# Gastric emptying during walking and running: effects of varied exercise intensity

P. D. Neufer, A. J. Young, and M. N. Sawka

US Army Research Institute of Environmental Medicine, Kansas Street, Natick, MA 01760-5007, USA

**Summary.** Gastric emptying is increased during running (50%–70% maximal aerobic uptake, $\dot{V}_{O_2 max}$) as compared to rest. Whether this increase varies as a function of mode (i.e. walking vs running) and intensity of treadmill exercise is unknown. To examine the gastric emptying characteristics of water during treadmill exercise performed over a wide range of intensities relative to resting conditions, 10 men ingested 400 ml of water prior to each of six 15 min exercise bouts or 15 min of seated rest. Three bouts of walking exercise ($1.57 \text{ m} \cdot \text{s}^{-1}$) were performed at increasing grades eliciting $\sim 28\%$, 41% or 56% of $\dot{V}_{O_2 max}$. On a seperate day, three bouts of running ($2.68 \text{ ms}^{-1}$) exercise were performed at grades eliciting $\sim 57\%$, 65% or 75% of $\dot{V}_{O_2 max}$. Gastric emptying was increased during treadmill exercise at all intensities excluding 75% $\dot{V}_{O_2 max}$ as compared to rest. Gastric emptying was similar for all intensities during walking and at 57% and 65% $\dot{V}_{O_2 max}$ during running. However, running at 74% $\dot{V}_{O_2 max}$ decreased the volume of original drink emptied as compared to all lower exercise intensities. Stomach secretions were markedly less during running as compared to walking and rest. These data demonstrate that gastric emptying is similarly increased during both moderate intensity ($\sim 28\%$–65% $\dot{V}_{O_2 max}$) walking or running exercise as compared to resting conditions. However, gastric emptying decreases during high intensity exercise. Increases in gastric emptying during moderate intensity treadmill exercise may be related to increases in intragastric pressure brought about by contractile activity of the abdominal muscles.

**Key words:** Gartric emptying — Exercise intensity — Stomach secretions

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*Offprint requests to:* P. D. Neufer

## Introduction

The importance of fluid ingestion in maintaining euhydration and endurance performance during exercise is well documented (Adolph et al. 1947; Pitts et al. 1944). However, fluid ingestion during exercise does not necessarily insure an adequate replacement of body water stores. Both gastric emptying and intestinal absorption can be adversely affected by factors such as the volume, osmolality, acidity, and carbohydrate composition/concentration of the ingested fluid (for review see Murray 1987).

Previous studies designed to examine the gasric emptying characteristics of various solutions have primarily been conducted under resting conditions (Brener et al. 1983; Costill and Saltin 1974; Coyle et al. 1978; Foster et al. 1980; Seiple et al. 1983). It has generally been assumed that low to moderate intensity exercise has no significant effect on gastric emptying or intestinal absorption (Seiple et al. 1983; Wheeler and Banwell 1986). This conjecture has primarily been based of the work of Costill and Saltin (1974) who demonstrated that cycling exercise performed at 40%–70% of the subjects' maximal oxygen uptake ($\dot{V}_{O_2 max}$) did not alter gastric emptying as compared to resting conditions. In contrast, more recent findings have shown that gastric emptying rate is actually increased during running exercise (50%–70% $\dot{V}_{O_2 max}$) as compared to rest (Neufer et al. 1986). It was suggested that this enhanced gastric emptying rate was facilitated by an increased mechanical movement of fluid within the stomach (Neufer et al. 1986).

The aim of the present study was to examine the gastric emptying characteristics of water during treadmill exercise performed over a wide range of exercise intensities relative to resting

conditions. More specifically, it was our intent to determine if gradual increments in exercise intensity would elicit progressive increases in gastric emptying, possibly due to greater gastric fluid movement or a more complex neurohumoral mechanism linked to metabolic rate. We further reasoned that if greater mechanical movement of fluid within the stomach during exercise does facilitate gastric emptying as compared to rest, then it would be expected that walking and running at the same metabolic rate would result in different gastric emptying responses due to variations in stomach movements. Thus, we studied the effects of walking and running on gastric emptying at both similar and varied exercise intensities.

## Materials and methods

*Subjects.* Ten physically fit men volunteered to participate in this study. Each was informed of the requirements and possible risks associated with the study before signing a letter of informed consent. One week prior to experimental testing, each subjects's $\dot{V}_{O_{2 max}}$ and maximal heart rate were determined from a progressive treadmill test (Sawka et al. 1985). The characteristics (mean $\pm$ SE) of the subjects were age $19 \pm 1$ year, height $1.73 \pm 0.02$ m, weight $66 \pm 1$ kg, maximal heart rate (HR) $198 \pm 2$ bt $\cdot$ min$^{-1}$ and $\dot{V}_{O_{2 max}}$ $57.9 \pm 0.8$ ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$.

*Experimental design.* Two experimental sessions were completed over a two week period, each following a 12–16 h fast. The subjects wore underwear, T-shirt, shorts, socks, and running shoes during all testing sessions. After dressing, the subjects were intubated with a number 14 French-Levine tube through the nasal passage. The tubes were lubricated with a 2% xylocaine viscous solution to minimize subject discomfort. Each subject drank 200–300 ml of water during the intubation procedure to facilitate passage of the tube. Once intubated, the subjects ingested an additional 200 ml of water and performed a 10 min warm-up treadmill run (2.68 m $\cdot$ s$^{-1}$, 0% grade). This procedure has previously proven effective in eliminating any reduction in the initial gastric emptying rate that may occur due to an overnight fast or lack of physical activity (Neufer et al. 1986). After the warm-up exercise, the gastric contents were removed via aspiration with a 50 ml syringe and discarded. The nasogastric tube was moved systematically within the stomach during aspiration to insure complete evacuation of the gastric residue.

Water served as the test drink for all trials. The drinks were administered cold ($\sim 4°$ C) and contained 25 mg $\cdot$ l$^{-1}$ of phenol red, a nonabsorbable marker (Schedl 1966). The protocol for each experiment was similar. After completing the warm-up exercise, the subjects drank 400 ml and immediately completed 15 min of treadmill exercise. During the first experimental session, each subject walked (1.57 m $\cdot$ s$^{-1}$) at either a 0%, 6%, or 12% grade. Immediately after exercise, stomach contents were aspirated. A second 400 ml drink was then taken, followed by another 15 min exercise bout at one of the remaining two treadmill grades. After the second exercise bout, stomach contents were again aspirated and the process repeated. Each subject completed the three different grades in a random order. During the second experimental session, the

subjects randomly completed three 15 min running (2.68 m $\cdot$ s$^{-1}$) bouts at a grade of either 0%, 3%, or 6%. Each exercise bout was preceded by drinking 400 ml of water and followed by aspiration of the gastric residues. In addition, each subject performed one 15 min ingestion/evacuation trial while remaining seated quietly. This trial was performed during the second experiment after the warm-up exercise and before the three 15 min running exercise bouts. The reliability of this method for repeated measures within the same individual has previously been reported (Costill and Saltin 1974). In addition, the reliability coefficient for 10 subjects performing 4 identical gastric emptying trials (2.68 m $\cdot$ s$^{-1}$, 0% grade) in a related study was 0.83 (unpublished).

Oxygen uptakes were measured during treadmill exercise at each of the six intensities on a separate day. After a 10 min warm-up exercise, the subjects completed each treadmill exercise in progressive 3 min stages. Steady-state oxygen uptake and HR values were obtained during the final minute of each stage.

*Physiological and biochemical analysis.* Submaximal and maximal $\dot{V}_{O_2}$ determinations were performed using an automated system (Sensormedics Horizon MMC). Heart rates during the $\dot{V}_{O_{2 max}}$ test were determined from the electrocardiogram recorded during the last 10 s of each increment of exercise intensity. During the experimental sessions, heart rates were obtained with bipolar (CM5) chest electrodes and radiotelemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard).

Following aspiration, the volume of gastric residue was measured and an aliquot transferred to a tube, capped, and stored at 5° C. Prior to analysis, all residues were centrifuged at 5° C to separate any mucous within the residue. A 1 ml sample of the supernatant was then placed in 5 ml of a water/boric acid buffer. The pH of the buffered solution was adjusted to 9.2 and the absorbance measured spectrophotometrically at 560 nm. The ratio of the absorbance of the residue to the absorbance of the original drink allowed quantification of the dilution of the original drink by gastric secretion (Schedl 1966). Further, the volume (ml) of ingested water emptied into the intestine (original drink emptied) and the volume of stomach secretion added to the residue were calculated. The gastric emptying rate was estimated by dividing the volume of original drink emptied by the total time of each exercise bout (15 min). The percent of original drink emptied was determined by dividing the volume of original drink emptied by the volume ingested (400 ml).

*Statistical analysis.* Statistical comparisons were made using an analysis of variance for repeated measures. If significant main effects were indicated, Tukey's critical difference was calculated to locate significant differences at the $P < 0.05$ level. All data are presented as mean $\pm$ SE. One subject was unable to participate in the second experiment due to illness. Data are presented from nine subjects for each of the three running intensities and from ten subjects for each of the walking intensities and resting experiment.

## Results

Presented in Table 1 are the subjects' HR and $\dot{V}_{O_2}$ for each of the six exercise bouts. Mean HR ranged from $97 \pm 3$ bt $\cdot$ min$^{-1}$ at the lowest exercise intensity (treadmill speed = 1.57 m $\cdot$ s$^{-1}$, 0%

**Table 1.** Heart rate and oxygen uptake

| Exercise bout | Heart rate<br>(bt · min$^{-1}$) | $\dot{V}_{O_2}$<br>(l · min$^{-1}$) | $\%\dot{V}_{O_{2max}}$ |
|---|---|---|---|
| Walking (1.57 m · s$^{-1}$) | | | |
| 0% grade | 97 | 1.06 | 28 |
| | ±2 | ±0.03 | ±1 |
| 6% grade | 113 | 1.57 | 41 |
| | ±3 | ±0.04 | ±2 |
| 12% grade | 140 | 2.13 | 56 |
| | ±4 | ±0.04 | ±2 |
| Running (2.68 m · s$^{-1}$) | | | |
| 0% grade | 145 | 2.18 | 57 |
| | ±4 | ±0.05 | ±2 |
| 3% grade | 160 | 2.49 | 65 |
| | ±4 | ±0.05 | ±2 |
| 6% grade | 174 | 2.84 | 75 |
| | ±4 | ±0.06 | ±2 |

Values are mean ±SE for heart rate and oxygen uptake ($\dot{V}_{O_2}$) expressed as l · min$^{-1}$ and percent maximal oxygen uptake ($\%\dot{V}_{O_{2max}}$) during each of six treadmill bouts of exercise

grade) to 174±4 bt · min$^{-1}$ at the highest exercise intensity (treadmill speed = 2.68 m · s$^{-1}$, 6% grade). Mean $\dot{V}_{O_2}$ ranged from 1.06±0.03 l · min$^{-1}$ (27.8% $\dot{V}_{O_{2max}}$) while walking at 0% grade to 2.84±0.06 l · min$^{-1}$ (74.5% $\dot{V}_{O_{2max}}$) while running at 6% grade. The $\%\dot{V}_{O_{2max}}$ required while

walking at the 12% grade was very similar ($P > 0.05$) to running at the 0% grade (55.8% ± 1.5% vs 57.2% ± 2.0%, respectively).

Table 2 gives the characteristics of the gastric residues obtained following 15 min of seated rest and after each of the six exercise bouts. The volume of original drink emptied during 15 min seated rest was significantly lower (270.3 ± 12.8 ml) than values obtained after treadmill exercise performed at ~28%-65% $\dot{V}_{O_{2max}}$ (mean = 323.0 ± 5.7 ml). No significant differences were noted for the volumes of original drink emptied during either walking (~28%, 41%, and 56% $\dot{V}_{O_{2max}}$) or moderate intensity running (~57% and 65% $\dot{V}_{O_{2max}}$). As shown in Fig. 1, the volume of original drink emptied at rest averaged only 68% of the ingested volume (400 ml) as compared to ~81% during walking and moderate intensity running (~57% and 65% $\dot{V}_{O_{2max}}$). This corresponded to an increased estimated gastric emptying rate of 21.5 ± 0.4 ml · min$^{-1}$ during treadmill exercise (~28%-65% $\dot{V}_{O_{2max}}$) as compared to seated rest (18.0 ± 0.9 ml · min$^{-1}$). However, treadmill exercise performed at ~75% $\dot{V}_{O_2}$ decreased the volume of original drink emptied (268.1 ± 23.5 ml) as compared to all other exercise intensities (Table 2). The volume of original drink emptied averaged only 67% of the ingested vol-

**Table 2.** Characteristics of gastric residues

| Exercise bout | Gastric residue (ml) | Stomach secretions (ml) | Original drink emptied (ml) | ~ Emptying rate (ml · min$^{-1}$) |
|---|---|---|---|---|
| Seated rest | 181.0 | 51.3 | 270.3[b] | 18.0[b] |
| | ±15.7 | ±5.0 | ±12.8 | ±0.9 |
| Walking ($\dot{V}_{O_{2max}}$) | | | | |
| 28% | 122.0 | 56.7 | 334.7 | 22.3 |
| | ±14.3 | ±7.5 | ±10.7 | ±0.7 |
| 41% | 114.5 | 46.5 | 332.0 | 22.1 |
| | ±19.1 | ±6.4 | ±17.0 | ±1.1 |
| 56% | 152.1 | 59.8 | 307.7 | 20.5 |
| | ±27.2 | ±7.1 | ±22.5 | ±1.5 |
| Running ($\dot{V}_{O_{2max}}$) | | | | |
| 57% | 98.7 | 29.0[a] | 330.3 | 22.0 |
| | ±19.8 | ±5.1 | ±19.4 | ±1.3 |
| 65% | 115.2 | 26.3[a] | 311.1 | 20.7 |
| | ±19.3 | ±3.5 | ±18.7 | ±1.2 |
| 75% | 159.7 | 27.8[a] | 268.1[c] | 17.9[c] |
| | ±23.9 | ±3.7 | ±23.5 | ±1.6 |

Values are mean ±SE for the volume (ml) of gastric residue, stomach secretions, and original drink emptied during each 15 min rest or exercise session. Also presented is the estimated average gastric emptying rate during each experiment

[a] Significantly different ($P < 0.05$) from values obtained during walking and seated rest
[b] Significantly different from all corresponding values excluding 75% $\dot{V}_{O_{2max}}$
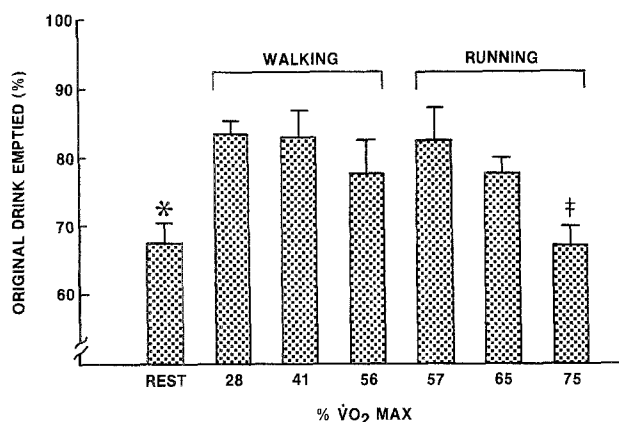[c] Significantly different from all corresponding values excluding seated rest

**Fig. 1.** Volume (mean $\pm$ SE) of original drink emptied, expressed as a percentage of the volume ingested (400 ml), during seated rest, three different walking (1.57 m · sec$^{-1}$) and running (2.68 m · sec$^{-1}$) exercise intensities expressed in terms of percent maximal oxygen uptake (% $\dot{V}_{O_2 max}$). * Significantly different ($P<0.05$) from all exercise intensities excluding 75% $\dot{V}_{O_2 max}$. $\ddagger$ Significantly different from all other exercise intensities

ume, similar to the value obtained during seated rest (Fig. 1).

Stomach secretions were similar following seated rest and all treadmill exercise bouts performed at 1.57 m · sec$^{-1}$ (walking), averaging 56.9 $\pm$ 2.0 ml (Table 2). In contrast, treadmill exercise performed at 2.68 m · sec$^{-1}$ (running) resulted in a decrease in stomach secretions as compared to all other values, averaging 27.7 $\pm$ 0.8 ml (Table 2).

## Discussion

The effects of exercise on gastric emptying of fluids is not well understood. Previous research has generally indicated that exercise performed below 70%-75% $\dot{V}_{O_2 max}$ does not alter gastric emptying rate as compared to resting conditions (Costill and Saltin 1974; Fordtran and Saltin 1967; Feldman and Nixon 1982). In contrast however, it has recently been reported that gastric emptying is actually greater during running exercise (50%-70% $\dot{V}_{O_2 max}$) as compared to rest (Neufer et al. 1986). The results of the present study support and extend these most recent findings, demonstrating an increased gastric emptying during treadmill exercise performed over a wide range of low to moderate exercise intensities ($\sim$28%-65% $\dot{V}_{O_2 max}$). Moreover, increases in gastric emptying were similar during both walking (1.57 m · s$^{-1}$) and running (2.68 m · s$^{-1}$) exercise relative to resting conditions. However, treadmill

exercise performed at a relatively high intensity ($\sim$75% $\dot{V}_{O_2 max}$) significantly reduced gastric emptying as compared to all lower intensities.

The mechanism(s) by which gastric emptying is increased during treadmill exercise as compared to rest is not readily apparent. Under resting conditions, gastric emptying of liquids is primarily regulated by resistance of the pylorus to pressure gradients between the stomach and the duodenum. This intragastric pressure is generated mainly by slow, sustained contractions of the proximal stomach (Minami and McCallum 1984). With the ingestion of fluids, these proximal contractions are partially inhibited via neural and/or hormonal mechanisms. This allows the stomach to store relatively large volumes of liquid while maintaining control over intragastric pressure and, therefore, emptying rate (Minami and McCallum 1984). With exercise, it is possible that the inhibitory neural and/or hormonal signals controlling proximal contractions may decrease, resulting in a greater gastric contractile activity and emptying rate. Unfortunately, little is known regarding the possible influence of exercise on the neural and hormonal mechanisms controlling contractile activity of the stomach.

Another possible mechanism for the improved gastric emptying rate may simply involve an increase in gastric motility brought about by the mechanical effects of upper body movements during treadmill exercise. Contractile activity of the abdominal muscles during treadmill exercise could enhance movement of the stomach, thereby increasing intragastric pressure and gastric emptying. Conversely, activities in which the abdominal muscles are relaxed would be expected to elicit similar gastric emptying responses to those obtained at rest. This concept is supported by the fact that gastric emptying during moderate intensity (40%-70% $\dot{V}_{O_2 max}$) cycling exercise is similar to the responses observed during seated rest, conditions in which abdominal movement and contractile activity should be minimal (Costill and Saltin 1974). It has also been suggested that an increase in the actual movement of fluids around the pylorus during treadmill exercise may contribute to an enhanced gastric emptying rate (Neufer et al. 1986). Curiously however, improvements in gastric emptying in the present study were similar during walking and running at the same relative intensity. It would seem likely that mechanical effects on the stomach and the associated fluid movement within the stomach would differ between walking and running due to gait and stride differences. Thus, these findings appear to indi-

cate that improvements in gastric emptying during low to moderate intensity (28%–65% $\dot{V}_{O_2\,max}$) treadmill exercise may be related to increases in abdominal contractile activity, resulting in an overall increase in intragastric pressure. However, the exact mechanism by which gastric emptying is enhanced during treadmill exercise relative to resting conditions remains to be determined.

In agreement with earlier findings (Costill and Saltin 1974; Fordtran and Saltin 1967), high intensity exercise (75% $\dot{V}_{O_2\,max}$) reduced gastric emptying relative to all lower exercise intensities (Fig. 1). Although Fordtran and Saltin (1967) have previously reported that 1 h of treadmill exercise ($\sim 71\%$ $\dot{V}_{O_2\,max}$) did not influence gastric emptying, it is important to note that comparisons were made between exercise and resting conditions. In the present study, gastric emptying during exercise at $\sim 75\%$ $\dot{V}_{O_2\,max}$ also did not differ from resting conditions (Fig. 1). However, because gastric emptying is greater during low to moderate treadmill exercise (below $\sim 70\%$ $\dot{V}_{O_2\,max}$) as compared to rest, gastric emptying rate during exercise performed at $\sim 75\%$ $\dot{V}_{O_2\,max}$ is regarded as having decreased relative to all lower exercise intensities. Whether treadmill exercise performed at intensities greater than 75% $\dot{V}_{O_2\,max}$ results in even more pronounced declines in emptying rate is not known. Costill and Saltin (1974) have reported significantly increasing volumes of gastric residue during cycling exercise performed at 70%, 80%, and 90% of $\dot{V}_{O_2\,max}$, indicative of progressively decreasing volumes of original drink emptied. It has been suggested that this high intensity, exercise-mediated reduction in gastric emptying may be associated with the inhibitory effects of increased catecholamine and endogenous opioid levels on splanchnic blood flow and gastric motility (Konturek 1980; Murray 1987; Rowell 1983).

Stomach secretions were significantly lower following treadmill exercise performed when running ($\sim 57\%$–75% $\dot{V}_{O_2\,max}$) as compared to resting conditions, an observation which has previously been noted (Neufer et al. 1986). Conversely, treadmill exercise performed when walking ($\sim 27\%$–56% $\dot{V}_{O_2\,max}$) had no effect on stomach secretions as compared to rest and was also greater than all values obtained during running treadmill exercise. Although the mechanism(s) of this response is not clear, the reduction in stomach secretions appears to be a function of the exercise mode, i.e., walking versus running. Under resting conditions, stomach secretions are regulated by stimulation of the parasympathetic fibers of the vagus nerve. This occurs both directly by stimula-

tion of the gastric secretory glands and indirectly through the release of the gut hormone, gastrin. It is possible that a reduced parasympathetic activity during exercise, as evidenced by increases in heart rate, may in part limit the stimulous for stomach secretion. This, however, does not appear likely. Heart rate responses, and presumably parasympathetic activity, were nearly identical during walking at 56% $\dot{V}_{O_2\,max}$ and running at 57% $\dot{V}_{O_2\,max}$ (Table 1) despite an $\sim 50\%$ reduction in stomach secretions during running at 57% $\dot{V}_{O_2\,max}$ (Table 2). Moreover, progressive elevations in heart rate concomitant with increases in exercise intensity did not appear to influence this response, i.e., stomach secretions were similar within all walking and running exercise bouts. Thus, the mechanism and significance of the decrease in stomach secretions observed during running exercise remains unknown.

In summary, this study demonstrates that gastric emptying is increased during treadmill exercise performed over a wide range of exercise intensities (28%–65% $\dot{V}_{O_2\,max}$) as compared to rest. Moreover, this enhanced gastric emptying response is similar during treadmill exercise performed when walking (1.57 m · s$^{-1}$) and running (2.68 m · s$^{-1}$). Treadmill exercise performed at $\sim 75\%$ $\dot{V}_{O_2\,max}$ decreases gastric emptying rate relative to all lower exercise intensities. In addition, stomach secretions are dramatically reduced during treadmill exercise performed when running as compared to walking and rest. These findings suggest that improvements in gastric emptying may be related to increases in intragastric pressure brought about by contractile activity of the abdominal muscles during treadmill exercise.

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