energy drinks con aining caffeine aurine or guarana o improve acu e s reng h performance and aerobic and anaerobic endurance No s udies compare he effec iveness of hese produc s wi h inges ing caffeine alone and here are impor an concerns regarding harms

Professional athletes Limi ed low quali y evidence suppor s he use of energy drinks con aining caffeine aurine or guarana o improve endurance in modera e in ensi y ac ivi y of around 60 minu es No s udies compare he effec iveness of hese produc s wi h inges ing caffeine alone and here are impor an concerns regarding harms

Required research High quali y randomised rials in real world se ings evalua ing he compara ive effec iveness of energy drinks and caffeine alone on spor s performance

Bottom line: protein and carbohydrate supplements

General public There is a lack of evidence o suppor combined carbohydra e and pro ein supplemen s af er exercise o improve recovery and reduce muscle breakdown

Professional athletes The resul s of s udies of supplemen s con aining a varie y of carbohydra e o pro ein ra ios show inconsis en and generally small bene i s in some measures of spor s performance bu generally do no show benefi s over and above a balanced and nu ri ious die

Required research High quali y randomised con rolled rials evalua ing specific ra ios of carbohydra es and pro eins ha are adequa ely powered o de ec a meaningful increase in subsequen spor s performance

chain amino acids around the time of exercise is proposed to ensure maximum availability for synthesis of muscle.[84] High blood levels of amino acids stimulate insulin release, which also promotes muscle synthesis. They also increase the activity of the mTOR (mammalian target of rapamycin) pathway, which regulates muscle cell growth and protein synthesis.[8]

What the evidence says

We found two systematic reviews; one did not report the inclusion criteria and the search strategy was poor quality,[85] and the other concluded that any performance improvement was due to the energy value of the amino acids rather than muscle protein metabolism.[86] We identified 27 randomised controlled trials, of which 20 (with 6 41 participants) measured athletic performance or recovery. There was no consistent use of objective measures for athletic performance or recovery and adverse effects of amino acid administration were not recorded across studies.

Crossover studies, which used a single dose of amino acids at the time of exercise testing, found no effect on work done during cycling sprints,[87] distance travelled in a cycling time trial,[88] maximum oxygen consumption,[89] or time to exertion during cycling,[90] and no effect was seen in parallel group studies on running to exhaustion[91] or strength during squat weight lifting.[92]

Trial designs with longer durations of amino acid supplementation showed variable effects. One trial showed no effect over the course of a 32 hour yachting race on hand grip strength and vertical jump height.[9] Studies using amino acid supplementation of up to one week reported no effect on cycling sprint power[94] but found small increases in maximum oxygen consumption,[95] increased time to exhaustion,[96] and increased hand grip strength.[97] Supplmentation for more than three weeks alongside regular weight training had no effect compared with standard protein on maximum leg and bench presses,[98] but compared with placebo increased leg strength,[99] upper body strength,[100 101] and rowing time to exhaustion.[102]

Short term ingestion of branched chain amino acids reduced perceived exhaustion at the time of testing independently of changes in performance. Significant reductions in fatigue have been reported in studies over the first hour of exercise,[86] a reduction of 2.9 points on a 16 point exertion scale at 90 minutes[87] and a 2.6 point difference on a 20 point scale at 120 minutes after exercise.[10] Studies of longer term supplementation also showed subjective mean improvements on a 0 to 10 cm visual analogue scale (VAS) of 1.1 cm,[104] small improvements on arbitrary indices from a VAS 12, and a difference of 2 points between BCAA and placebo on a 15 point scale.[101] Amino acids significantly attenuated the reduction in leg flexion torque and maximal isometric leg muscle contraction observed in the placebo groups.[105 106]

Three trials reported the effect of amino acids on delayed onset muscle soreness after exercise. Amino acids significantly reduced muscle soreness by 1.2 points on a 10 point scale at 24 hours after endurance training[105] but had inconsistent effects after intensive squats, with one trial showing no effect over 72 hours[91] and another showing a reduction of 2 points on a 10 point scale at 24 hours.[106]

Trials with a high risk of bias that use longer term supplementation report improved athletic performance under laboratory conditions. All trials reporting subjective measures of endurance showed positive effects, irrespective of objective measures of performance.

Compression garments improve performance or enhance recovery

"This ultra tight, second skin fit delivers a locked in feel that keeps your muscles fresh and your recovery time fast" (www.underarmour.com/shop/uk/en/mens coldgear action legging/pid1000525).

Science behind the claims

Sports compression garments are made of body hugging fabric that exerts various degrees of pressure and are designed to be worn next to the skin. They can cover the entire body or only the lower or upper halves.

Wearing compression garments during exercise is thought to improve venous return and increase removal of metabolites such as lactic acid. Additionally the garments are claimed to work by reducing the oscillation (or "wobble") of muscles and tendons that occurs during repetitive exercise, thus reducing muscle pain and fatigue. By reducing damage the garments may reduce the predisposition to serious injury later.[107] Finally, for contact sports such as rugby or American football, compression garments may cushion direct trauma to the body.[107]

Bottom line: branched chain amino acids

General public High quali y evidence is lacking ha branched chain amino acids enhance performance or recovery

Professional athletes There is no evidence ha branched chain amino acids enhance performance in compe i ive se ings There is limi ed evidence o sugges ha muscle soreness and recovery may be reduced and ha longer erm supplemen a ion may increase some s reng h and endurance measures

Required research High quali y large randomised rials evalua ing he effec on ou comes ha are direc ly relevan o a hle es such as run imes or maximal weigh lif s in he compe i ive se ing

What the evidence says

We identified three trials that examined the effect of compression garments on actual sporting performance measures, all of which had negative results. One study of cyclists found no difference in 1 hour time trial performance,[108] and two studies of runners found no significant difference in 10 km time trial performance or lactic acid levels.[109 110]

A further 10 studies found no benefit from compression garments on various exercise protocols in controlled or laboratory settings. This included treadmill running or sprinting performance,[111 115] performance in a netball specific circuit,[116] cricket players' sprinting performance and ball throwing distance,[117] sprinting performance or lactate levels in hockey players,[118] and tests on speed, aerobic endurance, agility, or power.[119] Finally, a small study of cycling on ergometers found participants wearing compression stockings had significantly higher blood lactate levels at the end of exercise period and during the recovery period.[120]

Four studies reported improvements in exercise performance and reduced lactic acid levels in participants wearing compression garments; however, effects sizes were generally small.[121 124]

In terms of recovery from exercise, one study found compression substantially improved performance in a 40 km cycling time trial by a mean of 1.2%.[125]

Six studies reported a beneficial effect of compression garments (worn during or after exercise) on muscle soreness in runners,[109 110] cricket players,[117] weight lifters, general sprinting and jumping exercise session,[126] untrained women doing arm exercises,[128] and rugby players.[127] Of these, three reported significantly lower levels of creatine kinase in the compression groups, a surrogate marker of muscle damage.[117 128]

Finally, three studies that compared recovery using compression garments to other forms of recovery treatment (such as massage, hot and icy cold water therapy, low intensity exercise) found that all strategies were better than nothing but that compression garments had similar effects to those of these other treatments.[107 1 0]

Several studies have found that compression garments increased skin temperature compared with normal clothing. Although the single study that examined core temperature was done in cool conditions,[118] it found no effect on core temperature. But for exercise in hot or humid environments, the alteration of normal skin thermoregulation could be important. One study of compression garments noted a reduced range of motion of the hips during exercise.[119]

Competing interests: A authors have comp eted the CMJE uniform disc osure form at www icmje org/coi disc osure pdf (avai ab e on request from the corresponding author) and dec are: no support from any organisation for the submitted work; no financia re ationships with any organisations that might have an interest in the submitted work in the previous three years no other re ationships or activities that cou d appear to have inf uenced the submitted work

Provenance and peer review: Commissioned; externa y peer reviewed

1 Heneghan C, Howick J, O Neill B, Gill J, Lasserson D, Cohen D, et al. The evidence underpinning sports performance products a systematic assessment. *BMJ Open* 2012 2 e001702.
2 owerade. A coach s manual. www.sportingpulse.com/get file.cgi?id 1643735
3 Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc* 2007 39 377-90.
4 Nutrition Working Group of the nternational Olympic Committee. Nutrition for athletes. www.teamdanmark.dk/ /media/Team%20Danmark/Media%20Archive/Documents/Forside/Eksperter/Sportsern%C3%A6ring/en-ioc-nutrition-2010.ashx.
5 Armstrong LE, Maresh CM, Castellani JW, Bergeron MF, Kenefick RW, LaGasse KE, et al. Urinary indices of hydration status. *Int J Sport Nutr* 1994 4 265-79.
6 Armstrong LE, Soto JA. Urinary indices during dehydration, exercise, and rehydration. *Int J Sport Nutr* 1998 8 345-55.
7 Eberman LE, Minton DM, Cleary MA. Comparison of refractometry, urine color, and urine reagent strips to urine osmolality for measurement of urinary concentration. *Athletic Training andSports Health Care* 2009 1 267.
8 Cheuvront SN, Ely BR, Kenefick RW, Sawka MN. Biological variation and diagnostic accuracy of dehydration assessment markers. *Am J Clin Nutr* 2010 92 565-73.
9 Kovacs EM, Senden JMG, Brouns F. Urine color, osmolality and specific electrical conductance are not accurate measures of hydration status during postexercise rehydration. *J Sports Med Physical Fitness* 1999 39 47-53.
10 ollock NW, Godfrey RJ, Reilly T. Evaluation of field measurements of urine concentration. *Med Sci Sports Exercise* 1997 29l(5 261.
11 Lew CH, Slater G, Nair G, Miller M. Relationship between changes in upon-waking urinary indices of hydration status and body mass in adolescent Singaporean athletes. *Int J Sport Nutr Exerc Metab* 2010 20 330-5.
12 Harvey G, Meir R, Brooks L, Holloway K. The use of body mass changes as a practical measure of dehydration in team sports. *J Sci Med Sport* 2008 11 600-3.
13 Graff L. A handbook for routine urinalysis. Lippincott, 1983 2-19.
14 Manz F, Wentz A. 24-h hydration status parameters, epidemiology, and recommendations. *Eur J Clin Nutr* 2003 57(suppl 2 S10-8.
15 Shirreffs SM, Maughan RJ. ost-exercise rehydration in man effects of volume consumed and drink sodium content. *Med Sci Sports Exerc* . 1996 28 1260-71.
16 Almond CS, Shin AY, Fortescue EB, Mannix R, Wypij D. Hyponatremia among runners in the Boston marathon. *N Engl J Med* 2005 352 1550-6.
17 Johnson AK, Thunhorst RL. The neuroendocrinology of thirst and salt appetite visceral sensory signals and mechanisms of central integration. *Front Neuroendocrinol* 1997 18 292-353.
18 WHO. WHO position paper on oral rehydration salts to reduce mortality from cholera. WHO, 2012.
19 Guard A, Gallagher SS. Heat related deaths to young children in parked cars an analysis of 171 fatalities in the United States, 1995-2002. *Inj Prev* 2005 11 33-7.
20 Adrogue HJ, Madias NE. Hyponatremia. *N Engl J Med* 2000 342 1581-9.
21 Arieff A , Llach F, Massry SG. Neurological manifestations and morbidity of hyponatremia correlation with brain water and electrolytes. *Medicine* 1976 55 121-9.
22 Goulet ED, Aubertin-Leheudre M, lante GE, Dionne J. A meta-analysis of the effects of glycerol-induced hyperhydration on fluid retention and endurance performance. *Int J Sport Nutr Exerc Metab* 2007 17 391-410.
23 Goulet ED. Effect of exercise-induced dehydration on time-trial exercise performance a meta-analysis. *Br J Sports Med* 2011 45 1149-56.
24 Robinson TA, Hawley JA, almer GS, Wilson GR, Gray DA, Noakes TD, et al. Water ingestion does not improve 1-h cycling performance in moderate ambient temperatures. *Eur J Appl Physiol Occup Physiol* 1995 71 153-60.
25 Noakes T. Waterlogged the serious problem of overhydration in endurance sports. Human Kinetics, 2012.
26 Kipps C, Sharma S, edoe DT. The incidence of exercise-associated hyponatraemia in the London marathon. *Br J Sports Med* 2011 45 14-9.
27 Maughan RJ, Depiesse F, Geyer H. The use of dietary supplements by athletes. *J Sports Sci* 2007 25 S103-13.
28 Higgins J , Tuttle TD, Higgins CL. Energy beverages content and safety. *Mayo Clin Proc* 2010 85 1033-41.
29 Huxtable R. hysiological actions of taurine. *Physiol Rev* 1992 72 101-63.
30 Smith N, Atroch AL. Guarana s journey from regional tonic to aphrodisiac and global energy drink. *Evid Based Complement Alternat Med* 2010 7 279-82.
31 Fisone G, Borgkvist A, Usiello A. Caffeine as a psychomotor stimulant mechanism of action. *Cell Mol Life Sci* 2004 61 857-72.
32 Clauson KA, Shields KM, McQueen CE, ersad N. Safety issues associated with commercially available energy drinks. *J Am Pharm Assoc* 2008 48 e55-63.
33 Davis JK, Green JM. Caffeine and anaerobic performance ergogenic value and mechanisms of action. *Sports Med* 2009 39 813-32.
34 Conger SA, Warren GL, Hardy MA, Millard-Stafford ML. Does caffeine added to carbohydrate provide additional ergogenic benefit for endurance? nt J Sport Nutr Exerc Metab 2011 21(1 71-84.
35 Astorino TA, Roberson DW. Efficacy of acute caffeine ingestion for short-term high-intensity exercise performance a systematic review. *J Strength Condition Res* 2010 24 257-65.
36 Doherty M, Smith M. Effects of caffeine ingestion on exercise testing a meta-analysis. *Int J Sport Nutr Exerc Metab* 2004 14 626-46.
37 Doherty M, Smith M. Effects of caffeine ingestion on rating of perceived exertion during and after exercise a meta-analysis. *Scand J Med Sci Sports* 2005 15 69-78.

Bottom line: compression garments

General public There is a lack of evidence o suppor use of compression garmen s o improve spor ing performance They may reduce muscle soreness if worn for 24 hours af er an exercise session

Professional athletes There is no consis en evidence ha compression garmen s improve spor ing performance Muscle soreness seems o be reduced if garmen s are worn for 24 hours af er exercise bu objec ive measures of recovery are less consis en and compression garmen s seem o work no be er han o her recovery s ra egies such as low grade exercise or con ras ba hing Po en ial adverse effec s of hese garmen s may include increased skin empera ure decreased hermoregula ion and reduced range of mo ion

Required research Larger s udies in individual spor s and research generalisable o ei her highly rained a hle es or he general popula ion wi h ou comes rela ed o spor s performance and examina ion of adverse effec s and accep abili y of compression garmen s

38 Ganio MS, Klau JF, Casa DJ, Armstrong LE, Maresh CM. Effect of caffeine on sport-specific endurance performance a systematic review. *J Strength Condition Res* 2009 23 315-24.
39 Alford C, Cox H, Wescott R. The effects of red bull energy drink on human performance and mood. *Amino Acids* 2001 21 139-50.
40 Astorino TA, Matera AJ, Basinger J, Evans M, Schurman T, Marquez R. Effects of red bull energy drink on repeated sprint performance in women athletes. *Amino Acids* 2012 42 1803-8.
41 Candow DG, Kleisinger AK, Grenier S, Dorsch KD. Effect of sugar-free Red Bull energy drink on high-intensity run time-to-exhaustion in young adults. *J Strength Condition Res* 2009 23 1271-5.
42 Duncan MJ, Smith M, Cook K, James RS. The acute effect of a caffeine containing energy drink on mood state, readiness to invest effort and resistance exercise to failure. *J Strength Condition Res* 2011 Nov 24. [Epub ahead of print .
43 Forbes SC, Candow DG, Little J , Magnus C, Chilibeck D. Effect of Red Bull energy drink on repeated Wingate cycle performance and bench-press muscle endurance. *Int J Sport Nutr Exerc Metab* 2007 17 433-44.
44 Gwacham N, Wagner DR. Acute effects of a caffeine-taurine energy drink on repeated sprint performance of American college football players. *Int J Sport Nutr Exerc Metab* 2012 22 109-16.
45 vy JL, Kammer L, Ding Z, Wang B, Bernard JR, Liao YH, et al. mproved cycling time-trial performance after ingestion of a caffeine energy drink. *Int J Sport Nutr Exerc Metab* 2009 19 61-78.
46 Del Coso J, Salinero JJ, Gonzalez-Millan C, Abian-Vicen J, erez-Gonzalez B. Dose response effects of a caffeine-containing energy drink on muscle performance a repeated measures design. *J Int Soc Sports Nutr* 2012 9 21.
47 Geiß KR, Jester , Falke W, Hamm W, Waag K-L. The effect of a taurine-containing drink on performance in 10 endurance-athletes. *Amino Acids* 1994 7 45-56.
48 Baum M, Weiss M. The influence of a taurine containing drink on cardiac parameters before and after exercise measured by echocardiography. *Amino Acids* 2001 20 75-82.
49 Reissig CJ, Strain EC, Griffiths RR. Caffeinated energy drinks—a growing problem. *Drug Alcohol Depend* 2009 99 1-10.
50 Wolk BJ, Ganetsky M, Babu KM. Toxicity of energy drinks. *Curr Opin Pediatr* 2012 24 243-51.
51 Orbeta RL, Overpeck MD, Ramcharran D, Kogan MD, Ledsky R. High caffeine intake in adolescents associations with difficulty sleeping and feeling tired in the morning. *J Adolesc Health* 2006 38 451-3.
52 Seifert SM, Schaechter JL, Hershorin ER, Lipshultz SE. Health effects of energy drinks on children, adolescents, and young adults. *Pediatrics* 2011 127 511-28.
53 Nicholas CW G , Hawkins RD, Williams C. Carbohydrate intake and recovery of intermittent running capacity. *Int J Sport Nutr* 1997 7 251-60.
54 Betts JA, Williams C. Short-term recovery from prolonged exercise exploring the potential for protein ingestion to accentuate the benefits of carbohydrate supplements. *Sports Med* 2010 40 941-59.
55 American Dietetic Association Dietitians of Canada American College of Sports Medicine RN, Di Marco NM, Langley S. American College of Sports Medicine position stand. Nutrition and athletic performance. *Med Sci Sports Exerc* 2009 41 709-31.
56 Fallowfield JL WC, Singh R. The influence of ingesting a carbohydrate-electrolyte beverage during 4 hours of recovery on subsequent endurance capacity. *Int J Sport Nutr* 1995 5 285-99.
57 Betts JA, Stevenson E. Should protein be included in CHO-based sports supplements? *Med Sci Sports Exerc* 2011 43 1244-50.
58 Floyd JC Jr FS, ek S, Thiffault CA, Knopf RF, Conn JW. Synergistic effect of essential amino acids and glucose upon insulin secretion in man. *Diabetes* 1970 19 109-15.
59 Zawadzki KM YB, vy JL. Carbohydrate-protein complex increases the rate of muscle glycogen storage after exercise. *J Appl Physiol* 1992 72 1854-9.
60 Berardi JM NE, Lemon W. Recovery from a cycling time trial is enhanced with carbohydrate-protein supplementation vs. isoenergetic carbohydrate supplementation. *J Int Soc Sports Nutr* 2008 5 24.
61 Berardi JM Noreen EE, Lemon W. ostexercise muscle glycogen recovery enhanced with a carbohydrate-protein supplement. *Med Sci Sports Exerc* 2006 38 1106-13.
62 Rowlands DS, Thorp RM, Graham DF, Timmons BW, Stannard SR, Tarnopolsky MA. Effect of dietary protein content during recovery from high-intensity cycling on subsequent performance and markers of stress, inflammation, and muscle damage in well-trained men. *Appl Physiol Nutr Metab* 2008 33 39-51.
63 Rowlands DS, Rossler K, Graham DF, Rockell MJ. Effect of protein-rich feeding on recovery after intense exercise. *Int J Sport Nutr Exerc Met* 2007 17 521-43.
64 Millard-Stafford MWG, Thomas LM, Doyle JA, Snow T, Hitchcock K. Recovery from run training efficacy of a carbohydrate-protein beverage? *Int J Sport Nutr Exerc Met* 2005 15 610-24.
65 Lunn WR, Colletto MR, Karfonta KE, Carbone JW, Anderson JM, Rodriguez NR. Chocolate milk and endurance exercise recovery protein balance, glycogen, and performance. *Med Sci Sports Exerc* 2012 44 682-91.
66 Luden ND, Todd MK. ostexercise carbohydrate-protein antioxidant ingestion decreases CK and muscle soreness in cross country runners. *Int J Sport Nutr Exerc Met* 2007 17 109-23.
67 Williams MB, Fogt DL, vy JL. Effects of recovery beverages on glycogen restoration and endurance exercise performance. *J Strength Condition Res* 2003 17 12-9.
68 Thomas K, Stevenson E. mproved endurance capacity following chocolate milk consumption compared with 2 commercially available sport drinks. *Appl Physiol Nutr Metab* 2009 34 78-82.
69 Thomson JS, Rowlands DS. Leucine-protein supplemented recovery feeding enhances subsequent cycling performance in well-trained men. *Appl Physiol Nutr Metab* 2011 36 242-53.
70 Betts JA, Duffy K, Gunner F. The influence of carbohydrate and protein ingestion during recovery from prolonged exercise on subsequent endurance performance. *J Sports Sci* 2007 25 1449-60.
71 Karp JR, Tecklenburg S, Mickleborough TD, Fly AD, Stager JM. Chocolate milk as a postexercise recovery aid. *Int J Sport Nutr Exerc Met* 2006 16 78-91.
72 Gilson SF, Moran CW, Moore RW, Womack CJ, Todd MK. Effects of chocolate milk consumption on markers of muscle recovery following soccer training a randomized cross-over study. *J Int Soc Sports Nutr* 2010 7 19.
73 Ferguson-Stegall LME, Ding Z, Doerner G 3rd, Wang B, Liao YH, Kammer L, et al. ostexercise carbohydrate-protein supplementation improves subsequent exercise performance and intracellular signaling for protein synthesis. *J Strength Condition Res* 2011 25 1210-24.
74 Spaccarotella KJ. The effects of low fat chocolate milk on postexercise recovery in collegiate athletes. *J Strength Conditon Res* 2011 25 3456-60.
75 Betts JA, Stevenson E, Williams C, Sheppard C, Grey E, Griffin J. Recovery of endurance running capacity effect of carbohydrate-protein mixtures. *Int J Sport Nutr Exerc Met* 2005 15 590-609.
76 Green MS, Doyle JA. Carbohydrate-protein drinks do not enhance recovery from exercise-induced muscle injury. *Int J Sport Nutr Exerc Met* 2008 18 1-18.
77 Wojcik JR, Smith LL, Gwazdauskas FC. Comparison of carbohydrate and milk-based beverages on muscle damage and glycogen following exercise. *Int J Sport Nutr Exerc Met* 2001 11 406-19.
78 Cockburn E, Hayes R, Robson-Ansley , Howatson G. Effect of milk-based carbohydrate-protein supplement timing on the attenuation of exercise-induced muscle damage. *Appl Physiol Nutr Metab* 2010 35 270-7.
79 Cockburn E, French DN. Acute milk-based protein-CHO supplementation attenuates exercise-induced muscle damage. *Appl Physiol Nutr Metab* 2008 33 775-83.
80 Clarkson M. Exercise-induced muscle damage in humans. *Am J Phys Med Rehabil* 2002 81(11 suppl S52-69.
81 Millward DJ. rotein and amino acid requirements of athletes. *J Sports Sci* 2004 22 143-4.
82 May ME, Buse MG. Effects of branched-chain amino acids on protein turnover. *Diabetes Metab Rev* 1989 5 227-45.
83 Walker DK, Dickinson JM, Timmerman KL, Drummond MJ, Reidy T, Fry CS, et al. Exercise, amino acids, and aging in the control of human muscle protein synthesis. *Med Sci Sports Exercise* 2011 43 2249-58.
84 Tipton KD, Ferrando AA, hillips SM, Doyle D, Jr., Wolfe RR. ostexercise net protein synthesis in human muscle from orally administered amino acids. *Am J Physiol* 1999 276 E628-34.
85 Deldicque L, Francaux M. Functional food for exercise performance fact or foe? *Curr Opin Clin Nutr Metab Care* 2008 11 774-81.
86 Stearns RL, Emmanuel H, Volek JS, Casa DJ. Effects of ingesting protein in combination with carbohydrate during exercise on endurance performance a systematic review with meta-analysis. *J Strength Condition Res* 2010 24 2192-202
87 Blomstrand E, Hassmen , Ek S, Ekblom B, Newsholme EA. nfluence of ingesting a solution of branched-chain amino acids on perceived exertion during exercise. *Acta Physiol Scand* 1997 159 41-9.
88 Greer BK, White J , Arguello EM, Haymes EM. Branched-chain amino acid supplementation lowers perceived exertion but does not affect performance in untrained males. *J Strength Condition Res* 2011 25 539-44.
89 Varnier M, Sarto , Martines D, Lora L, Carmignoto F, Leese G , et al. Effect of infusing branched-chain amino acid during incremental exercise with reduced muscle glycogen content. *Eur J Appl Physiol Occup Physiol* 1994 69 26-31.
90 Van Hall G, Raaymakers JS, Saris WH, Wagenmakers AJ. ngestion of branched-chain amino acids and tryptophan during sustained exercise in man failure to affect performance. *J Physiol* 1995 486 789-94.
91 itkanen HT, Oja SS, Rusko H, Nummela A, Komi V, Saransaari , et al. Leucine supplementation does not enhance acute strength or running performance but affects serum amino acid concentration. *Amino Acids* 2003 25 85-94.
92 Stock MS, Young JC, Golding LA, Kruskall LJ, Tandy RD, Conway-Klaassen JM, et al. The effects of adding leucine to pre and postexercise carbohydrate beverages on acute muscle recovery from resistance training. *J Strength Condition Res* 2010 24 2211-9.
93 ortier H, Chatard JC, Filaire E, Jaunet-Devienne MF, Robert A, Guezennec CY. Effects of branched-chain amino acids supplementation on physiological and psychological performance during an offshore sailing race. *Eur J Appl Physiol 2008;104:787-94*
94 Nelson AR, hillips SM, Stellingwerff T, Rezzi S, Bruce SJ, Breton , et al. A protein-leucine supplement increases branched-chain amino acid and nitrogen turnover but not performance. *Med Sci Sports Exercise* 2012 44 57-68.
95 Matsumoto K, Koba T, Hamada K, Tsujimoto H, Mitsuzono R. Branched-chain amino acid supplementation increases the lactate threshold during an incremental exercise test in trained individuals. *J Nutr Sci Vitaminol* 2009 55 52-8.
96 Gualano AB, Bozza T, Lopes De Campos , Roschel H, Dos Santos Costa A, Luiz Marquezi M, et al. Branched-chain amino acids supplementation enhances exercise capacity and lipid oxidation during endurance exercise after muscle glycogen depletion. *J Sports Med Physical Fitness* 2011 51 82-8.

97 De Lorenzo A, etroni ML, Masala S, Melchiorri G, ietrantuono M, erriello G, et al. Effect of acute and chronic branched-chain amino acids on energy metabolism and muscle performance. *Diabetes Nutr Metab* 2003 16 291-7.
98 Kerksick CM, Rasmussen CJ, Lancaster SL, Magu B, Smith , Melton C, et al. The effects of protein and amino acid supplementation on performance and training adaptations during ten weeks of resistance training. *J Strength Conditioning Res 2006;20:643-53*
99 Coburn JW, Housh DJ, Housh TJ, Malek MH, Beck TW, Cramer JT, et al. Effects of leucine and whey protein supplementation during eight weeks of unilateral resistance training. *J Strength Conditioning Res* 2006 20 284-91.
100 Nissen S, Sharp R, Ray M, Rathmacher JA, Rice D, Fuller JC, et al. Effect of leucine metabolite beta-hydroxy-beta-methylbutyrate on muscle metabolism during resistance-exercise training. *J Appl Physiol* 1996 81 2095-104.
101 Walker TB, Smith J, Herrera M, Lebegue B, inchak A, Fischer J. The influence of 8 weeks of whey-protein and leucine supplementation on physical and cognitive performance. *Int J Sport Nutr Exercise Metab* 2010 20 409-17.
102 Crowe MJ, Weatherson JN, Bowden BF. Effects of dietary leucine supplementation on exercise performance. *Eur J Appl Physiol* 2006 97 664-72.
103 Hsu MC, Chien KY, Hsu CC, Chung CJ, Chan KH, Su B. Effects of BCAA, arginine and carbohydrate combined drink on post-exercise biochemical response and psychological condition. *Chin J Physiol* 2011 54 71-8.
104 Matsumoto K, Koba T, Hamada K, Sakurai M, Higuchi T, Miyata H. Branched-chain amino acid supplementation attenuates muscle soreness, muscle damage and inflammation during an intensive training program. *J Sports Med Physical Fitness* 2009 49 424-31.
105 Greer BK, Woodard JL, White J , Arguello EM, Haymes EM. Branched-chain amino acid supplementation and indicators of muscle damage after endurance exercise. *Int J Sport Nutr Exercise Metab* 2007 17 595-607.
106 Shimomura Y, naguma A, Watanabe S, Yamamoto Y, Muramatsu Y, Bajotto G, et al. Branched-chain amino acid supplementation before squat exercise and delayed-onset muscle soreness. *Int J Sport Nutr Exercise Metab* 2010 20 236-44.
107 Gill ND, Beaven CM, Cook C. Effectiveness of post-match recovery strategies in rugby players. *Br J Sports Med* 2006 40 260-3.
108 Scanlan AT, Dascombe BJ, Reaburn R, Osborne M. The effects of wearing lower-body compression garments during endurance cycling. *Int J Sports Physiol Performance* 2008 3 424-38.
109 Ali A, Caine M , Snow BG. Graduated compression stockings physiological and perceptual responses during and after exercise. J Sports Sci 2007 25 413-9.
110 Ali A, Creasy RH, Edge JA. The effect of graduated compression stockings on running performance. *J Strength Condition Res* 2011 25 1385-92.
111 Menetrier A, Mourot L, Bouhaddi M, Regnard J, Tordi N. Compression sleeves increase tissue oxygen saturation but not running performance. *Int J Sports Med* 2011 32 864-8.
112 Sperlich B, Haegele M, Achtzehn S, Linville J, Holmberg HC, Mester J. Different types of compression clothing do not increase sub-maximal and maximal endurance performance in well-trained athletes. *J Sports Sci* 2010 28 609-14.
113 Varela-Sanz A, Espana J, Carr N, Boullosa DA, Esteve-Lanao J. Effects of gradual-elastic compression stockings on running economy, kinematics, and performance in runners. *J Strength Condition Res* 2011 25 2902-10.
114 Duffield R, Cannon J, King M. The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *J Sci Med Sport* 2010 13 136-40.
115 Doan BK, Kwon YH, Newton RU, Shim J, opper EM, Rogers RA, et al. Evaluation of a lower-body compression garment. *J Sports Sci* 2003 21 601-10.
116 Higgins T, Naughton GA, Burgess D. Effects of wearing compression garments on physiological and performance measures in a simulated game-specific circuit for netball. J Sci Med Sport 2009 12 223-6.
117 Duffield R, ortus M. Comparison of three types of full-body compression garments on throwing and repeat-sprint performance in cricket players. *Br J Sports Med* 2007 41 409-14.
118 Houghton LA, Dawson B, Maloney SK. Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. *J Sci Med Sport* 2009 12 303-9.
119 Bernhardt T, Anderson GS. nfluence of moderate prophylactic compression on sport performance. *J Strength Condition Res* 2005 19 292-7.
120 Rimaud D, Messonnier L, Castells J, Devillard X, Calmels . Effects of compression stockings during exercise and recovery on blood lactate kinetics. *Eur J Appl Physiol* 2010 110 425-33.
121 Berry MJ, McMurray RG. Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. *Am J Phys Med* 1987 66 121-32.
122 Chatard JC, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guezennec CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol* 2004 93 347-52.
123 Kemmler W, von Stengel S, Kockritz C, Mayhew J, Wassermann A, Zapf J. Effect of compression stockings on running performance in men runners. *J Strength Condition Res* 2009 23 101-5.
124 Kraemer WJ, Bush JA, Bauer JA, Triplett-McBride, axton NJ, Clemson A, et al. nfluence of compression garments on vertical jump performance in NCAA Division 1 Volleyball players. *J Strength Condition Res* 1996 10(3 180-83.
125 De Glanville KM, Hamlin MJ. ositive effect of lower body compression garments on subsequent 40-kM cycling time trial performance. *J Strength Condition Res* 2012 26 480-6.
126 Davies V, Thompson KG, Cooper SM. The effects of compression garments on recovery. *J Strength Condition Res* 2009 23 1786-94.
127 Duffield R, Edge J, Merrells R, Hawke E, Barnes M, Simcock D, et al. The effects of compression garments on intermittent exercise performance and recovery on consecutive days. *Int J Sports Physiol Perform* 2008 3 454-68.
128 Kraemer WJ, Flanagan SD, Comstock BA, Fragala MS, Earp JE, Dunn-Lewis C, et al. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *J Strength Condition Res* 2010 24 804-14.
129 French DN, Thompson KG, Garland SW, Barnes CA, ortas MD, Hood E, et al. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sports Exerc* 2008 40 1297-306.
130 Jakeman JR, Byrne C, Eston RG. Efficacy of lower limb compression and combined treatment of manual massage and lower limb compression on symptoms of exercise-induced muscle damage in women. *J Strength Condition Res* 2010 24 3157-65.

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FEATURE

SPORTS DRINKS

The truth about sports drinks

Sports drinks are increasingly regarded as an essential adjunct for anyone doing exercise, but the evidence for this view is lacking. **Deborah Cohen** investigates the links between the sports drinks industry and academia that have helped market the science of hydration

Deborah Cohen *investigations editor*

BMJ London WC1H 9JR UK

Prehydrate; drink ahead of thirst; train your gut to tolerate more fluid; your brain doesn't know you're thirsty the public and athletes alike are bombarded with messages about what they should drink, and when, during exercise. But these drinking dogmas are relatively new. In the 1970s, marathon runners were discouraged from drinking fluids for fear that it would slow them down, says Professor Tim Noakes, Discovery health chair of exercise and sports science at Cape Town University. At the first New York marathon in 1970, there was little discussion about the role of hydration it was thought to have little scientific value.

So how did the importance of hydration gain traction? An investigation by the *BMJ* has found that companies have sponsored scientists, who have gone on to develop a whole area of science dedicated to hydration. These same scientists advise influential sports medicine organisations, which have developed guidelines that have filtered down to everyday health advice. These guidelines have influenced the European Food Safety Authority, the EU agency that provides independent advice on the evidence underpinning health claims relating to food and drink. And they have spread fear about the dangers of dehydration.

Much of the focus on hydration can be traced back to the boom in road running, which began with the New York marathon. Manufacturers of sports shoes and the drink and nutritional supplement industries spotted a growing market.

One drink in particular was quick to capitalise on the burgeoning market. Robert Cade, a renal physician from the University of Florida, had produced a sports drink in the 1960s that contained water, sodium, sugar, and monopotassium phosphate with a dash of lemon flavouring.[1 2]

Gatorade named after the American Football team, the Gators, that it was developed to help could prevent and cure dehydration, heat stroke, and muscle cramps, and improve performance, it was claimed.[2]

The first experimental batch of the sports drink cost $43 (£28; €35) to produce but has spawned an industry with sales of

dcohen@bmj.com

Video on bmj.com (see also http://bmj.com/video)

Tim Noakes talks about the myths perpetuated around hydration for sports people.

Tim Noakes talks about what stimulates thirst, and how isotonic drinks won't quench it more effectively than water.

Hydration grabs the headlines, but hyponatremia is more dangerous for marathon runners. Arthur Seigel explains the physiology and Jonathan Williams explains treatment during a marathon.

around £260m a year in the UK alone and consumption is increasing steadily.

"The buzz around sports and energy drinks is here to stay. This has remained the fastest growing sector in the UK soft drinks market in recent years," an industry report suggests. In the US the market is even bigger. In 2009, forecasters, Mintel, valued it at $1.6bn, and the market is projected to reach $2bn by 2016.[4]

The rapid rise in consumption is hardly surprising sports drinks have the might of multinationals behind them. PepsiCo bought Gatorade in 2001 and both Coca Cola and GlaxoSmithKline (GSK) have their own sports drinks Powerade and Lucozade respectively. The companies are a partner and service provider, respectively, to the London 2012 Olympics.

The key behind the meteoric rise in consumption of sports drinks lies in the coupling of science with creative marketing. What started life as a mixture of simple kitchen food stuffs has become an "essential piece of sporting equipment."[5]

According to Noakes, the sports drink industry needed to inculcate the idea that fluid intake was as critical for athletic performance as proper training. "It became common for athletes to state that the reason why they ran poorly during a race was not because they had trained either too little or too much, but because they had dehydrated. This was a measure of the success of the industry in conditioning athletes to believe that what they drank during exercise was as important a determinant of their performance as their training," he says.

Indeed, after the "invincible" Australian cricket team lost the 2005 Ashes test series to rivals England, a research fellow at the Australian Institute of Sport (AIS) started to monitor players' levels of dehydration.[6]

The previous year (2004), the institute had entered a partnership with Gatorade. The AIS's first Gatorade fellow, Kelly Drew, conducted a study on hydration among the cricketers, taking urine samples and testing their sweat.

"We do know that 50% of them turned up today dehydrated, which is not a good sign," she told the Australian press.[6]

The AIS is just one organisation backed by Gatorade other powerful sports medicine organisations also receive funding from drinks companies. The US National Athletic Trainers' Association (NATA), a representative body of sports health professionals with over 35 000 members, works closely with Gatorade.

The company has taken out advertisements in NATA's newssheet that look like academic papers. These "research adverts" are just one example of how companies promote the idea that the benefits of their drinks are based on decades of thorough scientific research.

Selling science

Gatorade documents from 2010 show that sales staff are encouraged to watch an internal video called "Selling the Science" and told to "make sure consumers understand the science behind Gatorade." Promotion also hinges on the notion that sports drinks are among the "best researched food products on the planet," Bob Murray, a former director of the Gatorade Sports Science Institute wrote in 2001.[7]

And they're not the only ones when GSK reshuffled its entire communications department earlier this year, it said a key part of its strategy would be promoting the science behind its products. "The science that goes into our brands is a competitive advantage. Lucozade, for example, is subject to more than 100 clinical trials," a spokesperson said.[8 9] The company has suggested that the "market is all about credibility."[10]

In recognition of this, GSK set up the Lucozade Sports Science Academy (LSSA) in 2003, comprising a sports nutrition website, links with leading universities, and a high tech gym at the company's headquarters.[10] Marketers intended that bottles of the drink would be stamped with the LSSA insignia to reaffirm the scientific credibility when sports nutrition toolkits were handed out to gym instructors to educate them in the use of Lucozade Sport products. [10]

Indeed, just as drug companies have appointed key opinion leaders to influence doctors' prescribing patterns, sports drink and supplement companies seek to work with gyms and instructors. Virgin Active has a partnership with Powerade, for example,[11] and the GSK owned supplement brand, Maximuscle, has a partnership with LA Fitness.[12]

Like GSK, Gatorade has pushed heavily on the science. In 1985, Gatorade, then owned by Quaker Oats, set up its Gatorade Sports Science Institute (GSSI) in Barrington, Illinois, to conduct and publish research and to educate sports health professionals and athletes on sports nutrition and exercise science.

Just as drug companies held sponsored symposiums in exotic locations, Quaker Oats held invitation only annual conferences in locations around the world . Attendees included advisers to the world's most influential sports authorities.

Indeed, the editors of a sports medicine book on performance were among them. Ron Maughan, Louise Burke, and Edward Coyle, coeditors of *Food, Nutrition and Sports Performance II: The International Olympic Committee Consensus on Sports Nutrition*, published in 2004, all have financial links (personal or institutional) to Gatorade and their book was supported by Coca Cola, the makers of Powerade.

Taking on thirst

Perhaps one of GSSI's greatest successes was to undermine the idea that the body has a perfectly good homeostatic mechanism for detecting and responding to dehydration thirst. "The human thirst mechanism is an inaccurate short term indicator of fluid needs . . . Unfortunately, there is no clear physiological signal that dehydration is occurring," Bob Murray from the Gatorade Sports Science Institute declared in 2008.[1]

Others have followed suit. Powerade say: "Without realising, you may not be drinking enough to restore your fluid balance after working out."[14]

And the International Olympic Committee's nutrition advice for athletes published in 2003 and updated in 2008 in conjunction with Powerade doesn't mention thirst once, even though it includes detailed advice on fluid intake. "Dehydration impairs performance in most events, and athletes should be well hydrated before exercise," it says in its booklet, *Athletes Medical Information*.[15]

Athletes are bombarded with different advice and given complex algorithms to calculate their individual hydration needs. They are told, for example, to rehydrate with a pint for every pound in body weight lost a drop of 2% is considered a cause for concern. They are also told how to calculate their sweat rate and to check the colour of their urine (box).[15 16]

This advice has filtered down to healthcare organisations giving advice to patients playing sport. Diabetes UK, for example, advises people: "Drink small amounts frequently, even if you are not thirsty approximately 150 ml of fluid every 15 minutes because dehydration dramatically affects performance."[20]

"P" charts and urine tests

The science of dehydra ion has led o ano her widely held belief ha is no based on robus evidence ha he colour of urine is a good guide o hydra ion levels

Like a hle es Bri ish soldiers are old o check heir urine The Minis ry of Defence signed a £1 5m hree year deal wi h GSK in 2005 o supply soldiers wi h Lucozade " is only recen ly ha we have s ar ed o examine he science behind wha our soldiers drink " he defence secre ary John Reid said a he ime

The drink's packaging includes a "P char " a colour code allowing soldiers o check heir hydra ion levels by s udying he colour of heir urine [7]

The Mayo Clinic's online guidance o pa ien s also sugges s urine is a good guide of hydra ion "Unfor una ely hirs isn' always a reliable gauge of he body's need for wa er especially in children and older adul s A be er indica or is he color of your urine Clear or ligh colored urine means you're well hydra ed whereas a dark yellow or amber color usually signals dehydra ion " i says [8]

However a review of he evidence Oxford Universi y's Cen re of Evidence Based Medicine linked o his inves iga ion has assessed he predic ive value of urine colour as a diagnos ic es

"There is a lack evidence for he widely recommended prac ice of assessing hydra ion s a us by looking a he colour of urine " i sugges s [9]

"The limi ed evidence shows ha only irs morning urine colour can be reliably used o assess dehydra ion and rehydra ion " i adds

Studies suggest that thirst is a more reliable trigger. A meta analysis of data from cyclists in time trials concluded that relying on thirst to gauge the need for fluid replacement was the best strategy.[21]

"The problem was industry wanted to sell more products so it had to say that thirst was not adequate," Noakes says. And he should know Noakes developed a sports drink with South African company, Leppin, in the early 1980s.

Link ups with industry

Academics were in the vanguard of the drive against thirst and the promotion of the dangers of dehydration.

In 1993, a group of experts led by Ron Maughan, professor of sport and exercise nutrition at Loughborough University and a member of GSSI's sports medicine review board since 1990, produced a consensus statement at a meeting funded by Isostar, a sports drink then owned by drug company, Novartis. "There is a need to make athletes more aware of the dangers of dehydration and of the importance of adequate fluid intake. Water is not the best fluid for rehydration, either during or after exercise," they wrote in an article published in the *British Journal of Sports Medicine*.[22]

In America, the sports drinks industry also made a push into the area of clinical science. In 1992, the American College of Sports Medicine the "premier organization in sports medicine and exercise science" with over 45 000 members accepted a $250,000 donation from Gatorade.

Four years later, in 1996, the American College of Sports Medicine produced guidelines that adopted a "zero % dehydration" doctrine, advising athletes to "drink as much as tolerable."[2] This guidance grew out of a roundtable meeting in 1993 "supported" by Gatorade.[24]

Half the guideline's authors either worked with the US military the world's biggest customer of Gatorade or had a financial relationship with the Gatorade institute. Over time, these authors would strengthen their relationship with the college, with Lawrence Armstrong and Michael Sawka who both work for the United States Army Research Institute of Environmental Medicine becoming senior editors of the college's journal in the past 10 years.

The college's president during the 2000s, W Larry Kenny, even wrote that the college cautioned against physically active people "letting their thirst guide them."[25]

The 1996 guidance stood until 2007, when in updated guidance the college acknowledged that people should drink according to the dictates of thirst. However, it still promoted the idea that people should lose no more than 2% of body weight during exercise, and this remains the position in the published literature although how people are meant to know how much weight they are losing while exercising isn't made clear.[26]

Three of the six authors of the updated guidance declared major financial conflicts of interest. Randy Eichner and Nina Stachenfeld had financial ties to Gatorade, and Ronald Maughan had received funding from Coca Cola and GSK, as well as being on the GSSI review board. Louise Burke had no personal financial ties, although her institution, the AIS, received funding from Gatorade. The other two authors, Michael Sawka (chair of the committee) and Scott Montain, worked for the US military and had attended the exclusive Quaker Oats meetings in the 1990s. Even two of the five reviewers Michael Bergeron and Mark Hargreaves declared financial links to Gatorade.

There is nothing wrong with working with industry. Indeed, a UK parliamentary select committee heard in 2006 that "sports science tends to be a Cinderella subject, which does not have the drivers. A lot of the money does come from the drinks industry and so on but it cannot be entirely independent." Links with industry are also seen as a badge of honour.

However, Paul Laursen, adjunct professor at the Sports Performance Research Institute in New Zealand, thinks that people with conflicts of interest shouldn't be writing guidance.

"Those people would say that 'we've done all the research, so we know the subject'. You need people who are more objective than that who can put the studies into context and account for important limitations to the research," he says.

The *BMJ* asked the college why it chose people with such conflicts of interest to produce its guidance. A spokesperson said: "ACSM follows best practices regarding corporate relationships, disclosures, and conflicts of interest," adding that the college has "demanding requirements in the areas of disclosure and avoidance of conflict of interest." The college also maintains that the "chairs of both the 1996 and 2007 Position Stands on fluid replacement were US federal government employees with no professional affiliations with the sports beverage industry."

Despite all the guidance about the dangers of dehydration during exercise, Arthur Siegel, associate professor of medicine at Harvard University and adviser to the Boston marathon, says that there is no evidence that anyone doing a marathon has ever died from it.

"Dehydration has gotten all the press and attention partly because of sports medicine associations who have endorsed the dangers of dehydration, but in fact dehydration is not life threatening," Siegel says.

Fluid is freely available throughout the races should a runner need to drink they are not stranded in the desert with no access to fluids, he says.

"It [dehydration is a normal biological response to exercise. You lose water; you get thirsty; you drink. End of story," Noakes adds. He is, however, considered maverick in his views.

Hyponatraemia

Against this background of what Noakes says is disease mongering, a genuine illness associated with sport has become a real concern that of exercise associated hyponatraemia. There have been 16 recorded deaths and 1600 people taken critically ill during competitive marathon running due to a drop in their serum sodium (see linked commentary).[27]

The cause of this is keenly debated in particular whether it is the volume or type of fluid consumption that is most to blame. The largest prospective study, conducted in a diverse group of marathon runners (funded by the National Institutes of Health and published in the *New England Journal of Medicine*), found no association with the composition of fluids consumed and concluded that it is the volume of fluid that is the main factor leading to hyponatraemia.[28]

According to lead author Christopher Almond, assistant professor of paediatrics at Boston Children's Hospital: "The available evidence indicates that the most effective way to prevent hyponatremia during marathon running is to avoid a positive fluid balance."[28]

A literature review in a nephrology journal also backed this up saying there is no evidence that "consumption of sports drinks (electrolyte containing hypotonic fluids) can prevent the development of exercise associated hyponatraemia."[29]

However, companies are keen to imply that it is water that is the problem.

Coca Cola, for example, acknowledges that hyponatraemia is a cause for concern "for anyone doing endurance sports," but says that this is due to the failure to "replace the sodium lost through sweat or drinking a very large volume of very low sodium beverages such as water." The Powerade webpage describing hyponatraemia does not mention that it can also happen if sports drinks are consumed. [0] The company has subsequently said it has updated the advice on its website "to ensure that it is clear that athletes should not over consume any liquids."

Again, the message that sports drinks confer protection has filtered down. "To prevent hyponatremia and electrolyte imbalances, athletes should replace lost body fluid with drinks that contain electrolytes, such as sports drinks," MedicineNet website says. [1]

Outreach to schools

The industry push has not stopped with adults participating in sports. GSK has developed an educational outreach programme called Scientists in Sport (www.scientistsinsport.com) as part of its involvement in the Olympic antidoping operations. The programme includes materials for "GSK Ambassadors to take into schools, and free classroom resources."

One lesson looks at osmosis and water: "During intense exercise, heavy sweating removes water and salts from the body. If large quantities of water alone are consumed, this will dilute the normal concentrations of sugars and ions in the blood and tissues. Water will enter, by osmosis, and stop the muscles, nerves and the brain from working properly. In extreme cases, water intoxication can occur and may lead to death," it says. Students are then asked which drinks are closest to being isotonic and whether sports drinks justify their prices.

GSK maintains that the programme does not specifically mention its sports drink. However, it admits that the introduction to the osmosis lesson as quoted above could be "made more relevant to the subject." "We are therefore going to update this section," a spokesperson told the *BMJ*.

But efforts to encourage children to drink sports drinks do not end there. This year, Gatorade and the National Athletic Trainers' Association united to declare 11 July the first annual National Recovery Day for high school athletes. This was "to focus the attention of athletes on the importance of proper athletic recovery." Children were told to "drink 16 24 ounces of fluid with sodium for each pound of body weight lost during exercise following a workout or game." [2]

Many schools in the UK now encourage children to stop every 15 20 minutes during exercise to drink. Football teams also instruct children to bring a bottle no football field is seen without a colourful array of sports drinks.

This practice may be one that originated with Gatorade. In 2000, a former professor of paediatrics at McMaster University in Canada, Oded Bar Or, who was also a member of the GSSI medicine review board, promoted the need for children to stop during sporting activities in order to drink.

"One should make certain that children arrive fully hydrated for a practice session or for competition and enforce drink pauses every 15 20 min during prolonged activities, even when the child does not feel thirsty. If necessary, rules of the sport should be modified to facilitate periodic drinking," he wrote in 2000. That same year he was the main consultant to the American Academy of Pediatrics guidance on heat illness and exercise. [4]

"Children frequently do not feel the need to drink enough to replenish fluid loss during prolonged exercise. This may lead to severe dehydration," it said, adding: "A major consequence of dehydration is an excessive increase in core body temperature."

Updated advice in 2011 had Michael Bergeron who has financial ties to Gatorade as the main consultant and one of the lead authors. "Appropriate fluid should be readily accessible and consumed at regular intervals before, during, and after all sports participation," it added giving specific details about sweat replacement and amounts to drink. All references to this were to studies either funded by Gatorade or included authors with financial ties. [5]The Institute of Medicine, however, says: "Thirst and consumption of beverages at meals are adequate to maintain hydration." [6]

A spokesperson for Gatorade also confirmed that there were no systematic reviews on hydration in children. Instead, it pointed to three position papers that consider the relation between exertional heat related illness and hydration. These were from the American College of Sports Medicine and the National Athletics Trainers' Association and cite "carbohydrate electrolyte solutions as one of many potential preventative steps."

In the UK, Maughan took a similar view. He wrote in 2001: "Children are particularly likely to forget to drink unless reminded to do so," adding that "mild levels of dehydration and hyperthermia will reduce exercise capacity."[7]

This advice was soon adopted by groups lobbying for increased attention to hydration in schools. In the UK, an expert group on hydration was launched in June 2005, supported by the British

Soft Drinks Association, with the "goal of improving the nation's hydration." Maughan was a key adviser. [7]

"If children have no understanding of why they need to drink frequently, and little or no encouragement is given, their health, wellbeing and performance may be at risk," the group's report concludes. It also laments the "demonisation of vending machines" in schools. [7]

War on water

The promotion of hydration has created a battle ground for the fight between bottled water companies and the sports drinks industry. While they both agree about the need to drink plenty of fluids, [8] there is disagreement on what that fluid should be.

The Natural Hydration Council which represents the bottled water industry warns that one in four adults drink sports drinks at their desk, thereby consuming unnecessary calories. [9] It urges that people should be encouraged to drink water rather than sugary drinks. [9] Sports drinks companies, however, promote the notion that their products are a superior source of hydration.

In its guidelines to casual runners taking part in the Lucozade sponsored national UK event Parkrun Lucozade say that "water alone isn't enough to maintain hydration."[40] Powerade's website also suggests "Water is not enough." "Water doesn't have the performance benefits of a sports drink," it says but it does not go on to quantify what those benefits are.[41]

However, this is permitted. Earlier this year, the UK's Advertising Standards Authority (ASA) rejected a complaint against Powerade for television advertisements featuring Olympic heptathlon medal hopeful, Jessica Ennis, that said, "Powerade ION4 hydrates better than water." A national press advert running around the same featured Ennis saying: "So it hydrates me better than water."[42]

How good is the evidence?

Companies claim that the sodium in sports drinks stimulates thirst, resulting in the consumption of a higher volume of fluid and better retention compared with drinking water. Their claims also hinge on the physiological observation that the carbohydrate content of sports drinks aids water absorption from the small intestine. Consumers are told that another key benefit is the taste, as this encourages higher fluid intake.

The ASA's judgment in favour of Powerade was revealing. Despite over 38 years of research, there was no published meta analysis of studies in this area to help uphold the complaint.[42] But the reason for this lack of evidence is clear, says Noakes. "A commercial company would never do research that it was not certain of the answer before it did the study," he says.

Yet Coca Cola, GSK, and PepsiCo maintain that the scientific evidence supports their case and they're not the only ones. In 2006, the European Union adopted new regulation that aimed "to ensure that consumers are not misled by unsubstantiated, exaggerated or untruthful claims about foodstuffs." The European Food Safety Authority (EFSA) was charged with assessing the evidence supporting health claims.

Two related to sports drinks have been upheld: that they hydrate better than water and that they help maintain performance in athletes doing endurance exercise. This judgment did not apply to the ordinary person going to the gym or children playing football for an hour a week, Albert Flynn, chair of EFSA's dietetic products, nutrition, and allergies panel, told the BBC.

Because EFSA has reviewed the literature, companies say the evidence supporting the performance benefits of sports drinks is "very strong." But an analysis of the studies submitted to EFSA accompanying the investigation does not uphold this view. It also finds a troubling circularity in the industry influenced evidence base and this does not just apply to the funding of the studies. EFSA also says it relied on the American College of Sports Medicine's 2007 review on hydration.[4] The *BMJ* asked the college about its methodology. While not providing substantive comment on the methods used in the past, it said it "now uses an independent expert consultant in meta analysis process."

When the Institute of Medicine analysed the same dataset in 2004 they concluded that "many of the questions raised about the requirements for and recommended intakes of these electrolytes and of water cannot be fully answered because of inadequacies in the present database".[44]

In their determination to show that a solution of salt and sugar can produce a beneficial effect, companies have funded hundreds of studies over the past 40 years. The *BMJ* asked several companies for lists of these studies (see box for overview of research). GSK was the only one willing to provide such a list, comprising references to the "100 clinical trials" that suggest its sports drinks have important benefits. Gatorade did not respond, and Coca Cola sent a detailed response explaining how their drink works.[45] An accompanying analysis of the studies found that the quality of the evidence was so poor that it was impossible to draw firm conclusions about the effects of the sports drink (box).[9]

Marketing to athletes or ordinary people?

Noakes has other concerns about the evidence. He questions how generalisable the results are to the ordinary population. The studies feature highly trained volunteers who sustain exercise at high intensity for long periods. "They are never going to study a person who trains for two hours per week, who walks most of the marathon which form the majority of users of sports drinks."

Yet it's precisely these people that companies are targeting. Kelly Brownell, director of the Rudd Center for Food Policy and Obesity at Yale University has studied the way sports drinks are marketed. "They are marketed through a general route rather than just in runners' magazines, which shows they actually want a broad audience," he says.

Not all companies shy away from this description of their activities. John Brewer, director of the Lucozade Sport Science Academy, told a parliamentary select committee in 2006 that "It is really looking to get elite endorsement for high quality products that would then be preferred by the consumer at the mass market level."

But GSK's response suggests it would prefer not to be viewed in this light. A spokesperson told the *BMJ*: "Lucozade Sport is for adults who train and take part in sport and other vigorous physical exercise and this is stated on the bottle." The company also says that Lucozade is not marketed to children under 16.

Despite such reassurances, last year the company turned to pop stars Tinie Tempah and Blink 182 drummer, Travis Parker both popular with younger children to become "brand ambassadors" and attract "sporty teenagers."[46]

Assessment of evidence behind sports products

A eam a he Cen re of Evidence Based Medicine a Oxford Universi y assessed he evidence behind 431 performance enhancing claims in adver s for 104 differen spor s produc s including spor s drinks pro ein shakes and rainers

f he evidence wasn' clear from he adver s hey con ac ed he companies for more informa ion Some like Puma did no provide any evidence while o hers like GlaxoSmi hKline makers of Lucozade Spor provided hundreds of s udies

Ye only hree (2 7%) of he s udies he eam was able o assess were judged o be of high quali y and a low risk of bias They say his absence of high quali y evidence is "worrying" and call for be er research in his area o help inform decisions

What the research found

As par of he *BMJ*'s analysis of he evidence underpinning spor s performance produc s i asked manufac urers o supply de ails of he s udies Only one manufac urer GlaxoSmi hKline provided a comprehensive bibliography of he rials used o underpin i s produc claims for Lucozade a carbohydra e con aining spor s drink [5] O her manufac urers of leading spor s drinks did no and in he absence of sys ema ic reviews we surmise ha he me hodological issues raised apply o all o her spor s drinks

Carl Heneghan Rafael Perera David Nunan Kamal Mah ani and Pe er Gill se ou o appraise he evidence and found a series of problems wi h he s udies (see online for full ar icle) [9]

Small sample sizes limit the applicability of results Only one of he 106 s udies in 257 mara hon runners exceeded he accep able arge for a small s udy of 100 par icipan s per group The nex larges had 52 par icipan s and he median sample size was nine Thus he resul s canno be generalised beyond people wi h he s udy group charac eris ics

Poor quality surrogate outcomes undermine the validity Many s udies used ime o exhaus ion or o her ou comes ha are no direc ly relevan o performance in real life even s

Poorly designed research offers little to instil confidence in product claims Mos s udies (76%) were low in quali y because of a lack of alloca ion concealmen and blinding and of en he findings con ras ed wi h each o her The s udies of en had subs an ial problems because of use of differen pro ocols empera ures work in ensi ies and ou comes

Data dredging leads to spurious statistical results S udies of en failed o de ine ou come measures before he s udy leaving open he possibili y of numerous analyses and increasing he risk of finding a posi ive resul by chance

Biological outcomes do not necessarily correlate with improved performance Reduc ions in use of muscle glycogen for example did no correla e wi h improved a hle ic performance Physiological ou comes such as maximal oxygen consump ion have also been shown o be poor predic ors of performance even among eli e a hle es

Inappropriate use of relative measures inflates the outcome and can easily mislead One s udy infla ed he rela ive effec of carbohydra e drinks from 3% o 33% by excluding from he analysis he 75 minu es of exercise bo h groups under ook before an exhaus ion es

Studies that lack blinding are likely to be false S udies ha used plain wa er as he con rol found posi ive effec s whereas hose ha used as e ma ched placebos didn'

Manipulation of nutrition in the run in phase significantly affects subsequent outcomes Many s udies seemingly s arve par icipan s he nigh before and on he morning of he research s udy

Changes in environmental factors lead to wide variation in outcomes Al hough dilu e carbohydra e drinks may have some bene i in hea s udies found no effec in cold environmen s No plausible reason given for benefi s

There was no subs an ial evidence o sugges ha liquid is any be er han solid carbohydra e in ake and here were no s udies in children Given he high sugar con en and he propensi y o den al erosions children should be discouraged from using spor s drinks Through our analysis of he curren spor s performance research we have come o one conclusion people should develop heir own s ra egies for carbohydra e in ake largely by rial and error

Influence over journals

Another problem with the research is transparency. Even though a large proportion of the studies have been conducted by scientists with financial ties to Gatorade (PepsiCo), GSK, and Coca Cola, the authors' individual conflicts of interest are either not published or not declared. Conflicts of interest also exist within the key journals in sports medicine GSSI funded scientists pepper their editorial boards and editorships.

Around half of the studies supplied by GSK appeared in four journals the *Journal of Applied Physiology* (20), *Medicine and Science in Sports and Exercise* (24), *International Journal of Sport Nutrition and Exercise Metabolism* (11) and the *Journal of Sports Science* (9). Several of these journals belong to organisations that have long relationships with Gatorade (box).

These links between sports medicine journals and the sports drinks industry may help to explain a characteristic of the sports drinks literature that is familiar to those who have analysed drug trials over the past 30 years the relative (or almost complete) absence of negative studies.

Several people have told the *BMJ* how difficult it is to publish studies that question the role of hydration. Paul Laursen is one of them. "[A negative study gets rejected by reviewers and the editors for really spurious reasons particularly when you consider what does get published. It's a frustrating experience and it makes you wonder if it's a case of money winning out."

In response to concerns that drug companies were burying negative studies or those that demonstrated harm, the US government implemented the FDA Amendment Act. This stipulated that prospective studies had to be registered on a publicly accessible database. However, this has not caught on in nutrition.

When the *BMJ* asked companies if they had any knowledge of negative trials where sports drinks have not shown improvement in outcomes Coca Cola responded that it didn't. "We would suggest you direct this question to an active researcher in the field," a spokesperson said. But finding out what studies are being conducted isn't easy.

The *BMJ* turned to Loughborough University, which will form one of the UK's main hubs directing research into sport and exercise as part of delivering the Olympic legacy. The university receives funding from Gatorade.

Using the Freedom of Information Act, the *BMJ* asked for the university's contract with Gatorade and for the protocols of studies conducted on humans. The request was turned down under a commercial interests exemption. A subsequent letter said they didn't have any studies underway, yet declined to say what they receive funding for.

"The public interest in maintaining the exemption outweighs the public interest in disclosing the information," the Freedom of Information officer said.

UK Sport, a quango accountable to the UK's Department for Culture, Media and Sport, has also entered into a "research and

Journals' links to industry

While many journals have scien is s on heir edi orial boards who have links wi h he manufac urers of spor s drinks including he BMJ Group's *British Journal of Sports Medcine* some have such people in prominen edi orial roles

The one wi h he bigges reach is *Medicine and Science in Sports and Exercise* 's owned by he American College of Spor s Medicine which has a longs anding financial rela ionship wi h Ga orade and now Powerade Since 1999 here has been a s eady increase in he number of Ga orade af ilia ed scien is s who are edi ors or on he edi orial board Over he pas 12 years he edi ors in chief have been Ken Pandolf and Andrew Young bo h of whom work for he US mili ary Ga orade's bigges cus omer and have been ins rumen al in he science of hydra ion Pandolf has been a speaker a invi a ion only GSS conferences Ano her senior edi or Michael Sawka was chair of he commi ee who draf ed he ACSM's 1996 "zero% dehydra ion" guidance on fluids This was based on a round able funded by Ga orade Sawka has been and con inues o be a speaker a Ga orade sponsored even s since 1989 is no clear if he receives funding direc ly

Ron Maughan is also a senior edi or of he journal He has a longs anding financial rela ionship wi h Ga orade as well as financial rela ionships wi h Coca Cola and GSK Maughan has played senior edi orial roles on several o her journals over he pas 20 years including he *British Journal of Sports Medicine Nutrition* he *European Journal of Applied Physiology* and he *Journal of Sports Sciences* he of icial journal of he Bri ish Associa ion of Spor s and Exercise Science which has a financial rela ionship wi h Ga orade [52]

Maughan is also coedi or of he *International Journal of Sport Nutrition and Exercise Metabolism* wi h Louise Burke who works a he Aus ralian ns i u e of Spor which has a par nership wi h Ga orade This journal also has several Ga orade af ilia ed scien is s on i s edi orial board

Several o her prominen Ga orade scien is s si on he board of he *Journal of Sports Science* Mark Hargreaves professor of exercise physiology and me abolism a Melbourne Universi y and a member of he Science Advisory Board of he Ga orade Spor s Science ns i u e (GSS) is a consul ing edi or for he *Journal of Applied Physiology* along wi h Sawka This journal is owned by he American Physiological Socie y which again has financial links o Ga orade

Ano her prominen edi or of *Medicine and Science in Sports and Exercise* was Oded Bar Or a professor of paedia rics who had a long s anding financial rela ionship wi h GSS He has been a key consul an o he American Academy of Pedia rics on i s hydra ion s ra egy

Mos of he scien is s iden ified as being on he GSS board have prominen roles in journals Even i s global senior direc or Asker Jeukendrup professor of exercise me abolism a Birmingham Universi y is an edi or of he *European Journal of Sport Science* he of icial journal of he European College of Spor Science His biography s a es ha "he has been a member of he advisory edi orial board of he *Journal of Sports Sciences* and served on he edi orial board of he *International Journal of Sports Medicine* and Medicine and Science in Spor and Exercise To da e Asker has served as a reviewer for 35 differen scien ific journals "[53] Jeukendrup is one of he main au hors of a series of research papers given o he *BMJ* by GSK o demons ra e he effec iveness of i s spor s drinks [9]

development partnership" with GSK. This is "to investigate the role that nutrition has in improving athletic performance through the training process." They too turned down the Freedom of Information requests for study protocols, calling them "commercial in confidence."

Links to obesity

As sports drinks rise in popularity among children, there is concern their consumption is contributing to obesity levels. A 500 mL bottle of Powerade Ion4 contains 19.6 g of sugar, and the same sized bottles of Lucozade Sport and Gatorade Perform contain 17.5 g (32g carbohydrate) and 30 g respectively (a teaspoon of sugar weighs about 4 g).

A report in June 2012 by the US philanthropic organisation, the Robert Wood Johnson Foundation, says that "the increased consumption of sports drinks in recent years is of growing concern for parents, health professionals, and public health advocates."[47]

Coca Cola denies that the drinks are a problem. "No one single food or drink alone is responsible for people being overweight or obese. All foods and soft drinks can have a place in a sensible, balanced diet, as long as over time you do not take in more calories than you burn," it said.

However, endorsement by elite athletes and claims of hydration benefits have meant that sports drinks have been able to shrug off any unhealthy associations. An analysis by Yale University's Rudd Center for Food Policy and Obesity found that over a quarter of American parents believe that sports drinks are healthy for children.[48]

A recent campaign against the UK government levying value added tax on "sports nutrition drinks" by UK Sports Specialist Nutrition Alliance also shows how sport products are now thought of as essential. "You complain about obesity then charge us to live a healthy lifestyle!" says one signatory. "Why penalise individuals for choosing to use products designed to maintain health and vitality which ultimately help reduce the burden on the already stretched and under resourced NHS. We're sitting on a diabetes and obesity time bomb," says another.

This is why New York City's mayor, Michael Bloomberg, has proposed a ban on supersized bottles of soft drinks, including sports drinks. As one marketing pundit put it, drinking a sports drink "may be a way for consumers to convince themselves that they are looking after the bodies without having to break out into a sweat." [9]

Far from sports drinks turning casual runners into Olympic athletes, Noakes suggests: "If they avoided the sports drink they would get thinner and run faster."

Competing interests: The author has comp eted the CMJE unified disc osure form at www icmje org/coi disc osure pdf (avai ab e on request from the corresponding author) and dec ares no support from any organisation for the submitted work; no financia re ationships with any organisation that might have an interest in the submitted work in the previous three years; and no other re ationships or activities that cou d appear to have inf uenced the submitted work

Provenance and peer review: Commissioned; externa y peer reviewed

1 Robert Cade Scientist who invented Gatorade, the world s first and biggest-selling sports drink. *Times* 2007 Nov 29.
2 Kays J, hillips-Han A. Gatorade the idea that launched an industry. *Explore* 2003 8(1 . URL.
3 British Soft Drinks Association. By popular demand. 2011. URL.
4 nternational Markets Bureau. Overview of the global sports nutrition marketfood, beverages and supplements. 2010. www.ats.agr.gc.ca/inter/5569-eng.htm.
5 Kleinman M. Lucozade Sport backs repositioning with £4m. Marketing 2003 Apr 24. www.marketingmagazine.co.uk/news/177948/.
6 Urine tests help Aussie cricket squad. 2005. URL.
7 Maughan RJ, Murray R. Sports drinks. Basic science and practical aspects. CRC ress, 2001.
8 ears E. GlaxoSmithKline launches review of multimillion-pound UK R roster. *PR Week* 2012 Jan 31. www.prweek.com/uk/news/1114704/.
9 Heneghan C. Forty years of Lucozade sports performance research and little insight gained. *BMJ* 2012 345 e4797
10 Rogers D. Lucozade to set up academy of sports nutrition. *Marketing* 2003 Mar 6. www.marketingmagazine.co.uk/news/172984/.
11 Virgin Active Health Clubs. Our partners. www.virginactive.co.uk/our-partners/powerade.
12 Maximuscle Dragan challenge 2012. www.maximuscle.com/draganchallenge/.
13 Murray B. reventing dehydration sports drinks or water. 2008. URL.
14 owerade.www.poweradegb.com/powerade/ion4.html.
15 Nutrition Working Group of the nternational Olympic Committee. Nutrition for athletes. 2010. URL.
16 Coca-Cola. Hydration tips. URL.
17 Armed forces to use new Lucozade drink. Marketing Week 2005 Oct 6. URL
18 Mayo Clinic. Dehydration. URL.
19 Heneghan C, Gill , O Neill B, Lasserson D, Thake M, Cohen D, et al. Mythbusting sports and exercise products for improved performance. *BMJ* 2012 345 e4848.
20 Diabetes UK. Training for events and competitions. URL
21 Goulet ED Effect of exercise-induced dehydration on time-trial exercise performance a meta-analysis. *Br J Sports Med* 2011 45 1149-56.

Lucozade's transformation

Al hough i is now associa ed wi h spor Lucozade had a sickly s ar in life ni ially developed by a pharmacis in Newcas le Glucozade as i was hen called was launched as a glucose supplemen o help people recover from common illnesses such as influenza and was soon snapped up by Beecham (now par of GSK's Nu ri ional Heal hcare division) Bu illness doesn' sell in qui e he same way as s reng h and heal h The Lucozade ha is familiar oday was effec ively crea ed in 1983 by UK branding agency Ogilvy & Ma her was relaunched wi h Bri ish Olympic gold medal winner Daley Thompson under he proposi ion ha energy and empowermen was a s ronger sell han recovery

Scaremongering over the effects of dehydration

The American College of Spor s Medicine (ACSM) guidelines also emphasised he rela ion be ween dehydra ion and serious illness in spor saying ha i causes hea exhaus ion hea s roke muscle cramps and exacerba es rhabdomyolysis As well as a few labora ory s udies he ACSM draws on findings ha dehydra ion was presen in 17% of hospi al admissions for hea s roke in he US mili ary and a similar number in srael [2] did no conduc a sys ema ic review on he area

Sandy Fowkes Godek direc or of he HEAT ns i u e and a professor of spor s medicine a Wes Ches er Universi y has conduc ed dozens of s udies on Na ional Foo ball League players in he US and failed o show ha dehydra ion has any effec on core empera ure " 's a scare ac ic ha has worked very well " she says "We don' unders and wha causes exer ional hea s roke "

S udies ha have shown ha dehydra ion causes hea illness she argues have been se up o show i Paul Laursen agrees

"Wha is done in a lab doesn' always urn ou o be rue in ou door condi ions S udies in hydra ion are of en conduc ed in a clima e chamber wi hou appropria e airflow They ypically don' use a good fan so he abili y o remove hea from he body is reduced and core empera ure rises While his migh be wha happens in an indoor i ness class i isn' applicable o wha goes on ou side Bu companies have aken his lab inding and made i gospel " he says

A review in he *British Journal of Sports Medicine* suppor s his "There are very few recen well con rolled exercise physiology s udies of hea and exercise in children ha are direc ly applicable o real world ield condi ions " i says [9] ndeed a spokesperson from Ga orade con irmed ha here have been no sys ema ic reviews ha address he rela ionship be ween exer ional hea rela ed illness and hydra ion

From a heal h perspec ive Fowkes Godek worries ha if people are going o be fooled in o hinking ha drinking fluids is going o s op hem ge ing hea s roke hey won' ake o her preven ive measures This advice has been picked up widely NHS Choices websi e says ha dehydra ion in exercise "is he primary cause of hea exhaus ion " i says [50]

Disease mongering is a well documen ed phenomenon in heal hcare [5] and Noakes sugges s ha indus ry has followed a similar pa ern wi h dehydra ion and exercise

"When indus ry wan ed o sell more produc i had o develop a new disease ha would encourage people o overdrink " he said adding "Here's a disease ha you will ge if you run Here's a produc ha is going o save your life Tha 's exac ly wha hey did They said dehydra ion is a dreaded disease of exercise "

22 Maughan RJ, Goodburn R, Griffin J, rani M, Kirwan J , Leiper JB, et al. Fluid replacement in sport and exercise—a consensus statement. *Br J Sports Med* 1993 27 34.
23 Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC Jr, et al. ACSM position stand exercise and fluid replacement. *Med Sci Sports Exercise* 1996 28 i-vii.
24 American College of Sports Medicine. Roundtables exercise and fluid replacement. 1993. www.acsm.org/access-public-information/roundtables.
25 Kenny WL. *NATA News* 2004 June.
26 American College of Sports Medicine. osition stand. Exercise and fluid replacement. *Med Sci Sports Exercise* 2007 37 377-90
27 Noakes TS. Commentary role of hydration in health and exercise. *BMJ* 2012 345 e4171.
28 Almond CS, Shin AY, Fortescue EB, Mannix R, Wypij D. Hyponatremia among runners in the Boston marathon. *N Engl J Med* 2005 352 1550-6.
29 Rosner MH, Kirven J. Exercise-associated hyponatremia. *Clin J Am Soc Nephrol* 2007 2 151-61.
30 owerade. Hyponatraemia. URL.
31 MedicineNet. Exercise associated hyponatremia who s at risk? www.medicinenet.com/script/main/art.asp?articlekey 47388
32 The National Athletic Trainers Association and Gatorade declare July 11 "National Recovery Day." ress release, 26 June 2012. URL.
33 Error Hyperlink reference not valid.Bar-Or O. Nutrition for child and adolescent athletes. 2000. www.gssiweb.com/Article Detail.aspx?articleid 235&level 2&topic 24
34 American Academy of ediatrics. Climatic heat stress and the exercising child and adolescent. *Pediatrics* 2000 106 158-9.
35 American Academy of ediatrics. Climatic heat stress and the exercising child and adolescent. *Pediatrics* 2011 128 e741-7.
36 nstitute of MeDietary reference intakes. URL.
37 Expert Group on Hydration. Drinking in schools. URL.
38 McCartney M. Waterlogged? *BMJ* 2011 343 d4280.
39 Natural Hydration Council. New research shows nationwide inappropriate use of sports drinks. 2012. URL.
40 Lucozade. Nutrition tips fluids. URL.
41 owerade. Water is not enough. URL.
42 ASA Adjudication on Beverage Services Ltd. URL.
43 Thompson M, Heneghan C, Cohen D. How valid is the European Food Safety Authority s assessment of sports drinks? *BMJ* 2012 345 e4573.
44 nstitute of Medicine, Food and Nutrition Board. Dietary reference intakes for water, potassium, sodium, chloride, and sulfate. 2004. www.nutrisci.wisc.edu/NS623/driwatersum.pdf.
45 Heneghan C, Howick J, O Neill B, Gill J, Lasserson D, Cohen D, et al. The evidence underpinning sports performance products a systematic assessment. *BMJ Open* 2012 2 e001702.
46 Eleftheriou-Smith L-M. Lucozade Sport changes strategy with Tinie Tempah. Marketing 2011 Mar 30. URL.
47 Robert Wood Johnson Foundation. Consumption of sports drinks by children and adolescents. A research review. 2012. URL.
48 Harris JL, Schwartz MB, Brownell KD. Sugary drink facts. 2011. www.sugarydrinkfacts.org/.
49 Marshall SW. Heat injury in youth sport. *Br J Sports Med* 2010 44 8-12.
50 NHS Choices. Symptoms of dehydration. www.nhs.uk/Conditions/Dehydration/ ages/Symptoms.aspx.
51 Moynihan R, Heath , Henry D. Selling sickness the pharmaceutical industry and disease mongering. *BMJ* 2002 324 886.
52 British Association of Sport and Exercise Sciences. Gatorade Sports Science nstitute visits top UK universities. ress release, 3 December 2008. URL.
53 Gatorade Sports Science nstitute. The GSS team. Asker Jeukendrup. www.gssiweb.com/GSS Team Detail.aspx?person D 18.

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BMJ

FEATURE

SPORTS DRINKS

Forty years of sports performance research and little insight gained

Carl Heneghan and colleagues take a critical look at the evidence used to back up claims that Lucozade enhances sporting performance

Carl Heneghan *clinical reader in evidence based medicine*, Rafael Perera *university lecturer in statistics*, David Nunan *research fellow*, Kamal Mahtani *clinical lecturer*, Peter Gill *DPhil candidate*

Centre for Evidence Based Medicine Department of Primary Care Hea th Sciences University of Oxford Oxford OX1 2ET UK

Sports drinks manufacturers are keen to emphasise that their products are supported by science, although they are more reticent about the details. As part of the *BMJ*'s analysis of the evidence underpinning sports performance products, it asked manufacturers to supply details of the studies. Only one manufacturer, GlaxoSmithKline, complied. It provided us with a comprehensive bibliography of the trials used to underpin its product claims for Lucozade a carbohydrate containing sports drink.[1] Other manufacturers of leading sports drinks did not supply us with comprehensive bibliographies, and in the absence of systematic reviews we surmise that the methodological issues raised in this article could apply to all other sports drinks.

Of this list of 176 studies, we were able to critically review 106 studies (101 clinical trials) dating from 1971 through to 2012. We did not review posters, supplements, theses, or unavailable articles (see the linked data supplement).

Clinical trials are the best study design we have to evaluate what effect a "treatment" in this case Lucozade sports drinks will have on performance. However, not all trials are created equal,[2] and the label of randomised controlled trial is no guarantee that a study will provide adequate or useful evidence. As it turns out, if you apply evidence based methods, 40 years of sports drinks research does not seemingly add up to much, particularly when applying the results to the general public. Below we set out the main problems we identified together with some examples.

The smaller the sample size, the lower the confidence around the reported effect

Only four studies included a power calculation at the outset, [6] and very few studies discussed the importance of statistical power: we identified only one study, in seven moderately trained subjects, that reported the inability to detect significant differences in muscle glycogen use between treatments "may be due to a lack of statistical power given the small number of subjects."[7] Within sports science, given the small sample sizes, it is plausible that any hypothesis could be tested and subsequently reported in a peer reviewed journal as positive.[8] Small studies are known to be systematically biased towards the effectiveness of the interventions they are testing. Researchers have previously defined "small" as less than an average of 100 participants in each arm.[9] Yet, only one of the 106 studies in 257 marathon runners exceeded this target.[10] The next largest had 52 participants,[11] and the median sample size was nine.

There is one caveat to the requirements for larger sample sizes: where the variability in the outcome measure is low. The greater the level of variability, the higher the sample size required to detect the same effect.[12] By choosing homogenous groups of athletes and physiological measures, studies aimed to reduce variability and thus negate the need for larger sample sizes; however, this means that the results apply only to these highly selected groups.[1]

Poor quality surrogate outcomes undermine the validity of reported effects

A study of carbohydrate ingestion among 16 university football players with compromised glycogen stores (that is, after overnight fasting) reported participants significantly differed in the mean points scored per shot on the Loughborough Soccer Shooting Test (LSST).[14] Yet, this test does not discriminate elite from non elite players.[15] Although plasma glucose concentrations and carbohydrate oxidation rates were significantly increased in 12 football players during football specific exercises, sprint power was not significantly affected by the ingestion of

Correspondence to: C Heneghan carl.heneghan@phc.ox.ac.uk

Details of studies included in the analysis (see http://www.bmj.com/content/345/bmj.e4797?tab=related#webextra) carbohydrate or placebo. Studies that provided no exercise or performance outcomes were even more difficult to interpret.[16 17] Moreover, tests with a high coefficient of variation, such as time to exhaustion, are often misleading. Cycling at 75% maximal oxygen consumption to exhaustion has a coefficient of variation as high as 27%, whereas time trial cycling has been shown to have a coefficient as low as 3.8%.[18] Thus time trials are likely to be a more valid measure of cycling performance.[19] Also poor reproducibility of a test, such as time to exhaustion, means psychological factors may contribute significantly to performance, independent of the intervention under scrutiny. Worryingly, most performance tests used to assess sports drinks have never been validated.[20] Furthermore, we are not aware of any major sporting events that use time to exhaustion as the outcome. Yet it was used in 17 of the included studies and is often used as a performance measure in sports research.

Poorly designed research offers little to instil confidence in product claims

Most studies (76%) were low in quality because of a lack of allocation concealment and blinding, and often the findings contrasted with each other. One of the few trials that used a sports related outcome, long distance canoeing, shows some of the design problems.[21] The study found that use of a glucose syrup drink meant canoeists were able to maintain a consistent lap time whereas there was a gradual worsening of performance in the placebo group. But, the "effect is masked to some extent by the fact that four of the volunteers participated in two man kayaks." This resulted in each two man crew having one person taking the drink and the other placebo; inevitably the times recorded for both were virtually identical, despite the difference in drinks being used. The studies often had substantial problems because of use of different protocols, temperatures, work intensities, and outcomes.[22]

Data dredging leads to spurious statistical results

Data dredging is the inappropriate use of statistics to uncover misleading relations within the data and is common in studies where a clear protocol with a primary outcome of interest has not been defined. When glucose syrup was given to one football team before matches over a season the number of goals scored in the second half was double that scored by the control team, with 15/20 being scored in the final half hour of the match. The goals conceded in both halves without glucose, and in the first half with glucose, were almost identical. However, the data showed a marked improvement in defensive performance, with only one goal conceded during the final 30 minutes of the 20 matches.[2] Since outcomes were not defined beforehand, it is possible that the researchers also examined the last 20 minutes, the last 10, or even extra time, thus increasing the chance of a type I error (false positive) arising because of the number of outcome tests.

Biological outcomes do not necessarily correlate with improved performance

In a study of six trained soccer, hockey, or rugby players use of muscle glycogen during high intensity running was reduced in those who had a carbohydrate drink compared with those who had a non carbohydrate drink. Yet, the average sprint times were the same for both groups.[24] Several of the outcomes used are subject to higher order interactions   that is, they are affected by two or more variables.[25] For example, several factors independently influence the oxidation of ingested carbohydrate, including the timing, the exercise intensity, and the type of carbohydrate. These interactions can mask the effectiveness of the intervention, making it hard to determine causation from association. In addition, physiological outcomes such as maximal oxygen consumption, used in many studies, have been shown to be poor predictors of performance, even among elite athletes.[26]

Inappropriate use of relative measures inflates the outcome and can easily mislead

The finding that consuming carbohydrate containing drinks during high intensity exercise "delayed fatigue and improved endurance running capacity by 33% when compared with the same volume of artificially sweetened water" sounds impressive. However, the crossover study that reported this result was in nine participants who had fasted overnight for at least 10 hours, done a 15 minute warm up followed by 75 minutes of exercise, and then ran to exhaustion. In one arm they consumed a carbohydrate drink (concentration 6.9%) while in the other they consumed a non carbohydrate placebo. The absolute difference in run time to exhaustion was 2.2 minutes (8.9 min *v* 6.7 min). By the time of the exhaustion run, the control group had not eaten for at least 11.5 hours.[27] In addition, exclusion of the initial first 75 minutes from the outcome calculation dramatically inflates the relative effect. If this is included the difference is 83.9 min *v* 81.7 min, an improvement of only 3% rather than the claimed 33%. Improved running capacity by 33% for sports performance is implausible   it would be the difference between running a marathon in two hours rather than three.

Studies that lack blinding are likely to be false

In a study where the control group drank plain water with no artificial sweetener, the endurance running capacity of nine participants was measured after a 12 hour fast and the 6.9% carbohydrate drink was found to give better performance.[28] Yet, a study of high intensity running that used correct blinding   "the solutions ingested were of the same colour, texture, and taste, and were administered in a double blind fashion"   found no difference in the run time to exhaustion after 100 minutes of exercise.[29] A study using the Loughborough Intermittent Shuttle running Test (90 minutes in six blocks of 15 minutes separated by 3 minute rest periods) in which the placebo was taste matched found that mean 15 m sprint times were similar in both groups after 90 minutes and there was no effect on muscle glycogen use.[0] Of the 106 studies, only 38 (36%) reported blinding but even these gave poor descriptions of who exactly was blinded, particularly outcome assessors.

Manipulation of nutrition in the run-in phase significantly affects subsequent outcomes

Many studies seemingly starve participants the night before and on the morning of the research study. However, in one study that gave subjects breakfast[1] the high glycogen levels at the outset of exercise negated the effects of carbohydrate ingestion during exercise. The study, among eight cyclists, gave high or low glycogen food before exercise in a factorial crossover design with either a carbohydrate or non carbohydrate drink during exercise. Over the final period of the time trial, power output and pace were significantly lower only during the arm in which participants had low glycogen food before exercise and non carbohydrate drinks during exercise. [2] It is important that studies represent real life situations: when would an athlete fast for 12 hours before a major performance event?

Biological gradients are useful to establish the relation between cause and effect

Studying the dose response relation reveals important differences. For example, a study analysing carbohydrate feedings and exercise performance showed glucose solutions at a concentration of 4% or more delayed gastric emptying compared with more dilute solutions. The 20 g/L glucose solution was emptied at the same rate as water and the 40 and 60g/L solutions were emptied at a slower rate. In a crossover study of carbohydrate versus water in marathon running a lemon drink containing 5.5% carbohydrate was the preferred option among endurance trained runners and performed better than an orange 6.9% carbohydrate drink.[28]

Changes in environmental factors lead to wide variation in outcomes

Fluid replacement with dilute carbohydrate drink (2%) was found to be beneficial when exercising in heat (ambient temperature 30.2ºC) compared with a 15% carbohydrate electrolyte drink, which was no better than no drink at all. The mechanisms for the improvements in exercise capacity reported were unclear. Many of the suggested benefits across trials did not seemingly have a plausible or known mechanism of why they would even work. [4] Although drinking a carbohydrate electrolyte solution after a 12 hour fast induced greater metabolic changes than flavoured water and placebo solutions, endurance capacity (intermittent running of high intensity in hot environmental conditions at 30ºC) was not significantly affected. [5] In a cold environment (mean temperature 10ºC) , the effect of carbohydrate drinks (glucose concentrations of 2%, 6%, and 12%) on exercise capacity was no better than that of flavoured water, as measured by cycle rides to exhaustion. [6]

Studying the general population requires larger samples

Larger sample sizes are required to take account of the substantial variability in sports performance among untrained people. Of note, the study of 257 participants in the 2009 London marathon [10] concluded that, in addition to sex, body size, and training, pre race day carbohydrate intake can significantly and independently influence marathon running performance. Interestingly, there was no mention of carbohydrate feeding as a factor in predicting improved performance for marathon runners.

From our analysis of the current evidence, we conclude that over prolonged periods carbohydrate ingestion can improve exercise performance, but consuming large amounts is not a good strategy particularly at low and moderate exercise intensities and in exercise lasting less than 90 minutes. There was no substantial evidence to suggest that liquid is any better than solid carbohydrate intake and there were no studies in children. Given the high sugar content and the propensity to dental erosions children should be discouraged from using sports drinks. [7] Through our analysis of the current sports performance research, we have come to one conclusion: people should develop their own strategies for carbohydrate intake largely by trial and error.

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1 Heneghan C, Howick J, O Neill B, Gill J, Lasserson D, Cohen D, et al. The evidence underpinning sports performance products a systematic assessment. *BMJ Open* 2012 2 e001702.
2 oannidis J , Haidich AB, Lau J. Any casualties in the clash of randomised and observational evidence? *BMJ* 2001 322 879-80.
3 Betts JA, Toone RJ, Stokes KA, Thompson D. Systemic indices of skeletal muscle damage and recovery of muscle function after exercise effect of combined carbohydrate-protein ingestion. *Appl Physiol Nutr Metab* 2009 34 773-84.
4 Jeukendrup AE, Moseley L. Multiple transportable carbohydrates enhance gastric emptying and fluid delivery. *Scand J Med Sci Sports* 2010 20 112-21.
5 eacock OJ, Thompson D, Stokes KA. Voluntary drinking behaviour, fluid balance and psychological affect when ingesting water or a carbohydrate-electrolyte solution during exercise. *Appetite* 2012 58 56-63.
6 Rollo , Williams C, Nevill M. nfluence of ingesting versus mouth rinsing a carbohydrate solution during a 1-h run. *Med Sci Sports Exerc* 2011 43 468-75.
7 Arkinstall MJ, Bruce CR, Nikolopoulos V, Garnham A , Hawley JA. Effect of carbohydrate ingestion on metabolism during running and cycling. *J Appl Physiol* 2001 91 2125-34.
8 oannidis J . Why most published research findings are false. *PLoS Med* 2005 2 e124.
9 Nüesch E, Trelle S, Reichenbach S, Rutjes AW, Tschannen B, Altman DG, et al. Small study effects in meta-analyses of osteoarthritis trials meta-epidemiological study. *BMJ* 2010 341 c3515.
10 Atkinson G, Taylor CE, Morgan N, Ormond LR, Wallis GA. re-race dietary carbohydrate intake can independently influence sub-elite marathon running performance. *Int J Sports Med* 2011 32 611-7.
11 eacock OJ, Stokes K, Thompson D. nitial hydration status, fluid balance, and psychological affect during recreational exercise in adults. *J Sports Sci* 2011 29 897-904.
12 Eng J. Sample size estimation how many individuals should be studied? *Radiology* 2003 227 309-13.
13 Atkinson G, Nevill AM. Selected issues in the design and analysis of sport performance research. *J Sports Sci* 2001 19 811-27.
14 Ali A, Williams C, Nicholas CW, Foskett A. The influence of carbohydrate-electrolyte ingestion on soccer skill performance. *Med Sci Sports Exerc* 2007 39 1969-76.
15 Clarke ND, Drust B, MacLaren D , Reilly T. Strategies for hydration and energy provision during soccer-specific exercise. *Int J Sport Nutr Exerc Metab* 2005 15 625-40.
16 Jentjens RL, Jeukendrup AE. High rates of exogenous carbohydrate oxidation from a mixture of glucose and fructose ingested during prolonged cycling exercise. *Br J Nutr* 2005 93 485-92.
17 Lancaster G , Khan Q, Drysdale T, Wallace F, Jeukendrup AE, Drayson MT, et al. Effect of prolonged exercise and carbohydrate ingestion on type 1 and type 2 T lymphocyte distribution and intracellular cytokine production in humans. *J Appl Physiol* 2005 98 565-71.
18 Jeukendrup A, Saris WH, Brouns F, Kester AD. A new validated endurance performance test. *Med Sci Sports Exerc* 1996 28 266-70.
19 Currell K, Jentjens RL, Jeukendrup AE. Reliability of a cycling time trial in a glycogen-depleted state. *Eur J Appl Physiol* 2006 98 583-9.
20 Williams C, Nute MG, Broadbank L, Vinall S. nfluence of fluid intake on endurance running performance. A comparison between water, glucose and fructose solutions. *Eur J Appl Physiol Occup Physiol* 1990 60 112-9.
21 Green LF, Bagley R. ngestion of a glucose syrup drink during long distance canoeing. *Br J Sports Med* 1972 6 125-8.
22 Carter J, Jeukendrup AE, Mundel T, Jones DA. Carbohydrate supplementation improves moderate and high-intensity exercise in the heat. *Pflugers Arch* 2003 446 211-9.
23 Muckle DS. Glucose syrup ingestion and team performance in soccer. *Br J Sports Med* 1973 7 340–3.
24 Nicholas CW, Tsintzas K, Boobis L, Williams C. Carbohydrate-electrolyte ingestion during intermittent high-intensity running. *Med Sci Sports Exerc* 1999 31 1280-6.
25 Green LF, Thomas V. Some effects of glucose syrup ingestion during vigorous exercises of differing intensities and duration. *Proc Nutr Soc* 1972 31 5-6A.
26 Noakes TD. Maximal oxygen uptake "classical" versus "contemporary" viewpoints a rebuttal. *Med Sci Sports Exerc* 1998 30 1381-98.
27 Nicholas CW, Williams C, Lakomy HK, hillips G, Nowitz A. nfluence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. *J Sports Sci* 1995 13 283-90.
28 Tsintzas OK, Williams C, Singh R, Wilson W, Burrin J. nfluence of carbohydrate-electrolyte drinks on marathon running performance. *Eur J Appl Physiol Occup Physiol* 1995 70 154-60.
29 Nassis G , Williams C, Chisnall . Effect of a carbohydrate-electrolyte drink on endurance capacity during prolonged intermittent high intensity running. *Br J Sports Med* 1998 32 248-52.
30 Foskett A, Williams C, Boobis L, Tsintzas K. Carbohydrate availability and muscle energy metabolism during intermittent running. *Med Sci Sports Exerc* 2008 40 96-103.
31 Bilzon JL, Allsopp AJ, Williams C. Short-term recovery from prolonged constant pace running in a warm environment the effectiveness of a carbohydrate-electrolyte solution *Eur J Appl Physiol* 2000 82 305-12.

32 Widrick JJ, Costill DL, Fink WJ, Hickey MS, McConell GK, Tanaka H. Carbohydrate feedings and exercise performance effect of initial muscle glycogen concentration. *J Appl Physiol* 1993 74 2998-3005.
33 Vist GE, Maughan RJ. Gastric emptying of ingested solutions in man effect of beverage glucose concentration. *Med Sci Sports Exerc* 1994 26 1269-73.
34 Morris JG, Nevill ME, Thompson D, Collie J, Williams C. The influence of a 6.5% carbohydrate-electrolyte solution on performance of prolonged intermittent high-intensity running at 30 degrees C. *J Sports Sci* 2003 21 371-81.
35 Galloway SD, Maughan RJ. The effects of substrate and fluid provision on thermoregulatory and metabolic responses to prolonged exercise in a hot environment. *J Sports Sci* 2000 18 339-51.
36 Galloway SD, Wootton SA, Murphy JL, Maughan RJ. Exogenous carbohydrate oxidation from drinks ingested during prolonged exercise in a cold environment in humans. *J Appl Physiol* 2001 91 654-60.
37 Hooper S, West NX, Sharif N, Smith S, North M, De Ath J, et al. A comparison of enamel erosion by a new sports drink compared to two proprietary products a controlled, crossover study in situ. *J Dent* 2004 32 541-5.

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