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The influence of carbohydrate content and type on gastrointestinal tolerance during endurance cycling

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The Influence of Carbohydrate Content and Type on Gastrointestinal Tolerance During Endurance Cycling

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Abstract

The purpose of this study was to examine the effects of carbohydrate ingestion on cycling time trial performance and gastrointestinal tolerance during endurance exercise. Eight trained male cyclists (age: 25 ± 6 years old, height: 180 ± 4 cm, weight: 77 ± 9 kg, and VO_{2max}: 62 ± 6 ml/kg/min) completed the study. Subjects consumed either a placebo beverage (PL), a high glucose beverage (HG: 1.5 g/min), a moderate glucose beverage (MG: 1.0 g/min), or a glucose and fructose beverage (1.5 g/min; 2:1 ratio) during approximately 3 hours of exercise, which consisted of 2 hours of constant load cycling (55% W_{max}) followed by a computer-simulated 30-km time-trial. Gastrointestinal distress was assessed every 30 minutes during the first 2 hours of cycling and throughout the time-trial, and performance was measured by time to complete the time-trial. Treatment differences were analyzed using one-way ANOVA with simple contrasts performed between individual treatments. Frequencies of gastrointestinal distress symptoms were calculated. Time-trial performance was improved with GF consumption compared to PL and HG ($p<0.05$), but not versus MG. GI distress scores were generally low throughout all trials, and were not significantly affected by the treatments. In conclusion, cycling performance was improved with GF ingestion in comparison to HG, but differences in performance could not be attributed to decreased GI complaints with GF. Performance in the GF trial was not significantly faster than MG, so it is not clear whether GF beverages improve performance in comparison to recommended doses of glucose alone.

Introduction

Carbohydrate ingestion during endurance exercise is believed to enhance performance because it spares the body's glycogen stores, thereby increasing the total amount of carbohydrate available for oxidation (40, 44). A dose-response effect between carbohydrate quantity and performance benefit has been suggested (40). Glucose consumed at moderate and high doses resulted in an increase in exogenous glucose oxidation, and a concomitant reduction in endogenous liver glycogen oxidation (40). Furthermore, ingesting multiple carbohydrate types during endurance exercise may provide additional benefits. Exogenous carbohydrate is oxidized at higher rates when two or more sugars are combined, known as multiple carbohydrate transportation (1, 10, 11, 15). This increased carbohydrate oxidation advantage may translate to enhanced performance (4, 37, 43).

Recent studies have reported a performance benefit from consuming glucose+fructose beverages during prolonged cycling (4, 43). For example, Currell et al. (4) found that a glucose+fructose beverage (60+30 g/hr) increased exogenous carbohydrate oxidation and improved cycling performance compared to a glucose-only beverage (90 g/hr). Triplett et al. (43) reported an 8% improvement in 100-kilometer time trial time with GF consumption compared to a matched calorie glucose beverage. However, the glucose-only beverages in both of these studies likely exceeded the capacity of intestinal glucose absorption, so it is possible that the performance improvement seen with the glucose+fructose beverage was a result of gastrointestinal (GI) distress in the glucose-only trial, rather than greater carbohydrate oxidation with glucose-fructose intake.

The limiting factor in carbohydrate oxidation is widely believed to be the rate of absorption in the small intestine (3, 8, 16, 17, 26). Malabsorption occurs when carbohydrate is

ingested at higher rates than receptors in the small intestine can accommodate (33), and may explain GI distress during exercise (5, 26, 32). Glucose and fructose are absorbed by separate receptors in the small intestine (6, 7), and consuming multiple types of carbohydrate has been proposed to maximize absorbance (21, 23, 39). Increasing the absorption rate may improve performance by increasing the amount of carbohydrate that can be delivered to the blood and by reducing the prevalence of GI symptoms associated with malabsorption.

The purpose of this study was to examine exercise performance and gastrointestinal tolerance when consuming a high glucose (HG) beverage (90 g/hr), a moderate glucose (MG) beverage (60 g/hr), and a glucose+fructose (GF) beverage (60+30 g/hr) during endurance cycling. A goal of the present study was to determine if potential performance improvements with glucose-fructose ingestion were due to increases in carbohydrate oxidation, or simply due to reductions in GI distress that occur with high rates of glucose consumption (90 g/hr). Because both GF and MG contain the same amount of glucose, a performance improvement with GF (above that seen with MG) can be attributed to increased carbohydrate availability with multiple transportable carbohydrates. Furthermore, if GI distress is more severe with HG than in GF, it may be inferred that high doses of glucose can overload the capacity of intestinal absorption and result in greater GI distress, both of which may be mitigated with consumption of a mixed carbohydrate beverage. In this study, performance was measured by a 30-kilometer (30-km) time trial (TT) following a two-hour steady state cycle, and GI symptoms were measured by questionnaire. It was hypothesized that the GF beverage would result in the fastest time trial times and the lowest GI distress, while the slowest time trial times and the highest GI distress (among carbohydrate beverages) would come from consuming the HG beverage.

Literature Review

Table 1. Studies Investigating the Oxidation Rates and Possible Performance Effects of Consuming Multiple Transportable Carbohydrates During Endurance Exercise.

Study	Subjects	Exercise	CHO Type & Amount	Results	Conclusions
Bjorkman et al., 1984	8 healthy, trained subjects	TTE at 70% VO_{2max}	250 mL 7% glu 250 mL 7% fru	subjects rode longer with glu	Ingestion of fru does not attenuate muscle glycogen depletion or positively influence performance over glu
Adopo et al., 1994	6 active, healthy males	120 min cycle at ~60.7% VO_{2max}	50 g glu 100 g glu 50 g fru 100 g fru 50 g glu +50 g fru (in 500 mL water)	More exogenous CHO oxidized in glu+fru than glu or fru only (both 50g and 100g of each); glu oxidized more readily than fru	There is a potential advantage in administering mixed CHO drinks because glu and fru can be absorbed separately and individually, and albeit not equally, can contribute to total CHO oxidation
Mitchell et al., 1989	10 end trained male cyclists	105 min cycle at 70% VO_{2max} followed by 15 min all out effort	6% glu 8.5% glu + 3.5% fru 14.5% glu + 3.5% fru	Performance improved over placebo with 12% CHO solution	There is an optimum combination of glu+fru to positively affect performance
Riddell, et al, 2001	12 boys (11-14 yrs)	-3 cycling bouts (30 min at 55% VO_{2peak}) with 5 min rest between -ride to exhaustion at 90% peak power	6% glu 3% glu + 3% fru	glu and glu+fru oxidized at similar rates during moderate intensity exercise	Contradictions to Adopo et al. (1994) may be a result of the subjects' age difference between the two studies or because the Riddell study had subjects ingest the glu+fru during exercise and not consume a bolus before exercise like the Adopo protocol
Jentjens et al., 2004	8 end trained male cyclists or triathletes	120 min cycle at 50% W_{max}	1.2 g/min glu 1.8 g/min glu 1.2 glu + 0.6 fru g/min	Peak CHO oxidation rates of glu+fru (1.3 g/min) are higher than that of med glu (~0.8 g/min) and high glu (~0.83 g/min)	Exogenous CHO oxidation rates were ~55% higher with glu+fru than with glu only trials

Jentjens & Jeukendrup, 2005	8 end trained male cyclists	150 min cycle at 50% W_{max}	1.2 g/min glu 1.2 glu + 1.2 fru g/min	Peak CHO oxidation rate of 1.75 g/min with glu+fru ingested at high rates (2.4 g/min)	Exogenous CHO oxidation rates can be further increased with higher rates of ingested glu+fru
Jeukendrup et al. 2006	8 end trained male triathletes or cyclists	5 hr steady state cycle at 58% VO_{2max}	1.5 g/min glu 1.0 glu + 0.5 fru g/min	-glu+fru: significantly higher peak rate of CHO(Exo) (1.40 +/- 0.08 g/min) -increase in the percentage of CHO(Exo) oxidized (65-77%)	Perceived exertion lower with glu+fru trial, cyclists more able to maintain cadence towards the end of trial with glu+fru
Wallis et al., 2007	8 trained female cyclists	120 min cycle at 60% VO_{2max}	0.5 g/min glu (low) 1 g/min glu (mod) 1.5 g/min glu (high)	Highest exogenous oxidation and lowest endogenous oxidation with mod glu	-all CHO quantities resulted in lower liver glu output -endogenous oxidation lower
Currell & Jeukendrup, 2008	8 end trained male cyclists	120 min cycle at 55% W_{max} followed by a ~60 min TT at 75% W_{max}	1.8 g/min glu 1.2 glu + 0.6 fru g/min	TT time with glu+fru 8% faster than glu only	glu+fru increases exogenous CHO oxidation and improves performance
Rowlands et al., 2008	10 end trained male cyclists or triathletes	-120 min cycle at 50% W_{max} -10, 2-3min sprints at max effort with 5-6 min rest between at ~40% VO_{2max}	0.6 g/min MD 0.6 MD + 0.3 fru g/min 0.5 g/min fru (low) 0.6 MD + 0.5 fru g/min 0.8 g/min fru (med) 0.6 MD + 0.7 fru g/min 1.2 g/min fru (high)	Perceived exertion, muscle tiredness, and fatigue lower with med and high fru	Low to medium fru ingestion rates result in the most efficient use of exogenous CHO, but also result in higher fatigue and perceptions of exercise stress and nausea
Pfeiffer, et al., 2009	~75 end trained males and females	16 km run	Study 1 -1.0 g/min glu -1.4 g/min glu Study 2 -1.4 g/min glu -1.4 g/min glu+fru (2:1)	No differences in performance	For exercises under ~70min, fatigue may be triggered by central mechanisms, rather than CHO availability

Jeukendrup & Moseley, 2010	8 males	120 min cycle at 60% VO_{2max}	1.5 g/min glu 1.0 glu + 0.5 fru g/min	Perceived exertion (in legs) lower with glu+fru	Suggested that glu+fru attenuates the disruption in homeostasis that occurs with exercise
Smith et al., 2010	12 end trained males cyclists or triathletes	120 min cycle at ~77% VO_{2peak} followed by 20 km TT	15 g/hr glu 30 g/hr glu 60 g/hr glu	With increasing doses of CHO, TT time improved and exogenous glu oxidation increased. Endogenous liver glu oxidation was reduced with 30 & 60 g/hr glu	Dose-response effect between CHO consumed and performance
Triplett et al., 2010	9 end trained males cyclists	100 km cycle TT with intermittent 1 km and 4 km sprints	2.4 g/min glu 1.6 glu + 0.8 fru g/min	CHO oxidation not statistically different between trials; all subjects completed the TT faster with glu+fru; power output higher with glu+fru	glu+fru improves TT performance by 8.1% compared to glu only

Key: end = endurance (trained); CHO = carbohydrate, glu = glucose, fru = fructose, MD = maltodextrin, TT = time trial, TTE = time to exhaustion, GE = gastric emptying

Table 2. Studies Investigating Gastrointestinal Distress Associated with Carbohydrate Intake During Endurance Exercise.

Study	Subjects	Exercise	CHO Type & Amount	GI Distress	Conclusions
Sullivan, 1981	57 distance runners	interview	n/a	-30% occasionally/frequently had urge to defecate -25% had abdominal cramps or diarrhea during or after competition -6% had severe nausea or retching	Alterations in GI functioning are prevalent in distance running and the mechanisms need to be addressed
Keefee et al., 1984	707 marathon participants 41.6% response rate (responders were probably more likely to have GI problems)	Questionnaire	n/a	-lower GI symptoms more prevalent in running than upper -urge to defecate most common -some symptoms reported more frequently by younger runners -all lower GI symptoms reported more in women than men -nausea and vomiting more troublesome during hard runs/after running	-pathophysiology of GI distress during running is unknown -intra-abdominal complaints may be explained by type/intensity of exercise, dietary habits, CHO absorption, GE, or alterations in blood flow
Rumessen & Gudmand-Høyer, 1986	10 healthy adults	Absorption capacity measured	suc: 50, 75, 100g (20%) fru: 15, 25, 37.5, 50g (10%) glu: 50g (10%) glu+fru: 50+50g (10%+10%) 50+25g (10%+5%), 50+12.5g (10%+2.5%)	Some reporting of mild flatulence, abdominal rumbling, or distention during or after the challenges	Absorption capacity of fru in enhanced by adding glu in a dose-dependent manner; individual tolerances for sugars may be important
Brouns et al., 1987	-fewer abdominal complaints in sports where body is relatively stable compared to running -training decreases the occurrence of GI symptoms				

Murray et al., 1989	12 healthy adults	115 min intermittent cycle at 65-80% VO_{2max} , followed by timed bout of 600 pedal revolutions	6% glu 6% fru 6% suc	More GI symptoms seen with fru, particularly during the final 30 min	Fru: poorest performance, highest perceived exertion, and greater plasma volume changes – may result from absorptive mechanisms of fru (facilitated diffusion, rather than glu's active transport)
Rehrer et al., 1989	114 previously untrained males and females were trained for a marathon (18 mo)	44 subjects completed questionnaire of fluid intake and GI distress during their first 25 km race (12 mo into training) and first marathon	-in general, fluid intake was low	-25% had complaints in 25 km race -52% had complaints in marathon -complaints not associated with fluid intake volume, but rather dehydration -80% in marathon who lost >4% body weight had GI problems	GI problems could result from reduced blood flow to GI, reduced blood volume (may reduce absorption), or rising core body temperature
Rehrer et al., 1992	172 ultra-marathon participants	67 km race	Varied -all subjects consumed fluid -most drank water -mean CHO intake (of those who drank CHO) was >129 g -85% periodically consumed solid foodstuffs, mostly fruit	-43% complained of GI distress -no direct relationship found between type/amount of beverage consumed and prevalence of GI symptoms -increased post-race plasma [K+] in those with GI complaints (no increase in those without symptoms)	heightened [K+] may be explained by an inability of the sodium-potassium pump to keep pace with demands of skeletal muscle and may have led to GI distress
Brouns & Beckers, 1993	-GI symptoms during endurance events may result from maldigestion, malabsorption, changes in small intestine transit, and improper food and fluid intake – seen in 30-50% of participants -adequate training attenuates the decrease of GI blood flow during submaximal exercise and may prevent GI symptoms -recommended to dilute CHO solutions				
Peters et al., 1993	32 male triathletes	-51 min cycle at 75% VO_{2max} (cycling) -43 min run at 75% VO_{2max} (running) -43 min cycle at 75% VO_{2max} (cycling) -43 min run at 75% VO_{2max} (running) -rest after each bout, supramaximal test after bouts 2, 3, 4	solid: 1.2 g CHO + 0.1 g protein + 0.02 g fat per kg body weight per hour isocaloric liquid: 1.3 g CHO per kg body weight per hr	-GI symptoms more frequent and longer lasting when running than when cycling -presence of GI symptoms not statistically different between solid and liquid trials -energy depletion, CHO malabsorption, intensity, experience, and age significantly related to GI symptoms during exercise	GI cramps associated with H_2 excretion (breath hydrogen concentration is indicative of CHO malabsorption)

Peters et al., 1995	-10-81% of athletes experience GI symptoms -severe GI symptoms may limit performance -decreased blood flow to GI can inhibit the active transport of glu (reduced CHO absorption) -CHO malabsorption can cause CHO to be passed into the colon ("CHO spillover"), which may give rise to GI symptoms of abdominal distention cramps, and flatulence due to stretching of the colonic wall -too much ingested CHO may cause GI problems, but too little is detrimental to long-duration activity				
Ferraris & Diamond, 1997	-fru uptake capacity is reduced during exercise -fru transported by GLUT5 (brush-border) -glu, other sugars transported by SGLT 1 (brush-border) -glu, galactose, and fru transported by GLUT 2 (basolateral)				
Peters et al., 1999	606 end trained athletes	GI questionnaire sent to cyclists, runners, and triathletes	Self-selected by individual athletes	-runners had more lower GI symptoms -cyclists had lower and upper GI symptoms -triathletes' symptoms support this trend -cyclists had the most GI symptoms, possibly due to younger mean age, shorter competition duration, or CHO chosen	GI symptoms during competition correlate to symptoms at rest, which suggests that GI distress may be individually determined
Jeukendrup et al., 2000	30 triathletes	Ironman distance triathlon	Self-selected by individual athletes	-93% reported GI symptoms -68% had endotoxaemia 1hr post race	Circulating endotoxin LPS may cause cytokine release, which was associated with GI distress
Riddell et al., 2001	12 boys (11-14 yrs)	-3 cycling bouts (30 min at 55% VO_{2peak}) with 5 min rest between -10 min rest -ride to exhaustion at 90% peak power	6% glu 3% glu + 3% fru	Similar stomach fullness in all trials	More research needed to determine if a higher concentration of glu+fru (relative to glu) would affect the stomach fullness results
Jentjens, Achten, & Jeukendrup, 2004	8 end trained male cyclists	150 min cycle at ~60% VO_{2max}	2.4 g/min glu 1.2 glu + 0.6 fru + 0.6 suc g/min	more severe GI problems reported in glu trial	GE may have decreased in the glu trial and contributed to the greater number of GI complaints
Jentjens, Venables, & Jeukendrup et al., 2004	9 end trained male cyclists	150 min cycle at 50% W_{max}	1.8 g/min glu 1.2 glu + 0.6 suc g/min 1.2 glu + 0.6 maltose g/min	More severe problems reported in glu and glu+maltose trials	The higher oxidation rate of glu+suc compared to glu may be because of greater CHO absorption, which has been associated with lower GI discomfort

Jentjens, et al., 2004	8 end trained male cyclists or triathletes	120 min cycle at 50% W_{max}	1.2 g/min glu 1.8 g/min glu 1.2 glu + 0.6 fru g/min	Severe symptoms were seen most often in the high-glu trial compared to the low-glu or glu+fru trials	glu and fru are absorbed by separate intestinal receptors, allowing for higher absorption rates and less GI discomfort
Jentjens & Jeukendrup, 2005	8 end trained male cyclists	150 min cycle at 50% W_{max}	1.2 g/min glu 1.2 glu + 1.2 fru g/min	No statistical difference in the number of complaints among the trials	glu and fru are absorbed by separate intestinal receptors, allowing for higher absorption rates and less GI discomfort
Jentjens, et al., 2005	8 end trained male cyclists	120 min cycle at 50% W_{max}	1.2 g/min glu (8.7%) 1.2 g/min suc (8.7%) 0.6 glu + 0.6 suc g/min (8.7%) 1.2 glu + 1.2 suc g/min (17.5%)	No statistical difference in GI complaints among trials	Did not discuss GI distress
Wallis, et al., 2005	8 end trained male cyclists	150 min cycle at 55% W_{max}	1.8 g/min MD 1.2 MD + 0.6 fru g/min	4 severe complaints in MD trial, 1 severe complaint in MD+fru trial	Did not discuss causes of GI complaints
Jeukendrup, et al. 2006	8 end trained male triathletes or cyclists	5 hr steady state cycle at 58% VO_{2max}	1.5 g/min glu 1.0 glu + 0.5 fru g/min	Perceived stomach fullness decreased with time in glu+fru (increased in glu)	Supports findings that fru results in faster gastric emptying than glu and/or fru increases glu uptake and/or multiple CHOs allows for utilization of multiple transporters
Jentjens et al., 2006	8 end trained male cyclists or triathletes	120 min cycle at 50% W_{max}	1.5 g/min glu 1.0 glu + 0.5 fru g/min	2 subjects experienced severe GI symptoms in glu (no severe GI discomfort in glu+fru)	glu is shown to have a higher gastric emptying rate/lower absorption rate than glu+fru (explains severe GI symptoms)
Rowlands, et al., 2008	10 end trained M cyclists or triathletes	-120 min cycle at 50% W_{max} -10, 2-3min sprints at max effort with 5-6 min rest in between at ~40% $VO2_{max}$	0.6 g/min MD 0.6 MD + 0.3 fru g/min 0.5 g/min fru (low) 0.6 MD + 0.5 fru g/min 0.8 g/min fru (med) 0.6 MD + 0.7 fru g/min 1.2 g/min fru (high)	Fewer complaints of nausea in med and high fru trials compared to low fru	The improved performance in the med fru trial could be related to the fewer GI symptoms reported

Pfeiffer, et al., 2009	~75 end trained males and females	16 km run	Study 1 -1.0 g/min MD+fru -1.4 g/min MD+fru Study 2 -1.4 g/min MD -1.4 g/min MD+fru (2:1)	Study 1: -nausea occurred more frequently with the high dose Study 2: -glu: 12% had symptoms -glu+fru: 23% had symptoms	Symptoms were low with both treatments in both studies with no statistical difference, suggesting that GI tolerance is individual
Pfeiffer et al., 2010	8 end trained male cyclists or triathletes	180 min cycle at ~60% VO_{2max}	Bar: 0.67 glu + 0.33 fru g/min + water drink: 1 MD + 0.5 fru g/min	No severe GI symptoms; stomach fullness was greater in the bar trial	Did not discuss GI distress
Pfeiffer et al., 2010	8 end trained male cyclists or triathletes	180 min cycle at ~60% VO_{2max}	Gel: 1.2 glu + 0.6 fru g/min Drink: 1.2 glu + 0.6 fru g/min	No severe GI symptoms and no difference in stomach fullness among CHO trials and water	High CHO intake rates are well tolerated
Triplett et al., 2010	9 end trained male cyclists	100 km cycle TT with intermittent 1 km and 4 km sprints	2.4 g/min glu 1.2 glu+ 1.2 fru g/min	4/9 subjects reported symptoms after the glu only TT; 7/9 subjects reported they felt less gastric emptying with glu only; no symptoms reported with glu+fru	Large amounts of CHO consumed during exercise are not always tolerated well, but mixing CHO has been known to ease discomfort because there are more intestinal receptors at work to absorb the CHO
O'Brien & Rowlands, 2011	10 end trained male cyclists	150 min cycle at 50% peak power; incremental test to exhaustion	Fru and MD 1.8 g/min 1) 4.5% fru and 9% MD (0.5) 2) 6% fru and 7.5% MD (0.8) 3) 7.5% fru and 6% MD (1.25)	Abdominal cramping, stomach fullness, and nausea lowest with 0.8 followed by 1.25 solution. Best GI comfort with 0.8	Enhanced performance may be associated with lower GI distress
Pfeiffer et al., 2011	8 end trained male cyclists and triathletes (equally trained in both running and cycling)	120 min run at ~60% VO_{2max} 120 min cycle at ~60% VO_{2max}	1.0 glu + 0.5 fru g/min	No severe GI complaints in either trial	Exercise intensity was moderate in this study (studies that have shown GI distress have been at higher intensities)
Pfeiffer et al., 2012	221males and females end athletes in their respective disciplines	-2 full Ironman triathlons -1 half Ironman -marathon -100 and 150km cycling race	Mean CHO intake rates: not statistically different between the 3 Ironmans, lower in cycle, and even lower in marathon	Prevalence of GI symptoms from highest to lowest: Ironmans > half-Ironman > cycle & marathon (tied)	- CHO intake correlated with GI symptoms - history of GI distress important predictor

Rowlands, Swift, Ros, & Green, 2012	10 competitive mountain bikers, 16 male cyclists	-2.5 hr mountain bike race -94 min at submax workload followed by performance test	~1.4 g/min glu + MD ~1.4 g/min fru + MD	-race performance times associated with lower GI complaints -sprint power increased with GI distress -reduced GI distress with fru+MD	GI distress and performance relationship is inconsistent

Key: end = endurance (trained); CHO = carbohydrate, glu = glucose, fru = fructose, suc=sucrose, MD = maltodextrin, GE = gastric emptying, GI = gastrointestinal

Table 3. Studies Investigating Carbohydrate Absorption and Gastric Emptying, Particularly During Endurance Exercise and with Multiple Transportable Carbohydrates.

Study	Subjects	Exercise	CHO Type & Amount	Results	Conclusions
Holdsworth & Dawson, 1964	19 healthy adults	CHO absorption measured	glu galactose fru fru+glu galactose+glu	-glu and galactose follow Michaelis-Menten kinetics -no inhibition between glu and fru	-fru absorbed slower than glu -fru absorption stimulated by presence of glu -limiting factor of glu and galactose absorption is transporter saturation
Gray, 1975	-glu and galactose actively transported via Na+ -fru transported by a carrier mechanism independent of both Na+ and the glu-galactose transport mechanism				
Chen & Whistler, 1977	-uptake of fru is slower than glu and galactose (actively transported) but faster than sorbose and mannose (passive diffusion)				
Coyle et al., 1978	12 healthy adults	GE measured 15 min after ingestion	400 mL Gatorade 400 mL Braketime 400 mL Body Punch	Gatorade associated with slowest GE, but had the highest CHO delivery per min	High concentration of CHO slows GE
Moran & McHugh, 1981	6 male monkeys	GE measured	37.5g in 150mL glu 37.5g in 150mL xylose 37.5g in 150mL fru	-higher food intake 2hr post-feeding with fru, but same after 4hr -glu and xylose empty slowly with increasing concentration, linear -fru empties faster, exponentially	-other mechanisms at play to cause 4hr food intake to be the same even though GE was higher with fru
Ravich et al., 1983	16 healthy adults	Fructose absorption measured	50g fru (10%) 37.5g fru (10%) 50g suc (10%)	-6 incompletely absorbed 50g fru -3 incompletely absorbed 37.5g fru -all subjects completely absorbed 50g (10%) suc	-malabsorption of fru both concentration and dose related -malabsorption of fru associated with GI distress

Neufer, et al., 1986	25 male and female runners	GE measured at rest and after 15 min running at 50-70% VO_{2max}	5% MD 3% MD + 2% glu 4.5% MD + 2.6% fru 5.5% MD + 2% glu 5.5% MD + 2% fru	most CHO delivered after 15 min exercise with drinks containing fru	-fru does not inhibit GE but glu might -possible advantage to adding fru as a CHO source
Rumessen & Gudmand-Høyer, 1986	10 healthy adults	Absorption capacity measured	suc: 50, 75, 100g (20%) fru: 15, 25, 37.5, 50g (10%) glu: 50g (10%) glu+fru: 50+50g (10%+10%), 50+25g (10%+5%), 50+12.5g (10%+2.5%)	fru is absorbed best in combination with glu or when ingested as suc	glu stimulates fru uptake (dose-dependent), hypothesize that a small intestine glu/fru ingested as suc transporter exists
Van den Berghe, 1986	-fru is metabolized at roughly half the rate of glu, fru is transported in the liver via carrier-mediated transport -1/3 healthy adults incompletely absorb fru (may be the cause of abdominal symptoms after the ingestion of fruit)				
Erickson et al., 1987:	5 competitive cyclists	90 min cycle at 65-70% VO_{2max}	1.0 g/kg fru before exercise 5.0 mg/kg caffeine before 1.0 g/kg glu during caffeine/fru before and glu during	fru likely to cause GI distress	GI distress in fru trial likely caused by slower absorption
Mitchell et al., 1988	8 end trained male cyclists	7 x 12 min cycle at 70% VO_{2max} with 3 min rest in between followed by 12 min TT	-5% (2.7 MD + 2.3 glu) -6% (2.14 MD + 1.88 fru + 1.95 suc) -7.5% (5.55 MD + 2 fru) -units: g/100 mL	Significantly less fluid emptied from the stomach with the 5% CHO beverage compared to the placebo	GE should decrease as concentration increases, but they justified the discrepancies by the change in protocol from previous studies
Mitchell et al., 1989	10 end trained male cyclists	105 min cycle at 70% VO2max followed by 15 min max effort	6% glu 8.5% glu + 3.5% fru 14.5% glu + 3.5% fru	No difference in GE between exercise and resting	There was a difference in CHO delivery between the trials, which suggests that CHO oxidation is not limited by GE
Sole & Noakes, 1989	7 end trained athletes	GE measured	5%, 10%, and 15% solutions of fru, glu, glu polymer	-GE rate declined with increasing concentration -fru 15% and polymer 15% emptied faster than glu 15% -fru 10% and 15% emptied faster than glu 10% and 15%	fru empties faster than glu
Maughan et al., 1990	6 healthy male adults	40 min cycle at 40%, 60%, 80% VO2max	200 mL glu/electrolyte solution (200 mmol/L glu)	Rate of plasma accumulation greater at rest than during exercise at 60 or 80% VO_{2max}	Exercise above moderate intensity may delay GE or reduce the CHO absorption rate

Rehrer et al., 1992	8 end trained male cyclists	80 min cycle at 70% VO_{2max}	4.5% glu 17% glu 17% MD	With increasing concentration of CHO, GE increased	GE and fluid absorption do not limit exogenous CHO oxidation
Cole et al., 1993	10 end trained male cyclists	105 min cycle at 70% VO_{2max} followed by 15 min all out	6% glu+suc 8.3% high fru corn syrup 6.3% high fru corn syrup + 2% glu polymer	No differences in GE	More CHO delivered to intestine with HFCS and HFCS+glu polymer solutions
Brouns & Beckers, 1993	-GE is not influenced by exercise at intensities less that ~70% VO_{2max} -GE is delayed at intensities over 70% VO_{2max} -GE is not affected by training status or type of exercise at intensities lower than 70% VO_{2max} -less concentrated solutions empty faster than more concentrated solutions				
Shi et al., 1995	8 healthy males	75 min (rest)	6-8% glu 6-8% MD 6-8% glu+fru 6-8% glu+suc	Highest CHO absorption with glu+fru	Multiple transporters available for absorption with multiple CHOs
Shi et al., 2000	8 healthy adults	GE measured	6% glu 6% fru 3% glu + 3% fru 6% suc	No difference in GE	CHO concentrations not expected to change the GE rate (these concentrations were low)
Jeukendrup & Jentjens, 2000	-glu, suc, maltose, MD oxidation rate ~1.0 g/min and fru, galactose, and amylose oxidation rate ~0.6 g/min -CHO absorption appears to be limiting factor in oxidation rate -oxidation rate of CHO intake of 1.0g/min seems to be capped at ~1.0g/min				
Jeukendrup, 2004	-ingestion of multiple CHOs can increase absorption 20-50% by maintaining blood glu/oxidation, liver/muscle glycogen sparing, or glyconeogenesis during low intensity exercise				
Rogers et al., 2005	5 healthy adults	85 min cycle at ~65% VO_{2max} followed by 3mi TT	1% glu + 2% suc 2% glu + 4% suc	No difference in GE and performance, CHO absorption highest with 6% solution	CHO concentrations not expected to change the GE rate (these concentrations were low)
Jeukendrup & Moseley, 2010	8 healthy males	120 min cycle at 50% W_{max}	1.5 g/min glu 1.0 glu + 0.5 fru g/min	GE rate faster with glu+fru versus glu	Addition of fru to glu increases GE *they suggest the difference in protocol can explain the discrepancy from Shi et al., 2000

Key: end = endurance (trained); CHO = carbohydrate, glu = glucose, fru = fructose, suc=sucrose, MD = maltodextrin, GE = gastric emptying, GI = gastrointestinal

Methods

Subjects

8 trained male cyclists voluntarily participated in this study. Subjects were 25 ± 6 years old, 180 ± 4 cm tall, 77 ± 9 kg in weight, and had a VO_{2peak} of 62 ± 6 ml/kg/min. Participants were designated as low-risk for experiencing health complications during exercise per ACSM guidelines (42). Each subject provided informed consent after receiving oral and written information about experimental procedures and potential risks of the study. The Institutional Review Board of James Madison University approved all testing procedures.

Exercise Trials

Pre-testing

Subjects performed a graded exercise test on a cycle ergometer (Velotron, Racermate, Inc., Seattle, WA, USA) to determine their peak oxygen uptake (VO_{2peak}) and associated power output (W_{max}). Subjects began cycling at a self-selected pace defined as "a comfortable, but not easy pace for a 1-hour ride". Workload was increased by 25 watts every two minutes until the subjects voluntarily requested to stop due to fatigue or if their cadence fell below 50 rpm. VO_{2peak} was determined by the highest 30-second mean oxygen uptake value. Metabolic measurements were assessed at each stage of the test using a Moxus Modular Metabolic System (AEI Technologies, Pittsburgh, PA, USA).

Familiarization Trial

Following the VO_{2peak} test, subjects completed a familiarization trial. Procedures during this test were identical to the subsequent experimental trials described below. Subjects consumed only water during this trial.

Experimental Trials

Subjects completed four experimental trials on a Racermate Velotron cycle ergometer (Seattle, WA, USA). The duration of each trial was approximately 3 hours. Every trial consisted of 2 hours of

fixed intensity at 55% W_{max} (based on data obtained from the VO_{2peak} test) followed immediately by a 30-km simulated time trial (TT) conducted at maximal effort. During the TT portion of the trials, the subjects did not receive verbal encouragement or performance feedback other than elapsed distance. The trials were performed in the morning, following an overnight fast and standardized breakfast (below). Trials were separated by 5-14 days, and were identical other than the treatment beverage consumed during each trial. The subjects' height and weight were taken immediately prior to each experimental trial.

Treatments

Four beverage treatments were assigned in a randomly counterbalanced, double-blind design. Subjects consumed 600 mL of treatment beverage immediately prior to the familiarization and experimental trials. Subjects consumed 150 mL every 15 minutes during the steady-state portion of the trial and also at kilometers 7.5, 15, and 22.5 of the TT. The specific treatment beverages are described below. All treatment beverages also included 470 mg/L added sodium (Morton Salt, Chicago, IL, USA) and 200 mg/L added potassium (NOW Foods, Bloomingdale, IL, USA). The treatments were as follows:

1. Placebo (PL): non-caloric water sweetened with Splenda® (5.3 g/L) (Splenda, Fort Washington, PA, USA).

2. High Dose Glucose (HG): 120 g/L glucose, resulting in a carbohydrate intake rate ~ 90 g/hr.

3. Moderate Dose Glucose (MG): 80 g/L glucose, resulting in a carbohydrate intake rate ~ 60 g/hr.

4. Glucose+Fructose (GF): 80 g/L glucose + 40 g/L fructose (Tate and Lyle, Decatur, IL, USA), resulting in a carbohydrate intake rate ~ 90 g/hr.

Measurements

Time Trial Performance

TT performance was measured using exercise time and mean power output (Watts) during the 30-km TT segment of the trial. Subjects were told neither their TT time nor their power output for each trial until the entire study was completed.

Physiological Measurements

Oxygen uptake (VO_2), minute ventilation (VE), and respiratory exchange ratio (RER) were assessed using a Moxus Modular Metabolic System (AEI Technologies, Pittsburgh, PA, USA) at minutes 15-20, 55-60, and 115-120 of the steady-state portion and 20-km into the TT. Total carbohydrate oxidation during the TT was calculated from these measurements (18).

Gastrointestinal Distress

Subjects verbally rated the presence of gastrointestinal (GI) symptoms on a scale of 1-10 (1 = not at all, 10 = very, very much) at minutes 30, 60, 90, and 120 of the steady-state portion and 20-km and 30-km into the TT. The 11 GI symptoms on the questionnaire included stomach problems, GI cramping, bloated feeling, diarrhea, nausea, dizziness, headache, belching, vomiting, urge to urinate and urge to defecate [modified from: (41) (Attachment 1)].

Dietary and Exercise Controls for Experimental Trials

Subjects avoided vigorous exercise 48 hours prior to each trial. Subjects were required to record their dietary intake during the 24 hours preceding their first experimental trial and then replicate their dietary intake during the 24 hours preceding each subsequent experimental trial. The night before each trial, subjects consumed a liquid meal replacement (Ensure® Shakes, Abbott Laboratories, Abbott Park, IL, USA) at an amount that equated to ~20% of their daily caloric intake. Subjects also consumed a standardized breakfast 2 hours prior to starting each trial. The standardized breakfast was ~500 kcals, and

consisted of 8 oz. orange juice (Minute Maid®), 1 serving (34g) Frosted Flakes® cereal (with ~6 oz. low-fat milk), and 6 oz. strawberry (Yoplait®) yogurt.

Statistical Analysis

A one-way ANOVA (randomized complete block) was used to identify differences between treatment conditions, with simple contrasts performed between individual treatments. GI distress scores were analyzed with a frequency table for severity. Subjects who reported GI distress ratings $\geq$5 during the steady state portion were visually examined analyzed to determine if symptoms were exacerbated by specific beverage treatments. All analyses were performed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA). The alpha level for significance was set at $P < 0.05$.

Results

Performance

30 km time trial times by treatment are displayed in Figure 1. A significant main-effect ($p < 0.05$) was observed for treatment. Consumption of GF significantly reduced 30-km time trial times compared to PL and HG. Time trial time also tended to be faster with the MG treatment versus PL ($p = 0.06$).

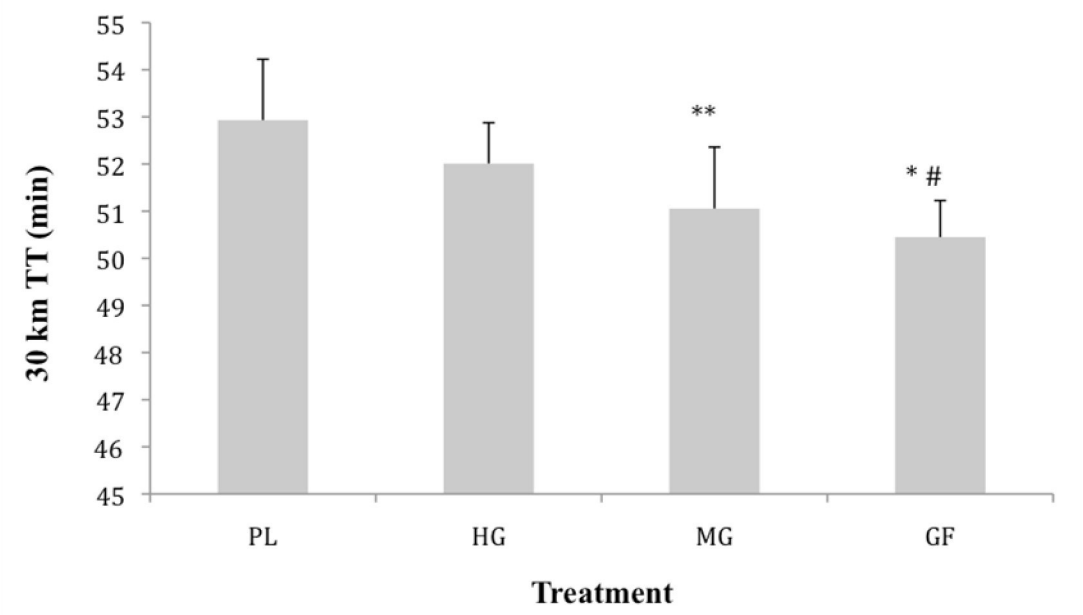

Figure 1. The effect of treatment beverages on 30-km time trial times. Values are means ± standard error.

* = Significantly faster time than placebo ($p < 0.05$)

** = Trend towards faster time than placebo ($p = 0.06$)

= Significantly faster than HG ($p < 0.05$)

GI Distress

Table 4 shows GI distress ratings during the steady state portion of each trial. GI distress ratings were not significantly influenced by treatments. In addition, ratings were not significantly changed over time, with one exception: Urge to urinate increased significantly over time, as shown in Figure 2.

Table 4. Effect of treatment beverages on GI distress ratings during steady state exercise. Values are means ± standard deviation.

	Time (min)																			
	30					60					90					120				
Variable	**PL**	**HG**	**MG**	**GF**	**AVG**	**PL**	**HG**	**MG**	**GF**	**AVG**	**PL**	**HG**	**MG**	**GF**	**AVG**	**PL**	**HG**	**MG**	**GF**	**AVG**
Stomach Problems	1.25 ± 0.7	1.50 ± 1.1	1.25 ± 0.7	1.50 ± 0.9	1.38 ± 0.7	1.00 ± 0.0	1.25 ± 0.7	1.50 ± 0.9	1.25 ± 0.7	1.25 ± 0.5	1.75 ± 1.8	1.38 ± 0.7	1.50 ± 1.4	1.00 ± 0.0	1.41 ± 0.6	1.25 ± 0.7	1.50 ±0.9	1.50 ± 1.4	1.40 ± 1.1	1.41 ± 0.7
Cramping	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.50 ± 0.9	1.13 ± 0.2	1.00 ± 0.0	1.25 ±0.7	1.25 ± 0.7	1.13 ± 0.4	1.16 ± 0.4	1.00 ± 0.0	1.63 ± 1.2	1.50 ± 1.4	1.00 ± 0.0	1.28 ± 0.6	1.00 ± 0.0	1.63 ± 1.2	1.63 ± 1.8	1.38 ± 1.1	1.41 ± 1.0
Bloated Feeling	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.03 ± 0.1
Diarrhea	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.031 ± 0.1
Nausea	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.50 ± 1.4	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.75 ± 2.1	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.19 ± 0.5	1.75 ± 2.1	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.19 ± 0.5
Dizziness	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.03 ± 0.1
Headache	1.00 ± 0.0	1.25 ± 0.7	1.00 ± 0.0	1.00 ± 0.0	1.06 ± 0.2	1.25 ± 0.7	1.25 ± 0.5	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.3	1.50 ± 1.4	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.16 ± 0.4	1.25 ± 0.7	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.09 ± 0.3
Belching	1.00 ± 0.0	1.25 ± 0.5	1.50 ± 1.1	1.38 ± 0.7	1.28 ± 0.4	1.13 ± 0.4	1.38 ± 0.7	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.2	1.00 ± 0.0	1.25 ± 0.5	1.00 ± 0.0	1.63 ± 1.1	1.22 ± 0.3	1.00 ± 0.0	1.37 ± 0.7	1.00 ± 0.0	1.13 ± 0.4	1.13 ± 0.3
Vomiting	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.03 ± 0.1	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0
Urge to Urinate	1.25 ± 0.7	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.09 ± 0.2	1.75 ± 1.5	1.00 ± 0.0	1.63 ± 1.2	1.00 ± 0.0	1.34 ± 0.4	2.00 ± 1.8	1.00 ± 0.0	2.00 ± 1.2	1.25 ± 0.7	1.56 ± 0.6	2.62 ± 2.4	1.25 ± 0.7	3.63 ± 2.1	2.25 ± 1.5	2.44 ± 0.9
Urge to Defecate	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.00 ± 0.0	1.50 ± 1.4	1.00 ± 0.0	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.13 ± 0.4	1.00 ± 0.0	1.00 ± 0.0	1.03 ± 0.1	1.00 ± 0.0	1.25 ± 0.5	1.00 ± 0.0	1.00 ± 0.0	1.06 ± 0.1

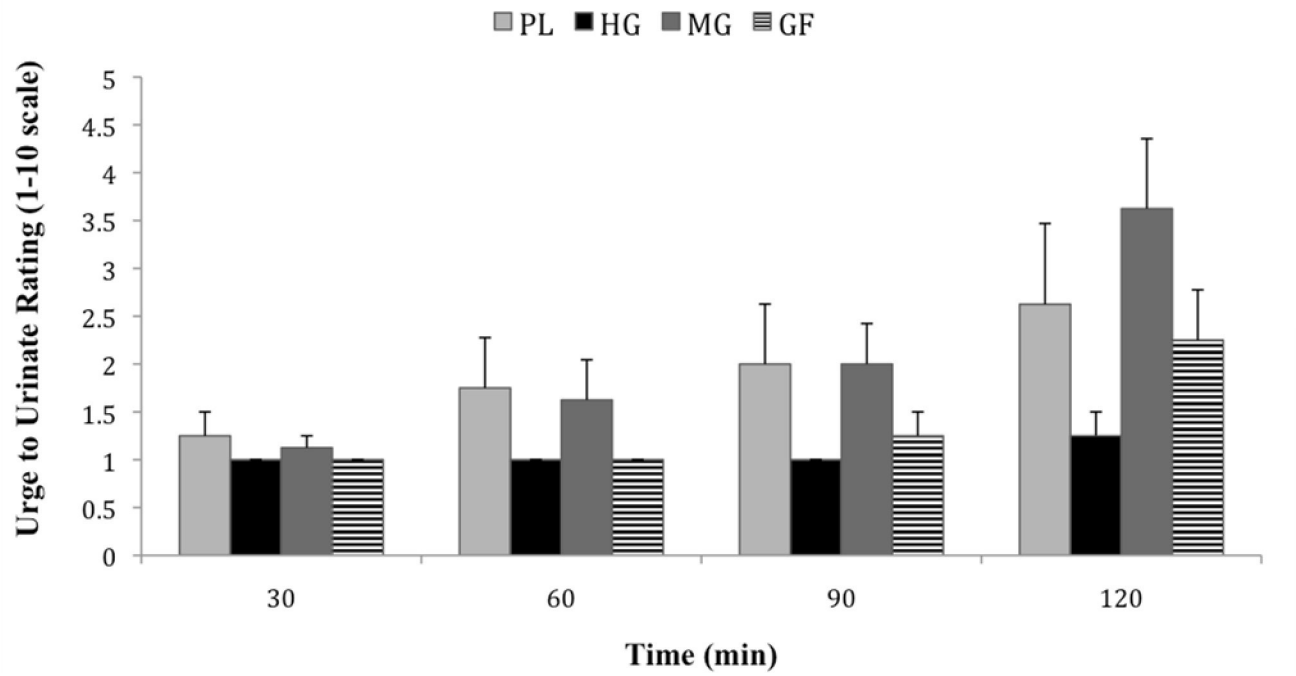

Figure 2. Effect of treatment beverages on urge to urinate rating during 120-minute steady state portion. Values are means ± standard error. Main-effect for time ($p < 0.05$).

Individuals with High GI Distress

Only two subjects reported upper GI distress symptoms with ratings ≥ 5 during the steady state portion. TT performances for these individuals are shown in table 5, in comparison to the entire group. The percent (%) benefit of GF versus HG in these individuals (3.85%) was comparable to the entire group (3.09%), while the benefit of MG versus HG in these same individuals (-1.26%) was less than that of the entire group (1.84%).

Table 5. Improvements in 30-km time trial time with MG and GF consumption versus HG.

Entire Group	**PL**	**HG**	**MG**	**GF**	**HG vs MG**	**HG vs GF**
Mean	52.93	52.01	51.06	50.45	0.96	1.56
% Improvement					1.84	3.09
Those with GI Distress	**PL**	**HG**	**MG**	**GF**	**HG vs MG**	**HG vs GF**
Mean	54.44	51.36	52.00	49.45	-0.65	1.91
% Improvement					-1.26	3.85

Discussion

Consuming multiple transportable carbohydrates (glucose+fructose) during prolonged exercise has been shown to enhance performance versus isocaloric amounts of glucose alone (4, 43). Our study examined the performance effects of a mixed carbohydrate beverage (GF) versus an isocaloric high glucose beverage (HG), a moderate glucose beverage (MG), and a placebo (PL). This study also assessed how the treatment beverages affected perceived GI distress and individual tolerances to the beverages. In the current study, 30-km TT time was significantly reduced when GF was consumed versus PL and HG, but not significantly reduced versus MG. Treatment beverages did not significantly affect GI distress ratings.

Our findings are consistent in some respects with those from previous studies that investigated the performance effects of GF intake during prolonged cycling. Triplett et al. (2010) reported an 8% improvement in 100-km TT time with GF consumption compared to a matched calorie glucose beverage (43). Additionally, Currell & Jeukendrup (2008) observed that GF consumption improved 30-km TT time by 8% over glucose only trials (4). Similarly, we observed 3% faster TT times with GF versus HG. Performance improvements seen with mixed carbohydrate beverages have been largely attributed to increased exogenous carbohydrate oxidation (1, 10, 11, 15), which could spare endogenous reserves and allow higher carbohydrate availability in late-exercise. Carbohydrate oxidation is largely dependent on intestinal absorption (3, 8, 16, 17, 26), which can be maximized by combining multiple carbohydrates because glucose and fructose use separate absorption receptors in the intestine (6, 7). It has been proposed that there may be a potential performance advantage to this mechanism since more carbohydrate can theoretically be ingested (and oxidized) during exercise (21, 23, 39).

While GF ingestion may provide an ergogenic effect by increasing carbohydrate oxidation rates, it was not reflected in our study. Total carbohydrate oxidation during the TT was elevated in all carbohydrate trials (MG = 2.74 ± 0.69 g·min^{-1}; HG = 2.57 ± 0.58 g·min^{-1}; and GF = 2.79 ± 0.34 g·min^{-1}) versus PL (1.77 ± 0.46 g·min^{-1}), but was not significantly different among MG, HG and GF trials. Likewise, Triplett et al. (2010) did not report any differences in total carbohydrate oxidation rates between a glucose-fructose beverage and an isocaloric glucose beverage during a 100-km TT (43). While others have reported increased exogenous carbohydrate oxidation with GF, total carbohydrate oxidation was not significantly elevated (1, 4, 10, 14, 15, 40, 44). In our study, ingestion of the GF beverage did not increase performance over the MG beverage, suggesting that CHO oxidation did not affect performance. Although our small sample size could have limited our ability to detect small differences in performance between treatments, our findings suggest that previous reports regarding the benefits of glucose+fructose ingestion may have been overstated. Currell & Jeukendrup (2008) and Triplett et al. (2010) reported a performance benefit with GF over a matched calorie glucose beverage, but did not use a moderate-dose glucose beverage for comparison (4, 43). The glucose-only beverage in these studies was a high dose and thus was probably not absorbed completely. It is possible that the differences in performance seen in our study (and prior studies) with GF over HG were not a result of increased carbohydrate oxidation, but rather due to problems with excess glucose from the HG beverage.

The pathophysiology of GI distress during endurance exercise is relatively unknown because GI discomfort can vary based on the type and intensity of the exercise, dietary habits, CHO absorption, gastric emptying, and alterations in blood flow (2, 19, 26, 34). Glucose consumption over ~60g/hr has been shown to overload the intestinal absorption receptors and

may be related to GI discomfort (2, 3, 11, 28, 37). Multiple transportable carbohydrates are used to attenuate intestinal receptor saturation, which may help alleviate GI discomfort (6, 9, 11, 13–15, 22, 24, 37, 38, 43). In this study, it was hypothesized that the HG beverage would exceed intestinal absorption rates and result in greater GI discomfort than the GF beverage.

Contrary to our hypothesis, GI distress ratings were not systematically affected by treatment beverages in the current study. This may have been influenced by the generally low GI distress ratings under all treatment conditions. Individual tolerances to GI distress are widely varied (25, 28, 29, 38) and may explain why clear relationships between carbohydrate intake rates and GI distress have not been reported (10, 12, 27, 30, 31, 35, 36). In the present study, only two subjects reported GI distress ratings ≥ 5 during any of the beverage trials. It was speculated that these 'GI intolerant' individuals would experience higher GI distress in the HG trial (due to excess glucose), and therefore derive greater performance benefits when consuming the GF or MG beverages. However, as shown in table 5, this hypothesis was not supported by the performance outcomes in these individuals. It has been suggested that endurance training decreases the occurrence of GI distress (2, 3), which may provide an explanation for why our subjects experienced few GI symptoms. Our subjects likely ingested carbohydrate on a regular basis while training and therefore built up a high tolerance to glucose in comparison to less trained individuals.

The evidence above implies that the performance benefit seen with GF over HG was unrelated to GI distress. Interestingly, other data suggests that excess carbohydrate intake can negatively affect performance independent of GI distress (20, 24). Obrien and Rowlands (24) speculated that the central nervous system (CNS) may blunt motor output when carbohydrate concentrations are too high (in order to minimize GI discomfort), due to feedback from

osmosensitive and chemosensitive pathways in the gut. High concentrations of glucose seem to increase the presence of intestinal glucose receptors, which is likely due to a localized chemoreceptor response (20). It is therefore possible that the high CHO content of HG could not be fully absorbed by the intestine, and in order to prevent GI distress, motor output was blunted by the CNS – resulting in poor TT times without high ratings of GI distress.

In conclusion, GF ingestion significantly improved late-exercise cycling performance in comparison to HG and PL, but did not improve TT time significantly over MG. In addition, total carbohydrate oxidation was not significantly different among the carbohydrate beverages studied here. Collectively, these findings suggest that GF may not enhance performance significantly versus recommended doses of glucose ($\leq$ 60 g/hr). Furthermore, our data suggest that prior reports of enhanced performance with GF may be related to excess glucose used in comparison beverages, which could have elevated GI distress. However, this hypothesis cannot be directly supported by the present findings, as GI distress ratings were generally low in all beverage trials.

Appendix

Attachment 1. Gastrointestinal distress rating scale.

Rating of Perceived Gastrointestinal Distress

Stomach Problems

1	2	3	4	5	6	7	8	9	10
None		Slight		Moderate		Significant		Very much	Severe

GI Cramping

1	2	3	4	5	6	7	8	9	10
None		Slight		Moderate		Significant		Very much	Severe

Bloated Feeling

1	2	3	4	5	6	7	8	9	10
None		Slight		Moderate		Significant		Very much	Severe

Diarrhea

1	2	3	4	5	6	7	8	9	10
None		Slight		Moderate		Significant		Very much	Severe

Nausea

1	2	3	4	5	6	7	8	9	10
None		Slight		Moderate		Significant		Very much	Severe

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