GASTRIC EMPTYING RATE OF YOUNG CYCLISTS BY MAGNETIC RESONANCE IMAGING: THREE CASE STUDIES

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Gastric emptying rate during exercise has been documented in adult athletes, but not in younger athletes because of the utilization of invasive techniques. However, magnetic resonance imaging (MRI) is a noninvasive alternative. The aim of this study was to pilot the sequencing of MRI to a typical fluid intake strategy, in order to assess the viability of the procedure. Therefore, we compared the gastric emptying rate of water and a carbohydrate drink in three well-trained 17-year-old cyclists using MRI. Each participant cycled 4 bouts of 15 minutes each at moderate intensity followed by a ~15-minute time trial. Water or carbohydrate drinks were distributed in amounts of 200–250 mL. After an initial baseline MRI scan, cyclists ingested the first drink, cycled 15 minutes, followed by an MRI scan to assess remaining gastric volume. This feeding-exercise-scanning protocol was repeated thereafter. Relative to the initial volume at the start of the time trial, 69% and 72% of water and carbohydrate emptied during the time trial. MRI appears to be a feasible technique to assess gastric emptying rates in youth cyclists. [*J Exerc Sci Fit* • Vol 8 • No 1 • 34–40 • 2010]

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Introduction

Most methods used to evaluate gastric emptying rate are highly invasive and therefore may be considered unethical in young cyclists. Magnetic resonance imaging (MRI) is a powerful tool, which can be used to examine the gastrointestinal tract without being invasive. The MRI technique has been validated against other invasive techniques such as gastric aspiration and scintigraphy (Schwizer et al. 2003; Ploutz-Snyder et al. 1999; Maughan & Leiper 1996; Schwizer et al. 1992). Schwizer et al. (1992) reported similar meal volumes, gastric emptying rates and secretory rates when comparing MRI against the scintigraphy technique. Linear correlation of the two methods was $r = 0.90$ and the intraclass correlation was $r = 0.91$ for the half time areas under the curve and percentage of the gastric meal retained. Feinle et al. (1999) have also described high intraclass correlation coefficients (ICC) between MRI and scintigraphy for solid and liquid meals. Their ICCs were reported as $r = 0.98$ and $r = 0.92$, respectively. An intra-individual day-to-day variation in adults of 10–20% in gastric emptying rate has been reported by Schwizer et al. (2003). Recently, the variability of the C-acetate breath test was assessed against the "gold standard", the scintigraphy method, for measuring gastric emptying in children (Hauser et al. 2006). Coefficient of variation for the median transit time (t1/2) of liquids was 8.3% (range, 1.6–16.2%), with a gastric lag phase (tlag) of 16.6% (range, 2.0–26.6%). However, no data on gastric emptying rate or intestinal absorption rates of carbohydrate

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drinks are available in the younger adolescent population. Therefore, the purpose of this study was to assess the utility of MRI for estimating gastric emptying in young cyclists. Specifically, we addressed whether suggested volumes of 200–250 mL of water and carbohydrate provided every 15 minutes would empty completely from the stomach.

Methods

Participants and preliminary preparation

Three well-trained and competitive male cyclists (age, 17 ± 1 years; body mass, 79.7 ± 22.9 kg; stature, 183.9 ± 6.9 cm; estimated body fat, 14.9 ± 12.9%) volunteered to participate in the study. All testing was conducted in the morning to prevent the effects of any circadian rhythm. No cyclists were on any type of prescription drugs or had experienced a recent gastrointestinal illness or infection. The experiment was described verbally and in written form to the cyclists and their parents. Written informed consent was obtained from the parents and the cyclists. Ethical approval was obtained from the Institutional Ethics Committee.

Participants were asked to report all food eaten on the day before the first cycling test, which was then replicated for the following test. On the day of the study, a 4-hour fast was required in order to ensure an empty stomach at the start of the test (Paley & Ros 1997). On the day of the test, the cyclists had a small breakfast 4 hours before the commencement of the study (e.g. bread with jam or small sandwich). Tea, coffee and carbonated drinks were not consumed on the days of the test. Two hours before the test started, cyclists were encouraged to drink 250 mL of water; thereafter, no drink or food was allowed.

Preliminary testing

On the first visit to the laboratory, a Par-Q form was completed. Participants avoided strenuous exercise, alcohol and coffee 24 hours before each test. Stature (Harpenden Stadiometer; Holtain, Pembrokeshire, Wales, UK) and body mass were measured. Percent body fat was assessed with air displacement plethysmography, the BOD POD Body Composition System (V.1.69; Life Measurement Instruments, Concord, CA, USA). Predicted percent body fat was calculated by using the age- and sex-specific equation by Lohman (1989). Participants then completed a combined continuous incremental cycle protocol for the determination of lactate threshold and peak oxygen uptake (peak $\dot{V}O_2$).

Lactate threshold and peak $\dot{V}O_2$ tests were performed on an SRM ergometer (Schoberer Rad Messtechnik, Jülich, Germany). Before each test, the ergometer was calibrated following the manufacturer's instructions. Participants were able to use their own pedals and cleats, and the ergometer was adjusted for stature and length to the participants' needs. Heart rate was measured using a telemetry system (Polar Vantage NV, Kempele, Finland). $\dot{V}O_2$ was measured using an Oxycon Sigma metabolic cart (Mijnhardt, The Netherlands), which was calibrated before all tests and once during the test according to the manufacturer's instructions. After a 5-minute warm up, the test started at a work rate of 125 W. The work rate was increased by 25 W every 240 seconds until blood lactate concentration reached or was close to 4 mM. Finger tip capillary whole blood samples (25 μL) were collected and analyzed for lactate (YSI 2300 Sport; YSI Life Sciences, Yellow Springs, OH, USA) at rest and in the last 30 seconds of each stage. On completion of the lactate threshold protocol, the cyclists dismounted the ergometer and rested for ~15 minutes. Thereafter, the test recommenced and peak $\dot{V}O_2$ was determined. The initial work rate was set to start at two stages below the final work rate reached during the lactate threshold. The work rate was increased by 25 W every 90 seconds until volitional exhaustion was reached or until the cyclist could no longer keep a cadence of 60 rpm despite strong verbal encouragement. A finger tip blood sample was taken 3 minutes after the test to assess peak blood lactate concentration. Peak $\dot{V}O_2$ was determined as the average $\dot{V}O_2$ in the last 60 seconds of the test. Maximal power output was determined as $W_{max} = W_{out} + (t/90) \times 25$, where W_{out} is the workload of the last completed stage, t is the time in seconds in the final but not completed stage, and 25 is the increase in W for the last stage.

Plots of blood lactate concentration against power output were provided to two independent reviewers who determined individual lactate threshold, defined as the intensity that elicits the first sudden and sustained increase in blood lactate above resting concentration by at least 1 mM (Spurway & Jones 2007).

Cycling protocol

The protocol was adapted from the study of Jeukendrup et al. (1996). Briefly, the protocol combines a constant work rate, followed by a time trial of a preset amount of work (J) to be cycled in the shortest possible time. The constant work rate was set at a power output equivalent to 80% of the individual's lactate threshold with the work rate independent from the pedaling rate

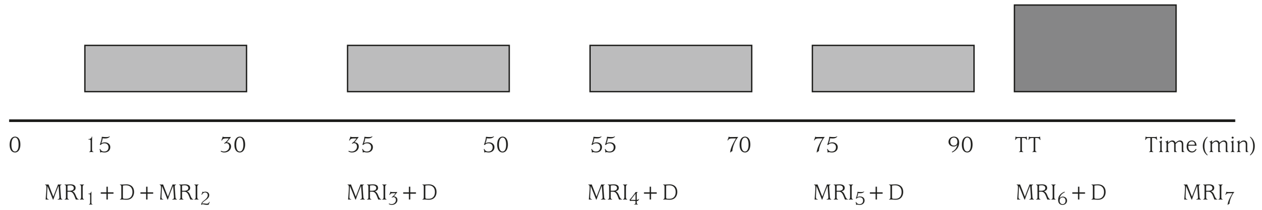

Fig. 1 Schematic representation of the gastric emptying protocol. TT = time trial; MRI = magnetic resonance imaging; D = drink.

(hyperbolic mode). The time trial started with 3 minutes at the constant intensity, and then the ergometer changed automatically into its linear mode. These details, including reliability statistics, have been previously detailed (Montfort-Steiger et al. 2005).

The cyclists were randomly assigned to either the water or the carbohydrate drink and completed two identical cycling protocols separated by at least 1 week. The cycling protocol consisted of 60 minutes of intermittent cycling at a constant intensity on an electromagnetically braked ergometer (Excalibur Sport; Lode, Groningen, The Netherlands). The cycling-hour was divided into 4 bouts each of 15 minutes' duration. On completion of the 4 bouts, a time trial of ~15 minutes commenced. The time trial was designed to last 15 minutes if a cadence of 90 rpm was maintained (Figure 1).

At the end of each 15-minute cycling bout, the ergometer program was paused, the cyclists dismounted the ergometer, took off their cycling shoes and heart rate monitor and walked to the adjacent scanning room where they were placed in the magnet. Scanning took place in a supine position. This procedure lasted not more than 5 minutes. Once scanned, the cyclists drank 250 mL of either water or the carbohydrate drink, attached the heart rate monitor to the chest, mounted the ergometer and started the next 15-minute bout. All testing was conducted at the same time of day. Room temperature during the tests was 21 °C, and relative humidity of the room during the water protocol was 80 ± 10%, and during the carbohydrate protocol was 82 ± 11%.

Drinking protocol

The drinks were kept overnight in a refrigerator. At the start of the test, the temperature of the drinks was ~10 °C. The volume of the drink was calculated so that the carbohydrate drink (commercially available sports drink) provided 1 g of carbohydrate per $kg \cdot hr^{-1}$. During the 75-minute cycling bout, participants drank 250 mL every 15 minutes, but the initial volume varied between participants. Hence, the individual volumes were adjusted to cover for the total volume needed to ingest 1 g of carbohydrate per $kg \cdot hr^{-1}$.

The initial MRI scan was used to identify an "empty" stomach. After the first MRI scan, participants drank their first quota of fluid, immediately followed by the second MRI scan. The cycling protocol (first bout of cycling) started 15 minutes after the second scan. During this period, the ergometer was adjusted for seat and handlebar height and length, and the cyclists completed a 5-minute cycling warm up. The third MRI scan took place after the first 15-minute cycling bout. On average, the elapsed time between the end of an exercise bout, the MRI scan and the start of the next cycling bout was between 5 and 8 minutes.

Calculation of emptying volumes

The volume (mL) emptied per bout of exercise was calculated as:

MRI reading (mL) + fluid intake (mL) = volume at start of each exercise bout = Initial volume with the;
Ivol (mL) minus MRI reading (mL) from the next exercise bout = emptied volume (mL) and expressed as a percent (%) of emptied volume from Ivol and then;
Total emptied volume (mL) = total intake + resting volume (mL) MRI scan 1 – volume (mL) remaining from the last MRI scan (after time trial).

Scanning procedures

Participants were placed within the magnet head first in a supine position (Philips Intera 1.5T MRI system with built-in quadrature body coil; Royal Philips Electronics, Amsterdam, The Netherlands). Initially, to ensure correct subject positioning, a fast gradient echo survey sequence was undertaken, with a 25° excitation pulse and 180° pre-pulse, a repetition time (TR) of 7.7 ms, echo time (T_E) of 4.6 ms, and images acquired in all three orthogonal planes. The entire scanning sequence was acquired in 12 seconds. Due to the presence of the inversion pulse, the stomach fluid contents appeared dark within the images. Following any necessary subject repositioning (undertaken by appropriate movement of the subject bed, rather than having to move the subject) to assess the volume of fluid within the stomach, fast gradient echo, T1-weighted images were obtained with a TR of 3.7 ms, T_E of 1.73 ms and a 75° flip angle. The sequence aimed to achieve as high a fluid: tissue contrast as possible. To cover the entire volume of the stomach, between 14 and 20 continuous transverse slices were obtained, with a slice thickness of 8 mm. With a matrix size of 256^2 and field of view of 375 mm, this resulted in voxel dimensions of typically $1.46 \times 1.46 \times 8.0$ mm. To avoid motion artefacts due to breathing, all images were obtained within a single breath hold lasting between 9 and 14 seconds, depending on the exact number of slices necessary to cover the stomach volume.

The consistency in the calculation of the gastric volume was assessed by recalculating 12 MRI slices four times. Two slices were selected from each participant's scan. The coefficient of variation was 2.7%. Gastric fluid volume was calculated by defining the fluid area within each image based on its relatively high intensity signal and then summing all individual slices. The procedure is essentially non-interventional, does not use contrast agents, and all scanning conformed to National Radiological Protection Board guidelines.

Statistical analysis

All descriptive data analyses were performed using SPSS version 10.0 (SPSS Inc., Chicago, IL, USA) for Windows. Both individual values representative of the three participants and some descriptive data as means and standard deviations are presented.

Results

The peak $\dot{V}O_2$ and maximal power output relative to body mass of the cyclists were 54.4 ± 14 mL·kg^{-1}·min^{-1} and 4.6 ± 1.3 W·kg^{-1}, respectively. Peak heart rate and blood lactate at peak $\dot{V}O_2$ were 196 ± 12 beats·min^{-1} and 6.4 ± 1.2 mM, respectively. The power output and percent of peak $\dot{V}O_2$ at lactate threshold were 233 ± 52 W and 75 ± 6%, respectively. The power output of the constant work rate was set at 187 ± 42 W, equivalent to 60 ± 5% peak $\dot{V}O_2$. The intensity of the time trial was set at 244 ± 41 W, equivalent to 78 ± 3% peak $\dot{V}O_2$. The carbohydrate and the water time trials were completed in similar performance times, 801 ± 149 and 774 ± 180 seconds, respectively.

Table 1. Individual values for emptied fluid immediately after first ingestion

Cyclist	Initial intake (mL)	MRI scan #2*	
		Carbohydrate drink (mL)	Water (mL)
1	268	262	164
2	328	355	288
3	500	489	252

*Includes the initial basal volume which corresponds to gastric secretions.

The total fluid intake during the ~75 minutes of cycling was $1,365 \pm 121$ mL (17.7 ± 3.1 mL·kg^{-1}). The total carbohydrate intake was 87 ± 8 g in ~75 minutes. At the end of the test, a total amount of $1,287 \pm 42$ mL of water and $1,303 \pm 83$ mL of the carbohydrate drink was emptied. Baseline gastric volumes were 17 ± 8 mL and 18 ± 14 mL for the water and the carbohydrate drink protocols, respectively. After the first initial fluid intake, gastric volume increased to 235 ± 64 mL and 368 ± 114 mL for the water and carbohydrate drink, respectively. The individual response immediately after the ingestion of the first drink (resting state) can be observed in Table 1. Figure 2 shows the MRI scanning sequences of the empty and full stomach for one of the participants.

Absolute volumes

During the constant cycling bout, a higher emptying rate from the carbohydrate drink compared to water was observed (Table 2); this amounted to ~100 mL of fluid and was the highest volume emptied in one bout. Subsequent bouts did not present important differences between drinks; however, there was a constant increase in the volume being emptied by the stomach for both drinks. For the time trial, a considerable decrease in emptied volume from both drinks was observed, with the water showing less gastric emptying volume compared to carbohydrate.

Emptied volume (%) of initial volume at each bout

Table 3 shows the volume emptied expressed as a percentage (%) at the start of each bout of exercise to account for individual drinking volumes and different initial stomach volumes. After the first bout of exercise, a similar percentage of fluid volume was emptied from the stomach for both drinks (~93%). Thereafter, a greater percentage of water was emptied compared to the carbohydrate drink during the constant work.

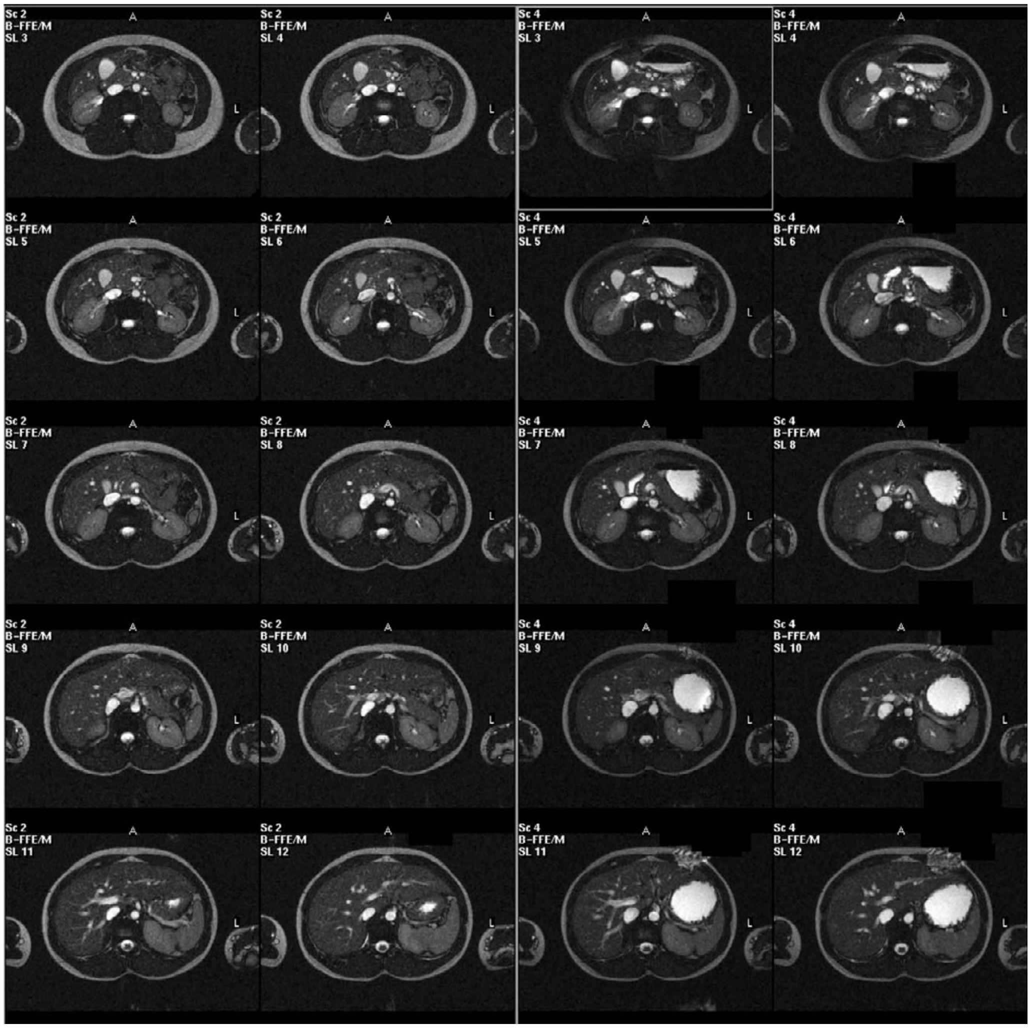

Fig. 2 Series of scans to assess the empty and full stomach. The left half panel represents the first 12 images (out of ~20) taken to assess the empty stomach. The right half panel illustrates the serial scans taken to assess the volume of the full stomach. The white colored circle on the right panel represents the fluid content in the full stomach. The volume of each slice is added up to get the total fluid volume.

Table 2. Individual values for resting, initial and emptied volume at the end of each 15-minute cycling bout

	Rest	Ivol	Cycling bout				Time trial
			1	2	3	4	
Water (mL)							
Cyclist 1	21	164	141	246	256	244	233
Cyclist 2	22	288	279	218	276	260	233
Cyclist 3	8	252	246	204	196	278	109
Carbohydrate (mL)							
Cyclist 1	9	262	247	150	223	296	310
Cyclist 2	34	355	326	185	249	288	216
Cyclist 3	11	489	467	263	251	251	144

Ivol = initial volume after the first drink (rest).

Discussion

The present study is the first to measure the gastric emptying pattern of a carbohydrate drink and water during exercise in adolescent athletes using MRI. This pilot study, despite the small sample size, has shown the feasibility of using MRI for the estimation of gastric emptying rate in young people. The main findings from this study were that similar volumes of water and a carbohydrate drink emptied after approximately 45 minutes of cycling. Overall, a similar relative amount (%) of the water was emptied compared to the carbohydrate drink. However, if values are represented as an emptied percentage from the initial volume of each

Table 3. Individual values for emptied volume expressed as a percent (%) of starting gastric volume at each bout for water and carbohydrate drink*

	Cycling bout				Time trial
	1	2	3	4	
Water (emptied %)					
Cyclist 1	86	90	92	90	84
Cyclist 2	97	84	94	98	91
Cyclist 3	98	80	65	78	33
Carbohydrate (emptied %)					
Cyclist 1	94	57	61	76	90
Cyclist 2	92	66	72	83	70
Cyclist 3	96	97	97	97	56

*Initial volume (mL) minus MRI reading (mL) = emptied volume (mL) expressed as a percent (%) of initial volume.

bout, water showed a greater emptied volume than the carbohydrate drink. During the higher intensity of the time trial, the gastric emptying rate of the carbohydrate drink showed similar trends compared to water.

The estimated basal gastric content (before any fluid intake) indicated a volume of 17 ± 8 mL in the water and 18 ± 14 mL in the carbohydrate drink protocols (Table 2). This basal secretion is within the published ranges of gastric secretions under resting conditions (Murray et al. 1994; Houmard et al. 1991; Mitchell et al. 1989). During resting conditions, water has been reported to empty at faster rates (Vist & Maughan 1994; Houmard et al. 1991), and in the present study, an initial faster emptying trend was observed when water was ingested. After the first baseline scan, participants received an initial drink, and in less than 5 minutes, a greater amount of water had been emptied, whereas none of the carbohydrate drink had left the stomach (Table 1). This pattern, indicating that water does have an immediate emptying response when it enters the empty stomach, has not been previously documented in adolescents. Houmard et al. (1991) observed that when participants were given a carbohydrate drink (7% carbohydrate) during resting conditions, the gastric secretion accounted for 113 mL, compared to 36 mL for water. However, it was not possible to account for the gastric secretion in the present study.

Table 2 shows a greater emptying volume of the carbohydrate drink after the first bout of exercise compared to water. This observation is most probably a result of the initial greater volume in the stomach, because water had a faster emptying rate immediately after its ingestion. It is most likely that similar amounts had already left the stomach, but in different timings: one immediately before the first exercise bout and the carbohydrate drink after the first bout of exercise. Due to protocol differences and inter-individual variations, it has been suggested that results from gastric emptying studies should not only provide the gastric emptying rate per total volume or unit time, but also as a percentage of initial volume emptied (Noakes et al. 1991). Since volume is one factor that influences the gastric emptying rate, and the volumes at the start of each bout varied between drinks, results were also expressed as a percentage of the initial volume. These factors are important to consider in gastric emptying rate experiments because when standardizing drinks to deliver equivalent amounts of carbohydrate per hour, the volume must be adjusted according to body mass. Hence, there will be individual variations in volumes entering and emptying from the stomach, which might influence performance (Tables 1 and 2).

During exercise, most research on adults has reported similar gastric emptying rates between water and carbohydrate concentrations lower than 8%. The present study is in agreement with these findings. From the total amount (1,365 ± 121 mL) given to the cyclists, 95 ± 8% of water and 96 ± 2% of the carbohydrate drinks were emptied. Rehrer et al. (1992) found that 97% of water and 95% of a 4.5% carbohydrate drink were emptied after 80 minutes of cycling at 70% maximal oxygen consumption. Similarly, others (Lambert et al. 1996; Mitchell et al. 1989, 1988; Ryan et al. 1989) have observed that most of the ingested fluid had emptied by the end of the exercise when the carbohydrate concentrations were not greater than 8%. However, others have observed lower total emptying rates with similar concentrations. Houmard et al. (1991) found that 69% of a 7% carbohydrate drink and 72% of water had emptied after 60 minutes of cycling at 75% $\dot{V}O_{2max}$ from a total amount of 720 mL. The longer duration at a higher intensity of their study could be a plausible explanation for the observed differences. In the present study, the residual amounts in the stomach after the time trial were 95 ± 107 mL in the water protocol and 80 ± 40 mL in the carbohydrate drink protocol. The high standard deviation in the emptying pattern observed in the participants is not just due to the small sample but is in accordance with reports on the wide physiological variation of gastric emptying (Leiper 2001; Maughan & Leiper 1996; Mitchell & Voss 1991). The intra-individual day-to-day variation has been reported to be high in adults (Schwizer et al. 1992; Beckers et al. 1991) and in children (Hauser et al. 2006). Thus, the differences in the readings of the gastric volumes between drinks can partly be explained by the normal and physiological variability in gastric emptying. Although we anticipated high variance in the gastric emptying physiology and thus controlled for the food and fluid intake of the participants, until a larger sample size is collected, the MRI variability remains unknown.

Despite the suitability of MRI in determining gastric emptying in 17-year-old boys and its noninvasiveness and novelty of the results, there are limitations to this technique. The high cost of this instrument reduces its utilization for research purposes. It also requires the skills of specially trained personnel for assessing and interpreting the images. Furthermore, the positioning in the supine posture and the interruption of an exercise protocol may influence the exercise-related gastric emptying physiology. Other technical limitations have prevented previous use of MRI, such as a low signal-to-noise ratio and excessive motion artefact resulting from a combination of long imaging times and physiological motion due to respiration and peristalsis (Paley & Ros 1997). The motion artefact however has been reduced with the development of fast imaging techniques, with breath hold sequences. At present, it is not ethically possible to validate the MRI technique against invasive gastric emptying methods for younger children and adolescents. Although the results of the present study show similar observations to those conducted in adults with gastric aspiration and scintigraphy, and therefore provide some confidence that the MRI technique is able to measure gastric emptying, further work is needed.

In conclusion, volumes of 250 mL of either water or a carbohydrate drink (1 g of carbohydrate per $\text{kg}^{-1} \cdot \text{hr}^{-1}$) given every 15 minutes can be recommended to 17-year-old cyclists as approximately 95% of the fluid were passed into the duodenum during moderate and high intensity exercise. At higher intensities, gastric emptying rate may be reduced, but further research with increased numbers of adolescent cyclists is warranted to verify these initial findings.

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