Gastric Emptying With Repeated Drinking During
Running and Bicycling

N. J. Rehner, F. Brouns, E. J. Beckers, F. ten Hoor, and W. H. M. Saris
University of Limburg, Nutrition Research Center, Dept. of Human Biology, Maastricht, The Netherlands

Abstract


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The high prevalence of gastrointestinal complaints in long-distance runners makes the movements specific to this type of exercise suspected of causing a disruption of normal gastrointestinal function. Gastric emptying rate is one indicator thereof. In the present study trained volunteers performed similar repeated fluid ingestion tests while running and while bicycling for 80 min at 70% $\text{VO}_{2}\text{max}$. Control tests at rest were also conducted. Two drinks containing carbohydrate were tested, one hypertonic, and one isotonic. Artificially sweetened water was used as a control. Gastric emptying rate of the isotonic drink, expressed as a percentage of the volume in the stomach at the beginning of each measurement period, did not differ between cycling and running during the first 40 min and was faster during cycling than during running between 40 and 80 min. With the hypertonic drink no differences between cycling and running were observed. In comparing gastric emptying rates after each sequential bolus, at rest, the isotonic drink was observed to maintain a high emptying rate, equal to that of water, whereas the hypertonic drink emptied more slowly after the first 20-min period. A similar pattern was observed during both running and cycling. The isotonic drink continued to empty quickly after the initial 20 min, whereas GE rate of the hypertonic drink decreased after the initial 20 min.

Key words

gastric emptying, biking, running, repeated drinking

Introduction

Long, distance runners often experience gastrointestinal (GI) problems during competition. Problems of the upper and lower GI tract including stomach ache, nausea, vomiting, intestinal cramp, and diarrhea are common. The prevalence of GI distress among marathon runners typically ranges from 30-50% (11, 17, 18, 20). There is little documentation of these types of problems in cyclists and practitioners of other sports where the body remains relatively stable. This suggests that the type of body movements involved in running brings about alterations in normal gastrointestinal function. However, the mechanisms by which the alterations occur are largely unknown. One possibility is that gastric emptying (GE) may be delayed, possibly as a result of intestinal membrane alterations (absorption and/or secretion possibly being affected). Distention of the stomach due to delayed emptying and pressure in the intestines due to increased secretion and/or malabsorption may possibly result in distress in these areas. Also, altered GE rate may be a signal of a disturbed motor activity of the stomach (19) or hormonal milieu (5) and, as such, delayed GE may be a result of GI dysfunction rather than being causative. In either case, if GI function is disturbed, GE should be one of the indicators thereof. Since runners appear to be particularly prone to these problems, it is theorized that GE will be reduced to a greater degree while an individual is running than when he is bicycling.

Data from studies of gastric emptying during moderately to highly intensive exercise are conflicting. A delay, acceleration, or no change has been observed (6, 8, 13, 15, 16, for review see 3).

To evaluate other studies, the effect of the protocol must be taken into consideration. The majority of GE studies done during exercise have been conducted following administration of one bolus. In the practical situation an endurance athlete consumes beverages repeatedly during competition, dictated by the organization of refreshment posts at specific intervals in the case of running or, in the case of bicycling, by the route or situation among other cyclists (consumption taking place while coasting or riding where a less intense effort is required).

It is possible to speculate that GE rate follows a different pattern when the stomach is continually refilled than when the stomach is filled only once and contains a gradually decreasing volume with the passage of time. Volume is one of the positive effectors of GE, a larger volume tending to empty at a quicker rate than a smaller one, up to a maximum of 600...
Table 1 Subject characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>31.0 ± 1.5</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.9 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>Bicycling VO2max (l·min⁻¹) (ml·min⁻¹·kg⁻¹·BW⁻¹)</td>
<td>4.5 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>HR 70% VO2max (b. p. m.)</td>
<td>148.0 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>WM (Watts)</td>
<td>374 ± 11.1</td>
<td></td>
</tr>
<tr>
<td>Running VO2max (l·min⁻¹) (ml·min⁻¹·kg⁻¹·BW⁻¹)</td>
<td>4.4 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>HR 70% VO2max (b. p. m.)</td>
<td>148.8 ± 3.7</td>
<td></td>
</tr>
<tr>
<td>Km max (km·h⁻¹)</td>
<td>17.7 ± 0.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Drink compositions

<table>
<thead>
<tr>
<th>Drink</th>
<th>I</th>
<th>H</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osmolarity (mOsm·kg⁻¹)</td>
<td>286</td>
<td>444</td>
<td>40</td>
</tr>
<tr>
<td>Energy (kJ·100 ml⁻¹)</td>
<td>126.8</td>
<td>312.4</td>
<td>14.4</td>
</tr>
<tr>
<td>pH</td>
<td>4.0</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Sucrose (g·100 ml⁻¹)</td>
<td>6.0</td>
<td>3.0</td>
<td>—</td>
</tr>
<tr>
<td>Maltose (g·100 ml⁻¹)</td>
<td>1.0</td>
<td>1.5</td>
<td>—</td>
</tr>
<tr>
<td>Maltodextrin (g·100 ml⁻¹)</td>
<td>0.9</td>
<td>13.7</td>
<td>—</td>
</tr>
<tr>
<td>Glucose (g·100 ml⁻¹)</td>
<td>0.1</td>
<td>0.4</td>
<td>—</td>
</tr>
<tr>
<td>Fructose (g·100 ml⁻¹)</td>
<td>0.1</td>
<td>3.2</td>
<td>—</td>
</tr>
<tr>
<td>Sodium (mg·100 ml⁻¹)</td>
<td>58.0</td>
<td>26.0</td>
<td>—</td>
</tr>
<tr>
<td>Potassium (mg·100 ml⁻¹)</td>
<td>15.0</td>
<td>8.4</td>
<td>—</td>
</tr>
<tr>
<td>Chloride (mg·100 ml⁻¹)</td>
<td>49.0</td>
<td>26.0</td>
<td>—</td>
</tr>
<tr>
<td>Calcium (mg·100 ml⁻¹)</td>
<td>9.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Magnesium (mg·100 ml⁻¹)</td>
<td>8.0</td>
<td>12.8</td>
<td>—</td>
</tr>
<tr>
<td>Phosphorus (mg·100 ml⁻¹)</td>
<td>8.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Aspartame (mg·100 ml⁻¹)</td>
<td>—</td>
<td>—</td>
<td>8.0</td>
</tr>
</tbody>
</table>

700 ml (6). It is theorized that pressure receptors respond to the load placed by an increased gastric content and signal for an enhanced GE (10).

However, a number of other characteristics of the drink or meal can decrease the GE rate, such as glucose (energy) content and osmolality, pH, temperature, and the presence of other specific inhibitory nutrients.

One may speculate that under identical circumstances a particular drink will continually empty at a rapid rate when a large volume is maintained through repeated feedings, similar to the rate seen early on in a one bolus study, when the volume is large.

The purpose of the present study was two-fold, to examine the effects of running and bicycling on gastric emptying and to test the effect of repeated drinking on GE rate. More specifically: Is the fast-phase emptying noted in the first 10 min after receiving a large bolus continued with repeated drink ingestion?

Materials and Methods

This study was part of a five year research project on GI function during exercise, which had been approved by the university research review board.

Subjects

Triathletes (male) were recruited via magazine advertisement as well as through personal contact with local triathlon clubs. Prospective subjects were required to have completed at least one half-triathlon, to be actively training in both cycling and running, and to have had no history of GI disease. No selection was made according to frequency of GI complaints resulting from running. However, whether an individual was a sufferer of GI distress as a result of running was noted. A list of symptoms was read to the subjects. The list was divided into “severe complaints” and “mild complaints”.

Severe complaints included stomach ache, intestinal cramps, nausea, diarrhea, and vomiting. Mild complaints included ructus, fullness or pressure in the stomach or intestinal region, and flatulence.

The first twenty male triathletes who responded and who satisfied the minimum requirements were invited to the laboratory for preliminary tests. All potential subjects came to the lab on two separate days. On one of the two days maximal performance capacity (VO2max) was tested in an incremental cycle ergometer test (12) and, on the other day, in an incremental treadmill test. The treadmill test was similar to the cycle ergometer test except that in place of 30 Watt increments every 2.5 min, 2 km·h⁻¹ increments were used. Above a heart rate of 160 b. p. m. increments of 25 Watt and 1 km·h⁻¹, respectively, were used. On one of the two days, following the maximal exertion test and a cool-down, a nasogastric tube was placed and immediately thereafter removed. Heart rate was simultaneously monitored during maximal testing to enable determination of the heart rate that corresponded with 70% VO2max.

Based upon tolerance of the nasogastric tube, homogeneity in terms of the maximal exertion tests, and availability to come to the laboratory on days required, a final selection of ten subjects was made. All subjects were given a full explanation of experimental procedures and were informed that they may stop the experiment at any time. Subjects were then asked to sign a written informed consent form. After three trials one of the subjects voluntarily withdrew because of repeated nausea and vomiting during running with the nasogastric tube. The general characteristics and the results of maximal exertion tests of the remaining nine subjects are presented in Table 1.

Treatments

Gastric emptying of two commercially available sport drinks was compared at rest as well as during exercise, and a control drink was given at rest only. Sport drink I was an isotonic, primarily dextrose drink (296 mOsm·kg⁻¹) which provided 127 kJ per 100 ml (Isostar· liquid). Drink H was a hypertonic, primarily maltodextrin containing beverage (444 mOsm·kg⁻¹) which provided 312 kJ per 100 ml (20 g·100 ml⁻¹ Perform). The control drink (C) was tap water with 8.0 mg·100 ml⁻¹ aspartame and similar flavorings as in drink H, added to mask its identity. These additions to C provided 1.44 kJ per 100 ml (40 mOsm·kg⁻¹). Complete compositions are presented in Table 2.
WARM-UP
70% VO2 max RUNNING/BIKING

-10 0 20 40 60 80 (min)
D S D S D S D S S

Fig. 1. Sampling schedule where D indicates drink ingestion and S indicates sample removal. At time = 0, D = 8 ml·kg body wt⁻¹ and at all other sample points D = 2 ml·kg BW⁻¹.

Drink C was only administered at rest to give control values of gastric emptying for each individual to compare with the various commercial drinks in a situation of repeated drinking. All three drinks were tested previously in single bolus experiments (16). GE of the isotonic drink (I) and the hypertonic drink (H) were compared during rest as well as during bicycling (70% VO2max) and during running (70% VO2max). An initial bolus of 8 ml·kg body wt⁻¹ was given, followed every 20 min by additional bolus of 2 ml·kg body wt⁻¹. A complete schedule of dosing is presented in Fig. 1.

Experimental design

All nine subjects conducted all seven tests (complete cross-over) and were assigned treatments in random order without subject knowledge of what drink was being administered on a given day.

In exercise experiments, a 10-min warming-up period (100 Watt or 10 km·h⁻¹) preceded 70% VO2max exercise. To ensure similar exertional stress on separate days, heart rate was used instead of absolute speed or wattload. VO2 monitoring was impractical due to the presence of the nasogastric tube. Workload was increased on the cycle ergometer or speed of the treadmill was increased until a heart rate was achieved which corresponded to the heart rate at 70% VO2max during the maximal tests. The average running speed was 12.8 km·h⁻¹ (SE±0.2) and workload on the bicycle was 227.8 Watt + (SE±8.1).

Experimental procedure

Daily protocol is fully described elsewhere (16). This included a standardized liquid breakfast 2 h before exercise began (8:00 a.m.) and placement of the nasogastric tube and complete emptying and rinsing of the stomach 45 min prior to exercise (9:15 a.m.). Amounts of breakfast (5 ml·kg body wt⁻¹) and the amount of test drink given (8 mg·kg body wt⁻¹) were based upon body weight. The protocol called for 80 min of exercise at 70% VO2max. Warming-up was conducted for 10 min prior to administration of the test drink and the onset of 70% VO2max exercise (10:00 a.m.). Heart rate was continually monitored during exercise and workload or speed was adjusted when necessary to maintain a constant exertion level. All beverage bolus were administered via the nasogastric tube. For dosing and sampling schedule see Fig. 1. To measure gastric secretion and volume changes, a modified double sampling technique of George (9) was applied using phenol red as a marker. At each interval the added bolus had an increased concentration of dye. For a detailed description of the calculations involved, see Beckers et al. (1). This procedure was slightly altered with the addition of successive bolus. A sample was taken of the remaining gastric contents immediately prior to administration of additional beverage. Each new bolus was added to the partially emptied stomach, mixed with the remaining stomach contents, and a new sample was taken and a new begin point was achieved. Calculations can again be used similar to the ones applied after single bolus experiments.

Ambient temperature was 20 °C±2 °C for all experiments with a fine running constantly in front of the bicycle or treadmill. Body weight was measured immediately preceding exercise and immediately following exercise in order to give an indication of fluid losses. Total fluid losses were estimated by the difference in body weight. A correction was made for fluid intake. It is to be noted that these are approximations of net fluid loss since substrate utilization accounts for some body weight change, albeit a very small portion. Further, the sweat loss may also be somewhat underestimated due to sweat which may have remained in running shorts or hair.

Analyses

Wilcoxon's signed-rank test for non-parametric data was used to make paired comparisons. The proportion of drink remaining at each interval in running versus bicycling for each drink was analyzed separately. All three drinks were compared at rest. The relative amounts of drink (as a proportion of the drink content in the stomach at the beginning of each 20-min period) which had passed through the stomach were also compared to evaluate rates of emptying over time, taking into account the different gastric volumes.

The average GE rates (calculated in ml·min⁻¹ over 80 min) in subjects who had symptoms versus subjects who seldom or never had symptoms were compared. Wilcoxon's rank sum test was used to compare these two groups.

A confidence level of p < 0.05 was used in determination of significance in all analyses.

Results

Cumulative amounts of drink administered and emptied during exercise with I are presented in Fig. 2a and with H in Fig. 2b. These are averages for nine subjects, also for the amount administered, since each individual received a different amount based upon his body weight (8 ml·kg body wt⁻¹ initial bolus and 2 ml·kg body wt⁻¹, every sequential bolus). Although the amounts administered are large (X = 1022 ml, 80 min), none of the subjects complained of gastrointestinal distress.

There was no significant difference in the average gastric emptying rate in those individuals who had a history of GI problems in relation to running compared to the subjects who did not experience these problems. The mean emptying rate of H during 70% VO2max running in individuals who had reported having experienced severe symptoms (n = 4) was 10.4 ml·min⁻¹ and in those who had never or seldom experienced these problems it was (n = 5), 9.7 ml·min⁻¹. Within the group of individuals who had ex-
Fig. 2 a) Cumulative volumes of drink emptied (solid and striped) and total volumes given for bicycling and running with drink I. b) Cumulative volumes of drink emptied and total volumes ingested for bicycling and running with drink H.

Fig. 3 Absolute amounts of drink remaining in the stomach after a single bolus (8 ml·kg BW⁻¹) and after one bolus (8 ml·kg BW⁻¹) with repeated ingestion every 20 min (2 ml·kg BW⁻¹) compared.

performed severe symptoms two individuals reported having had these symptoms frequently. The mean GE rate of these two individuals, however, did not differ from that of the others (X̅=10.2, 10.1 ml·min⁻¹, resp.).

There were also no significant differences in absolute amounts emptied as a result of running as compared to bicycling. However, since volume is one of the factors which influences the rate of emptying, the variability in the volume of drink present in the stomach at any one time may mask effects of exercise. Therefore, a comparison of the relative emptying rates (percent of bolus ingested) was made. The percentage of ingestate (rest volume plus new bolus) which was emptied during each 20-min period for each condition was calculated. Statistical comparisons of bicycling and running with I revealed a significantly greater percentage of ingestate emptied during bicycling than during running between 40 and 60 min (X̅=77%, 62%, resp., p < 0.05) and between 60 and 80 min (X̅=83%, 68%, resp., p < 0.05). With H, the hypertonic drink, no significant differences were observed between bicycling and running.

To evaluate differences in emptying rate over a period of time, percentages for each drink and condition were compared in 20-min intervals. During cycling the "fast-phased" emptying rate appeared to be maintained with I. Percentage of drink emptied was the same between 20 and 40 min and 40 and 60 min as between 0 and 20 min, and, in fact, the relative amount emptied between 60 and 80 min was significantly greater than that which was emptied between 0 and 20 min (X̅=83%, 65%, resp., p < 0.05). A graphic representation of emptying rates comparing a one bolus experiment, previously conducted in our lab, with repeated drink of I during 70% VO₂max bicycling is shown in Fig. 3. With running, a similar pattern can be seen.

However, with H, after the initial 20-min fast-phase, GE rate was reduced in both bicycling and running. During bicycling the percentage emptied at 60–80 min was significantly less than that emptied at 0–20 min (X̅=34%, 66%, resp., p < 0.05). During running with H, GE was significantly slower during 40–60 min (X̅=32%) and 60–80 min (X̅=44%) vs 0–20 min (X̅=61%) (p < 0.05).

The percentages emptied each 20-min interval with all three drinks during rest are presented in Table 3. There were no significant differences in emptying rates between I and C at rest. H emptied slower than C at 20–40 min, 40–60 min, and 60–80 min (p < 0.05).

Average sweat losses for 80 min bicycling and 80 min running are presented in Fig. 4. During running the sweat loss was significantly greater than during bicycling (p < 0.05).

Table 3 Gastric emptying rates during rest as a percentage of start volume for each interval (n=9)

<table>
<thead>
<tr>
<th>Interval (min)</th>
<th>Drink</th>
<th>I</th>
<th>SEM</th>
<th>H</th>
<th>SEM</th>
<th>C</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20</td>
<td></td>
<td>79</td>
<td>±3</td>
<td>66</td>
<td>±2.7</td>
<td>79</td>
<td>±4.6</td>
</tr>
<tr>
<td>20–40</td>
<td></td>
<td>72</td>
<td>±3</td>
<td>49</td>
<td>±2.2</td>
<td>95</td>
<td>±3.8</td>
</tr>
<tr>
<td>40–60</td>
<td></td>
<td>87</td>
<td>±1</td>
<td>44</td>
<td>±2.1</td>
<td>79</td>
<td>±3.5</td>
</tr>
<tr>
<td>60–80</td>
<td></td>
<td>86</td>
<td>±2.9</td>
<td>37</td>
<td>±0.6</td>
<td>99</td>
<td>±3.8</td>
</tr>
</tbody>
</table>

No significant differences were observed between I and control (C). * indicates significant difference (p < 0.05) from control (C). Different superscripts represent significant difference (p < 0.05) within a treatment.
Discussion

Compared to fluid intakes measured during marathon running (17), the amounts administered were large and yet caused no GI upset or physical discomfort during running or bicycling.

Although slight differences were noted between bicycling and running with respect to GE rate, these were only significant with the isotonic drink (1) in the last two 20-min intervals, 40–60 min, and 60–80 min.

These findings cannot explain the difference in frequency of gastrointestinal problems in runners vs bicyclists. In fact, what is most noteworthy is the large amounts which are emptied during running as well as during bicycling.

Gastric emptying has been designated as one of the limiting factors during endurance competition (6, 8). However, from the present study, it has been demonstrated that it is not the effect of exercise per se on GE which has the greatest influence. Drink content and hydration status (14, 16) are probably of greater importance (not to mention effects of GI contents from previous meal(s)). Carbohydrate source and content and effects of other nutrients, including specific minerals, can act to limit or stimulate GE (7) and may also play a role in pre-disposition of GI disorders.

Nevertheless, the fact that a high frequency of GI disorders is reported among distance runners, and that there is little documentation of these types of problems in bicyclists, leads to speculation that the repeated concussions occurring during running (with a corresponding up and down movement of the internal organs) may play a role in the development of these disorders. However, the physical/mechanical effect that exists apparently does not exert its influence via gastric emptying. It cannot be denied that a delayed GE rate is one symptom of a disturbed GI function. Since none of the nine subjects who completed all tests had GI complaints, it follows that GE delay, as a result of GI dysfunction, could not have been present.

A myriad of "stress factors" may be the real key to GI disturbance in runners in combination with the physical jostling. The competitive atmosphere of a race is completely missing in laboratory experiments. This may alter levels of circulating stress related hormones and metabolites.

Another aspect which must be considered is the actual intakes found in participants of these two sports and fluid needs of individuals participating in both. Runners are known to consume far less fluid than is necessary to maintain euhydration. Body weight losses ranging from 3–5% are common in marathon runners (17).

The availability of a beverage as well as the ease of consumption during bicycling, where one experiences little vertical movement during exercise, certainly play a role in the difference in fluid consumption between runners and cyclists. In addition, water losses may be even greater during running than during bicycling, partially due to greater heat dissipation during convection in bicycling. Moreover, even in our laboratory setting where ventilation in the lab was similar for the same individuals while running and bicycling, sweat losses were greater during running. This can be accounted for by the larger exercising muscle mass used while running.

Due to the aforementioned differences in fluid losses and replacement, dehydration is seen to be a greater problem in runners than in cyclists.

Although, compared to average fluid consumptions of marathon runners, the amounts consumed in the present experiment were large, they were not large enough to replace fluid losses.

It has also been observed that higher levels of dehydration are associated with an increased incidence of GI distress (17) and decreased GE rate (14), intestinal ischemia, possibly playing a role. Blood flow is also known to be decreased to the GI region during intense exercise (4) and a decreased mesenteric blood flow has been observed to reduce carbohydrate absorption from the intestine (21).

Despite common "track-talk" of GI complaints after beverage consumption during running, no evidence was found in the present study to attribute this symptom simply to the consumption of beverage during running. Moreover, it appears probable that this complaint could be initiated by drinking too late after a state of dehydration has already been reached. If the blood flow is already decreased and a beverage is ingested which is hypertonic, demanding increased intestinal secretion, the effects of further decreased blood volume and ischemia of the GI region could be further induced. It is also possible that solid food present in the digestive tract during running may be improperly digested, causing a delay which could lead to abdominal discomfort. In support of this theory are anecdotal claims from runners that they can avoid problems by not consuming solid food for several hours previous to a hard run or race. The absence of problems in our subjects, who only received fluids, including a standardized liquid pre-exercise meal, also supports this theory.

In summary, we could not find important differences in gastric emptying rates between running and bicycling. Therefore it is not very likely that inherent differences in GE due to differing types of exercise alone would account for the discrepancy of GI disorders. Furthermore, the high rate of fluid/energy intake and emptying which was observed to be well tolerated during running has implications for performance, since improvement of endurance running per-
formance could theoretically be improved to the same extent as was observed for cyclists who bicycled for several hours at a high intensity with large intakes of the same hypertonic beverage (2).

References