Rehydration After Exercise in the Heat: A Comparison of 4 Commonly Used Drinks

Susan M. Shirreffs, Luis F. Aragon-Vargas, Mhairi Keil, Thomas D. Love, and Sian Phillips

To determine the effectiveness of 3 commonly used beverages in restoring fluid and electrolyte balance, 8 volunteers dehydrated by 1.94% ± 0.17% of body mass by intermittent exercise in the heat, then ingested a carbohydrate-electrolyte solution (Gatorade), carbonated water/apple-juice mixture (Apfelschorle), and San Benedetto mineral water in a volume equal to 150% body-mass loss. These drinks are all are perceived to be effective rehydration solutions, and their effectiveness was compared with the rehydration effectiveness of Evian mineral water, which is not perceived in this way by athletes. Four hours after rehydration, the subjects were in a significantly lower hydration status than the pretrial situation on trials with Apfelschorle (–365 ± 319 mL, \( P = 0.030 \)), Evian (–529 ± 319 mL, \( P < 0.0005 \)), and San Benedetto (–401 ± 353 mL, \( P = 0.016 \)) but were in the same hydration status as before the dehydrating exercise on Gatorade (–201 ± 388 mL, \( P = 0.549 \)). Sodium balance was negative on all trials throughout the study; only with Apfelschorle did subjects remain in positive potassium balance. In this scenario, recovery of fluid balance can only be achieved when significant, albeit insufficient, quantities of sodium are ingested after exercise. There is a limited range of commercially available products that have a composition sufficient to achieve this, even though the public thinks that some of the traditional drinks are effective for this purpose.

Key Words: fluid balance, electrolyte balance, hydration, rehydration, postexercise recovery

Athletes are encouraged to drink at a rate that closely matches sweat loss during exercise (4). In some situations and environments, however, such an approach might not be possible (4). Although individual drinking practices vary markedly, many athletes finish a bout of exercise in a hypohydrated state (20). Therefore, in addition to replenishment of carbohydrate stores, restoration of fluid and elec-
trolyte losses can form an integral part of the recovery process, the importance of which is accentuated if individuals have repeated exercise sessions scheduled on the same day or the fluid deficit is large. If the deficit is ignored, performance during subsequent exercise might be negatively affected (2) or, in severe cases, the hypohydration might become life threatening.

Despite a considerable amount of scientific literature on the effectiveness of various beverage formulations for the replacement of fluids and minerals lost through sweat, a few populations show a preference for choosing the drinks that they have traditionally had available. These choices might reflect cultural preference, availability, or cost, and according to the beverage industry (unpublished data), water and carbonated soft drinks such as colas represent an important portion of beverage consumption during active-thirst occasions. In the United States in 2005, tap and bottled water composed 64% of the active-thirst drinking volume, that is, of the total fluid volume ingested around occasions when people are or have been physically active. In Italy, where there is a very strong tradition of bottled-mineral-water consumption, 88% of the active-thirst volume was bottled mineral water. In Germany in 2004–2005, Apfelschorle, a carbonated water/apple-juice mixture, represented 10% of active-thirst drinking volume, compared with 13% for sports drinks, 24% for carbonated soft drinks, and 41% for bottled water. Although scientific studies should allow for the prediction of the rehydration effectiveness of commonly used drinks according to their composition, we think that measurement of the actual rehydration effectiveness of some of these beverages that are widely regarded and consumed around active-thirst occasions would be of interest to the scientific community and, in particular, practitioners who might find it more convincing.

The mechanisms whereby some specific components of drinks confer a hydration advance have been extensively studied. Plain-water ingestion after exercise results in a fall in plasma osmolality and sodium concentration, which stimulates urine production and reduces the drive to drink (21), both of which delay the rehydration process. In contrast, the addition of sodium chloride (equivalent to 77 mmol/L) to plain water increased intake while reducing urine output (21). The importance of the inclusion of sodium in rehydration beverages has also been reported by others (12, 25, 26, 29), and systematic evaluations suggest that the amount of fluid retained is inversely related to a drink’s sodium concentration. In some situations sodium might not be the only electrolyte that can improve fluid retention. Maughan et al. (15) reported that the addition of either potassium (25 mmol/L) or sodium (60 mmol/L) to a rehydration beverage proved equally effective in retaining fluids when given in a volume equal to body-mass loss, although their effects were not additive when combined in a drink.

Sweat sodium losses are larger than potassium losses, and it is partially on the basis that sodium is the primary cation lost in sweat that sodium is included in rehydration beverages. Shirreffs and Maughan (25) reported that sodium intake needs to be greater than sodium lost in sweat if subjects are to remain in positive fluid balance. This contention, however, is not supported by others; such discrepancies are most likely attributable to differences in study design. Considering the highly variable nature of sweat rates and sweat sodium concentrations (20–80 mmol/L) among individuals (27), it is not possible to prescribe an ideal drink formulation for all individuals in all conditions.
Nevertheless, for complete fluid restoration after dehydration, a volume greater than sweat loss must be consumed because of the ongoing obligatory urine losses that persist despite individuals being in body-water deficit (16, 26); sometimes, individuals do not have access to cool, dry areas for recovery after exercise, and ongoing sweat loss can be twice as high as ongoing urinary fluid losses (1). In day-to-day situations both psychological and physiological factors govern intake, so the palatability of ingested fluids can prove a determining factor in the rehydration process, especially considering the volumes that need to be consumed (22). Many factors influencing drink palatability have been investigated, including temperature, flavor, and carbonation (22). Passe et al. (23) reported that carbonated beverages have a negative impact on volitional intake, although whether or not beverages were carbonated or included carbohydrate they were equally effective in terms of fluid replacement after dehydration (9). Although the addition of sodium to fluids can increase volitional intake (21, 29), a high sodium content can make a drink unpalatable (18, 29). Commercially available sports drinks appear to meet a balance between efficacy and palatability and typically contain 10–30 mmol/L of sodium. Investigators have reported that a sports drink has a slight advantage over plain water in the restoration of fluid balance (7) and, taken in combination with its enhanced palatability (24), might confer a distinct advantage in terms of rehydration. It is important to consider both the volume and the composition of fluids ingested collectively because investigators have shown that despite adequate fluid intake, even up to twice that of body-mass loss (26), when electrolyte concentrations are low the resultant increase in urinary excretion is sufficient to leave subjects in negative fluid balance (1, 11, 26).

If the addition of potassium (25 mmol/L) or sodium (60 mmol/L) can confer similar benefits in terms of fluid retention (15), further scope in the variety of drinks suitable for consumption after exercise might occur, particularly if palatability becomes an issue. Published studies have included beverage-composition charts comparing popular hydration drinks, but very few have compared commercially available drinks experimentally. We were particularly interested in evaluating Apfelschorle, a carbonated apple-juice beverage commonly consumed in some regions of Europe and popular in Germany among both sportspeople and the general population. We are particularly interested in this because it typically consists of apple juice and carbonated mineral water mixed in a ratio of 60% to 40%, respectively, but it is also commercially available as a ready-to-drink product. In general, the sodium content of fruit juices tends to be very low, although apple juice and others are high in potassium, which makes Apfelschorle also relatively high in potassium. The fact that Apfelschorle has such a strong tradition of being consumed for hydration purposes, to the extent that people still take the time to prepare it when they could choose a drink involving less preparation, increases our interest in studying its effectiveness. We were also interested in evaluating mineral waters, which are perceived to be appropriate for rehydration because of their electrolyte (mineral) content, even though the minerals are present in small to insignificant amounts, particularly as far as sodium is concerned.

Therefore, the purpose of this study was to investigate the effectiveness in rehydrating subjects after intermittent exercise in the heat of Apfelschorle, European Gatorade, and San Benedetto mineral water, which are all regularly chosen as rehydration drinks in some European cultures, and to compare the effectiveness
of these with another commercially available mineral water (Evian) with a lower electrolyte content that is not generally chosen in the same way.

**Methods**

Eight healthy, physically active volunteers (4 men, 4 women) participated in this study, which had received prior approval from the local ethics committee. All subjects were informed about the experimental procedures and associated risks before their written consent to participate was obtained. Their physical characteristics (mean ± standard deviation) were age 23 ± 2 y, height 1.73 ± 0.03 m, body mass 68.92 ± 11.79 kg, body fat 20.3% ± 6.4%, and peak oxygen consumption (VO$_{2peak}$) 55.5 ± 10.7 mL·kg$^{-1}$·min$^{-1}$. It has been demonstrated previously that the menstrual cycle has no effect on acute fluid restoration after exercise (14), so we included both men and women in the study.

Subjects’ VO$_{2peak}$ was determined by way of a discontinuous exercise protocol on a cycle ergometer (Gould Corival 300, Groningen, Holland). Body fat was estimated using John Bull skinfold calipers according to the method of Durnin and Rahaman (6). One week before the first experimental trial, all subjects completed a familiarization trial in which they underwent all experimental procedures of the actual trials, but it was terminated immediately after the rehydration period. The 1 exception to this was that in the familiarization trial, blood samples were not taken from the subjects already accustomed to this procedure.

In all experimental trials sweat samples were collected during the exercise (dehydration) period by placing an absorbent patch (3M, Loughborough, UK) on the subjects’ backs after cleaning the skin with distilled, de-ionized water. The sweat patch was removed on completion of the exercise and immediately placed in a sealed container until analyzed. The volume of sweat in the patches was determined gravimetrically; then, an accurately weighed amount of distilled, de-ionized water (approximately 2 mL) was added to each tube. After thorough mixing, a diluted sample was removed and analyzed for sodium, potassium, and chloride concentration by ion chromatography (DX-80, Dionex, UK).

The remainder of the procedures used for this beverage-comparison study were as described in previous physiological studies (26), with the exception of the follow-up period, which was 4 h in this case, compared with 6 h in previously published studies. Previous work has shown that urine output is low and very similar among drinks of varying composition after 4 h (25). Briefly, we asked the subjects to keep a diary of their dietary and exercise regimens in the preceding 48-h period and to replicate their behaviors before each trial. All experimental trials started in the morning after an overnight fast and the consumption of 500 mL of water 2 h before the start of each trial. Venous blood samples were obtained on arrival, 30 min after the dehydration period, at the end of the rehydration period, and every hour for 4 h postrehydration; all samples were obtained after subjects sat quietly for 15 min. Urine samples were obtained at the same time points, with the participants’ emptying their bladders as completely as possible; the entire urine volume was measured, and a sample was kept for subsequent analysis. Subjective-feelings questionnaires regarding stomach fullness and bloatedness, using a 100-mm visual analogue scale, were filled out 5 min before each blood sample. Additional questions
regarding subjective perceptions of the test beverage (sweet, salty, pleasant) were asked at the end of the rehydration period.

Participants were dehydrated by exercising intermittently in an environmental chamber maintained at 36.0 ± 1.0 °C and 65% ± 5% relative humidity until approximately 2% body-mass loss was achieved. During the 1-h rehydration period of the experimental trials, subjects consumed one of the test beverages in a volume equal to 150% of the body-mass loss divided into 4 equal volumes; they ingested a carbohydrate-electrolyte solution (Gatorade), a water/apple-juice mixture (4 parts carbonated water [Highland Spring mineral water], 6 parts apple juice [Tesco apple juice]; Apfelschorle), or 1 of 2 brands of mineral water (Evian and San Benedetto; Table 1). The order of administration of test beverages was randomized using an incomplete Latin square.

Blood samples were analyzed for blood glucose concentration (GOD-PAP method, Randox, UK), spun hematocrit, and hemoglobin concentration (cyanmethemoglobin method); plasma-volume changes relative to the value postexercise were calculated according to Dill and Costill (5). Serum and urine samples were analyzed for sodium, potassium, and chloride concentrations by flame photometry and coulometric titration, and for osmolality, by freezing-point depression.

Data are expressed in text and tables as mean ± standard deviation or medians (range) when found not to be normally distributed and in figures as mean ± standard error of measurement. Data were analyzed by repeated-measures ANOVA followed by a 1-way ANOVA and Tukey or Dunnett post hoc test or Kruskal–Wallis and Mann–Whitney tests where appropriate. Statistical significance was set at \( P < 0.05 \).

### Results

#### Urine Volume and Fluid Balance

The subjects’ preexercise body mass was the same for all trials (Evian, 68.93 ± 12.56 kg; Apfelschorle, 68.77 ± 12.80 kg; Gatorade, 68.84 ± 12.49 kg; San Benedetto, 68.39 ± 12.13 kg; \( P = 1.000 \)), and there was a substantial body-mass loss over the exercise period in all trials equating to 1.33 ± 0.23 kg by the end of the exercise period. This is equivalent to a level of dehydration of 1.94% ± 0.17% of preexercise body mass. Exercise continued until subjects lost 1.71% ± 0.16% of their body mass, with the remaining 0.22% ± 0.16% lost during continued perspiration at the
end of exercise. The mean sweat sodium, potassium, and chloride concentrations were 64.2 ± 11.2, 4.8 ± 1.0, and 59.1 ± 12.6 mmol/L, respectively. These concentrations did not differ significantly between trials ($P = 0.839$, $P = 0.691$, and $P = 0.948$ for sodium, potassium, and chloride, respectively).

Subjects’ mean body fat was 20.1% ± 6.3% (16.1% ± 6.7% and 24.0% ± 2.7% for men and women, respectively). Based on the assumption that total-body water is 72% of lean body mass (10), subjects actually lost 3.5% ± 1.0% (2.7% ± 0.2% and 4.3% ± 0.8% for men and women, respectively) of their body-water content.

The time taken to reach the target body mass during the dehydration period was not significantly ($P = 0.916$) different between trials and took on average 81 ± 25 min (65 ± 16 and 98 ± 20 min for male and female subjects, respectively). There was no evidence of heat acclimation or a training effect—mean sweat rate was the same from week to week over the duration of the study ($P = 0.999$). Sweat loss was similar for each trial, so the volume of fluid consumed during the rehydration period was not significantly ($P = 0.994$) different between trials, with a mean intake for Evian of 2006 ± 364 mL, Apfelschorle of 1988 ± 376 mL, Gatorade of 1965 ± 348 mL, and San Benedetto of 2010 ± 360 mL.

Urine volume over time is shown in Figure 1. The total volume of urine produced by the end of the study period was 800 ± 277 mL in the Gatorade trial compared with 1155 ± 374 mL in the Evian trial ($P = 0.171$), 981 ± 333 mL in the Apfelschorle trial ($P = 0.729$), and 1022 ± 344 mL ($P = 0.857$) in the San Benedetto trial. A treatment effect on urine osmolality just failed to reach significance ($P = 0.054$), but it tended to mirror urine volume. The constancy of preexercise values for urine osmolality (475 ± 337 mosmol/kg, $P = 0.997$) and body mass suggests that each subject’s hydration status was similar before each trial and was considered euhydration.

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**Figure 1** — Urine output over the course of the experiment. Preexercise samples are not included. Points are mean values, and the group standard error of measurement is also shown for each time point.
Net fluid balance was calculated relative to the preexercise time point, taking into account the volumes of sweat lost, beverage ingested, and urine produced (Figure 2). The hydration status of the subjects was significantly lower than the pretrial situation in the trials with Evian (–529 ± 319 mL, \(P < 0.0005\)), San Benedetto (–401 ± 353 mL, \(P = 0.016\)), and Apfelschorle (–365 ± 319 mL, \(P = 0.030\)) but not in the Gatorade trial (–201 ± 388 mL, \(P = 0.549\)) at the end of the 4-h recovery period; this was apparent 3 h after rehydration in the Evian trial.

**Figure 2** — Whole-body net fluid balance over the course of the experiment. Preexercise urine sample not included in the calculations. Points are mean values, and the group standard error of measurement is also shown for each time point. *Significantly different from the preexercise hydration status for 1 trial. **Significantly different for 2 trials. ****Significantly different for all 4 trials (\(P < 0.05\)).

Net fluid balance was calculated relative to the preexercise time point, taking into account the volumes of sweat lost, beverage ingested, and urine produced (Figure 2). The hydration status of the subjects was significantly lower than the pretrial situation in the trials with Evian (–529 ± 319 mL, \(P < 0.0005\)), San Benedetto (–401 ± 353 mL, \(P = 0.016\)), and Apfelschorle (–365 ± 319 mL, \(P = 0.030\)) but not in the Gatorade trial (–201 ± 388 mL, \(P = 0.549\)) at the end of the 4-h recovery period; this was apparent 3 h after rehydration in the Evian trial.

**Electrolyte Balance**

Sweat samples were not collected on 1 subject, so electrolyte balance was calculated for 7 subjects. The sweat electrolyte losses did not differ between trials, but sodium and potassium intake did (Table 2). Despite the differences in sodium ingestion, no differences in urinary sodium excretion were observed between trials (36.2 ± 9.5, 36.2 ± 9.5, 32.9 ± 15.7, and 37.5 ± 20.7 mmol, for Evian, Apfelschorle, Gatorade, and San Benedetto, respectively, \(P = 0.556\)). Net sodium and potassium balance were calculated as for net fluid balance. Subjects remained in negative sodium balance for the entire follow-up period (Figure 3); by the end of the study, sodium balance was –122 ± 37 mmol in the Evian trial, –115 ± 36 mmol in the Apfelschorle trial, –67 ± 16 mmol in the Gatorade trial, and –125 ± 27 mmol in the San Benedetto trial.

Net potassium balance is shown in Figure 4. Only in the Apfelschorle trial did the subjects remain in positive balance at the end of the experiment, despite a
Table 2  Total Sweat Electrolyte Losses and Drink Electrolyte Intake, Mean ± Standard Deviation, mmol

<table>
<thead>
<tr>
<th>Drink</th>
<th>Evian</th>
<th>Apfelschorle</th>
<th>Gatorade</th>
<th>San Benedetto</th>
<th>P^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweat Na^+ loss</td>
<td>91 ± 32</td>
<td>90 ± 31</td>
<td>82 ± 24</td>
<td>89 ± 26</td>
<td>0.938</td>
</tr>
<tr>
<td>Sweat K^+ loss</td>
<td>5.9 ± 1.2</td>
<td>6.7 ± 1.5</td>
<td>6.2 ± 1.0</td>
<td>6.7 ± 1.5</td>
<td>0.594</td>
</tr>
<tr>
<td>Sweat Cl^- loss</td>
<td>84 ± 32</td>
<td>84 ± 32</td>
<td>77 ± 24</td>
<td>84 ± 28</td>
<td>0.969</td>
</tr>
<tr>
<td>Na^+ intake</td>
<td>1 ± 1</td>
<td>17 ± 3^b,c</td>
<td>51 ± 9^b,c,d</td>
<td>2 ± 1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>K^+ intake</td>
<td>0 ± 0</td>
<td>58.8 ± 11.2^b,c,e</td>
<td>11.4 ± 2.0^b,c</td>
<td>0 ± 0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cl^- intake</td>
<td>6 ± 10</td>
<td>2 ± 2</td>
<td>34 ± 7^b,c,d</td>
<td>9 ± 8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

^aP-values are calculated across all 4 trials.
^bHigher than Evian, P < 0.05.
^cHigher than San Benedetto, P < 0.05.
^dHigher than Apfelschorle, P < 0.05.
^eHigher than Gatorade, P < 0.05.

Figure 3 — Whole-body net sodium balance over the course of the experiment. Points are mean values, and the group standard error of measurement is also shown for each time point. A indicates Gatorade trial significantly different from Evian trial (P < 0.05); B, Gatorade trial significantly different from San Benedetto trial (P < 0.01); and C, Gatorade trial significantly different from Apfelschorle trial (P < 0.05).

A greater quantity of potassium being excreted than with Gatorade (39.1 ± 11.0 vs. 23.8 ± 6.1 mmol, respectively, P = 0.027).

No statistical differences were found in urinary chloride excretion among trials. Net cation balance was estimated from net sodium and potassium balance.
By the end of the study, the net cation deficit was significantly less in the Gatorade trial (–88 ± 15 mmol) than in the Evian (–156 ± 49 mmol, \( P = 0.010 \)) and San Benedetto trials (–163 ± 36 mmol, \( P = 0.004 \)) but similar to the Apfelschorle trial (–103 ± 38 mmol, \( P = 0.872 \)).

**Blood and Plasma Changes**

The first postexercise blood sample, obtained 30 min after the completion of exercise, showed a plasma-volume decline from preexercise values of 1.9% ± 3.5% across all trials (\( P > 0.05 \)). This did not differ significantly among trials (Figure 5). Immediately after the rehydration period (0 h), plasma volume was significantly lower (\( P = 0.050 \)) in the Apfelschorle trial than in all other trials. Expansion of plasma volume to a level greater than that before exercise was only achieved in the Gatorade trial, 3 h after the end of the rehydration period (\( P = 0.038 \)).

Table 3 shows serum osmolality and serum electrolytes over time. There was a tendency for serum osmolality to increase in all trials between pre- and postexercise samples, and this increase reached significance in the Apfelschorle trial (\( P = 0.026 \)). At no time did serum osmolality drop to levels significantly lower than preexercise values on any trial. Serum sodium concentration tended to increase with dehydration and decline after rehydration. Only in the Evian trial did this
Figure 5 — Changes in plasma volume over the course of the experiment. Points are mean values, and the group standard error of measurement is also shown for each time point. C indicates Gatorade trial significantly different from Apfelschorle trial \((P < 0.05)\); D, Apfelschorle trial significantly different from Evian trial \((P < 0.05)\); and E, Apfelschorle trial significantly different from San Benedetto trial \((P < 0.05)\).

Table 3 Serum Sodium Concentration and Osmolality Over the Experiment, Mean ± Standard Deviation

<table>
<thead>
<tr>
<th>Time after rehydration (h)</th>
<th>Evian</th>
<th>Apfelschorle</th>
<th>Gatorade</th>
<th>San Benedetto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(^+) (mmol/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre</td>
<td>140 ± 3</td>
<td>140 ± 3</td>
<td>140 ± 2</td>
<td>141 ± 3</td>
</tr>
<tr>
<td>post</td>
<td>141 ± 3</td>
<td>143 ± 3</td>
<td>142 ± 3</td>
<td>142 ± 1</td>
</tr>
<tr>
<td>0</td>
<td>137 ± 3</td>
<td>139 ± 3</td>
<td>141 ± 3</td>
<td>138 ± 3</td>
</tr>
<tr>
<td>1</td>
<td>137 ± 3</td>
<td>140 ± 4</td>
<td>139 ± 3</td>
<td>138 ± 4</td>
</tr>
<tr>
<td>2</td>
<td>134 ± 2</td>
<td>141 ± 5(^a)</td>
<td>140 ± 4(^a)</td>
<td>137 ± 2</td>
</tr>
<tr>
<td>3</td>
<td>139 ± 3</td>
<td>139 ± 2</td>
<td>140 ± 5</td>
<td>138 ± 3</td>
</tr>
<tr>
<td>4</td>
<td>139 ± 3</td>
<td>141 ± 5</td>
<td>139 ± 2</td>
<td>137 ± 4</td>
</tr>
<tr>
<td>Osmolality (mosmol/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre</td>
<td>285 ± 7</td>
<td>284 ± 3</td>
<td>286 ± 5</td>
<td>286 ± 5</td>
</tr>
<tr>
<td>post</td>
<td>291 ± 8</td>
<td>290 ± 4</td>
<td>293 ± 7</td>
<td>292 ± 5</td>
</tr>
<tr>
<td>0</td>
<td>280 ± 7</td>
<td>289 ± 4(^a)</td>
<td>294 ± 6(^ab)</td>
<td>281 ± 2</td>
</tr>
<tr>
<td>1</td>
<td>280 ± 8</td>
<td>284 ± 2</td>
<td>285 ± 5</td>
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<td>286 ± 6</td>
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<td>281 ± 2</td>
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<td>285 ± 1</td>
</tr>
<tr>
<td>4</td>
<td>282 ± 6</td>
<td>284 ± 3</td>
<td>285 ± 5</td>
<td>285 ± 7</td>
</tr>
</tbody>
</table>

\(^{a}\)Higher than Evian, \(P < 0.05\).

\(^{b}\)Higher than San Benedetto, \(P < 0.05\).
decline reach significance 2 h after the end of the rehydration period compared with pre- and postexercise levels. Serum potassium was little affected over the course of the experiment. Serum chloride concentration followed a pattern similar to that of serum sodium, but at no time did serum chloride concentrations differ significantly between trials.

Blood glucose concentration did not change over the duration of the 2 water trials, but in the Gatorade and Apfelschorle trials, it increased significantly at the end of the rehydration period to concentrations of 7.83 ± 0.98 and 6.99 ± 0.88 mmol/L, respectively, before declining back to preexercise levels within 1 h.

**Subjective Feelings and Drink Palatability**

A significant difference ($P < 0.001$) was observed for drink sweetness, with subjects reporting Apfelschorle (70 [51–89]) and Gatorade (63 [28–98]) to be sweeter than both Evian (7 [0–16]) and San Benedetto (2 [0–18]; median [range]). A significant difference ($P = 0.022$) in drink saltiness was also observed, with Gatorade (41 [3–83]) tending to taste more salty than Evian (7 [0–59], $P = 0.038$) and San Benedetto (7 [0–16], $P = 0.010$). No significant differences in drink pleasantness ($P = 0.414$) or feelings of fullness ($P = 0.602$) or bloatedness ($P = 0.644$) were identified among trials.

**Discussion**

This study investigated the effectiveness of 4 commercially available beverages in restoring fluid and electrolyte balance after exercise-induced dehydration of 1.94% ± 0.17% body mass. Despite ingesting a volume equal to 150% of body-mass loss, subjects in the Evian, San Benedetto, and Apfelschorle trials were in a lower hydration status than they had been at the start of the study, but in the Gatorade trial subjects were essentially not different from their pretrial hydration status, suggesting that they were euhydrated. The difference in fluid balance at the end of the study period was 328 mL (~0.5% of body mass) between the Gatorade and Evian trials. This difference is small in terms of total-body water, and it is debatable as to whether it would be meaningful.

Commercially available solutions have been investigated for their effectiveness in rehydration in the past. Gonzalez-Alonso et al. (7) reported that the ingestion of a carbohydrate-electrolyte solution resulted in more effective rehydration than plain water or diet cola, and others have observed lower urine output with a glucose-electrolyte solution than with water (3). In both studies a volume equivalent to body-mass loss was ingested, and as a result of ongoing urine excretion, subjects were in a negative fluid balance throughout. In the current study a volume equal to 150% of body-mass loss was ingested and subjects were essentially euhydrated in the Gatorade trial at the end of the experiment. Although Maughan et al. (13) reported that the consumption of a sports drink rendered subjects in negative fluid balance despite a volume ingested equivalent to 150% body-mass loss, studies differed in length and drink composition.

The beverages consumed in the current study were all commercially available products, or in the case of the Apfelschorle homemade from commercially available products. Therefore, the drinks differed from each other in several respects.
European Gatorade is higher in sodium than Gatorade in other countries (23 vs. 18 mmol/L), and mineral waters vary widely in their electrolyte content, especially sodium. The predominant electrolyte in Apfelschorle was potassium and in Gatorade was sodium, whereas both Evian and San Benedetto had negligible electrolyte content (Table 1). The addition of either potassium (25 mmol/L) or sodium (60 mmol/L) to a rehydration beverage has been reported to confer a similar benefit in terms of fluid retention when given in a volume equal to body-mass loss (15).

There is a need to replace the electrolytes lost in sweat after exercise, and because sodium is the primary cation in sweat, its replacement is a priority. In this study sweat composition was measured, which allowed us to calculate whole-body electrolyte balance. Sweat sodium concentrations have been estimated to be between 20 and 80 mmol/L (27), and the values obtained in this study fall in the upper half of this range (65 ± 11 mmol/L). Shirreffs and Maughan (25) have reported that for subjects to remain in positive fluid balance, the amount of sodium they consume needs to be greater than sweat sodium loss. In no trial in the current study was sufficient sodium consumed to replace losses, and in combination with urinary sodium excretion, subjects were in sodium deficit throughout, yet subjects in the Gatorade trial were essentially euhydrated at the end of the study. Previously, Mitchell et al. (17) reported that when sufficient volume was ingested, rehydration was achieved after consuming a beverage with a sodium concentration of 25 mmol/L, despite subjects’ remaining in negative sodium balance.

Potassium losses in sweat were small in comparison with sodium losses, but only in the Apfelschorle and Gatorade trials were sufficient amounts ingested to replace losses. In the Apfelschorle trial, potassium intake was ~900% greater than the sweat loss, and despite the tendency for increased potassium excretion compared with all other trials, subjects remained in positive potassium balance at the end of the study period.

In the study of Shirreffs and Maughan (25), the drinks administered contained little potassium (~0.6 mmol/L), whereas both sodium and potassium were present in Apfelschorle and Gatorade, so cation balance might allow a closer comparison between the 2 studies. Net fluid balance was significantly correlated with both net cation balance ($R^2 = 0.161$, $P = 0.03$) and net sodium balance ($R^2 = 0.145$, $P = 0.04$) at the end of our study.

The water lost in sweat is derived from all body compartments, but most of it is likely to originate from the extracellular space, especially during exercise in the heat (8). Our subjects experienced a nonsignificant 1.9% ± 3.5% decline in plasma volume between pre- and postexercise samples. It is possible that during the 30-min period that elapsed between the completion of exercise and the collection of the first postexercise blood sample a recovery of plasma volume occurred (19, 21).

The presence of potassium and sodium ions in a beverage might influence how the fluid is distributed among body-fluid compartments. The recovery of plasma volume to levels greater than postexercise was achieved 1 h after rehydration in the Gatorade trial, whereas in the Evian and San Benedetto trials this was achieved 3 h later. Costill and Sparks (3) reported that the ingestion of a glucose-electrolyte beverage resulted in a greater recovery of plasma volume than did plain water, and other investigators (21, 25, 29) have reported a preferential restoration of plasma volume after the ingestion of sodium-containing beverages. In some instances this resulted in an expansion above preexercise levels, as was seen in the current study.
In contrast, when the primary electrolyte in a beverage is potassium, its consumption after exercise has been reported to result in a slower rate of plasma-volume recovery than with beverages with low electrolyte content or that contained predominantly sodium (15, 19). This initial delay in plasma-volume recovery has been suggested to be the result of a preferential restoration of the intracellular fluid compartment, and it is possible that this occurred in the current study when Apfelschorle was consumed. Neither Maughan et al. (15) nor Nielsen et al. (19), however, reported a further decline in plasma volume immediately after rehydration as seen in the Apfelschorle trial. We cannot explain this result by a possible delay in fluid delivery, because both carbohydrate content and osmolality were reasonably low in the drink we used (28).

A sports drink has been reported to be more palatable than a range of commonly used beverages, including water (24), enhancing voluntary fluid intake. In the present study a fixed, statistically identical volume was consumed for all drinks. No differences were found in drink pleasantness, despite them differing in carbonation, saltiness, and carbohydrate content.

The objective differences between commonly used drinks that we have documented here must be balanced with their cost and availability, as well as with the cultural preferences of the active consumers. As mentioned in the introduction, water is the preferred choice of most of these consumers. If they are choosing mineral waters for their perceived rehydration benefits resulting from their electrolyte content, our data suggest that consumers are not making the best choice.

Summary

When a volume equal to 150% of body-mass loss was consumed after exercise-induced dehydration of 1.94% ± 0.17% body mass, subjects were essentially in the same hydration status as before the dehydrating exercise in the Gatorade trial but were in a significantly lower hydration status than the pretrial situation in the Apfelschorle, Evian, and San Benedetto trials 4 h after rehydration. Restoration of hydration status to the same levels as before the dehydrating exercise was achieved with only partial replacement of sweat sodium losses by Gatorade. Despite complete restoration of sweat potassium losses in the Apfelschorle trial, subjects did not recover to their preexercise hydration state. Although the published scientific evidence allows us to predict with reasonable certainty whether a drink will be more or less effective at restoring sweat losses after exercise, it does not prevent more traditional drinks from being chosen for this purpose. In situations when rehydration effectiveness is important, athletes would be advised to select a drink that has been shown to better meet this specific purpose.

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References


