Sodium ingestion and the prevention of hyponatraemia during exercise

The study of Twervenbold et al.1 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,2,3 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 Medicine4 and the Gatorade Sports Science Institute5 and the recently accepted by the United States Track and Field and the International Marathon Medical Directors Association.

Fortunately, the data of Twervenbold 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 lost (from sweat) an average of 54 kg. According to the formula of Montain et al.6 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+]i) 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 1909–1993 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+] of the W group who ingested only water during the race was 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 fluid7,8 to such an extent that the ECF volume is likely to fall less if either water or a dilute Na+ drink is ingested,9–11 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.12 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,9 the true ECF volume in the W group after the race would have been 14.5 litres—that is, it is unchanged from the post-race value. This value of ECF volume 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 therefore possible that, if the sweat [Na+] was higher (22–25 mmol/l) than the potentially acceptable limit of 23 mmol/l. This ingesting only water during exercise. This calculation elegantly shows why small changes in ECF volume determine whether or not hyponatraemic
encephalopathy will develop in those who over-drink, regardless of whether or not they also incur a Na⁺ deficit either during exercise⁹,¹ⁱ–¹₅ or at rest.¹⁶–¹⁸ A recent paper¹⁹ 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 over-drink 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”-¹⁰,¹¹–¹₃,¹⁵,¹⁶,¹₈–²₀ 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.¹⁰,¹¹,¹₆–²₁ 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.²²

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.¹⁵,¹⁶ 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 by simply 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 whatever. 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,²³ always finished those races with raised serum [Na⁺] despite having incurred what might have been quite sizeable Na⁺ deficits.

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,²⁴–²₆,²₈–₃₀ 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 2.5 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,²³,²⁴ let alone during and after prolonged exercise.²⁵,²⁶ Drinking at such rates would therefore only lead to progressive fluid accumulation and ultimately death from hyponatraemic encephalopathy.²⁷

In summary, these calculations explain (a) 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 unreplaced 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.¹⁵ Indeed if this inappropriate behaviour is approached with sufficient vigour, ultimately the result will be death from hyponatraemic encephalopathy,²⁸ which, as these calculations and this study again show, cannot occur without the presence of distinct fluid overload.²⁹

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,²⁰ 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 subtle 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.

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

<table>
<thead>
<tr>
<th>Pre-race [Na⁺] (mmol/l) (A)</th>
<th>Pre-race ECF volume (litres (B))</th>
<th>Pre-race [Na⁺] content (mmol) (A–B)</th>
<th>Post-race [Na⁺] (mmol/l) (C)</th>
<th>Post-race ECF volume (litres) (D)</th>
<th>Post-race [Na⁺] content (mmol) (C–D)</th>
<th>Post-race Na⁺ balance (mmol) (E)</th>
<th>Amount of Na⁺ ingested (mmol) (F)</th>
<th>Apparent amount (mmol/rate of Na⁺ loss during exercise (mmol/h) (E/F)</th>
<th>For 10 km/h</th>
<th>For 20 km/h</th>
<th>For 30 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>137.3</td>
<td>14.50*</td>
<td>1991</td>
<td>134.8</td>
<td>15.02</td>
<td>2025</td>
<td>43</td>
<td>74</td>
<td>24/3</td>
<td>48/6</td>
<td>72/9</td>
</tr>
<tr>
<td>L</td>
<td>137.2</td>
<td>14.50</td>
<td>1989</td>
<td>132.8</td>
<td>14.95</td>
<td>1985</td>
<td>4</td>
<td>7</td>
<td>76/19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>137.5</td>
<td>14.50</td>
<td>1993</td>
<td>131.8</td>
<td>14.95</td>
<td>1970</td>
<td>-23</td>
<td>0</td>
<td>24/6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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).

References


BOOK REVIEWS

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 debridement 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!

RATING

- Presentation 16/20
- Comprehensiveness 15/20
- Readability 15/20
- Relevance 16/20
- Evidence basis 13/20
- Total 75/100

T Wood

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 propaganda in the former East Germany, and more recently China, have led 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 fact is that the East German records still stand! Further, the book takes a look at the next big issue surrounding drugs in sport—genetic engineering.

Dying to win does not just describe the evolution of doping. It explains the complex relationship between anti-doping policy, implementation of those policies, and the role of governments, the IOC, and international and national sporting organisations. With the ever increasing involvement of the legal profession, a vicious circle occurs: it becomes too costly for sporting organisations to fight court battles, with their reliance on Government funding depending on results and punishments set in accordance with what will stand up in courts. This all leads to the relative inertia of the governing bodies to be pro-active in the anti-drugs campaign.

The inception of the World Anti-Doping Agency (WADA) after the 1998 Winter Olympics in France drugsiasco provided a way forward to standardise and implement anti-doping policy across the world by an independent body.

Problems and solutions to anti-doping policy are addressed. The major problem is inadequate definition of doping— to quote Arthur Gold “The definition lies not in words but in integrity of character.” It is interesting to note that those behind the athlete, namely coach, administrators, medical profession, and scientists, all seem to lose perspective along with their ethics and “integrity of character" when the race for “gold” is on.

Dying to win suggests that these people should be held just as accountable as the athletes themselves. Another unfortunate aspect of anti-doping policy is the difficulty in detecting some abused drugs and the fact that these strategies often lag behind the ability of the pharmaceutical industry to develop new drugs, often for genuine medical reasons but with the unfortunate ability to enhance performance. Education is proposed as a key aspect to anti-doping policy, and parallels with its success in the use of recreational drugs are made. Governments also play a role in limiting supply, decreasing demand for drugs, and the implementation of independent bodies to carry out drug testing. The success of anti-doping policy is also hard to measure. Fewer positive tests may simply reflect a move to less detectable methods rather than a decrease in use, and success may be better measured in terms of fewer world records.

Dying to win gives an accurate account of the problem of doping in sport and the difficulties and complexities in finding solutions to the problems. It makes interesting and provocative reading for anyone with an interest in sport, from the athlete and coach to the sport administrator, the medical profession, and governments.

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CORRECTIONS
doi: 10.1136/bjsm.2004.003921corr1
doi: 10.1136/bjsm.2004.000044corr1
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” in 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.