Sodium ingestion and the prevention of hyponatraemia during exercise

The study of Twerymold et al. is important for a number of reasons, not all of which may have been emphasised sufficiently by the authors. Firstly, it confirms that a rate of fluid intake of 1000 ml/h is too high for a group of female runners running at ~ 10 km/h and who would therefore complete a 42 km marathon in about 4.25 hours. As the athletes drank 4 litres and gained 2 kg during the trial, their average rate of weight loss (as opposed to sweat rate) was about 500 ml/h. As not all of the weight lost during exercise is sweat and as much as 1–3 kg of this weight loss may result from fuel and water losses that do not contribute to dehydration, the absolute maximum rate at which these athletes should have ingested fluid during exercise was probably even less than 500 ml/h. This is substantially less than the drinking guidelines of the American College of Sports Medicine and the Gatorade Sports Science Institute, which have promoted rates of fluid ingestion of up to 1200–1800 ml/h. As there is no evidence that gaining weight during exercise are increasingly likely to (a) have an impaired performance, (b) develop troubling gastrointestinal symptoms, (c) or (c) finish the race with serum sodium concentrations below about 128 mmol/l caused hyponatraemic encephalopathy, it is not immediately clear why the authors chose such high rates of fluid intake in these athletes. Except, perhaps, if they wished to "prove" the value of sodium ingestion during exercise. I note, for example, that the study was funded by a commercial company that, I am informed, markets a sports drink containing sodium chloride.

For it seems highly probable that if athletes overdrink so that they retain fluid and gain weight, then the extent to which their serum sodium concentration falls will be influenced, albeit to a quite limited extent, by the sodium content of the ingested fluids. This indeed was shown by the results of this study. But whether that finding has relevance to the sodium requirements of athletes who are specifically advised not to overdrink during exercise to ensure that they do not develop hyponatraemic encephalopathy is an entirely different question, which cannot be answered with the study design chosen by these authors.

For example, the presence of a control group who drank according to the dictates of thirst ("ad libitum") and not according to the guidelines of influential sports medical and commercial organisations, so that they may be less prone to overdrink and so to gain weight during exercise, would have established that athletes who lose more than 1–3 kg during exercise do not develop symptomatic hyponatraemic encephalopathy even though they are both dehydrated and sodium deficient. Rather, they are more likely to finish such races with raised serum sodium concentrations.

I would rather argue that a fundamental feature of all prospective trials that aim to evaluate a novel intervention such as the role of sodium ingestion in the prevention of hyponatraemia during exercise should be to compare the new intervention with the currently established best practice.

As the currently established best practice is not to ingest fluid at such high rates that weight is gained during exercise, because this practice can produce a fatal outcome, so this study design should, in retrospect, not have been sanctioned. Rather, the control group in the study should have ingested fluid according to guidelines based on the strongest body of current information. It is, for obvious reasons, my biased opinion that the guidelines that come closest to a defensible evidence base are those that have been recently accepted by the United States Track and Field and the International Marathon Medical Directors Association. The evidence base are those that have been evidence based, best practice.

Fortunately the data of Twerymold et al. do allow some calculations to estimate the likely value of the extra sodium that was ingested by two of their groups. Thus, the athletes in their study ran a marathon of 54 kg. According to the formula of Montain et al. their predicted extracellular fluid (ECF) volume would be about 14.5 litres (25% of body weight). As the starting serum (and ECF) sodium concentration ([Na⁺]) in the three groups of runners was ~137 mmol/l (table 3 of their article), the average total ECF Na⁺ content of the three experimental groups was 1899–1993 mmol at the start of the race. As weights increased by 1.8–2.1 kg in the three groups during exercise (table 3 of their article), the increases in ECF volume would have been 450–525 ml in the respective groups, assuming that the ECF increased in proportion to the increase in total body water (TBW). Multiplying this new ECF volume by the serum [Na⁺] after the race gives the new total ECF Na⁺ content after the race. As shown in table 1, the total ECF Na⁺ content increased by 34 mmol in the group that ingested the high salt drink (H) during the race, but fell by 23 mmol in the group drinking water (W). As all groups ran for about four hours, according to these calculations these hourly changes in ECF volume, the hourly rates of Na⁺ loss would have varied from 6 to 21 mmol/h, giving a sweat [Na⁺] of 12–42 mmol/l in the W and H groups respectively (as their total sweat losses were ~2 litres in each of these groups).

The clear paradox identified by the calculations in table 1 is that (a) the total Na⁺ loss apparently increases with increased Na⁺ intake and (b) the estimated Na⁺ loss in the group who ingested water during the race (W) is less than one third of that in the group who ingested the most Na⁺ (H) during the race.

As these calculations are based on two real measurements (body weight changes and changes in plasma [Na⁺]), this apparently ludicrous conclusion can only be explained if (a) Na⁺ ingestion during exercise increases whole body Na⁺ losses in sweat and urine or (b) the estimated ECF volume in the W group after exercise is less than the value calculated. That is, specifically in the W group, the ECF volume contracted despite an increase in TBW of 1.9 litres. Indeed, this response is to be expected. There is consistent evidence that the response of the ECF and the intracellular fluid (ICF) volumes to fluid ingestion during prolonged exercise are influenced by the Na⁺ content of the ingested fluid, so that the ECF volume is likely to fall if the ingested fluid is iso-osmotic, to fall less if either water or a dilute Na⁺ drink is ingested, or to expand if a concentrated (50–100 mmol/l) Na⁺ drink is ingested at the same rate that body weight is lost during exercise. In the latter case, any reduction in the TBW appears to come from a reduction in the ICF.

For example, if each group did indeed lose 84 mmol Na⁺ as did group H (table 1), a value that seems eminently reasonable as it equates to a quite reasonable sweat [Na⁺] of ~40 mmol/l, then the true ECF volume in the W group after the race would have been 14.5 litres—that is, it is unchanged from the pre-race value. This value (equivalent to the TBW) is calculated as: [pre-race ECF Na⁺ content − 84] in mmol divided by post-race serum [Na⁺] in mmol.

Indeed, if subjects in the W group did lose 84 mmol Na⁺ during the race but also had a post-race ECF volume expanded to 14.95 litres, then their post-race [Na⁺] would have been even lower (128 mmol/l) than that actually measured after the race (132 mmol/l; table 1). It is probable that, if the Na⁺ lost in [Na⁺], they would have exhibited the early symptoms of hyponatraemic encephalopathy. That they did not have such low serum [Na⁺] indicates the importance of small changes in ECF volume in this case (in this case only 450 ml or ~3% of the total ECF volume) in determining the extent to which the serum [Na⁺] changes during prolonged exercise in which subjects both sweat and ingest fluid to excess.

Unfortunately, the vital importance of these small changes in ECF volume in determining whether hyponatraemic encephalopathy will develop in those who overdrink during exercise has been ignored by those who argue incorrectly that it is the Na⁺ deficit that determines the extent to which the serum [Na⁺] falls in those who develop hyponatraemia during exercise. This calculation elegantly shows why small changes in ECF volume determine whether or not hyponatraemic
encephalopathy will develop in those who overdrink, regardless of whether or not they also incur a Na\(^+\) deficit either during exercise\(^{17,18,21}\) or at rest.\(^{9,10}\) A recent paper\(^{8}\) confirms these predictions by showing that mathematical modelling supports the argument that changes in TBW exert a much greater effect on serum [Na\(^+\)] than does whole body Na\(^+\) content in those who overdrink and hence gain weight during exercise.

Perhaps the point of these calculations is to show that it is not possible to calculate the state of Na\(^+\) balance in athletes during exercise and so to determine whether or not athletes have developed a Na\(^+\) ‘deficit’\(^{17,18,21}\) simply by measuring serum [Na\(^+\)]. This is because the ECF volume will not be the same before, during, and after exercise and will change depending on the nature of the fluid ingested and the extent of any fluid deficit or excess that develops during exercise.\(^{17,18,21}\)

But more importantly, these calculations clearly show why the regulation of the TBW and the ECF volume will have a much greater influence on serum [Na\(^+\)] than will either the expected Na\(^+\) losses in sweat or the amount of Na\(^+\) ingested from sodium-containing sports drinks.\(^{9,10}\)

For example a 1 litre (7%) reduction in the ECF volume would ‘release’ 140 mmol Na\(^+\) into the contracted ECF volume. This means that it is possible to lose 140 mmol Na\(^+\) in sweat and urine without any change in serum [Na\(^+\)] provided that the ECF volume were to contract by only 7%. If sweat [Na\(^+\)] is about 40 mmol/l, as appears to have been the case in this study of Twerenbold et al.\(^{17}\) (table 1), then this 140 mmol is the equivalent of the Na\(^+\) content of about 3.5 litres of sweat.

As athletes in this study sweated at a maximum rate of only 500 ml/h when running at 10 km/h, this means that simply by reducing their ECF volume by 1 litre, those athletes could have maintained their pre-race serum [Na\(^+\)] while running for seven hours and drinking just sufficient water to allow for a 1 litre reduction in ECF volume and without requiring any Na\(^+\) replacement whatsoever. This simple calculation explains why those endurance athletes who, before about 1969, were advised either not to drink at all, or only sparingly during exercise,\(^{17,18,21}\) always finished those races with raised serum [Na\(^+\)] despite having incurred what might have been quite sizeable Na\(^+\) deficits.\(^{9,10}\)

In contrast, athletes in this study who believed the incorrect advice that ingesting Na\(^+\) at high rates is essential to maintain a normal serum [Na\(^+\)] during exercise,\(^{9,10}\) so they overdrank sufficiently to increase their ECF volume by 1 litre, would need to ingest and retain at least an additional 140 mmol Na\(^+\) in addition to the ~80 mmol lost in sweat (table 1). This is equivalent to the Na\(^+\) content of 1.24 litres of the low and 7.5 litres of the high sodium drinks respectively in this trial. To maintain fluid balance in this four hour trial when drinking at those high rates and sweating at about 500 ml/h, they would then need to urinate at rates of 1375–2600 ml/h. Both of these rates exceed the maximum at which human kidneys are able to produce urine at rest,\(^{19,20}\) let alone during and after prolonged exercise.\(^{17,18,21}\) Drunking at such rates would therefore only lead to progressive fluid accumulation and ultimately death from hyponatraemic encephalopathy.\(^{17}\)

In summary, these calculations explain why contraction of the ECF in athletes who lose body weight during exercise will maintain the serum [Na\(^+\)] even in the face of quite large and un replacing Na\(^+\) loss in sweat, and (b) why the ingestion of sodium-containing sports drinks in the vain hope of matching the rates of Na\(^+\) loss in sweat can only lead to fluid retention and progressive hyponatraemia, as elegantly shown by this study.\(^{17}\) Indeed if this inappropriate behaviour is approached with sufficient vigour, ultimately the result will be death from hyponatraemic encephalopathy,\(^{17}\) which, as these calculations and this study again show, cannot occur without the presence of distinct fluid overload.\(^{17}\)

Finally, it is important to note that, even though Na\(^+\) ingestion marginally increased serum [Na\(^+\)] in the group that ingested the most concentrated Na\(^+\) drink, this practice was without benefit as running performances were unaltered by Na\(^+\) ingestion, and the incidence of symptoms was no different between the groups as no athletes reportedly developed symptoms. However, the symptoms of mild hyponatraemic encephalopathy are mild and may not have been sought with sufficient diligence. For example, all subjects, myself included, in our study in which mild hyponatraemia was induced by fluid overload at rest,\(^{22}\) developed quite disabling symptoms at serum [Na\(^+\)] of ~136 mmol/l or lower. Indeed it would have been most interesting to determine whether the presence of subjective mental symptoms was different in the three groups in this study, as all had similar degrees of fluid overload despite different serum [Na\(^+\)]. If the symptoms in this condition are due purely to fluid overload, then the incidence of symptoms should have been the same in all groups despite different serum [Na\(^+\)]. Alternatively, if the symptoms are related to the degree of hyponatraemia, then they should have been most obvious in the W group, who finished with the lowest post-race serum [Na\(^+\)]. My bias would be to expect that the extent of any symptoms are more likely related to the degree of fluid overload, and hence the increase in the ECF, than to the level to which the serum [Na\(^+\)] has been reduced.

T Noakes

Correspondence to: University of Cape Town, Research Unit for Exercise Science and Sports Medicine, Sports Science of South Africa, PO Box 115, Newlands 7725, South Africa; tnnoakes@sports.uct.ac.za
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Conflict of interest: none declared

References


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Table 1 Sodium balance calculations for three groups of runners running at ~10 km/h for four hours while ingesting solutions with different [Na\(^+\)]

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<tr>
<th>Pre-race ECF volume (litres)</th>
<th>Pre-race Na(^+) content (mmol/l)</th>
<th>Post-race ECF volume (litres)</th>
<th>Post-race Na(^+) content (mmol/l)</th>
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<tbody>
<tr>
<td>H</td>
<td>137.3</td>
<td>14.50*</td>
<td>1991</td>
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<td>L</td>
<td>137.2</td>
<td>14.50</td>
<td>1989</td>
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<tr>
<td>W</td>
<td>137.5</td>
<td>14.50</td>
<td>1993</td>
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<th>Pre-race Na(^+) content</th>
<th>Post-race Na(^+) content</th>
<th>Post-race Na(^+) balance</th>
<th>Amount of Na(^+) ingested</th>
<th>Apparent amount (mmol/l) of Na(^+) loss during exercise</th>
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<tr>
<td>(A)</td>
<td>(A-B)</td>
<td>(C-D)</td>
<td>(E)</td>
<td>(F)</td>
</tr>
<tr>
<td>H</td>
<td>134.8</td>
<td>15.02</td>
<td>2025</td>
<td>-34</td>
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<tr>
<td>L</td>
<td>132.8</td>
<td>14.95</td>
<td>1985</td>
<td>-4</td>
</tr>
<tr>
<td>W</td>
<td>131.8</td>
<td>14.95</td>
<td>1970</td>
<td>-23</td>
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*Based on 25% of mean body weight of 57.7 kg for the total group of runners. Weights for different groups were not reported.
†From table 2 of Twerenbold et al.: to convert mg sodium (table 2) into mmol sodium, divide by the molecular weight of sodium (22.99).


Tennis


It is widely recognised that each sport has its own unique demands and injuries. Therefore the IOC, ITF, ATP, WTA, and Society for Tennis Medicine and Science should be congratulated on producing, in this publication, a comprehensive overview of tennis sports medicine. Together they have assembled an impressive array of experts in this field to write succinct and relevant chapters.

Every aspect of tennis is covered to cater for a broad range of readers, including players themselves. Some areas are covered in a high level of technical detail to please the biomechanists, in particular. However, some of the sports medicine is basic in concept and lacking significant evidence based validity.

Nevertheless, I would highly recommend this book to any health professional who treats a large number of tennis players. Most chapters provide a link between common sports medicine problems and their occurrence in tennis, including conditions that are unique to this sport. At times, some authors are somewhat optimistic with their view of recovery time from surgery—for example, three weeks for arthroscopic debriement of the infrapatellar fat pad.

Overall it is well presented with relevant and useful photographs and diagrams to aid the reader, and each chapter gives a list of further recommended reading. Unfortunately the book does not provide an answer to where 14 million tennis balls go, imported each year into Australia, as discussed by the editor recently!

BOOK REVIEWS

Tennis


Dying to win


Dying to win gives an eye opening account of the extent to which drugs play a major role in sport. Doping is not new and has been used in sport since ancient Olympic times; it is just that drug use in modern times is at such a level of sophistication, it is now an industry in its own right. The book describes the privileged position sport holds in society, having appeal for both the participant and the spectator. This has led to the massive media interest, commercialism, professionalism, and governmental regulation and manipulation. Economic pressure in the industrialised world and governmental propagandistic strategies in the former East Germany, and more recently China, have contributed to increasing pharmaceutical intervention in sport. With the fall of the GDR, the world saw for the first time what it had long suspected, the extent of systematic doping on a State run basis, and the most interesting aspect of that is that the East German sports records had been broken, even without such records! Further, the book takes a look at the next big issue surrounding drugs in sport—genetic engineering.
Rating

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E Clisby
Chair Drugs in Sport, Sports Medicine Australia; eclisby@healthon-net.com

CALENDAR OF EVENTS

UK Radiological Congress 2005 (UKRC 2005)
6–8 June 2005, Manchester, UK
The UK Radiological Congress (UKRC) meeting will encompass the medical, scientific, educational, and management issues that are of interest and relevance to all those involved in the diverse fields of radiological sciences and oncology.

The UKRC provides a forum in which to bring together clinicians, scientists, radiographers, technicians, and other professionals to present and discuss the latest developments and challenges in diagnostic imaging, radiotherapy, and allied radiological sciences.

Key subjects to be covered include: diagnostic radiology; ultrasound; nuclear medicine; interventional radiology; veterinary radiology; emerging technologies; image analysis; computer applications; PACS; radiobiology; radiological physics; management & audit; computed tomography; magnetic resonance; equipment development.

Expected attendance (conference and exhibition): 4000
Further details: UKRC 2005 Organisers, PO Box 2899, London W1A 5RS, UK; Website: www.ukrc.org.uk; Fax: +44 (0)20 7307 1414; Conference tel: +44 (0)20 7307 1410, Email: conference@ukrc.org.uk; Exhibition tel: +44 (0)20 7307 1420, Email: exhibition@ukrc.org.uk

Osteosynthese International 2005
15–17 September 2005, Curiohaus, Hamburg
Congress-Chairman: Johannes M. Rueger, M.D., Professor and Chair
Topics:
- Innovations in intramedullary osteosynthesis
- New frontiers in osteoporosis and fracture treatment
- Current trauma research
- Special topic: Recent development in pelvic and acetabular fractures

Abstract submission deadline: 31 March 2005
Further details: INTERCONGRESS GmbH, Martin Berndt, Düsseldorfer Str. 101, 40545 Düsseldorf-Germany. Tel: +49 211 585897-80; fax: +49 211 585897-99; email: martin.berndt@intercongress.de; website: www.osteointern2005.de

4th European Sports Medicine Congress
13–15 October 2005, Lemesos, Cyprus
Further details: Email: pyrgos.com@cytanet.com.cy

BASEM Conference 2005
10–12 November 2005, Edinburgh, Scotland
Further details: Email: basemoffice@compuserve.com

CORRECTIONS

doi: 10.1136/bjsm.2004.003921corr1

doi: 10.1136/bjsm.2004.000044corr1
Dadebo B, White J, George K P. A survey of flexibility training protocols and hamstring strains in professional football clubs in England (Br J Sports Med 2004;38:388–94). The multiple regression equation within the Abstract section of this paper was published incorrectly. The correct equation is:
\[ HSR = 37.79 - (0.335\text{HFI} + 10.05\text{SSP} + 2.24\text{STI}) \]
± 2.34.
We apologise for this error.

doi: 10.1136/bjsm.2004.010876corr1
Sran M M. To treat or not to treat: new evidence for the effectiveness of manual therapy (Br J Sports Med 2004;38:521–5). The volume number for reference 23 (Sran et al) was incorrectly published as 24; the correct volume number is 29.
In Table 2 the results for Giles and Muller should read: Greater short term benefit for back pain with manipulation, but not for neck pain. Acupuncture more effective for neck pain.
In the section “Definitions and search strategy” the first line of paragraph 2 should read: I searched Medline, Cinahl, and Embase databases for randomised clinical trials comparing manual therapy, including spinal joint mobilisation (with or without manipulation) or manipulation only with other conservative treatments for back or neck pain.
We apologise for these errors.