Effects of dehydration on gastric emptying and gastrointestinal distress while running

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ABSTRACT

REHRER, N. J., E. J. BECKERS, F. BROUNS, F. TEN HOOR, and W. H. M. SARIS. Effects of dehydration on gastric emptying and gastrointestinal distress while running. Med. Sci. Sports Exerc., Vol. 22, No. 6, pp. 790–795, 1990. Gastrointestinal distress is commonly reported by athletes after ingestion of a beverage. We speculate that ingestion may be occurring after dehydration has taken place. The high prevalence of GI disorders in marathon runners who have lost ≥4% body weight supports this theory. To test this theory, the effects of dehydration, and dehydration in combination with endurance running, on gastric emptying (GE) and frequency of gastrointestinal (GI) complaints were tested in this experiment. A complete crossover study was designed. Sixteen subjects ingested 8 ml·kg BW⁻¹ of a 7% carbohydrate (296 mOsm·kg⁻¹) solution after a euhydration or dehydration regime. Dehydration (4% BW loss) was produced by 60% maximal speed running at 30°C or by intermittent sauna exposure at 100°C. euhydration experiments were conducted with a 2 h rest period with water administered at 20 and 40 min. Gastric emptying volumes were measured every 10 min for 40 min. Emptying curves were compared using semi-log transformation of the percentage emptying data and simple linear regression. The slope of each line was used as a measure of average GE rate. Dehydration-exercise resulted in slower GE than in all other treatments (P < 0.05). ANOVA revealed significant effects of dehydration (P < 0.05) and exercise (P < 0.05), these two effects being additive in delaying GE. GI complaints were reported by 37.5% of the subjects during dehydration-exercise experiments. No GI disturbance was reported in other tests. Core body temperature was significantly higher after the dehydration-exercise regime (39.1°C) than after the rest-dehydration regime (37.9°C) (P < 0.05). It is concluded that dehydration and/or thermal effects delay GE and may be related to a higher prevalence of GI disturbance.

HYPOHYDRATION, EXERCISE, GI FUNCTION, STOMACH

There appears to be a relationship between dehydration during endurance exercise and gastrointestinal dysfunction. Results of a field study indicate that body weight losses in the range of 4–5% during marathon running are associated with an increased prevalence of gastrointestinal (GI) disorders (16).

Neuffer et al. (12) observed delayed gastric emptying (GE) in a laboratory study where body weight loss averaged 5%. Reports by endurance athletes who complain of GI problems occurring only after they drink during long competition may partly be explained by these results. Contrarily to the supposition that GI disturbance is caused by the ingestion of fluid is the finding from laboratory experiments that, following ingestion of fluid (150–600 ml), GI complaints were virtually nonexistent at rest as well as during bicycling and running (14,15). The discrepancy may be partly due to the fact that, in practice, the athletes that complain of GI disturbance after drinking may only be drinking after dehydration has already occurred, as it is known that voluntary fluid consumption during exercise does not keep pace with needs (10,18). The intention of the present study was to evaluate the effects of dehydration, exercise, and the combination of dehydration with exercise on gastric emptying and the prevalence of gastrointestinal complaints.

MATERIALS AND METHODS

Subjects

Only male individuals who had completed half-marathons or longer competitions and were presently conducting occasional training runs in excess of 1.5 h were allowed to participate in the experiments.

Subject characteristics are presented in Table 1. All subjects received a complete written description of the experiment and were provided with an informed consent form to sign. Pre-trials were conducted including a maximal exertion test on a treadmill. After warming up for 10 min at 10 km·h⁻¹, the speed of the treadmill was increased by 2 km·h⁻¹ every 2.5 min until the heart reached 160 bpm (150 bpm for subjects who were known to have a lower maximal heart rate), at which point the speed was increased by 1 km·h⁻¹ every 2.5 min until exhaustion. After the maximal exertion test, trial placement of a nasogastric tube was conducted to allow for self-selection and to reduce anxiety on the first test day.
TABLE 1. Subject characteristics (males; N = 15).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>30.9</td>
<td>±1.80</td>
<td>(22-41)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.9</td>
<td>±1.46</td>
<td>(64-83)</td>
</tr>
<tr>
<td>Max. running speed (km-h⁻¹)</td>
<td>19.2</td>
<td>±0.26</td>
<td>(18-22)</td>
</tr>
</tbody>
</table>

Protocol

Subjects were instructed to eat and drink normally and to do only light training the day prior to an experiment. No solid food was to be consumed 12 h prior to coming to the laboratory. However, during the evening prior to the laboratory visit all fluids were allowed. On the morning of the experiment only water was to be consumed. At 8:00 a.m. subjects came to the laboratory and consumed a liquid breakfast consisting of 5 ml·kg BW⁻¹ Meritine®, a low fat liquid meal containing 24% protein, 13% fat, and 63% carbohydrate. The mean energetic content of this meal was 1500 kJ. Exactly 1.5 h after breakfast, a nasogastric tube was placed. Thirty minutes thereafter, subjects began the hydration or dehydration regime. The stomach contents were emptied, the stomach was rinsed, and a recovery test was completed, as has been fully described elsewhere (14).

Treatments

All treatments were conducted on separate days over a 3 month period, with no testing of any one subject on sequential days. A complete cross-over design was utilized. Fifteen of the original 16 subjects recruited completed all treatments.

Dehydration-exercise treatment. The dehydration-exercise experiment (DE) was conducted in the laboratory where a constant dry-bulb temperature of 30°C was maintained. Relative humidity ranged from 52-55%. During this treatment, subjects ran on a treadmill at 60% maximal speed. Although oxygen consumption was not measured, heart rate was monitored continually during the maximal exertion test. The heart rates corresponding to this exercise intensity were well below the anaerobic threshold. (No plateauing of heart rate was seen, and several of the subjects had conducted maximal exertion tests prior to this experiment where oxygen consumption was measured.) The speed was chosen to simulate that of a long training run. Subjects found this speed quite slow at the beginning of the experiment, but the majority found it difficult to maintain in the latter stages of the experiment. A fan was continually blowing directly on each subject and any visible sweat was periodically wiped off with a towel. Subjects ran until 4% body weight loss was achieved or until 2 h, whichever came first. A time limit was set to preclude extreme differences in time to last meal, which may influence gastric emptying. In addition, the time limit was set to avoid the possibility of exhaustion occurring before the experiment was completed. Subjects were briefly stopped to be weighed (after towel drying), after 1 h and thereafter at intervals of 30 or 15 min. As the weight loss approached 4%, the time between weighings was shortened. After 2 h, or when 4% body weight loss was achieved, subjects stopped running briefly for complete drying and final body weight measurements. All clothes were removed, except running shorts, as was done for initial body weight measurements. In 10 of the 16 subjects, rectal temperature was also taken immediately after this first dehydration phase was completed. Immediately following measurements, the subjects returned to the treadmill where 8 ml·kg BW⁻¹ of an isotonic, carbohydrate-electrolyte containing beverage (Isostar®) was administered and 60% max exercise was continued. Thereafter samples were taken for 40 min to determine volume of drink still present in the stomach, as well as gastric secretion, at several points throughout the emptying curve. All beverages were administered and samples were extracted via the nasogastric tube.

Dehydration-rest treatment. In the dehydration-rest experiments (DR), a 2 h sauna-dehydration regime replaced the dehydration-exercise regime. Subjects were repeatedly exposed to a dry sauna (100°C) for intervals of 12-15 min with intermittent cooling-off periods of 10-12 min. After each sauna exposure, subjects dried off and were weighed. When 4% body weight loss was achieved, or when 2 h had elapsed, subjects dried off and final body weights and rectal temperatures were taken. The subjects then sat down and were administered 8 ml·kg BW⁻¹ of the test beverage and gastric samples were taken.

Euhydration-exercise treatment. For euhydration experiments, the 2 h dehydration protocol was replaced by a 2 h wait period where 250 ml tap water was administered at 20 min and 40 min. In the euhydration-exercise experiment (EE), subjects began warming-up for 10 min (2 km·h⁻¹ less than 60% max speed) at 1 h 50 min, then at 2 h the test drink was administered, thereafter 60% max exercise started.

Euhydration-rest treatment. In the euhydration-rest experiment (ER), subjects remained sitting while the isotonic, carbohydrate-electrolyte beverage was administered and samples were being taken. In all treatments, subjects were asked to urinate immediately prior to the beginning of the 2 h hydration or dehydration phase and again after 2 h, immediately prior to the consumption of the test beverage and the 40 min GE test period. This was done to standardize pre-experimental conditions and to reduce the likelihood of the need to urinate during the run. If subjects needed to urinate during the dehydration period, body weights were taken before and after so as to correct for this loss when calculating 4% body weight loss.
Gastric Emptying Measurements

The colorimetric double-sampling technique of George, as modified by Beckers et al. (2), was used to measure remaining drink volumes and secretion volumes. Emptying rate of the isotonic, carbohydrate-electrolyte beverage, following the hydration or dehydration regime, was measured over a 40 min period. Samples were taken at 0, 10, 20, 30, and 40 min according to protocol (Fig. 1).

Statistics

To make comparisons between treatments possible, transformation of the data was performed. The percentage of the original bolus that was emptied at a given time was first calculated, since each subject was given a slightly different volume dependent upon body weight. Since the emptying curves were exponential, a semi-log transformation of the percentage data was then made. The slopes of the linear regression lines were compared to give a figure for the speed of emptying over the total emptying curve. Analysis of variance (ANOVA) was conducted to test the effects of hydration and exercise and to account for inter-individual differences. Differences among selected treatment means were compared using Wilcoxon's sign rank test. A level of significance was set at 0.05. Data are presented as means and standard errors of means.

RESULTS

The mean running time for the dehydration protocol was 1.87 h, with a range of 1.35–2.00 h. Average absolute weight loss was 2.64 kg ± 0.98 representing 3.74% ± 0.26 of the total body weight. Neither weight loss nor average time to loss was significantly different in the sauna experiment. However, rectal temperature was significantly higher as a result of exercise in combination with dehydration (Table 2).

Gastrointestinal distress was reported by six of the original 16 subjects (37.5%) during the dehydration-exercise experiment. Complaints included stomach ache, nausea, vomiting, and lower abdominal pain. Nausea was often accompanied by slight vertigo. In the majority of instances, the symptoms occurred immediately after ingestion of the test beverage. In some subjects the symptoms persisted; however, in the majority of the subjects the symptoms were of short duration (less than 10 min). One subject vomited during the DE test and withdrew from the experiment. No gastrointestinal disturbance was reported during the dehydration-rest experiment or during the euhydration experiments.

Gastric emptying (GE) rates, based upon slopes of the transformed data, varied significantly as a result of exercise and dehydration. No significant differences between mean emptying rates of euhydration-rest (ER), euhydration-exercise (EE), and dehydration-rest (DR) were observed. However, there was a trend for mean emptying rate of ER to be faster than DR or EE. Dehydration-exercise (DE) resulted in the slowest GE, being significantly slower than all other treatments (Table 3).

ANOVA revealed a significant main effect of dehydration and exercise on GE (P < 0.05). The effects, both to slow GE, were additive. Subject, included as a dependent variable, was also found to be highly significant (P < 0.01). Inter-individual differences in GE are known to be large, certain individuals being characterized by a slow GE, others by a faster GE (6). These consistent differences between individuals can mask treatment differences when comparing treatment

<table>
<thead>
<tr>
<th>DE</th>
<th>sitting</th>
<th>exercise</th>
<th>dehydration</th>
</tr>
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<tbody>
<tr>
<td>DR</td>
<td>sitting</td>
<td>sauna</td>
<td>sitting</td>
</tr>
<tr>
<td>EE</td>
<td>sitting</td>
<td>exercise</td>
<td>500 ml water intake</td>
</tr>
<tr>
<td>ER</td>
<td>sitting</td>
<td>sitting</td>
<td>500 ml water intake</td>
</tr>
<tr>
<td>8.00</td>
<td>10.00</td>
<td>12.00</td>
<td>12.40</td>
</tr>
<tr>
<td>breakfast</td>
<td>start</td>
<td>drink</td>
<td>end</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
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</table>

<table>
<thead>
<tr>
<th>DR</th>
<th>DE</th>
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</thead>
<tbody>
<tr>
<td>Rectal temp. (°C)</td>
<td>37.80</td>
</tr>
<tr>
<td>±0.14</td>
<td>±0.12</td>
</tr>
<tr>
<td>Absolute body weight loss (kg)</td>
<td>2.40</td>
</tr>
<tr>
<td>±0.11</td>
<td>±0.10</td>
</tr>
<tr>
<td>Relative body weight loss (%)</td>
<td>3.53</td>
</tr>
<tr>
<td>±0.13</td>
<td>±0.07</td>
</tr>
</tbody>
</table>

Values are mean ± SE. * DR vs DE significant difference (P < 0.01).

TABLE 3. Slopes of gastric emptying curves after semi-log transformation.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Slope</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydration Exercise (DE)</td>
<td>-0.0301*</td>
<td>0.007</td>
</tr>
<tr>
<td>Dehydration Rest (DR)</td>
<td>-0.0402*</td>
<td>0.010</td>
</tr>
<tr>
<td>Euhydration Exercise (EE)</td>
<td>-0.0409*</td>
<td>0.011</td>
</tr>
<tr>
<td>Euhydration Rest (ER)</td>
<td>-0.0463*</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Different letters as superscripts identify statistically significant differences in treatment means (P < 0.05).
means. However, the relative effect of a certain treatment is evident when the influence of inter-individual variation is included in the ANOVA.

To illustrate the shape of the actual emptying curves, the data for DE and EE, expressed as a percent of the original @600 ml bolus, are plotted in Figure 2A. During exercise, only 18.9% of the original drink remained with EE whereas with DE 30.2% remained after 20 min. After 40 min, 1.7% and 9.3%, respectively, remained. Logarithmic transformation of these data display linearity, r for EE being 1.0 and 0.98 for DE (Fig. 2B). In Figure 3A, the other most important comparison is displayed, that of DR versus ER. Also during rest, prior dehydration tended to slow GE of the isotonic beverage, although not significantly as was the case when dehydration and exercise were combined. Semi-log curves are displayed in Figure 3B, these transformed data also displaying linearity.

DISCUSSION

The results of the present study support those of Neuffer et al. (12) in demonstrating a delayed GE as a result of dehydration and thermal stress during exercise. Owen et al. (13), however, saw no effect of a warm environment (35°C) on gastric emptying during a 2 h run as compared to a similar 2 h run in a cooler environment (25°C). However, in Owen et al.'s study, fluid was given throughout exercise and not only after dehydration, as in the present study. Another point to be taken into consideration when evaluating Owen et al.'s results is the lack of gastric secretion measurements. Only total gastric volumes were compared, which can often be misleading when the intent is to measure the emptying of one beverage relative to another, or in one condition versus another. To make valid comparisons, the amount of actual drink emptied must be known. An example of the difference that can be obtained in results is found in earlier work of Foster et al. (8), where apparent differences between GE rates of two drinks of varying compositions, based upon total gastric residue, were no longer significant when secretion was accounted for (11). Also, differences that may have been apparent when points along the total emptying curve are known may not be apparent when the drink volume is measured only at the end of the protocol. An example of the significance of these differences can be observed in a comparison made in our
laboratory of the effect of exercise intensity on gastric emptying (14).

It is impossible to conclude, based on the results of the present experiment, whether the determining factor in slowing gastric emptying is the rise in core body temperature or the dehydration per se. Neuper et al. (12) did find a highly significant inverse correlation between rectal temperature and the amount of water emptied from the stomach after a 400 ml bolus during 15 min of running at 50% VO2max. Similarly, a significant negative correlation was found between heart rate and GE. Since in both Neuper's experiment and in the present experiment a rising core body temperature was found in combination with dehydration, the ultimate causative factor is impossible to isolate during exercise-dehydration experiments. In the present study, results of the rest experiment in the sauna, where rectal temperature was lower than during dehydration-exercise and GE was faster, tend to point to a thermal effect controlling GE. However, during exercise there are other factors to be taken into account. During exercise, the circulation to the abdominal viscera can be decreased by as much as 70–80% (5). Thus, this difference in the two experiments, DE versus DR, must not be overlooked. In addition, during dehydration blood volume is reduced. Costill and Fink (7) found a plasma volume decrease of 16–18% with body weight loss of 4%. This decrease in circulation to the GI region in combination with a decreased blood volume may bring about the disturbance in normal GI function, which is manifested by a decreased gastric emptying.

This alteration in GI function may be related to the common occurrence of GI complaints in this study when exercise and dehydration were combined. Ischemia of the gastrointestinal region may be related to these symptoms. The theory proposed by Hubbard et al. (9) of energy depletion (at a cellular level) in relation to hyperthermia may also explain the relationship that is observed between dehydration and alteration of GI function. Although the role of dehydration in predisposing one to GI malfunction during endurance running is given support by these results, numerous others factors most certainly may be of influence in runner's GI disturbance. The effect of catecholamines and opiate-like substances in the blood as a result of intense exercise (3) are known to influence motility and may delay gastric emptying (4). Levels of numerous GI hormones are also known to be altered as a result of marathon running and may also be involved in the development of GI irregularities (17).

The stress situation of a race and metabolic changes associated with it might also not be left out of the picture. Physical as well as mental stress is known to influence GI function (1). The high frequency of GI disturbance reported in field marathon studies (40–50%) versus the prevalence in the present laboratory study (37.5%) may reflect the difference in stress experienced by runners. In addition to the difference in psychological state, there is the difference in exercise intensity. The standardized nature of the laboratory study must also be taken into consideration. In addition to the familiar, noncompetitive sphere, there is the pre-exercise dietary regime. The fact that breakfast was liquid, low-fat, and low-fiber and was consumed at least 2 h before exercise and that no residue was in the stomach when exercise started may also have reduced the risk of GI disturbance. Nevertheless, when all these factors are held constant, the effect of dehydration on gastric function is clearly to delay emptying and increase the risk of GI complaints when combined with endurance running.

CONCLUSIONS

Based upon the results of the present study, which support those of Neuper et al. (12), it can be concluded that effects of dehydration (and hyperthermia) during endurance running not only may affect performance by reducing cooling capacity but may also play a role in predisposing one to GI symptoms. From earlier work in this laboratory (15) it has been shown that quite large quantities (@900 ml·h⁻¹) of water as well as carbohydrate-electrolyte-containing beverages are well tolerated during rest as well as during endurance bicycling and running. In addition to being well tolerated, they are also quite readily emptied (@800 ml·h⁻¹). In the present study, however, dehydration associated with a body weight loss of 3.5–4% during endurance running has been observed to bring about a delayed GE of a similar bolus, as well as an increased risk of GI distress. The lesson is quite clear to the athlete who will attempt to supplement fluids during exercise: drink sufficiently early on during a potentially dehydrating exercise bout, before a state of dehydration is reached. Drinking during endurance running after dehydration where 3.5–4% of the body weight is lost, is less than efficient in reinstating fluid balance and may possibly lead to GI problems.

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REFERENCES


