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Abstract

The ingestion of exogenous carbohydrates (CHO) during prolonged endurance exercise, such as long-distance triathlon, is considered beneficial with regard to performance. However, little is known about whether this performance benefit differs among different forms of CHO administration. To this end, the purpose of our study was to determine the impact of CHO ingestion from a semisolid source (GEL) on measures of performance and gastrointestinal (GI) comfort compared with CHO ingestion from a liquid source (LIQ). Nine well-trained triathletes participated in this randomized crossover study. Each participant completed a 60-min swim, 180-min bike exercise, and a 60-min all-out run in a laboratory environment under 2 conditions, once while receiving $67.2 \pm 7.2 \text{ g} \cdot \text{h}^{-1}$ ($M \pm SD$) of CHO from GEL and once while receiving $67.8 \pm 4.2 \text{ g} \cdot \text{h}^{-1}$ of CHO from LIQ. The amount of fluid provided was matched among conditions. Respiratory exchange ratio (RER), blood glucose, and lactate as well as GI discomfort were assessed at regular intervals during the experiment. The distance covered during the final all-out run was not significantly different among participants ingesting GEL ($11.81 \pm 1.38 \text{ km}$) and LIQ ($11.91 \pm 1.53 \text{ km}$; $p = .89$). RER, blood glucose, and lactate did not differ significantly at any time during the experiment. Seven participants reported GI discomfort with GEL, and no athlete reported GI discomfort with LIQ ($p = .016$). This study suggests that administration of GEL does not alter long-distance triathlon performance when compared with LIQ, but GEL seems to be associated with reduced GI tolerance. Athletes should consider this a potential disadvantage of GEL administration during long-distance triathlon.

Keywords: carbohydrate, endurance performance, nutrition

Triathlon is a multisport event that involves three continuous endurance disciplines—swimming, bicycling, and running. Classic long-distance triathlon events last between 4 and 7 hr for the Half-Ironman distance (1.9-km swim, 90-km bike, 21.1-km run) and between 8 and 17 hr for the Ironman distance (3.8-km swim, 180-km bike, 42.2-km run).

It is unanimously recommended that athletes ingest exogenous carbohydrates (CHO) during prolonged

endurance exercise to maintain adequate CHO oxidation rates (Jeukendrup, 2011). In particular, during long-distance triathlon the ingestion of exogenous CHO becomes more important as distance and duration of the event increase (Jeukendrup, 2011). According to current recommendations, athletes should aim to ingest $60\text{--}90 \text{ g} \cdot \text{h}^{-1}$ of CHO in form of multiple absorbable CHO such as glucose and fructose during events that last longer than 2.5 hr (Jeukendrup, 2011).

Currently, available guidelines on CHO consumption during prolonged endurance exercise have mainly been derived from studies that used CHO from liquid sources (Smith et al., 2010). However, literature data from cyclists (Havemann & Goedecke, 2008) as well as anecdotal evidence from long-distance triathletes have suggested that many endurance athletes prefer to consume CHO in a semisolid, highly concentrated form (GEL) during prolonged endurance events such as long-distance triathlon.

It is surprisingly that very little information is available on the impact of CHO administration in form of GEL on prolonged endurance exercise performance. Pfeiffer et al. (2010) reported no difference in CHO oxidation when cyclists exercising at 59% peak oxygen consumption ($V_{O_{2peak}}$) for 180 min were given $108 \text{ g}\cdot\text{h}^{-1}$ of CHO either in the form of GEL or from a liquid source. Likewise, the administration of GEL was found to be equally effective in maintaining blood glucose and improving performance in cyclists compared with an isocaloric sports drink (Campbell et al., 2008). In contrast, Burke et al. (2005) reported no significant performance benefit of GEL compared with water only during a half-marathon run (Burke et al., 2005). It is noteworthy that several runners using GEL reported gastrointestinal (GI) discomfort, which was found to have a negative impact on half-marathon performance (Burke et al., 2005).

To our knowledge, no study has directly assessed the impact of CHO administration in the form of GEL on long-distance triathlon performance. Several conditions unique to triathlon may limit athletes' ability to consume CHO as recommended. Indeed, athletes are usually unable to consume any food or fluid during the swim, and it has been speculated that the change in body position among the three disciplines may impair gastric emptying and increase GI distress (Peters et al., 1993), such that CHO uptake may be limited when compared with running or cycling alone.

Hence, the purpose of our study was to assess the impact of the form of presentation of exogenous CHO administration on long-distance triathlon performance and to evaluate the incidence of GI distress. To this end, well-trained triathletes were administered CHO in the form of GEL or LIQ during a simulated long-distance triathlon in a controlled laboratory environment. On the basis of the

available literature, we hypothesized that administration of CHO in the form of GEL would result in similar outcomes for performance and metabolism but an increased incidence of GI distress.

Methods

Experimental Design

The study was conducted as a randomized crossover trial to compare the impact of CHO administration in form of GEL and LIQ on long-distance triathlon performance, metabolic responses, and GI discomfort. On average, the nine participants who completed both trials were age $38.8 \pm 10.1 \text{ yr}$ ($M \pm SD$), weighed $79.1 \pm 7.8 \text{ kg}$, and had a $V_{O_{2peak}}$ of $58.6 \pm 6.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Table 1). Each participant completed two simulated long-distance triathlon trials under laboratory conditions. The trial consisted of a 60-min swim at 90% of each participant's individual 400-m personal best, a 180-min bike at 90% of each participant's ventilatory threshold (VT), and a final 60-min all-out run. The distance covered during the 60-min run served as our primary outcome of interest. This time-based approach was chosen over a classic time-trial approach because we intended to minimize the impact of inadequate pacing during the swim or bike on run performance. In addition, this design allowed us to compare the impact of GEL versus LIQ on metabolic responses and GI distress during the bike and run without having to account for differences in pacing as a potential confounder. In one condition, participants were given CHO in the form of GEL; in the other condition, participants were given CHO in form of LIQ. The order of the conditions was at random, and trials were separated by 7 days. The experimental protocol was approved by the ethical review board of the University of Ulm.

Preliminary Testing

Seven days before the start of the study, participants completed preliminary testing, which consisted of (a) body composition assessment, (b) an incremental exercise test protocol to determine $V_{O_{2peak}}$ and VT, and (c) a 1-hr continuous

Table 1. Physical Characteristics of the Participants Variable

	Men ($n = 9$; $M \pm SD$)
Age (years)	38.6 ± 10.7
Height (cm)	184.3 ± 8.0
Body mass (kg)	78.5 ± 8.1
Body fat (%)	9.1 ± 3.4
$V_{O_{2peak}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	58.6 ± 6.3
Peak power output (W)	410 ± 47.6
Power output at 90% VT (W)	218 ± 26.5
Sweat rate at 90% VT ($\text{L}\cdot\text{min}^{-1}$)	1.2 ± 0.2

$V_{O_{2peak}}$ = peak oxygen consumption; VT = ventilatory threshold

exercise test to approximate sweat rate. Three-point skinfold measurements (Harpenden Skinfold Caliper, West Sussex, United Kingdom) were used to assess body fat percentage. Both the incremental exercise tests and the 1-hr continuous exercise test were conducted on an electromagnetically braked bicycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). For the incremental exercise test, participants performed unloaded pedaling (0 W) for 1 min. The load was then increased by 2 W every 3 s until participants reached volitional exhaustion (average test length = 12 ± 1 min), which occurred when participants were unable to maintain a cadence of greater than 60 rpm and their respiratory exchange rate (RER) was greater than 1.1. During the incremental test, oxygen uptake was assessed using a computerized mixing chamber metabolic cart (Cortex MetaMax 3X, Leipzig, Germany), and VT was calculated using the V-slope method (Beaver et al., 1986). On the same day, participants exercised on the cycle ergometer for 1 hr at 90% of their individual VT, which was their designated bike workload for the main experiment. Each participant's sweat rate was assessed as the change in nude body weight over the course of this 1-hr test.

Pretest Conditions

In an effort to minimize the impact of pretest exercise or diet on any of our outcomes, participants had to refrain from strenuous exercise for at least 48 hr before each trial. In addition, participants were instructed to follow a diet of balanced macronutrient composition (> 50% of energy from CHO, protein intake > 1.4 g/kg/d) in agreement with current recommendations (Rodriguez et al., 2009) for at least 48 hr before the first trial and were asked to consume a CHO-rich meal no later than 4 hr before the first trial. Participants recorded their diet and physical activity for 48 hr before the first trial. Participants were given a

copy of their diet and physical activity logs and were instructed to consume the same diet and conduct the same type and amount of physical activity during the 48 hr before the second trial. Participants were advised to record any deviation from the previously recorded diet or physical activity on their logs.

Experimental Protocol

Both trials started at the same time of day. On arrival at the laboratory, participants were weighed without clothing (Model 86, Seca, Hamburg, Germany), and the exercise protocol (Figure 1) was initiated. The trial started with a 1-hr swim at a pace equivalent to 90% of each participant's 400-m personal best. To ensure appropriate pacing during the swim, split times were checked every 100 m and, in the case of inadequate pacing, participants were prompted to adjust their pace. Swimming was conducted in a chlorinated 25-m indoor pool with a water temperature of 23 °C. The distance covered during each trial was recorded. After the swim, participants were allowed to change and were transferred by car to the laboratory. The transfer time between swim and bike was 19.8 ± 2.4 min. After nude body weight was recorded, participants were positioned on an electromagnetically braked bicycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) and started to bike for 180 min at a workload corresponding to 90% of their individual VT.

After completing the 180-min bike, nude body weight was measured again, and participants began to run for 1 hr on a treadmill (Woodway, PPS Med, Weil am Rhein, Germany). The transfer time between bike and run remained less than 4 min in every case. Participants were asked to self-select their pacing during the 1-hr run, but they were strongly encouraged to cover the greatest distance possible. Participants were able to see and manually

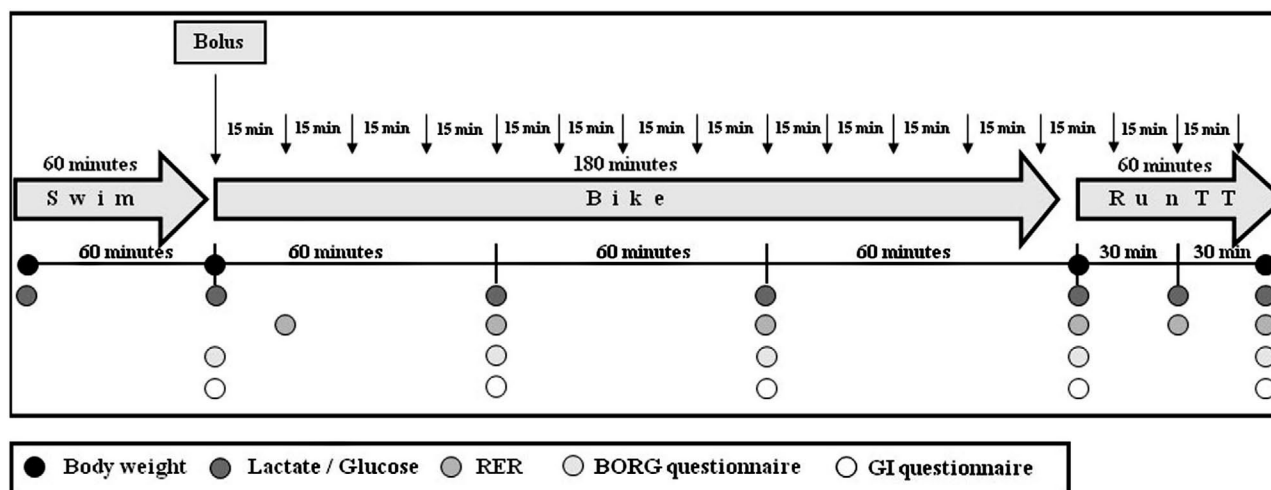


Figure 1. Study design. Arrows indicate ingestion time point of nutrition. Circles indicate time point of data acquisition. Lactate and glucose were measured in capillary blood. RER = respiratory exchange ratio; Run TT = run time trial.

modify the pace on the control panel of the treadmill, allowing them a continuous self-pacing similar to real-life conditions, where athletes are usually aware of their pace on because of the use of a GPS monitor, distance markers on the course, or both. The distance covered during the run was recorded. On completion of the run, nude body weight was recorded again. The bike and run were conducted in air-conditioned rooms at a temperature of 18 °C.

Carbohydrate Administration

During both conditions, the target intake of CHO was 81 g·h⁻¹ throughout the bike and run. This amount is in agreement with current guidelines for exogenous CHO administration during prolonged endurance exercise (Jeukendrup, 2011) and represents the dose that is ingested after the consumption of three servings of GEL.

For the GEL condition, we used a commercially available CHO gel that contains 27 g of CHO (maltodextrin, fructose) per serving with a glucose:fructose ratio of 2:1 (Power-Bar, Nestle, Vevey, Switzerland). For the current study, only GEL with vanilla flavor was chosen, and GEL did not contain caffeine as reported by the label. For each participant, the appropriate amount of GEL (three servings per hour) was loaded into a syringe, and participants discharged the syringe into their mouth under supervision. Additional fluid ingested during the GEL condition was bottled mineral water (Aloisius Quelle, Gundelfingen an der Donau, Germany). LIQ was prepared by adding 54 g of maltodextrin (Lamperts Maltodextrin 19, Berco, Kieve, Germany) and 27 g of fructose (Fruktosum, Fagron, Barsbüttel, Germany) to 1 L of bottled mineral water (Aloisius Quelle, Gundelfingen an der Donau, Germany).

Directly after completing the swim, participants ingested an initial bolus of 300 ml of LIQ containing 27 g of CHO, or 1 serving of GEL in addition to 300 ml of water. During the bike and the following run part, either GEL or LIQ were given in 15-min intervals such that CHO intake was 81 g·h⁻¹. To prevent dehydration, participants were provided with additional water (Aloisius Quelle, Gundelfingen an der Donau, Germany) at the same time points. Each participant was provided with the amount of water that matched his sweat rate as determined during preliminary testing. Participants were highly encouraged by staff to drink all fluid provided such that fluid intake was identical during both conditions. Salt was added to LIQ such that sodium intake from LIQ matched sodium intake from GEL (0.6 g·h⁻¹).

Data Acquisition and Calculations

Our primary outcomes of interest were the distance covered during the final run as well as RER, blood glucose and lactate concentrations, ratings of perceived exertion (RPE), and measures of GI distress. At the beginning of the bike, every 60 min during the bike, and at 30 min into the run as

well as at the end of the run, expired gases were collected for 1 min using a Douglas bag. Three samples were drawn from the bag, and oxygen and carbon dioxide concentrations were assessed using photoacoustic spectroscopy (Innocor, Innovision, Odense, Denmark). RER was calculated from the averages of the three measurements. At the beginning of the bike, every 60 min during the bike, and 30 min into the run and at the end of the run, capillary blood samples were collected from the hyperemized earlobe, and hemolyzed samples were assessed for glucose and lactate concentrations (EKF Diagnostics, Biosen C-Line, Cardiff, United Kingdom). RPE was assessed at the beginning of the bike, every 60 min during the bike, and at the beginning and end of the run using the 6–20 Borg scale (Borg, 1974). At the beginning of the bike, every 60 min during the bike, and at the beginning and end of the run, the participants were asked by study staff whether they experienced any form of GI distress. In addition, participants completed a questionnaire asking for common GI symptoms (bloating, flatulencies, urge for defecation, defecation, stomach cramps, pain, diarrhea) after the end of the trial.

Statistical Analysis

Statistical analysis of this crossover study was conducted as described previously by Wellek and Blettner (2012): To account for carryover effects such as physiological training effects as well as period effects, such as familiarization with the study and laboratory environment, preliminary data analysis based on unpaired *t* statistics was conducted. To test for differences in treatment effects, a Student's *t* test for independent samples was used (Wellek & Blettner, 2012). McNemar's exact test was conducted to compare the incidence of GI distress among conditions. Statistical significance was assumed for *p* < .05. All statistical analyses were performed using SPSS Version 19 for Windows (SPSS, Inc., Chicago, IL).

Results

Participants

A total of 10 triathletes were recruited for the study. One participant withdrew from the experiment at the beginning of the run of his second trial because of exhaustion and was subsequently excluded from data analysis.

Pretest Conditions

Self-reported caloric intake during the 48-hr period before the trials was not significantly different between the two conditions (Table 2). Average CHO intake during the 48-hr period before the experiments was 5.3 ± 0.5 g·kg⁻¹·d⁻¹ (GEL) and 5.1 ± 0.4 g·kg⁻¹·d⁻¹ (LIQ; *p* = .73). In addition, there were no significant differences in protein and fat intake before the experiment between conditions (Table 2).

Table 2. Self-Reported Diet During the Period Before the Trials Pretrial Diet

	Gel ($M \pm SD$)	Liquid ($M \pm SD$)	<i>p</i>
48 hr before the experiment			
Caloric intake (kcal/day)	2,788. \pm 351	2,608. \pm 265	.339
Carbohydrate intake (g/kg/day)	5.3 \pm 0.5	5.1 \pm 0.4	.727
Protein intake (g/kg/day)	1.2 \pm 0.3	1.1 \pm 0.3	.786
Fat intake (g/kg/day)	0.9 \pm 0.1	0.8 \pm 0.1	1.000
4 hr before the experiment			
Caloric intake (kcal)	1,623. \pm 306	1,670. \pm 257	.777
Carbohydrate intake (g/kg)	4.9 \pm 0.4	4.8 \pm 0.4	.671
Fiber intake (g/kg)	4.8 \pm 3.5	4.9 \pm 3.5	.780
Protein intake (g/kg)	0.3 \pm 0.1	0.3 \pm 0.1	.734
Fat intake (g/kg)	0.3 \pm 0.1	0.3 \pm 0.1	.687

Swim and Bike Performance

No significant difference was found in the distance covered during the 1-hr swim between the conditions (3,473.1 \pm 311.4 m [GEL] vs. 3,534.4 \pm 314.1 m [LIQ]; $p = .69$). Participants started cycling at an average load of 204.1 \pm 27.6 W. For 4 participants (GEL, $n = 3$; LIQ, $n = 1$), load was reduced by 22 \pm 7.7 W after 66.3 \pm 46.8 min during the first trial to avoid preemptive exhaustion and to allow the participants to complete the experiment. During the second trial, load was reduced by the same degree at identical time points to match load during both bike conditions.

Running Performance

On average, participants covered a distance of 11.81 km during the 1-hr run in the GEL condition and 11.91 km during the LIQ condition, which did not significantly differ from each other ($p = .88$).

Fluid and Carbohydrate Intake During the Experiment

There was a trend indicating that total fluid intake over the course of the experiment was lower in the GEL condition (3.9 \pm 0.54 L / 0.78 \pm 0.11 L·h⁻¹) than in the LIQ condition (4.2 \pm 0.25 L / 0.84 \pm 0.5 L·h⁻¹; $p = .10$). Body mass decreased during both conditions, but the reduction in body mass was not significantly different between the two conditions (1.6 \pm 0.7% [GEL] vs. 1.9 \pm 0.5% [LIQ]; $p = .17$). Total CHO intake was 336 \pm 36 g (67.2 \pm 7.2 g·h⁻¹) in the GEL condition and 339 \pm 21 g (67.8 \pm 4.2 g·h⁻¹) in the LIQ condition and did not significantly differ between conditions ($p = .85$). Figure 2 depicts the CHO intake during the experiment.

Glucose and Lactate

Blood glucose remained stable throughout the experiment in both conditions (Figure 3) and did not drop below

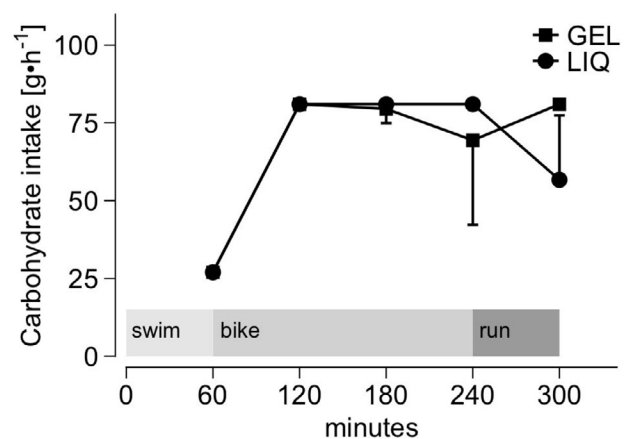


Figure 2. Carbohydrate (CHO) intake during the experiment. Values are arithmetic $M \pm SD$. GEL = carbohydrate ingestion from semisolid source; LIQ = carbohydrate ingestion from liquid source.

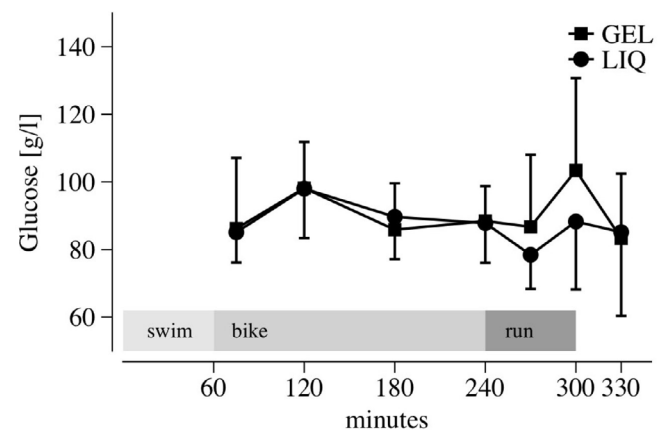


Figure 3. Blood glucose during the experiment. Values are arithmetic $M \pm SD$. GEL = carbohydrate ingestion from semisolid source; LIQ = carbohydrate ingestion from liquid source.

4 mmol•L⁻¹ at any time during the experiment. No statistically significant difference was found in blood glucose between conditions at any time during the experiment. At the end of the run, glucose was 5.7 ± 1.5 mmol•L⁻¹ in the GEL condition versus 4.4 ± 1.0 mmol•L⁻¹ in the LIQ condition ($p = .22$). Lactate increased after the bike part in both conditions (Figure 4), but no significant differences were found in lactate between conditions at any time point across the experiment. Lactate concentrations at the end of the run were 2.3 ± 0.9 mmol•L⁻¹ in the GEL condition and 2.1 ± 1.1 mmol•L⁻¹ in the LIQ condition ($p = .70$).

Respiratory Exchange Ratio

RER decreased continuously during the bike and run, and no significant differences were found in RER between the conditions at any time during the experiment. RER at the end of the run was 0.88 ± 0.21 in the GEL condition and 0.88 ± 0.37 in the LIQ condition ($p = .78$).

Rating of Perceived Exertion

RPE did not differ significantly between GEL and LIQ conditions during bike and run at any time point. Likewise,

RPE at the end of the run was not significantly different between conditions (GEL: 16.2 ± 1.9; LIQ: 16.3 ± 1.3; $p = .85$).

Gastrointestinal Distress

Seven of the 9 participants reported GI symptoms (Table 3) in the GEL condition. One participant had to defecate between the bike and the run. No participant reported GI symptoms in the LIQ condition. The difference in the incidence of GI distress between conditions was significant ($p = .016$).

Discussion

The purpose of the current study was to assess the impact of exogenous CHO administration in form of GEL versus LIQ on performance, metabolic measures, and GI distress during a 5-hr triathlon in a laboratory environment. Our primary finding was that performance was not affected by the ingestion of CHO in the form of GEL compared with CHO in the form of LIQ. However, we demonstrated that the use of GEL was associated with a significantly higher incidence of GI distress than was the use of LIQ.

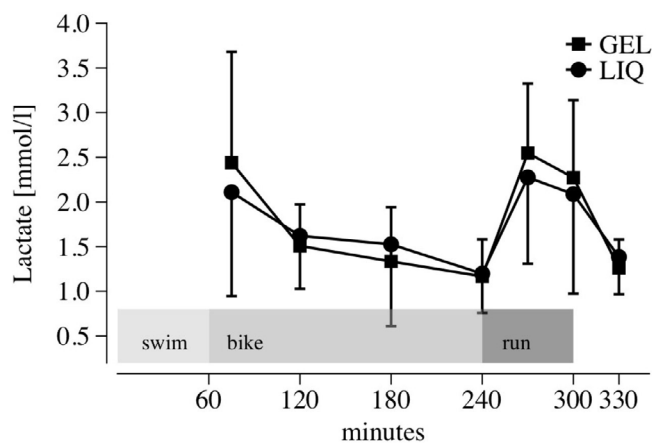


Figure 4. Blood lactate concentration during the experiment. Values are arithmetic $M \pm SD$. GEL = carbohydrate ingestion from semisolid source; LIQ = carbohydrate ingestion from liquid source.

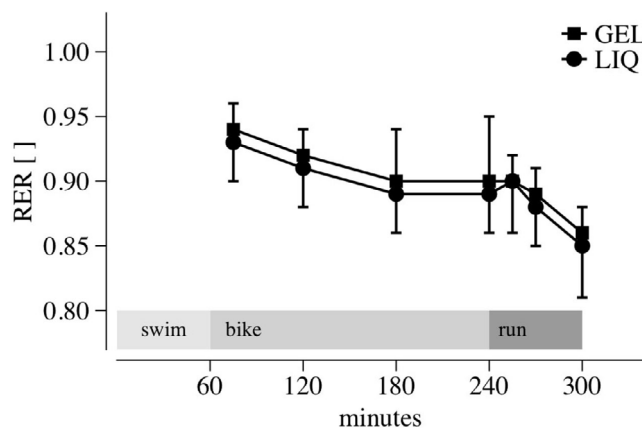


Figure 5. Respiratory exchange ratio (RER) during the experiment. Values are arithmetic $M \pm SD$. GEL = carbohydrate ingestion from semisolid source; LIQ = carbohydrate ingestion from liquid source.

Table 3. Symptoms of Gastrointestinal Distress During the Experiment

Symptom	Gel	Liquid
Bloating	5	0
Bloating + urge for defecation	1	0
Bloating + defecation	1	0
Total	7	0

$N = 9$. $p = .016$. Values express number of participants with corresponding gastrointestinal symptoms.

Our results obtained during prolonged exercise (300 min) complement previous results during shorter exercise durations, according to which CHO administration in form of GEL was not associated with differences in performance when compared with CHO administration in form of LIQ. Campbell et al. (2008) reported that CHO administration in form of GEL resulted in a 2.8% improvement in 10-km cycling time trial performance compared with water, but no performance benefit was observed when compared with administration of the same amount of CHO in form of LIQ or sport beans (Campbell et al., 2008).

In the current study, metabolic measures of blood glucose and RER did not suggest a difference in CHO uptake or oxidation between conditions. This observation is in agreement with a previous experiment with cyclists, in whom measures of CHO oxidation were similar between GEL and LIQ during 180 min of stationary cycling at 58% of their maximal oxygen uptake ($V_{O_{2max}}$; Pfeiffer et al., 2010).

Another important finding of our study was that the majority of the participants in the GEL condition reported symptoms of GI distress, whereas LIQ appeared to be tolerated well by every participant. This result is in agreement with a previous report of a higher prevalence of GI distress in half-marathon runners after gel administration compared with the use of water only (Burke et al., 2005). Symptoms reported in the current study included flatulencies, bloating, and the urge to defecate, which are common GI complaints in endurance sports (Brouns et al., 1987). A prevalence of GI distress of 3%–23% has been reported in running (Pfeiffer et al., 2009), and GI distress presents one of the leading causes of dropout in long-distance triathlon (Jeukendrup et al., 2000).

GI distress is more likely to occur with the ingestion of concentrated CHO solutions (Rehrer et al., 1992) such as gel products as the result of an osmotically driven influx of water into the gut. In this study, CHO uptake during the run was higher in the GEL condition ($81 \pm 0 \text{ g}\cdot\text{h}^{-1}$) compared with the LIQ condition ($54 \pm 21 \text{ g}\cdot\text{h}^{-1}$). In addition, total fluid intake was slightly lower in the GEL condition, leading to a higher concentration of CHO during that condition. The slightly higher CHO intake in conjunction with the slightly lower fluid intake may—at least in part—explain the higher GI distress observed in our study participants during the run and underlines the recommendation to consume a sufficient amount of water after gel consumption. A noteworthy finding was that 2 participants refused to consume the full amount of CHO provided in the GEL condition because of GI discomfort experienced during the bike part, indicating that some athletes experience GI distress even when consuming adequate amounts of water. Other diet-related causes of GI distress that have been reported for long-distance triathlon, such as a high fiber, fat, or protein content (Rehrer et al., 1992), can be ruled out because macronutrient intake was limited to the ingestion of CHO during the current study.

All participants experienced difficulties in consuming the whole amount of fluid during the run (explaining why CHO uptake was lower in the LIQ condition), but average fluid loss was less than 2% of the body mass, which is in agreement with current recommendations of the American College of Sports Medicine (Sawka et al., 2007).

The ability to maintain CHO intake at high levels may become more relevant during the final run of an Ironman-distance triathlon, when maintenance of exogenous CHO intake is essential to prevent fatigue and a consequent race dropout (Jeukendrup et al., 2000). Even though our 5-hr laboratory protocol did not show performance differences, the observed lower CHO intake during the run in the LIQ condition might limit performance during the final Ironman marathon after more than 5 hr of swimming and cycling. In this case, the use of an easily carried and consumed gel might be beneficial as long as hydration is assured. Consequently, athletes are required to carefully balance the potential risk of GI discomfort and the risk of CHO depletion and fatigue because a high CHO intake is associated not only with GI distress but also with performance benefits (Pfeiffer et al., 2012).

Another factor that athletes should consider is the financial cost associated with CHO administration during long-distance triathlon. The commercially available GEL product used in the current study was approximately 6 times more expensive than the ingredients used for preparing LIQ. Because the general recommendation is to test diet strategies during training, this difference in cost may become relevant particularly for nonprofessional athletes.

Limitations

This study used a newly developed long-distance triathlon simulation protocol, which was designed to mimic the multidisciplinary character of triathlon competition but still allow for standardized assessments under laboratory conditions. However, the duration of the bike (180 min) and run (60 min) were shorter than these sections in an Ironman-distance triathlon. Thus, it is possible that a longer bike or run could elicit performance effects of one form of CHO administration over another. However, in particular a longer run could have led to more conservative pacing, thus attenuating potential benefits of a potentially higher CHO availability from one form of administration than from another.

Intensity during swim and bike was clamped to minimize the risk of premature dropout due to overpacing and to allow for metabolic measurements to be conducted at steady-state exercise and following standardization of CHO intake. We used the distance covered during final 1-hr run as a surrogate for overall triathlon performance. Although this design might discriminate against triathletes who are strong cyclists but poor or mediocre runners, a constant power output and the consumption of high amounts of CHO on the bike were the main criteria of overall long-distance triathlon success (Wu et al., 2014).

We allowed our participants to see and manually modify the pace of the treadmill during the final all-out run to mimic real-life conditions. This strategy might have led the participants to match the pace of the first trial despite their perceived exertion and thus reduced the chances of seeing effects. However, neither running performance nor related physiological variables such as heart rate, lactate, and RPE changed, indicating that participants were not just sticking to a chosen speed despite sensory feedback.

Another limitation is the transfer time between swim and bike of 19.8 ± 2.4 min, which is approximately 5 times longer than in real-life long-distance triathlons. The longer transition was unavoidable to allow for the car transfer from the local pool to the laboratory.

The current experiment was neither blinded nor placebo controlled, which was deemed not feasible because of differences in texture and form of presentation between LIQ and GEL. In addition, we did not use a control group that did not administer CHO in the current study. Because it is unanimously accepted that CHO administration is associated with a performance benefit during prolonged endurance exercise (Jeukendrup, 2011), we decided against adding additional non-CHO control conditions, such as CHO-free GEL or CHO-free LIQ, in efforts to minimize participant burden.

Conclusion

This study demonstrates that the administration of CHO in form of a gel product is not associated with differences in performance during a simulated long-distance triathlon compared with a liquid CHO solution prepared from maltodextrin and fructose. In addition, our study confirms previous findings that the use of GEL is associated with an increased risk of GI distress. Athletes and supporting staff should carefully consider the potential advantages and disadvantages of different forms of CHO administration during long-distance triathlon.

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