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One Hour Cycling Performance Is Not Affected By Ingested Fluid Volume

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This study investigated the effect of differing fluid volumes consumed during exercise, on cycle time-trial (TT) performance conducted under thermoneutral conditions (20 °C, 70% RH). Ten minutes after consuming a bolus of 6 ml · kg^{-1} body mass (BM) of a 6.4% CHO solution and immediately following a warm-up, 8 male cyclists undertook a 1-h self-paced TT on 4 separate occasions. During a "familiarization" trial, subjects were given three 5-min periods (15–20 min, 30–35 min, and 45–50 min) to consume fluid ad libitum. Thereafter subjects undertook, in random order, trials consuming high (HF), moderate (MF), or low fluid (LF) volumes, where 300, 150, and 40 ml of fluid were consumed at 15, 30, and 45 min of each trial, respectively, and total CHO intake was maintained at 57.6 g. During exercise, power output and heart rate were monitored continuously, whilst stomach fullness was rated every 10 min. Additionally, BM loss and BM loss corrected for fluid intake was calculated during each trial. At 40, 50, and 60 min differences in ratings of stomach fullness were found between trials (LF vs. HF and MF vs. HF). There were however no differences in performance or physiological variables (heart rate or BM loss) between trials. These results indicate that when a pre-exercise CHO bolus is consumed, there is no effect of subsequent consumption of different fluid volumes when trained cyclists undertake a 1-h performance task in a thermoneutral environment.

Key Words: body mass loss, sweat loss, hydration, high intensity

Introduction

Over the past 10 years, many authors (6, 9, 11, 13, 16, 17) have investigated the effects of different fluid and carbohydrate (CHO) ingestion strategies on high-intensity (>80% peak oxygen uptake [VO_{2peak}]), moderate duration (~60 min) cycling performance. The results of these trials cause considerable confusion to both the sports scientist and the athlete in determining the optimal CHO/fluid replacement strategy for performance in a 1-h cycle time trial.

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The investigation undertaken by Walsh et al. (17) compared the effects of a fluid-electrolyte beverage (400 ml bolus, and 120 ml every 10 min of the trial) with no fluid intake on a 1-hour task undertaken in the heat (32 °C, 60% relative humidity; RH), showing significant improvements in performance with fluid ingestion. Below et al. (6) undertook a similar trial comparing the effect of high versus low fluid (1330 vs. 200 ml) and high versus no CHO (79 ± 4 vs. 0 g) in the heat (31 °C, 54% RH), indicating that the beverage containing both high fluid and CHO improved performance most. However, at such high temperatures, the athletes' performance in a 1-h task is significantly impaired (3) and, as a result, these findings may not relate to performance in thermoneutral conditions. The type of exercise performance measured in the study by Below et al. (6; 50 min of constant work rate ergometry at 80% VO_{2max} followed by a performance test) might not be relevant to competitive sport.

Further, studies conducted under thermoneutral conditions do not clearly identify the optimal fluid/CHO ingestion strategies for 1-h cycle performance. McConell et al. (13) and Robinson et al. (16) have both compared the effects of water ingestion, providing conflicting results. In the study by Robinson et al. (16), subjects received either no fluid, or attempted to replace their approximate sweat loss (1.7 L) by drinking flavored water. Cyclists drank 8 ml · kg^{-1} body mass (BM) at the start of the warm-up and the rest of the water in five equal aliquots at 0, 10, 20, 30, and 40 min in the 1-hour performance ride. McConell et al. (13) compared no fluid to fluid replacement equal to 100% of sweat loss or fluid replacement equal to 50% of sweat loss. Fluid (water at room temperature) was ingested in four equal aliquots, at 0, 15, 30, and 43 min of exercise. Whilst small BM losses (1–2% BM) have been reported to be detrimental to performance (2), Robinson et al. (16) actually found that a large fluid ingestion (to match 85% sweat loss) impaired 1-h time trial (TT) performance in endurance-trained cyclists. McConell et al. (13) showed no differences in performance outcome between replacement of 50 and 100% of sweat loss when well-trained men cycled for 45 min at 80% VO_{2peak} followed by a 15 min "all-out" performance ride. Additionally, CHO ingestion has been shown to increase performance when compared to water alone (9). Despite a drop in BM of ~2.7% (sweat loss equivalent to 1850 ml), and no fluid ingestion during exercise, El-Sayed et al. (9) showed that a pre-trial CHO bolus (4.5 g · kg^{-1} BM of 8% CHO) would significantly improve distance cycled in 1 hour. Similarly, a CHO beverage consumed both before and during cycling (11) has been shown to improve 1-h TT performance. Unfortunately, due to the conflicting beverages, drinking regimens, and environmental conditions used, these studies fail to indicate the most appropriate volume of a CHO solution for 1-h cycling TT performance in thermoneutral conditions.

Further to these laboratory-based investigations, Backx et al. (4) have recently reported that 96% of cyclists participating in one of two 40 km TT (~1 h) competitions that were held in moderate conditions (19 ºC, 48% RH or 16 ºC, 64% RH) actually chose not to drink during competition, whilst only 57% of the participants actually consumed a pre-event bolus. This would appear to conflict with current recommendations (2).

Therefore, the aim of this investigation was to clarify the benefits of consuming different volumes of fluid, with an identical CHO content ingested during a 1-h TT performance of trained cyclists conducted under thermoneutral conditions.

Methods

Subjects

Eight trained, male cyclists participated in this investigation. Each had competed in cycling time trials for at least the three previous seasons and was capable of completing a 25-mile (~40-km) cycling time trial in less than 55 min. Additionally, for the 6-week period preceding the investigation, subjects had been training for a minimum of 8 h a week, and competing at least once every 2 weeks. Prior to participation in the study, which was approved by the University Ethics Committee, athletes were fully informed of the nature and possible risks of the experiment, and gave their informed written consent to participate, in accordance with the guidelines of the American College of Sports Medicine (1).

Preliminary Testing

All subjects were assessed for body composition and required to perform a progressive maximal incremental test on a Kingcycle ergometer (Kingcycle Ltd., High Wycombe, Bucks, UK) before participation in the experimental trials. On arrival at the laboratory, subjects were required to void, and BM and height were then measured to determine subject characteristics. Their mean ± *SD* age, BM, and height were 29 ± 7 years, 76.6 ± 6.8 kg, and 182 ± 4 cm. Their mean ± *SD* peak oxygen uptake (VO_{2peak}), peak power output (PPO), and peak heart rate (HR_{peak}) were 63.6 ± 6.1 ml · kg^{-1} · min^{-1}, 441 ± 27 W, and 183 ± 10 beats · min^{-1}.

The subject's bicycle was placed on the Kingcycle ergometer, and following calibration of the ergometer according to the manufacturer's instructions, and a 10–15-min warm-up at a self-selected intensity, the incremental test was commenced at a workload of 3.3 W · kg^{-1} BM. This was increased continuously by 1 W every 3 s (20 W · min^{-1}), until the subjects could no longer maintain the desired workload, despite being offered strong verbal encouragement by the same investigator. The incremental test was conducted in an environmental chamber at an ambient temperature of 20 °C and 70% RH. The Kingcycle was placed in the center of the chamber, which was 2 m^2. Fresh air entered the chamber continuously via a duct (0.5 × 1 m), directed at the cyclist, in the ceiling of the chamber. Additionally a fan, directed away from the subject, was used to circulate air within the chamber at a rate of approximately 0.33 m · s^{-1}.

During the incremental test, expired air was continually measured and recorded using an online breath-by-breath gas analysis system (Oxycon Alpha, Jaeger, Germany). This was used to determine peak oxygen uptake, which was defined as the highest average oxygen uptake (VO_2) for a 60-s period. Similarly, power was continually measured, and the peak power output was determined by the Kingcycle software as the highest average power output for a 60-s duration. Heart rate (HR) was recorded at 5-s intervals throughout exercise using a Polar Vantage heart rate monitor (Polar Electro Oy, Finland), and the peak heart rate was taken as the highest recorded average over a 60-s period.

Experimental Testing

Athletes completed four 1-hour self-paced TT on the Kingcycle ergometer in which they were instructed to cover as much distance as possible during the 1-h period. The

Kingcycle ergometer, which continuously monitors distance covered and power output of the rider, has previously been found to be a valid and reliable method of assessing laboratory based 40-km (~1 h) TT performance and has been described in detail by Palmer et al. (14). For the ease of tabulation of data, 1-h TT were used, opposed to a best time for a set distance.

In order to provide and control optimal environmental conditions for performance, time trials were performed in an environmental chamber at an ambient dry bulb temperature of 20 °C, and at a RH of 70% (3). A fan, directed away from the subject, was used to circulate air within the chamber at a rate of approximately 0.33 $m \cdot s^{-1}$. It must be noted that convective cooling does not simulate what happens when cyclists compete out of doors and are exposed to air movement of 40 $km \cdot h^{-1}$ and higher. Subjects undertook all time trials wearing shorts only.

On arrival at the laboratory subjects were required to void, and nude BM was measured to the nearest 0.1 kg on a Seca platform scale (Seca Ltd., Birmingham, UK). Subjects then entered the environmental chamber, their bicycle was placed on the ergometer, and the standard calibration procedure was undertaken. Following calibration, subjects dismounted and sat in the environmental chamber for a period of 5 min, whilst a bolus solution (6 $ml \cdot kg^{-1}$ BM; Lucozade Sport, SmithKline Beecham) containing 6.4 g of CHO and 0.05 g sodium per 100 ml was consumed. After consumption of the bolus, subjects remounted their cycle and commenced a standardized 5-min warm-up at 150 W, after which the TT was started immediately.

During the rides, the only feedback given to the subjects was the elapsed time. Distance covered and peak power was recorded continuously and averaged every 60 s. HR rate was recorded every 5 s via a short wave telemetry device (Polar Vantage, Polar Electro Oy, Finland), and averaged every 60 s. Additionally, subjects were asked to rate stomach discomfort on a scale of 1 (empty) to 5 (uncomfortably bloated; 15) every 10 min during the trial. Five minutes after completion of the trial, subjects towel dried, were asked to void, and nude BM was measured. No metabolic data was collected during the rides, as such interference would compromise the cyclist's performance, and the amount of interference for each trial would be difficult to control.

Fluid Replacement Strategies

The first 1-h TT (FAM) was used to familiarize subjects with the experimental procedure. During this ride, an ad libitum drinking procedure was followed. Specifically, subjects were given a 500-ml beverage (Lucozade Sport) at 15, 30, and 45 min into the time trial, a 5-min period was allowed for drinking, and the consumed volume was recorded. The mean ± *SD* volume drunk in FAM was 686 ± 448 ml.

During the other experimental trials, subjects undertook the following drinking strategies in random order: High Fluid (HF), Moderate Fluid (MF), or Low Fluid (LF), consuming a total of 900 ml, 450 ml, and 120 ml during each trial, respectively. Volumes were divided into three equal amounts consumed at 15, 30, and 45 min into each trial. Excluding the pretrial bolus, subjects consumed a total of 57.6 g CHO and 0.45 g sodium during all rides. As Lucozade Sport was used as the "base fluid", additional amounts of maltodextrin and sodium citrate were added to maintain the same CHO and sodium intake during each ride. (Drink compositions are given in Table 1.)

Each experimental trial was performed 7 to 10 days apart and at the same time of day. In order to maintain experimental control, athletes were required to refrain

Table 1 Beverage Composition for Familiarization, High Fluid, Moderate Fluid, and Low Fluid Trials

Trial	Fluid intake	Added malto-dextrin ($g \cdot 100\ ml^{-1}$)	Added sodium citrate ($g \cdot 100\ ml^{-1}$)	CHO content (%)	Sodium content (%)	Osmolality ($mOsm \cdot kg^{-1}$)
FAM	3 × Ad lib*	0	0	6.4	0.05	280
HF	3 × 300 ml	0	0	6.4	0.05	280
MF	3 × 150 ml	6.667	0.2128	12.8	0.1	390
LF	3 × 40 ml	43.34	1.3832	48	0.375	780

*Total (mean ± *SD*) fluid intake during ad lib trial was 686 ± 448 ml. FAM: familiarization, HF: high fluid, MF: moderate fluid, LF: low fluid, CHO: carbohydrates.

from any strenuous exercise in the 24 h preceding the experimental trials, to abstain from alcohol during this period, and to maintain the same training regime during the 72 h preceding the trials. Additionally, prior to the first experimental trial, each individual was required to record his or her physical activity for 24 h and dietary intake for 72 h, which was then repeated prior to subsequent trials. Subjects had their last meal/snack 3 h before arrival at the laboratory. Subject compliance was verbally confirmed upon arrival at the laboratory before each experimental trial.

Data Analysis

Data was analyzed using Prism 3.0 software (GraphPad Software Inc., San Diego, CA, USA). Differences in mean power, distance, fluid intake, and BM loss between trials were analyzed for statistical significance with a one-way analysis of variance (ANOVA); differences in HR were analyzed using a two-way ANOVA for repeated measures. When results were significant, a Tukey's post hoc test was used to locate significant differences. Differences in stomach discomfort were analyzed using a Kruskal-Wallis ANOVA, Mann-Whitney U tests were used to locate the differences. A significance level of $p < .05$ was established prior to all analyses.

Results

Figure 1 illustrates the average performance for each trial condition, no significant differences in distance achieved were found. The average performance for the FAM (43.24 ± 2.29 km) and the LF (43.24 ± 2.45 km) trials were the same, the distance achieved in the MF and HF trials were 42.97 ± 2.30 km and 43.06 ± 2.09 km, respectively. Similarly, mean power did not differ significantly between trials (FAM: 294 ± 38 W, LF: 295 ± 42 W, MF: 290 ± 39 W, and HF: 291 ± 35 W). Power output converted to percentage of PPO (% PPO; Figure 2) shows that all trials were performed between 61 and 74% of PPO. Figure 2 shows the average HR and HR as a percentage of HR_{peak} (% HR_{peak}) for each 5-min period. Average HR did not differ significantly between trials (FAM: 164 ± 2 beats $\cdot$ min^{-1}, LF: 166 ± 3 beats $\cdot$ min^{-1},

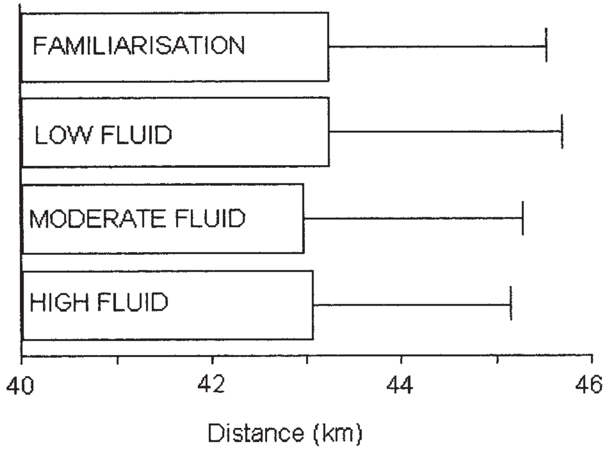

Figure 1 — Average (±*SD*) distance achieved during the 1-h time trial.

MF: 160 ± 3 beats · min^{-1}, HF: 167 ± 3 beats · min^{-1}), and no significant differences were found when the 5-min periods were compared.

Figure 3 illustrates the total fluid intake (including bolus) and BM loss during the trials. A significant difference in BM loss was found between trials ($F = 5.455$, $p < .01$), with a significantly greater loss in LF than FAM ($p < .05$), and HF ($p < .01$). Significant differences in BM loss corrected for ingested fluid were found between trials ($F = 22.54$, $p < .0001$); BM loss corrected for ingested fluid during FAM (1849 ± 511 ml) was significantly lower when compared to LF (1884 ± 413 ml), MF (1964 ± 440 ml), and HF (1926 ± 326 ml, $p < .001$; Table 2). Table 2 also shows fluid intake was significantly lower during LF than FAM ($p < .001$), MF ($p < .05$), and HF ($p < .001$), but there was no significant difference in fluid intake between FAM and MF or HF. Fluid intake was significantly higher during HF than MF ($p < .01$). The order in which trials were performed did not influence the BM loss. The percentage of BM loss replaced by fluid intake is shown in Table 2, ranging between 33 and 74% during the various trials. BM loss corrected for ingested fluid was significantly greater in HF and FAM compared to LF ($p < .001$) and in HF compared to MF ($p < .01$).

Subjects complained of nausea and stomach discomfort during the HF trial (Table 3). Ratings of abdominal fullness were significantly different between the LF and HF and the MF and HF trials ($p < .05$). Follow up tests showed a significantly lower rating of stomach fullness in LF than HF at 40, 50, and 60 min ($p < .05$), and significantly lower ratings in MF and HF at 40, 50 ($p < .05$), and 60 min ($p < .01$).

Discussion

The first major finding of this investigation was that no differences in performance (distance covered or mean peak power) were found between trials. This opposes findings by Below et al. (6), who found an increase in performance with fluid ingestion and improved performance with fluid and CHO replacement. This investigation undertaken by Below et al. (6) was, however, undertaken in the heat (31 °C, 54% RH, 3.5 m · s^{-1} wind speed), which has been shown to significantly impair

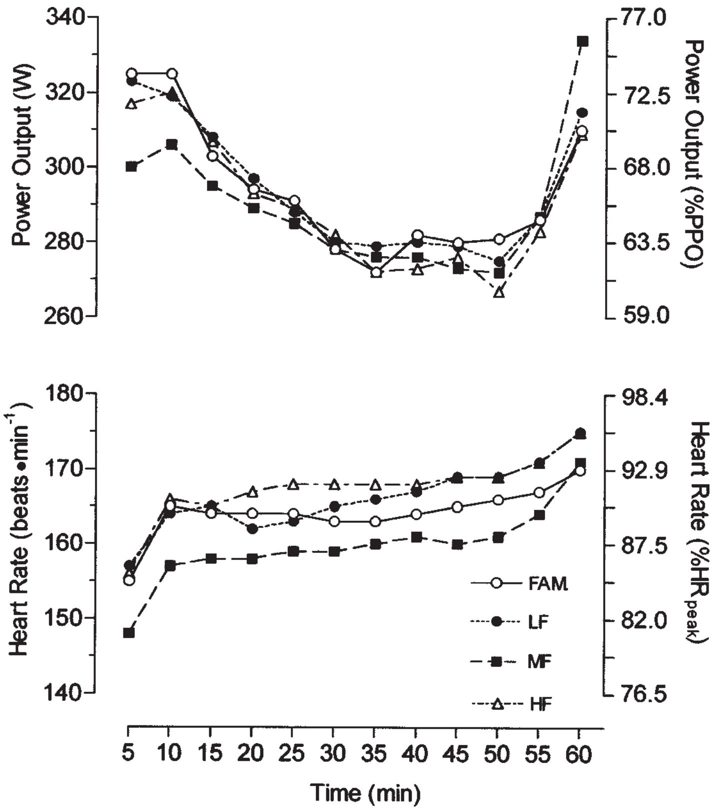

Figure 2 — Average power output and heart rate.

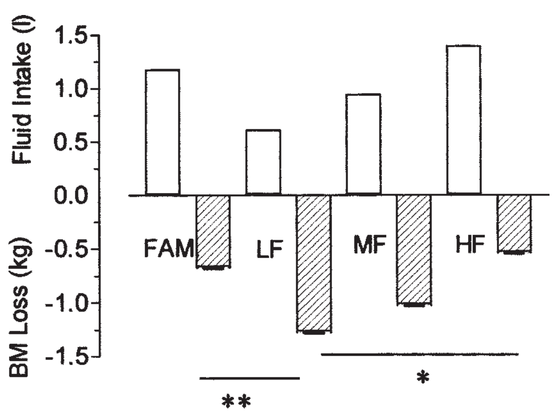

Figure 3 — Fluid intake and body mass loss. FAM: familiarization, HF: high fluid, MF: moderate fluid, LF: low fluid. *Significantly different to LF, $p < .01$; **significantly different to LF, $p < .05$.

Table 2 Total Fluid Intake and Body Mass Loss (Mean ± *SD*) During Trials

Trial	Total fluid intake (ml)	BM loss corrected for fluid intake (ml)	BM loss (g)	BM loss replaced by fluid intake (%)
FAM	1174 ± 441***	1849 ± 511***‡$	675 ± 520**	65 ± 21***
HF	1389 ± 53***†	1926 ± 326	538 ± 297*	74 ± 11***†
MF	935 ± 53**	1964 ± 440	1025 ± 403	50 ± 10
LF	609 ± 53	1884 ± 413	1275 ± 369	33 ± 5

Note. FAM: familiarization, HF: high fluid, MF: moderate fluid, LF: low fluid, BM: body mass. ***Significantly different from LF, $p < .001$; **significantly different from LF, $p < .05$; *significantly different from LF, $p < .01$; ‡significantly different from MF, $p < .001$; †significantly different to MF, $p < .01$; $significantly different from HF, $p < .001$

Table 3 Ratings of Abdominal Fullness (Mean ± *SD*), Ranked From 1 (*No Discomfort*) to 5 (*Extreme Discomfort*)

TT	0 min	10 min	20 min	30 min	40 min	50 min	60 min
FAM	2.9 ± 0.5	2.5 ± 0.5	2.9 ± 0.9	2.6 ± 1.2	2.9 ± 0.7	2.9 ± 0.9	2.6 ± 1.1
LF	3.3 ± 0.7	2.8 ± 0.5	2.8 ± 0.9	2.6 ± 0.9	2.6 ± 0.9**	2.6 ± 0.9**	2.4 ± 0.9**
MF	3.1 ± 0.6	2.9 ± 0.4	2.8 ± 0.7	2.4 ± 0.7	2.4 ± 0.9**	2.4 ± 1.1**	2.0 ± 0.9*
HF	3.2 ± 0.5	2.9 ± 0.6	3.5 ± 1.1	3.3 ± 1.0	3.8 ± 0.9	4.0 ± 0.9	3.8 ± 1.0

Note. FAM: familiarization, HF: high fluid, MF: moderate fluid, LF: low fluid. **Significantly different from HF, $p < .05$; *significantly different from HF, $p < .01$.

performance in a 1-h task (3) and, as a result, may not relate to performance in thermoneutral conditions. It must be noted that the convective cooling used in the study by Below et al. (6) does not simulate what happens when cyclists compete out of doors.

The effects of water ingestion in thermoneutral conditions were compared by McConell et al. (13) and Robinson et al. (16), providing conflicting results. Robinson et al. (16) found that a large fluid ingestion (to match 85% sweat loss) impaired performance, whilst McConell et al. (13) showed no differences in performance outcome with the replacement of 50 and 100% of sweat loss. During our investigation, between 33 and 74% of sweat loss was replaced, showing no differences in performance, which is similar to the findings of McConell et al. (13). CHO ingestion however has been shown to increase performance when compared to water. Despite a drop in BM of ~2.7% (sweat loss equivalent to ~1850 ml), El-Sayed et al. (9)

showed that a pre-trial CHO bolus (4.5 g · kg^{-1} BM of 8% CHO) would significantly improve distance cycled in 1 hour. Similar amounts of BM loss corrected for fluid ingestion were found during the current investigation (range: 1849 ± 511 ml [FAM] to 1964 ± 440 ml [MF]). Additionally, a CHO beverage consumed both before and during cycling (11) has been shown to improve 1-h TT performance in thermoneutral conditions. It may therefore be assumed that whilst CHO ingestion improves 1-h TT performance, differing volumes of fluid ingestion during exercise has no effect on performance in a thermoneutral environment. Differing volumes of fluid ingestion during exercise at higher environmental temperatures or during rides lasting longer than 1 hour might, however, increase performance.

No differences in physiological responses were found between trials during this investigation. This corresponds with findings by Walsh et al. (17), who found no measurable differences in HR when fluid intake was compared to no fluid intake. Robinson et al. (16) found that fluid intake decreased the mean average HR from 166 to 157 beats · min^{-1} ($p < .0001$) compared to no fluid intake.

Despite no differences in performance or physiological responses, there were significant differences in rating in stomach discomfort, sweat loss, and BM loss. Significantly higher ratings of stomach discomfort were found in the HF trial at 40, 50, and 60 min. Robinson et al. (16) found that an ingestion of about 1500 ml of fluid produced an uncomfortable feeling of stomach fullness during a 1-h TT. A total of 900 ml of fluid was consumed during the HF trial (1389 ± 53 ml including the bolus). It is generally recommended to ingest a large volume (~8 ml · kg^{-1} BM) immediately before exercise and then smaller volumes during exercise, since it increases stomach distension and gastric emptying (15). This practice has also been suggested to overcome the problem of reduced gastric emptying of drinks of a high osmolality (7). Further, drinks with a higher CHO concentration have in fact been shown to increase substrate availability to the intestine (12).

Although maximal rates of fluid absorption have been found to be about 800 ml · h^{-1} at rest (8), it has been suggested that this might decrease at high exercise intensities (5, 10, 18). The maximal rate of gastric emptying could be responsible for a decreased efficacy of fluid consumption during exercise. The delivery rate of fluid into circulation might have been limited by the rate of gastric emptying and/or fluid absorption. Although neither gastric emptying nor the fate of ingested fluid were determined during these trials, if the maximum rate of fluid absorption during exercise is < 800 ml · h^{-1}, it is likely that the fluid delivery is HF, MF, and FAM (and possibly LF) was the same, which might explain why no differences were found in TT performance The increased feeling of stomach discomfort and the lack of increased performance when fluid intake is above approximately 1200 ml, suggests that cyclists should be recommended not to drink more than 1200 ml during a 1-h cycling TT in a thermoneutral environment.

Conclusion

The results of this investigation indicate that when a pre-exercise CHO bolus is consumed, there is no effect of subsequent consumption of different volumes of CHO beverages when trained cyclists undertake a 1-h performance task under thermoneutral conditions. The ACSM guidelines (2) recommend that fluid replacement should attempt to equal fluid loss. However, under such thermoneutral conditions and for single events, there is no need to drink at such high rates recommended by these guidelines. The findings of the study presented are evidence based and show that the guidelines do not apply to cycling performance of 1-h duration in thermoneutral conditions in which there is no performance benefit to drinking anything more than a pre-ride bolus and an ad libitum CHO solution.

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