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# Effects of a Carbohydrate Hydrogel beverage on endurance cycling performance and gastrointestinal comfort

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# Effects of a Carbohydrate Hydrogel Beverage on Endurance Cycling Performance and Gastrointestinal Comfort

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Finally, I would like to thank my family and partner for their love and support throughout my life.

**Abstract**

PURPOSE: This study examined the effects of a novel maltodextrin-fructose hydrogel (MF-H) on cycling performance and gastrointestinal distress symptoms. METHODS: Nine endurance-trained male cyclists completed three experimental trials consisting of a 98-min varied-intensity cycling protocol followed by a performance test of ten consecutive sprint intervals. In a cross-over design, subjects consumed 250 mL of a treatment beverage every 15 min of cycling. The treatments consisted of 78 $g \cdot hr^{-1}$ of either a) MF-H, b) maltodextrin-fructose (MF), and c) maltodextrin only (MD) All data were assessed using repeated measures ANOVA's. RESULTS: There were no differences in average sprint power between treatments (MF-H, 284 ± 51 W; MF, 281 ± 46 W; and MD, 277 ± 48 W), or power output for any individual sprint. However, mean power output for sprints 7-10 was significantly lower in MD (259 ± 2 W) versus MF (269 ± 2 W; p=0.04) and versus MF-H (270 ± 2 W; p=0.01). Subjective ratings of gastrointestinal discomfort symptoms (nausea, fullness, and abdominal cramping) increased significantly over time during the cycling trials, but few individuals exceeded moderate levels in any trial with no systematic differences in gastrointestinal discomfort symptoms observed between treatments. CONCLUSIONS: Ingestion of a maltodextrin/fructose hydrogel beverage improved cycling performance late in exercise compared to maltodextrin alone, but provided no further performance benefits versus a maltodextrin/fructose beverage. In addition, the maltodextrin/fructose hydrogel beverage resulted no systematic benefits in gastrointestinal comfort versus the other beverages.

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# Chapter One

## Introduction

Carbohydrates and fats are the two primary sources of fuel utilized by the muscle during endurance exercise, and their proportional utilization varies depending on the intensity and duration of the activity (Romjin et al., 1993). During low and moderate intensity exercise, fat is the predominant substrate oxidized, with carbohydrate utilization increasing as intensity is increased (Loon et al., 2001, Romjin et al., 1993). Competitive endurance athletes have a high reliance on carbohydrate during exercise, but have a somewhat limited carbohydrate reserve from endogenous sources such as liver and muscle glycogen or blood glucose (Hermansen et al., 1967). Decreased muscle/liver glycogen and blood glucose during prolonged duration exercise leads to reduced carbohydrate oxidation rates, which may limit endurance performance during activities of approximately 2 h or longer (Coyle et al., 1986). As such, carbohydrate ingestion, typically in the form of carbohydrate-electrolyte beverages, has been utilized to sustain carbohydrate oxidation rates, maintain higher ATP turnover, and augment performance.

Several studies have reported that carbohydrate ingestion during prolonged exercise has positive effects on endurance performance. During exercise protocols $\geq$2 h, researchers have reported that carbohydrate ingestion improves time to fatigue by an average of 24.8% versus placebos, and time trial performance by 2-8 % (Stellingwerff & Cox 2014). Carbohydrate intake during exercise has resulted in ergogenic effects with ingestion rates as low as 10 g/h, as Smith et al. reported a 1% improvement in cycling performance compared to placebo (Smith et al., 2013). However, most studies reporting improvements in performance with carbohydrate intake

during exercise have utilized ingestion rates ≥ 30 g/hr (Jentjens et al., 2004). As such, published guidelines from sports nutrition groups generally recommend consuming 30 to 60 g of carbohydrate per hour of activity throughout prolonged endurance activities (Kreider et al., 2010).

There is evidence that exogenous carbohydrate oxidation rates and performance gains are elevated in dose-response fashion to the amount of glucose (or maltodextrin) ingested, up to 60 g/h (Smith et al., 2010). It is believed that the upper-limit for this dose is limited by gastrointestinal uptake of glucose, which is facilitated by the sodium-glucose linked transporter 1 (SGLT1) (Ferraris 2001). This transporter becomes saturated at ingestion rates of 1.0 – 1.1 g/min, preventing further uptake to the blood (and ultimately, delivery to the muscle for oxidation) (Jeukendrup et al., 2000, Triplett et al., 2010). As a result, very high rates of glucose ingestion (> 60 g/h or 1.1 g/min) do not result in further improvements in performance and are also associated with increased gastrointestinal discomfort (Triplett et al., 2010).

Although the maximum effective dose of glucose is limited by SGLT1, fructose utilizes a non-competitive sodium independent intestinal transporter (GLUT5), which is believed to be saturated at ingestion rates of 0.5 - 0.6 g/min (Currell & Jeukendrup 2008, Shi et al., 1997). Recent studies have reported that the combined ingestion of glucose (or maltodextrin) and fructose results in higher peak exogenous carbohydrate oxidation rates than glucose alone (Jentjens & Jeukendrup 2005; Jentjens et al., 2004a & 2004b). For example, in a review by Jeukendrup, it was reported that exogenous oxidation rates were significantly higher (1.26 g/min) in response to feedings of 1.8 g/min of glucose/fructose versus the same amount of glucose alone (0.80 g/min)

(Jeukendrup 2008). The resulting increase in exogenous carbohydrate oxidation with multiple transportable carbohydrates may be associated with sparing of endogenous carbohydrate reserves, which could result in higher total carbohydrate availability late in exercise, thereby improving performance (Jentjens & Jeukendrup 2005; Jentjens et al., 2004a & 2004b).

The use of multiple transportable forms of carbohydrate (glucose/maltodextrin and fructose) can potentially improve performance more than glucose alone during moderate to high intensity exercise (>2 h) by increasing exogenous carbohydrate oxidation (and possibly total carbohydrate oxidation late in exercise) in glucose/fructose compared to glucose only trials. Two studies have reported superior cycling performances (approximately 8%) when high doses of glucose/fructose (108-144 g/h) were consumed, versus isocaloric glucose-only trials (Currell & Jeukendrup 2008, Triplett et al., 2010).

Gastrointestinal distress from malabsorption of carbohydrates can interfere with potential ergogenic effects from carbohydrate supplementation during prolonged exercise. Nausea, vomiting, and other upper and lower GI tract issues have been reported extensively in long distance athletes (Keeffe et al., 1984, Rehrer et al., 1989). Using multiple transportable forms of carbohydrate may attenuate gastrointestinal distress due to having two non-competitive transport mechanisms for carbohydrate absorption (Wilson 2015). This is supported by Rowlands et al., who found improvements in performance with maltodextrin-fructose beverages to be related to improvements in gastrointestinal discomfort (Rowlands et al., 2012). Additionally, another factor which may influence gastrointestinal comfort is the rate of gastric emptying, or the rate at which contents from the stomach enters the intestinal tract (Costill et

al., 1970). Gastric emptying can be influenced by the concentration of carbohydrate, volume of fluid, caloric content, and a variety of other factors discussed in previous literature (Murray 1987). In an attempt to provide carbohydrate doses that optimize oxidation rates (i.e. ~ 1 g/min of GLU and ~ 0.5 g/min of FRUC) without gastrointestinal distress, Maurten sports drinks created a product utilizing hydrogels in their formula (using pectin and alginate) to promote enhanced gastric emptying. There are anecdotal reports that professional marathon runners have used this product successfully since 2016 (https://www.maurten.com/achievements). From a pharmacological standpoint, hydrogels have been used for drug delivery for site-specific release (Ahmed 2015; Hamidi 2008). Polymers containing pendant acids (carboxylic acid) such as those in pectin and alginate, change in accordance to their pH environment and other factors (Qiu & Park 2001). Due to the pH differences between the stomach and the intestines, pH-dependent polyelectrolyte hydrogels cause swelling of the mix in the stomach (< 3 pH), allowing controlled gastric emptying into the intestines where the pH is more neutral (~ 6-7) (Qiu & Park 2001). With oral administration, pH-sensitive carbohydrate hydrogels can theoretically control the release of their contents and mitigate gastrointestinal distress by controlling the rate of gastric emptying, while allowing for optimal absorption of carbohydrate from the intestines. Thus, carbohydrate hydrogels could theoretically provide increased carbohydrate delivery and attenuate gastrointestinal distress, potentially resulting in performance benefits during prolonged moderate to high intensity exercise (>2 h). However, no peer-reviewed studies have been completed to date on the effects of hydrogel use on carbohydrate delivery and endurance performance.

Therefore, the purpose of this study is to determine the effects of a Maurten hydrogel solution containing 80g/h of maltodextrin and fructose (MF-H) on endurance performance and gastrointestinal comfort compared to an isocaloric maltodextrin-fructose solution (MF) and an isocaloric maltodextrin-only solution (MD), during a 98-min varied-load cycle test followed by a sprint-interval performance test (Guillochon & Rowlands 2017). We predict that MF-H will result in attenuated gastrointestinal distress versus MD and MF, and improved cycling performance versus MD, with similar performance effects versus MF.

## Assumptions, Limitations, Delimitations

Due to the abundance of evidence suggesting exogenous carbohydrate improves performance through the mechanisms discussed previously, we are assuming MF-H, along with our other carbohydrate derivations will provide an ergogenic effect versus water alone and are therefore not including a placebo trial. We also assume that individuals will complete the tasks to the best of their ability, so we may assess variations among interventions and not from individual variations of performance effected by willingness, attentiveness, and other motivational factors.

We are examining the effects of carbohydrate ingestion on trained cyclists. This limits our generalizability to only trained individuals that are performing bouts of activity that are between 2 and 3 hours. With many studies looking at a carbohydrate intervention and exercise, our sample size will be limited in terms of numbers due to the lack of well-trained endurance athletes willing and able to participate to exhaustion in our study.

Delimitations of this study include using cyclists to assess the ergogenic effects of the aforementioned carbohydrate beverages. This limits our study to only being able to apply our data that we find to trained cyclists that are performance 2 to 3-hour bouts of activity. To provide sufficient controls for our study, we are standardizing the time of fasting and nutrient intake prior to testing, as well as time of day to better understand the carbohydrates effect on prolonged exercise.

## Definition of Terms

There are several definitions that require clarification as they relate to the data outcomes for the present study. First, fatigue is defined as the volitional withdrawal of the exercise intervention or an individual's inability to further perform the given task due to excessive exhaustion. Gastrointestinal distress will be defined by assessing ratings of gut discomfort, including the degree of sensations indicating likelihood of nausea, stomach fullness, or abdominal cramping. We define trained cyclists as individuals completing $\geq$ 3 d/wk of cycling, and a $VO_{2max}$ value $\geq$ 50 $ml \cdot kg^{-1} \cdot min$.

# Chapter Two

# Methods

## Subjects

Eleven endurance-trained male cyclists were recruited from the areas of Harrisonburg, VA and Elon, NC to participate in this study. Inclusion criteria were: males aged 18 to 45 years of age, cycling $\geq$ 3 d · wk for three months prior to the study, with a $VO_{2max} \geq 50$ ml·kg$^{-1}$·min, and competing regularly ($\geq$ 3 years of competitive cycling or training). Exclusion criterion for this study were: smokers (current or former), failure to meet inclusion requirements, and intolerance to testing procedures. Subjects were provided with information about study procedures and risks and provided consent to participate prior to initiating the study. This study was approved by the Institutional Review Boards of James Madison University and Elon University.

## Research Design

The study was a randomized, double-blinded, crossover design to test the effects of three carbohydrate beverages on performance, metabolic physiology, and gastrointestinal distress. Trials were separated by 3-7 days with subjects receiving standardized diet and exercise instructions. Trials were conducted at a consistent time of day to control variability within subjects. Subjects underwent four trials 1) preliminary testing and familiarization trial, 2-4) experimental trials with one of three carbohydrate interventions. Each trial consisted of a pre-loaded varied-intensity protocol of 98 min, followed immediately by a performance test to determine power output during 10 consecutive sprints.

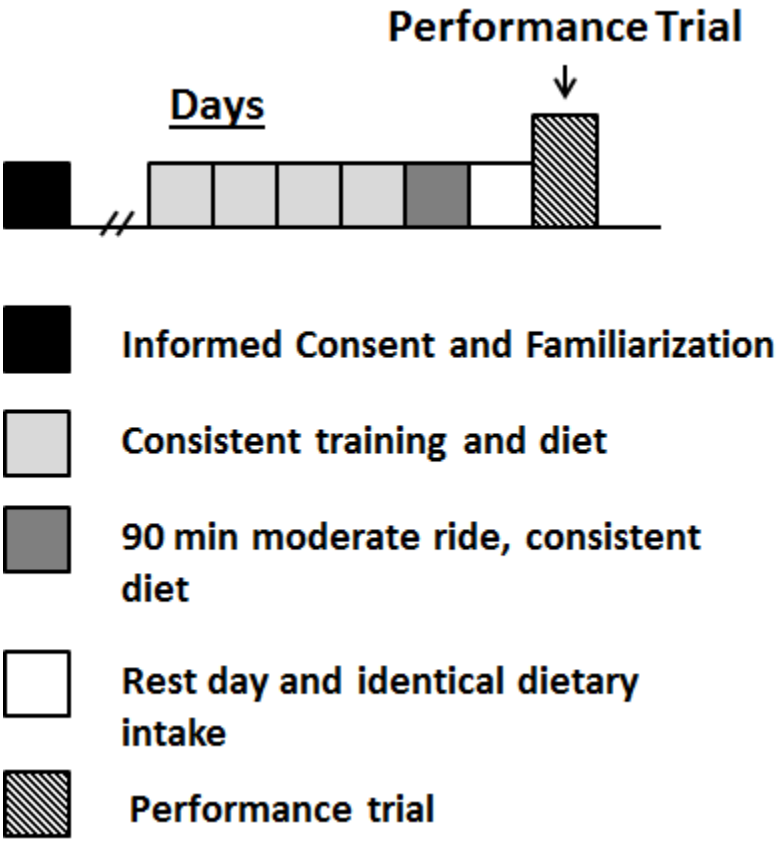
**Preliminary testing and familiarization trial**

Before any experimental trials were conducted, participants underwent a graded exercise test on a cycle ergometer (Velotron; RacerMate Inc., Seattle, WA) to determine maximal oxygen consumption ($VO_{2max}$) and maximal power output ($W_{max}$) using a protocol described previously (Triplett et al., 2010; Kreider et al., 2010). After a 10-min warm-up at 100 W, subjects began the test at a pre-determined wattage based on body weight (W = 3*subject BW (kg)). Power output was then increased by 25W every 2-min until volitional exhaustion. Metabolic responses during each stage was recorded using a Parvo Medics TrueOne 2400 (Parvo Medics, Sandy, UT). $VO_{2max}$ was determined by the highest 30 s mean oxygen uptake value. Following the $VO_{2max}$ trial, subjects were given 5-min rest, followed by a familiarization with the last 60-min of the pre-load protocol and the performance test.

**Diet and exercise control**

Subjects were instructed to 1) maintain consistent diet and training in the 72 h prior to each performance trials, 2) engage in a 90-min moderate intensity ride 48 h prior to performance trial, 3) record food intake and physical activity for 24 h prior to first experimental trial, 4) repeat food intake from recorded data in subsequent trials, 5) rest from exercise for 24 h leading to trial, and 6) refrain from consuming alcohol and caffeine for 24 h and 12 h, respectively, prior to trials (Fig 1). Subjects were all fed during performance trials as shown in Figure 2. Two hours prior to trials, subjects consumed standard meals consisting of a Clif Energy Bar (Clif Bar & Company; Emerysville, CA), and 300 mL of water.

Figure 1. Seven-day Exercise Instructions Leading to Experimental Trials

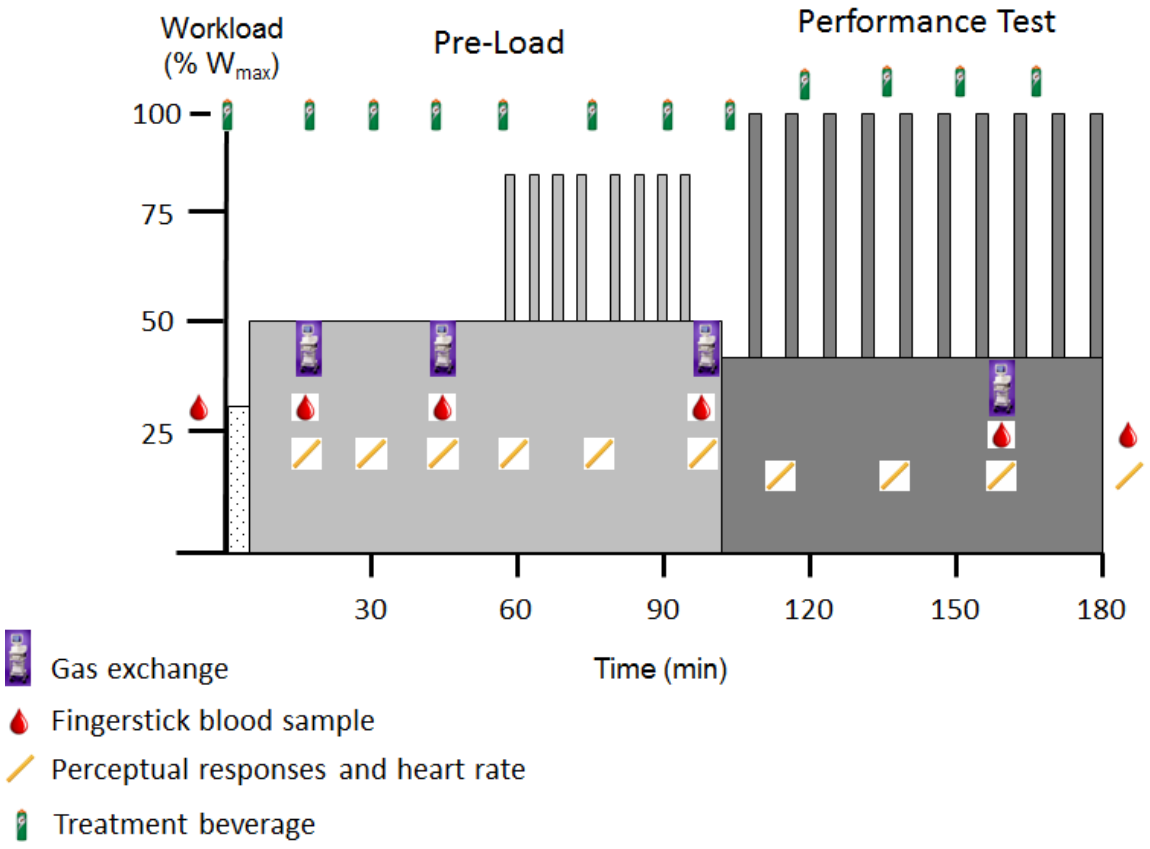



**Exercise trials**

As shown in Figure 2, subjects completed a 98 min pre-load trial to simulate a cycling road race using a cycle ergometer (Velotron; RacerMate Inc., Seattle, WA). This trial consisted of 60-min of constant-load exercise at 50% $W_{max}$ followed by eight, 2-min intervals at 80% $W_{max}$. Rest intervals were performed at 50% of $W_{max}$ and lasted 2 min, except for a 5-min rest interval between the the fourth and fifth work interval (Coggan & Coyle 1987). Following the 98-min protocol, subjects performed a performance test consisting of ten sprints. Subjects were instructed to give maximal efforts with each sprint and subsequent recovery until a predetermined kilocalorie requirement was met, based on the subject's wattage at max and body

weight in kilograms ($W_{max}$ * 0.125). Sprints were designed to be approximately 2-3 min in length with the rest period (40% $W_{max}$) lasting approximately 5 min. During the sprints, subject's power output data was withheld to prevent pacing versus other trials. Power output, time to complete sprints and rest periods were collected in addition to any physiological data and perceptual responses collected throughout the study duration.

Figure 2. Overview of Exercise Trial and Measurements




**Physiological measurements**

Heart rate (Polar Electro Inc.; Bethpage, NY) was recorded every 15 min, and at test termination (Fig. 2). Oxygen uptake ($VO_2$) respiratory exchange ratio (RER) were assessed using

a PARVO Metabolic System (PARVO Medics; Sandy, UT) at minutes 15-20, 45-50, and 93-98 during the pre-load phase, and at minutes 160-165 during the performance trial (Fig 2). Finger stick blood samples (0.5 mL) were obtained at the following time intervals: prior to exercise, at minutes 45, 98, and 160, and immediately following the performance test (Fig. 2). Lactate and glucose levels were assessed from whole blood using automated instrumentation (YSI 2900D Biochemistry analyzer YSI Life Sciences, Yellow Springs, OH).

**Perceptual Responses and Gastrointestinal Distress Scale**

Gastrointestinal distress symptoms and perceived exertion responses were indicated in writing at every 15-min interval (fig. 2) using a 100-point scale (i.e. 1 = no GI distress; 100 = absolute maximum) adapted from Jentjens et al. (2002). Subjects were instructed to draw a line across the scale every time interval to indicate their symptoms. Subjects rated symptoms including: nausea, fullness, and abdominal cramping, in addition to effort of cycling, tiredness, and leg strength. A ruler with mm increments was used to measure ratings for each variable.

**Treatments**

Subjects received 250 mL of treatment beverage immediately prior to the exercise trials, and 250 mL every 15-min of exercise. Participants consumed 78 $g \cdot hr^{-1}$ (1.3 $g \cdot min^{-1}$), and 1000 mL/hr fluid (7.8% concentration) or 3000 mL total over a 3 h period during all trials. Treatments consisted of either a) Maltodextrin-fructose hydrogel (MF-H) (Maurten AB, Gothenburg, Sweden), providing 78 g of carbohydrate (from maltodextrin and fructose), using Maurten's proprietary 160 mix (two sachets), b) maltodextrin-fructose (MF) beverage providing maltodextrin and fructose (Tate and Lyle, Decatur, IL) in a 3:1 ratio with 78 g total carbohydrate,

c) maltodextrin (MD) beverage providing 78 g of carbohydrate with maltodextrin only. Each beverage was made using spring water (Deer Park Spring Water, Nestlé Waters North America), and included 800 mg sodium (Morton salt; Chicago, IL) per liter, with the exception of the Maurten beverage, which was mixed using manufacturer's recommendations. Treatments were randomized and double-blinded.

**Statistical analysis**

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS). Mean values and standard deviations were calculated and reported for all dependent measures discussed above. Treatment differences in these variables were assessed using repeated measures ANOVA's, with individual treatment comparisons performed with Fisher's least significant difference test (i.e. no correction for multiple comparisons).

# Chapter Three

## Manuscript

# Effects of a Carbohydrate Hydrogel Beverage on Endurance Cycling Performance and Gastrointestinal Comfort

**Authors:** Harrison R. Toney, Michael J. Saunders, Nicholas D. Luden,

Daniel A. Baur, Christopher J. Womack, Katherine G. Baur

**Institution:** James Madison University, Harrisonburg VA, 22807

## Abstract

PURPOSE: This study examined the effects of a novel maltodextrin-fructose hydrogel (MF-H) on cycling performance and gastrointestinal distress symptoms. METHODS: Nine endurance-trained male cyclists completed three experimental trials consisting of a 98-min varied-intensity cycling protocol followed by a performance test of ten consecutive sprint intervals. In a cross-over design, subjects consumed 250 mL of a treatment beverage every 15 min of cycling. The treatments consisted of 78 $g \cdot hr^{-1}$ of either a) MF-H, b) maltodextrin-fructose (MF), and c) maltodextrin only (MD) All data were assessed using repeated measures ANOVA's. RESULTS: There were no differences in average sprint power between treatments (MF-H, 284 ± 51 W; MF, 281 ± 46 W; and MD, 277 ± 48 W), or power output for any individual sprint. However, mean power output for sprints 7-10 was significantly lower in MD (259 ± 2 W) versus MF (269 ± 2 W; p=0.04) and versus MF-H (270 ± 2 W; p=0.01). Subjective ratings of gastrointestinal discomfort symptoms (nausea, fullness, and abdominal cramping) increased significantly over time during the cycling trials, but few individuals exceeded moderate levels in any trial with no systematic differences in gastrointestinal discomfort symptoms observed between treatments. CONCLUSIONS: Ingestion of a maltodextrin/fructose hydrogel beverage improved cycling performance late in exercise compared to maltodextrin alone, but provided no further performance benefits versus a maltodextrin/fructose beverage. In addition, the maltodextrin/fructose hydrogel beverage resulted no systematic benefits in gastrointestinal comfort versus the other beverages.

**Introduction**

Competitive endurance athletes utilize carbohydrate extensively during exercise, but have limited endogenous carbohydrate reserves from liver/muscle glycogen and blood glucose (Hermansen et al., 1967). Decreased muscle/liver glycogen and blood glucose during prolonged exercise leads to reduced carbohydrate oxidation rates, which may limit endurance performance during activities ~ 2 h or longer (Coyle et al., 1986). Importantly, the ingestion of carbohydrate beverages during prolonged exercise has been shown to sustain carbohydrate oxidation rates, maintain higher ATP turnover, and augment performance.

Numerous studies have reported that carbohydrate ingestion during prolonged exercise has positive effects on performance. Sports nutrition guidelines generally recommend consuming 30 - 60 g/h of carbohydrate throughout prolonged endurance activities (Kreider et al., 2010). However, there is evidence that exogenous carbohydrate oxidation rates and performance gains are elevated in dose-response fashion to the amount of glucose/maltodextrin ingested, up to 60 g/h (Smith et al., 2010). Carbohydrate intake beyond 60 g/h can lead to gastrointestinal (GI) distress from malabsorption of carbohydrates, consequently interfering with the potential ergogenic effects of carbohydrate supplementation. Indeed, nausea, vomiting, and other upper and lower GI tract issues have been reported extensively in long distance athletes (Keeffe et al., 1984, Rehrer et al., 1989). A novel strategy to optimize performance gains while minimizing GI discomfort is the use of multiple transportable forms of carbohydrate which utilize non-competitive transport mechanisms for carbohydrate absorption (Wilson 2015). The ingestion of multiple carbohydrate types, which utilize non-competitive gastrointestinal (GI) uptake receptors [i.e. glucose (SGT1) + fructose (GLUT5)] allows for higher ingestion rates during

endurance exercise (Smith, 2013), resulting in greater ergogenic effects compared to ingestion of just glucose alone (i.e. Currell & Jeukendrup, 2008; Tripplett et al., 2010).

In an attempt to maximize carbohydrate intake without GI distress, Maurten sports drinks created a product utilizing hydrogels to enhance gastric emptying. Polymers containing pendant acids (i.e. carboxylic acid, such as in pectin and alginate) change in accordance to their pH environment and other factors (Qiu & Park 2001). Due to the pH differences between the stomach and intestines, pH-dependent polyelectrolyte hydrogels reportedly cause swelling of the mix in the stomach, allowing controlled gastric emptying into the intestines where the pH is more neutral (Qiu & Park 2001). Anecdotal reports suggest that some professional marathon runners have used this product successfully since 2016, and it has recently been marketed to competitive cyclists (https://www.maurten.com/achievements). However, no peer-reviewed studies have examined the effects of carbohydrate hydrogel ingestion on carbohydrate delivery and endurance performance.

Therefore, the purpose of this study was to determine the effects of a Maurten hydrogel solution containing 78 g/h of maltodextrin and fructose (MF-H) on endurance performance and GI comfort compared to an isocaloric maltodextrin-fructose solution (MF) and an isocaloric maltodextrin-only solution (MD), during a 98-min varied-load cycle test followed by a sprint-interval performance test (Guillochon & Rowlands 2017). We hypothesize that MF-H will result in attenuated GI distress versus MD, but not MF, and improved cycling performance versus MD, with similar performance effects versus MF.

# Methods

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Eleven endurance-trained male cyclists were recruited from the areas of Harrisonburg, VA and Elon, NC to participate in this study. Inclusion criteria were: males aged 18 to 45 years of age, cycling $\geq$ 3 d · wk for three months prior to the study, with a $VO_{2max} \geq 50$ ml·kg$^{-1}$·min, and competing regularly ($\geq$ 3 years of competitive cycling or training). Exclusion criterion for this study were: smokers (current or former), failure to meet inclusion requirements, and intolerance to testing procedures. Subjects were provided with information about study procedures and risks and provided consent to participate prior to initiating the study. This study was approved by the Institutional Review Boards of James Madison University and Elon University.

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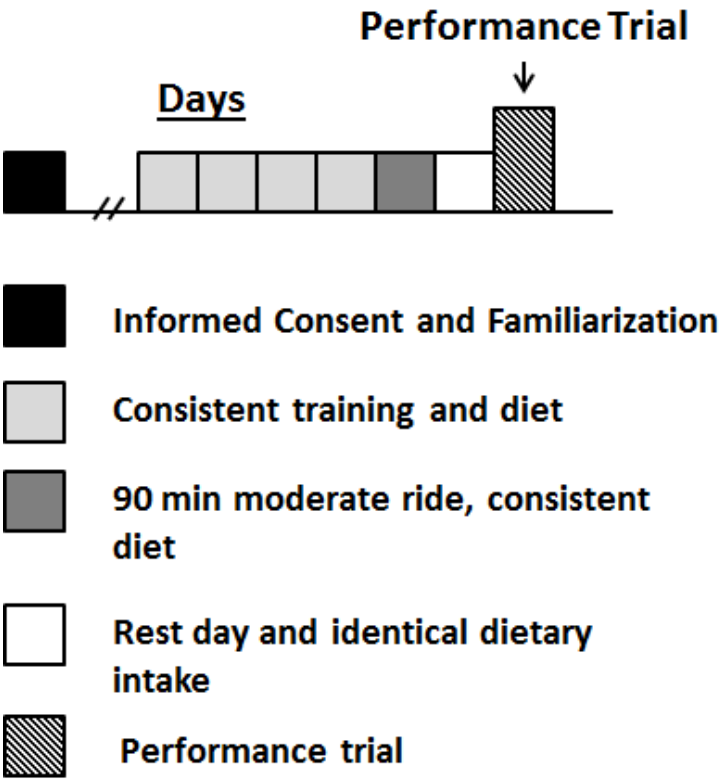


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requirement was met, based on the subject's wattage at max and body weight in kilograms ($W_{max}$ * 0.125). Sprints were designed to be approximately 2-3 min in length with the rest period (40% $W_{max}$) lasting approximately 5 min. During the sprints, subject's power output data was withheld to prevent pacing versus other trials. Power output, time to complete sprints and rest periods were collected in addition to any physiological data and perceptual responses collected throughout the study duration.

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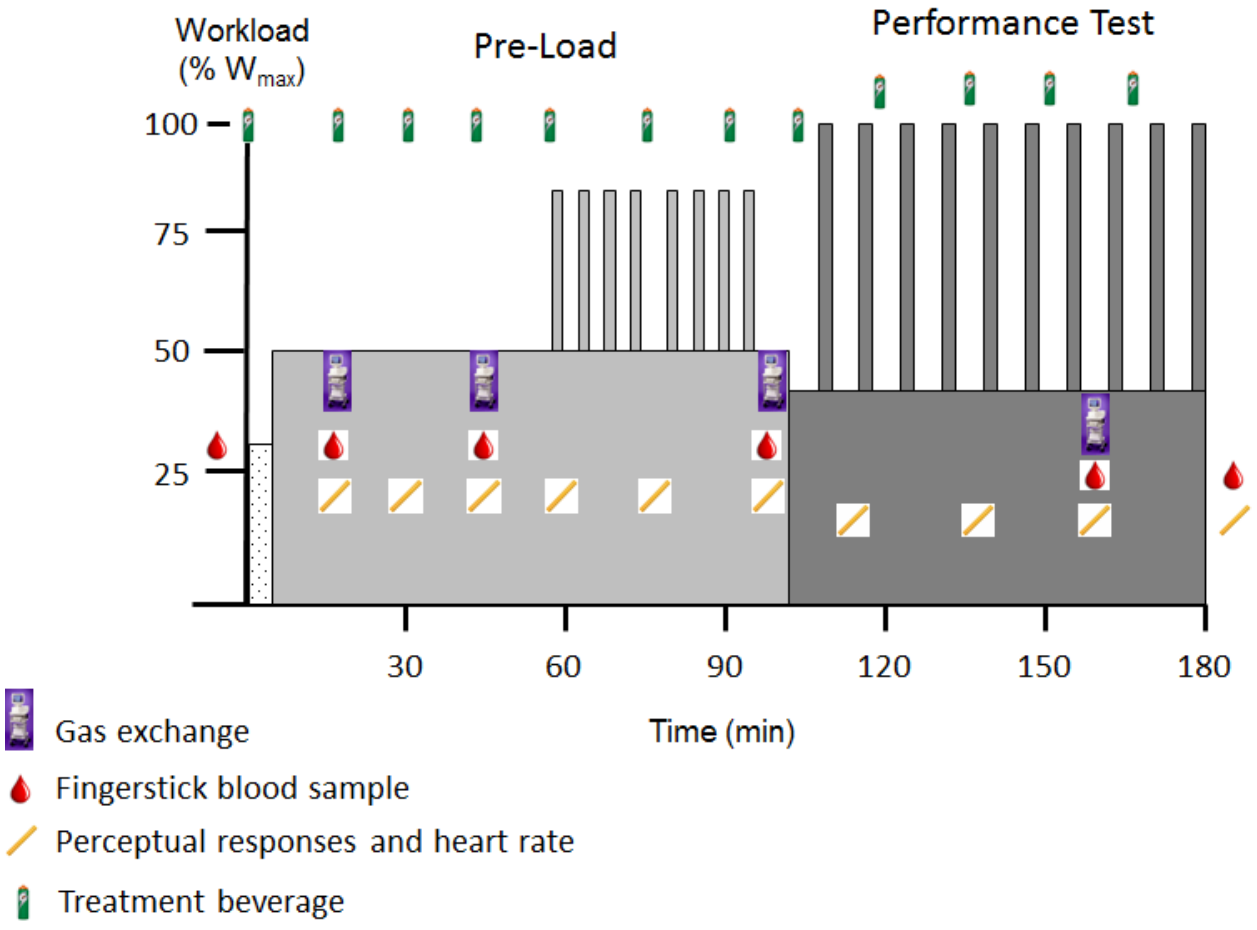

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Heart rate (Polar Electro Inc.; Bethpage, NY) was recorded every 15 min, and at test termination (Fig. 2). Oxygen uptake ($VO_2$) respiratory exchange ratio (RER) were assessed using a PARVO Metabolic System (PARVO Medics; Sandy, UT) at minutes 15-20, 45-50, and 93-98 during the pre-load phase, and at minutes 160-165 during the performance trial (Fig 2). Finger stick blood samples (0.5 mL) were obtained at the following time intervals: prior to exercise, at minutes 45, 98, and 160, and immediately following the performance test (Fig. 2). Lactate and glucose levels were assessed from whole blood using automated instrumentation (YSI 2900D Biochemistry analyzer YSI Life Sciences, Yellow Springs, OH).

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consisted of either a) Maltodextrin-fructose hydrogel (MF-H) (Maurten AB, Gothenburg, Sweden), providing 78 g of carbohydrate (from maltodextrin and fructose), using Maurten's proprietary 160 mix (two sachets), b) maltodextrin-fructose (MF) beverage providing maltodextrin and fructose (Tate and Lyle, Decatur, IL) in a 3:1 ratio with 78 g total carbohydrate, c) maltodextrin (MD) beverage providing 78 g of carbohydrate with maltodextrin only. Each beverage was made using spring water (Deer Park Spring Water, Nestlé Waters North America), and included 800 mg sodium (Morton salt; Chicago, IL) per liter, with the exception of the Maurten beverage, which was mixed using manufacturer's recommendations. Treatments were double-blinded and provided in a randomly-counterbalanced order.

**Statistical analysis**

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS). Mean values and standard deviations were calculated and reported for all dependent measures discussed above. Treatment differences in these variables were assessed using repeated measures ANOVA's, with individual treatment comparisons performed with Fisher's least significant difference test (i.e. no correction for multiple comparisons).

## Results

### Demographics

Eleven trained male cyclists ($VO_{2max}$ ≥ 50 ml·kg$^{-1}$·min) from James Madison University and Elon University enrolled in this study. Nine of the eleven subjects completed the study, as one withdrew due to an injury unrelated to the study, and another failed to complete an experimental trial. Subject demographics are displayed in Table 1.

**Table 1. Descriptive data of subjects (n=9); Mean ± SD**

| Age | Weight (kg) | Peak $VO_2$ (mL·kg$^{-1}$·min) | Peak Power (W) | Years Racing |
|---|---|---|---|---|
| 26.1 ± 6.6 | 80.9 ± 10.4 | 55.5 ± 3.6 | 356 ± 39 | 4.8 ± 3.2 |

### Physiological Responses

Physiological responses during the cycling trials ($VO_2$, RER, heart rate, blood glucose, and blood lactate) are displayed in Table 2. During the pre-load trials, $VO_2$ was higher in the MF-H treatment than MD at 15-min ($p=0.025$). There were no other treatment differences observed during the pre-load trials. During the sprint-interval trials, blood glucose was higher in the MF trial versus MD ($p=0.044$), with no other treatment difference in physiological responses. Data for lactate and glucose are reported for only eight subjects due to instrumentation errors during the exercise trials.

### Subjective Ratings

Subjective rating scores (mean ± SD) for effort, tiredness and leg strength during cycling are displayed in Table 3. Ratings of effort and tiredness were generally ≤ 50mm (less than a 'moderate' rating) during the pre-load trials. Ratings of effort increased significantly over time during the trials ($p < 0.05$), with the highest values during the sprint interval segment of the trials

**Table 2. Physiological Responses During the Cycling Protocol**

| Variable | Treatment | Mean ± SD | | | |
|---|---|---|---|---|---|
| | | 15-min | 45-min | 90-min | Sprint-7 |
| $VO_2$ ($mL \cdot min^{-1}$) | MF | 2476 ± 225 | 2486 ± 204 | 2725 ± 213 | 2325 ± 262 |
| | MF-H | 2528 ± 191* | 2622 ± 204 | 2740 ± 226 | 2302 ± 281 |
| | MD | 2392 ± 232 | 2457 ± 248 | 2677 ± 270 | 2269 ± 158 |
| RER | MF | 0.92 ± 0.07 | 0.93 ± 0.08 | 0.92 ± 0.06 | 0.91 ± 0.06 |
| | MF-H | 0.93 ± 0.05 | 0.93 ± 0.06 | 0.94 ± 0.06 | 0.91 ± 0.05 |
| | MD | 0.92 ± 0.07 | 0.92 ± 0.07 | 0.92 ± 0.06 | 0.91 ± 0.07 |
| Heart Rate (bpm) | MF | 131 ± 8 | 132 ± 6 | 145 ± 11 | 166 ± 7 |
| | MF-H | 132 ± 10 | 134 ± 11 | 145 ± 11 | 166 ± 6 |
| | MD | 131 ± 10 | 133 ± 9 | 145 ± 13 | 167 ± 8 |
| Glucose (mg/dL) | MF | 77.6 ± 7.9 | 86.7 ± 8.3 | 80.8 ± 10.4 | 87.5 ± 12.9* |
| | MF-H | 74.7 ± 13.3 | 87.4 ± 10.9 | 85.2 ± 11.4 | 88.9 ± 12.6 |
| | MD | 76.1 ± 8.9 | 88.5 ± 14.3 | 84.9 ± 14.0 | 81.9 ± 8.6 |
| Lactate (mmol/L) | MF | 0.97 ± 0.39 | 0.91 ± 0.37 | 2.76 ± 2.52 | 3.36 ± 3.14 |
| | MF-H | 0.98 ± 0.39 | 1.02 ± 0.31 | 3.01 ± 2.30 | 3.26 ± 2.44 |
| | MD | 1.04 ± 0.38 | 1.78 ± 2.85 | 2.84 ± 2.06 | 3.42 ± 2.55 |

Data are displayed as mean ± SD.
MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$
*Denotes significant difference in comparison to MD

(≥ 67mm in all trials; 'strong' to 'very strong'). There were no significant treatment-effects or treatment x time interactions for effort ratings. Similarly, tiredness ratings increased to ≥ 67mm ('strong' to 'very strong') across all trials with no systematic differences between treatments. Perceived leg strength was ≥ 67 mm ('strong' or greater) during the pre-load trials, and ≤ 50 mm ('moderate' to 'weak or mild') during the performance trial. No significant differences between treatments were observed for tiredness or leg strength, though all ratings increased significantly over time.

**Table 3. Subjective Ratings of Effort, Tiredness, and Leg Strength During Cycling**

| Variable | Treatment | Mean ± SD | | | |
|---|---|---|---|---|---|
| | | 15-min | 45-min | 90-min | Sprint-7 |
| Effort of Cycling (0-100 mm) | MF | 29.9 ± 21.9 | 34.2 ± 19.2 | 53.7 ± 17.2 | 75.1 ± 14.6 |
| | MF-H | 26.5 ± 13.9 | 34.9 ± 16.9 | 52.3 ± 15.3 | 72.2 ± 15.2 |
| | MD | 20.3 ± 15.3 | 29.8 ± 16.3 | 46.3 ± 11.6 | 75.6 ± 13.1 |
| Tiredness (0-100 mm) | MF | 19.3 ± 14.4 | 29.8 ± 16.2 | 51.5 ± 18.7 | 72.6 ± 11.5 |
| | MF-H | 14.9 ± 9.4 | 27.4 ± 15.4 | 49.4 ± 14.6 | 70.4 ± 9.7 |
| | MD | 16.5 ± 13.8 | 27.5 ± 13.7 | 46.9 ± 12.5 | 70.6 ± 14.3 |
| Leg Strength (0-100 mm) | MF | 79.4 ± 11.1 | 74.3 ± 10.5 | 58.1 ± 15.4 | 35.9 ± 14.8 |
| | MF-H | 81.4 ± 9.4 | 75.1 ± 8.2 | 60.8 ± 11.3 | 43.3 ± 12.3 |
| | MD | 83.2 ± 10.5 | 77.1 ± 7.6 | 58.6 ± 6.6 | 36.4 ± 9.9 |

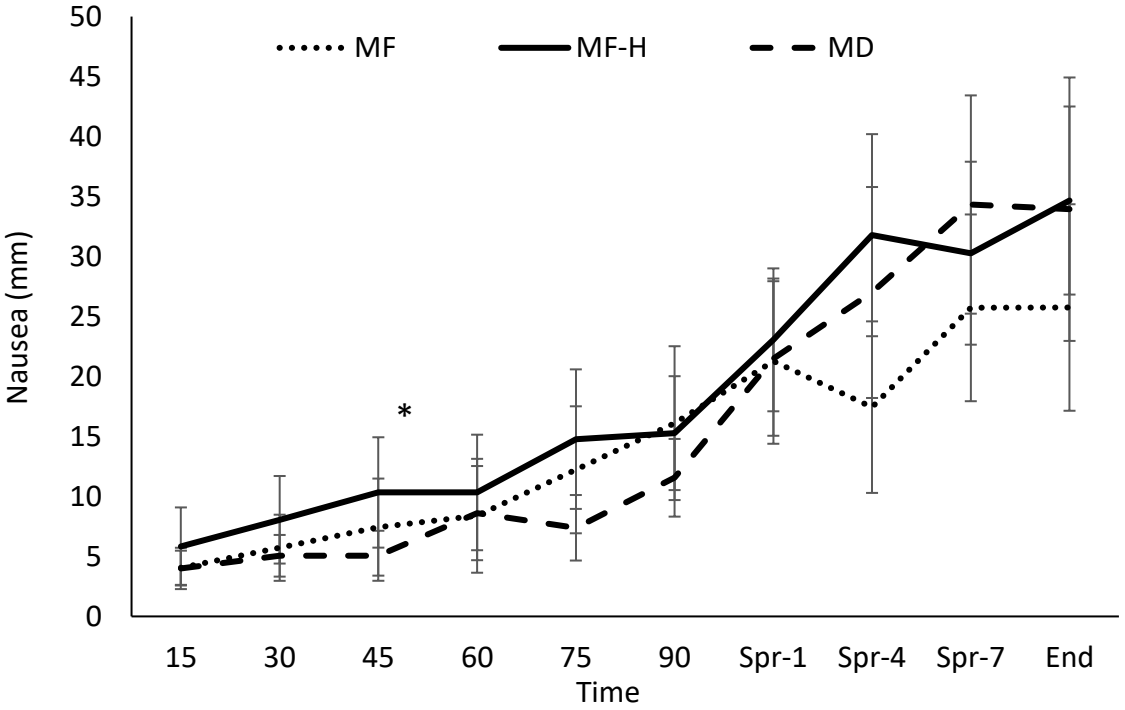
Data are represented as mean ± SD. MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$ ; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$

**Gastrointestinal distress symptoms**

GI symptoms (nausea, fullness, and abdominal cramping) are shown in Figures 3-5, respectively. In general, GI symptoms increased over time ($p < 0.05$ for all symptoms). Symptoms increased from 'extremely weak' (≤ 10 mm) at the onset of exercise to 'weak or mild' (≤ 30 mm) by the end of the pre-load trials. Despite further increases in symptoms during the sprint intervals, average values did not surpass 'moderate' ratings of discomfort. Individual responses resulted in varied degrees of GI distress, and individual GI distress symptoms exceeding moderate (≥ 50) and severe discomfort (≥ 65) are shown for each treatment in Table 4.

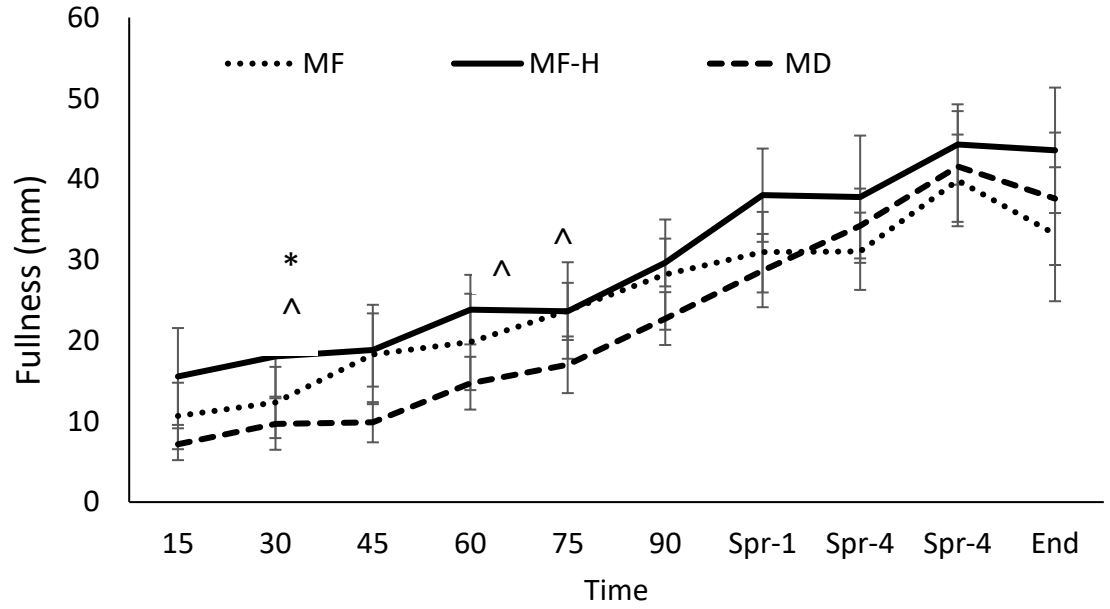
No significant treatment x time interactions were observed for any GI symptoms. However, nausea ratings at 45 min were higher in MF-H versus MF ($p=0.016$). Stomach fullness ratings at 30 min were higher in MF-H compared to MD ($p=0.046$) and MF ($p=0.005$), and stomach fullness at 60 min was higher in MF-H versus MF ($p=0.002$) and at 75-min versus MD ($p=0.037$).

**Figure 3. Effect of CHO beverages on nausea ratings across all time points**



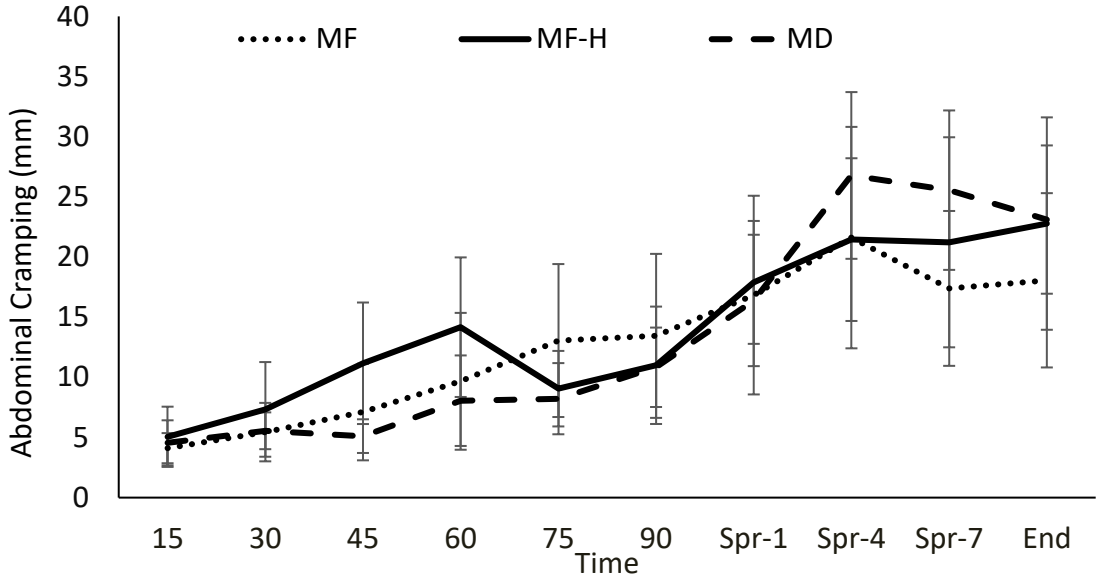

Data are displayed as mean ± SE. Significant main-effect for time ($p < 0.05$). MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$. *$p < 0.05$; MF vs. MF-H.

**Figure 4. Effect of CHO beverages on fullness ratings across all time points**




Data are displayed as mean ± SE. Significant main-effect for time ($p < 0.05$). MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$. ***** $p < 0.05$; MF vs. MF-H; ^ $p < 0.05$; MF-H vs. MD.

**Figure 5. Effect of CHO beverages on abdominal cramping ratings across all time points**




Data are displayed as mean ± SE. Significant main-effect for time ($p < 0.05$). MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$ ; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$.

**Table 4. GI distress symptom incidences of moderate (m; ≥ 50) and severe discomfort (S; ≥ 65).**

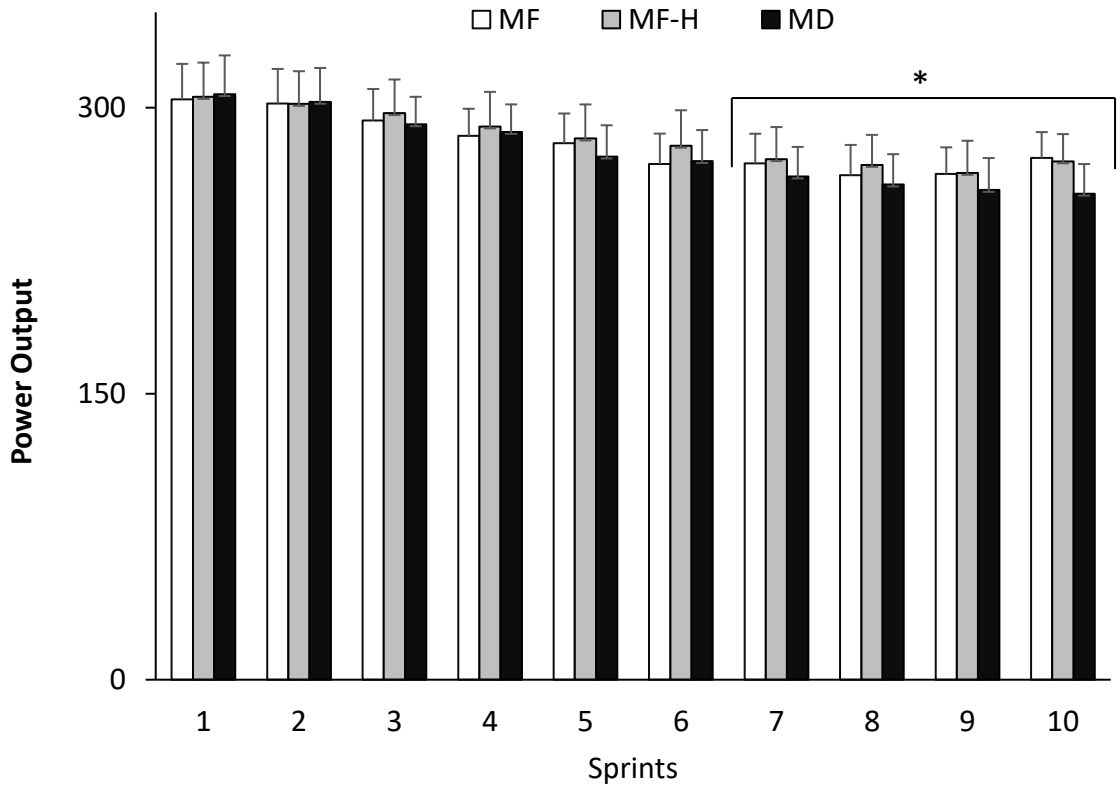
| **Nausea** | 15-min | 30-min | 45-min | 60-min | 75-min | 90-min | SPR1 | SPR4 | SPR7 | END |
|---|---|---|---|---|---|---|---|---|---|---|
| MF | | | | | | 1m | 1m | 1s | 1s | 1s |
| MF-H | | | | | | | 1m | 2m/1s | 1s | 2s |
| MD | | | | | | | 1m | 2m/1s | 1m/2s | 3s |
| **Fullness** | | | | | | | | | | |
| MF | | | | 1m | 1m | 1s | 1m | 1m | 1m/1s | 1m/1s |
| MF-H | | | | | | | 2m | 2m/1s | 3m/1s | 2m/2s |
| MD | | | | | | | 1m | 2m | 1m/2s | 1m/2s |
| **Abdominal cramping** | | | | | | | | | | |
| MF | | | | 1m | 1m | 1m | 1s | 1m/1s | 1m | 1m |
| MF-H | | | | | | | | 1m | 1m/1s | 1m/1s |
| MD | | | | | | | | 1m | 1m | |

MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$ ; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$.

**Performance**

Average power output over the 10 sprint intervals was not significantly different between MF (281 ± 46 W), MF-H (284 ± 51 W) and MD (277 ± 48 W). In addition, average power output during recovery periods between sprints was the same between MF (140 ± 13 W), MF-H (139 ± 14 W), and MD (139 ± 13 W). Sprint power output during individual sprint intervals is illustrated in Figure 6. There were no significant between-treatment differences in power output any individual sprint. However, there was a visual trend suggesting a tendency for power output to be lower in the MD trial during the latter stages of the sprint trial, and power output averaged over sprints 7-10 was significantly lower in MD (259 ± 2 W) versus MF (269 ± 2 W; p=.044), and versus MF-H (270 ± 2 W; p=0.01).

**Figure 6. Power Output during Sprint Intervals for Each Treatment**




MF (maltodextrin + fructose) 1.33 $g \cdot min^{-1}$; MF-H (maltodextrin + fructose hydrogel) 1.33 $g \cdot min^{-1}$; MD (maltodextrin-only) 1.33 $g \cdot min^{-1}$. ***** = significant difference between MF-H/MF versus MD.

**Discussion**

The primary goal of this study was to determine the effects of a MF-H beverage on endurance cycling performance and GI comfort ratings compared to MF and MD beverages, matched for carbohydrate/caloric content. To our knowledge, this is the first study examining the effects of carbohydrate hydrogels on these outcomes. Although ingestion of MF-H had no significant effects on average power output over the entire sprint interval test, both MF-H and MF provided greater sprint power over the final four sprints of the performance trial compared to MD. No differences in performance were observed between MF-H and MF beverages. GI distress symptoms increased throughout the duration of each trial, but there were no systematically different ratings of GI symptoms between treatments, particularly late in exercise.

We observed no differential effects of the beverages on average sprint performance in the present study (differences between MF-H/MF versus MD were 1.4/2.5%, respectively; N.S.). However, power output averaged over the final four sprints was ~ 4% higher ($p < 0.05$) in the beverages containing a mix of maltodextrin and fructose (MF-H and MF) versus maltodextrin alone. This observation is generally consistent with prior studies examining the effects of multiple transportable carbohydrate beverages (i.e. glucose/maltodextrin + fructose) on performance. For example, Currell and Jeukendrup (2008) examined endurance performance during a one-hour time trial that immediately followed 2 h of constant-load cycling, and reported that average power output was 8.1% higher when subjects consumed glucose+fructose versus an isocaloric amount of glucose alone. Similarly, Tripplett et al. (2010) found that average power output during a 100 km time trial was 7.1 % higher when subjects ingested glucose+fructose

versus an isocaloric glucose-only beverage. The large ergogenic effects reported in these studies may have been due to substantially higher carbohydrate ingestion rates (108 – 144 g/h) than the present study (78 g/h), which could have magnified the potential effects of glucose+fructose on exogenous carbohydrate oxidation (discussed below), or exacerbated ergolytic effects of excessive glucose in the glucose-only trials. In support of this concept, Baur and colleagues (2014) reported that maltodextrin+fructose ingestion improved cycling time-trial performance by 3.0 % compared to an isocaloric maltodextrin-only beverage (93 g/h); this effect was reduced to 1.2 % when compared to a lower rate of maltodextrin intake (60 g/h). Similarly, Rowlands et al (2012) found only modest improvements in cycling time-trial performance (1.8 %) and average sprint power (1.4%) when comparing maltodextrin+fructose versus maltodextrin/glucose beverages, when consumed at intake rates similar to the present study (~ 80 g/h). Therefore, our findings support the existing literature, suggesting that the consumption of multiple transportable carbohydrates provides modest ergogenic effects in comparison to single carbohydrate sources. However, our primary purpose was to determine if carbohydrate hydrogels influence performance versus conventional carbohydrate beverages. Although ingestion of MF-H improved late-exercise performance compared to MD, MF-H did not provide further benefits in comparison to MF. Our findings suggest that carbohydrate hydrogels do not affect cycling performance to a greater extent than conventional beverages with the same carbohydrate composition.

It is generally believed that the ergogenic effects of multiple transportable carbohydrates are due to influences on a) total carbohydrate oxidation, and/or b) gastrointestinal comfort. Maximal rates of carbohydrate oxidation with the consumption of glucose shows an upper limit

of 60 g · $hr^{-1}$ or 1 g · $min^{-1}$ (Jeukendrup and Jentjens 2000). Ingestion of higher rates of a single form of carbohydrate does not increase exogenous oxidation and is likely to be associated with increased incidences of GI distress. This is because the intestines absorb glucose/maltodextrin via the sodium-dependent glucose transporter 1 (SGT1) at a maximal rate ~1.0 to 1.1 g · $min^{-1}$ (Jeukendrup et al., 2000). However, intestinal uptake of fructose occurs via the sodium-independent transporter (GLUT5) which is a non-competitive uptake pathway to that of glucose (Shi et al., 1997), at a rate of ~0.6 g · $min^{-1}$ (Jeukendrup et al., 2004). Combining multiple transportable carbohydrates has been reported to increase total carbohydrate oxidation rates compared to single carbohydrate sources (Jentjens et al., 2004). The increase in exogenous carbohydrate oxidation is generally believed to be beneficial due to a decreased reliance on endogenous carbohydrate sources – mainly from the sparing of hepatic glycogen (Jentjens & Jeukendrup 2005; Wallis et al., 2005). This could result in higher total carbohydrate oxidation rates (exogenous + endogenous), supporting higher power output in the latter stages of prolonged exercise. However, most metabolic responses between trials in this study were similar between all treatments. It is worth noting that blood glucose levels during the sprint-intervals was higher in the MF/MF-H trials (88/89 mg/dL) versus MD (82 mg/dL) providing some evidence that carbohydrate availability may have been augmented in the MF/MF-H trials. However, we observed no differences in RER (indicative of carbohydrate/fat utilization) between treatments at any timepoint in the study. In addition, there were no differences in blood lactate values, which could augment carbohydrate oxidation late in exercise (Lecoultre et al., 2010; Jentjens et al., 2004). The lack of compelling evidence for elevated carbohydrate oxidation rates is in line with prior studies reporting ergogenic effects with multiple transportable carbohydrates versus

glucose/maltodextrin (i.e. Baur et al., 2014; Currell and Jeukendrup, 2008; Rowlands et al., 2012; Tripplett et al, 2010), thereby necessitating more data to confirm the mechanisms for superior performance.

The ergogenic effects of glucose/maltodextrin + fructose could also be related to influences on GI tolerance (Baur et al., 2014; Rowlands et al., 2012). As discussed previously, excessive glucose ingestion rates (and the associated effects on GI intolerance) could potentially explain large performance effects reported for glucose + fructose beverages in some studies (Currell and Jeukendrup, 2008; Tripplett et al., 2010). However, similar to Baur et al. (2014), we observed no systematic reduction in GI discomfort symptoms during cycling with MF versus MD, so we cannot directly associate the observed improvements in late-exercise power output with influences on GI comfort. In addition, contrary to anecdotal reports, we observed no positive effects of MF-H on GI distress symptoms such as nausea, fullness and abdominal cramping. In fact, some measures of GI discomfort were higher in MF-H than other beverages during the pre-load trials (i.e. nausea ratings at 45-min, fullness ratings at 30, 60 & 75 min). However, we conclude that any negative effects of MF-H on GI discomfort were trivial, as discomfort ratings at these times were low (below 'moderate') and treatment differences did not persist into the later stages of exercise, where discomfort ratings were higher and more likely to affect performance. Therefore, we observed no systematic effects of MF or MF-H on GI discomfort. However, it is worth noting that GI discomfort is influenced by a variety of exercise factors, such as intensity, duration, mode of exercise, and environmental conditions (Rehrer et al., 1994). In the present study (cycling exercise in a controlled environment at room temperature), the mean ratings for all GI distress symptoms were < 50 ('moderate'), suggesting that GI discomfort had a minimal

influence on performance for most individuals under these conditions. Very few individuals reported any 'severe' symptoms (≥ 65) at any time-point, but it could be instructive that the highest number of severe symptoms were reported in the MD trial (3 for nausea; versus 2/1 for MF-H/MF respectively). Therefore, it could be useful to further examine the effects of MF and MF-H on GI discomfort under exercise conditions that elicit more severe GI distress symptoms.

The present study utilized trained cyclists as subjects to determine the efficacy of a carbohydrate hydrogel on improvements in performance and GI distress during prolonged exercise. Our study design utilized a sprint interval protocol in order to examine the effects of carbohydrates on performance, and better replicate high-intensity efforts experienced during cycling competitions. Additionally, GI distress is more commonly associated with high intensity exercise, as illustrated by higher ratings of GI symptoms during the sprint interval segment of the test. Though there were no observed benefits of MF-H over MF, future studies should consider the influences of exercise modality and carbohydrate doses to determine whether MF-H influences endurance performance and GI distress under different conditions. Larger sample sizes would also provide greater statistical power to assess potentially small effects of carbohydrate hydrogels on endurance performance.

In conclusion, we observed that carbohydrate beverages with maltodextrin + fructose (MF and MF-H) improved late-exercise sprint performance versus MD alone. However, MF-H provided no further benefits on performance versus MF. In addition, MF-H had no positive effects on GI symptoms versus MF or MD. Therefore, our findings refute anecdotal reports that MF-H beverages reduce GI discomfort and improve endurance performance. It remains to be seen if carbohydrate hydrogels influence exercise performance or GI comfort when consumed:

a) at higher dosages (≥ 1.3 g · $min^{-1}$), or b) during exercise conditions that elicit more severe levels of GI distress.

**References**


1. Ahmed, E. M. (2015). Hydrogel: Preparation, characterization, and applications: A review. *Journal of advanced research*, *6*(2), 105-121.
2. Baur, D. A., Schroer, A. B., Luden, N. D., Womack, C. J., Smyth, S. A., & Saunders, M. J. (2014). Glucose-fructose enhances performance versus isocaloric, but not moderate, glucose. *Med. Sci. Sports Exerc*, *46*(9), 1778-1786.
3. Coggan, A. R., & Coyle, E. F. (1987). Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *Journal of Applied Physiology*, *63*(6), 2388-2395.
4. Costill, D. L., Kammer, W. F., & Fisher, A. (1970). Fluid ingestion during distance running. *Archives of Environmental Health: An International Journal*, *21*(4), 520-525.
5. Coyle E, Coggan A, Hemert M, et al. Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. J Appl Physiol. 1986;61(1):165–72.
6. Currell, K., & Jeukendrup, A. (2008). Superior endurance performance with ingestion of multiple transportable carbohydrates. *Medicine+ Science in Sports+ Exercise*, *40*(2), 275.
7. Ferraris, R. P. (2001). Dietary and developmental regulation of intestinal sugar transport. *Biochemical Journal*, *360*(2), 265-276.
8. Guillochon, M., & Rowlands, D. S. (2017). Solid, gel, and liquid carbohydrate format effects on gut comfort and performance. *International journal of sport nutrition and exercise metabolism*, *27*(3), 247-254.
9. Hamidi, M., Azadi, A., & Rafiei, P. (2008). Hydrogel nanoparticles in drug delivery. *Advanced drug delivery reviews*, *60*(15), 1638-1649.

10. Hermansen, L., Hultman, E., & Saltin, B. (1967). Muscle glycogen during prolonged severe exercise. *Acta Physiologica*, *71*(2-3), 129-139.
11. Jentjens, R. L., & Jeukendrup, A. E. (2005). High rates of exogenous carbohydrate oxidation from a mixture of glucose and fructose ingested during prolonged cycling exercise. *British Journal of Nutrition*, *93*(4), 485-492.
12. Jentjens, R. L., Achten, J., & Jeukendrup, A. E. (2004). High oxidation rates from combined carbohydrates ingested during exercise. *Medicine and science in sports and exercise*, *36*(9), 1551-1558.
13. Jentjens, R. L., Moseley, L., Waring, R. H., Harding, L. K., & Jeukendrup, A. E. (2004). Oxidation of combined ingestion of glucose and fructose during exercise. *Journal of Applied Physiology*, *96*(4), 1277-1284.
14. Jentjens, R. L., Moseley, L., Waring, R. H., Harding, L. K., & Jeukendrup, A. E. (2004). Oxidation of combined ingestion of glucose and fructose during exercise. *Journal of Applied Physiology*.
15. Jentjens, R. L., Wagenmakers, A. J., & Jeukendrup, A. E. (2002). Heat stress increases muscle glycogen use but reduces the oxidation of ingested carbohydrates during exercise. *Journal of applied physiology*, *92*(4), 1562-1572.
16. Jeukendrup, A. E. (2008). Carbohydrate feeding during exercise. *European Journal of Sport Science*, *8*(2), 77-86.
17. Jeukendrup, A. E., & Jentjens, R. (2000). Oxidation of carbohydrate feedings during prolonged exercise. *Sports Medicine*, *29*(6), 407-424.50.
18. Jeukendrup, A. E., Wagenmakers, A. J., Stegen, J. H., Gijsen, A. P., Brouns, F., & Saris, W. H. (1999). Carbohydrate ingestion can completely suppress endogenous glucose production

during exercise. *American Journal of Physiology-Endocrinology And Metabolism*, *276*(4), E672-E683.

19. Keeffe, E. B., Lowe, D. K., Goss, J. R., & Wayne, R. (1984). Gastrointestinal symptoms of marathon runners. *Western Journal of Medicine*, *141*(4), 481.
20. Kreider, R. B., Wilborn, C. D., Taylor, L., Campbell, B., Almada, A. L., Collins, R., ... & Kerksick, C. M. (2010). ISSN exercise & sport nutrition review: research & recommendations. *Journal of the international society of sports nutrition*, *7*(1), 7.
21. Lecoultre, V., Benoit, R., Carrel, G., Schutz, Y., Millet, G. P., Tappy, L., & Schneiter, P. (2010). Fructose and glucose co-ingestion during prolonged exercise increases lactate and glucose fluxes and oxidation compared with an equimolar intake of glucose. *The American journal of clinical nutrition*, *92*(5), 1071-1079.
22. Loon, L. J., Greenhaff, P. L., Constantin-Teodosiu, D., Saris, W. H., & Wagenmakers, A. J. (2001). The effects of increasing exercise intensity on muscle fuel utilisation in humans. *The Journal of physiology*, *536*(1), 295-304.
23. Murray, R. (1987). The effects of consuming carbohydrate-electrolyte beverages on gastric emptying and fluid absorption during and following exercise. *Sports Medicine*, *4*(5), 322-351.
24. Qiu, Y., & Park, K. (2001). Environment-sensitive hydrogels for drug delivery. *Advanced drug delivery reviews*, *53*(3), 321-339.
25. Rehrer, N. J., Janssen, G. M. E., Brouns, F., & Sa, W. H. M. (1989). Fluid Intake and Gastrointestinal Problems in Runners Competingin a 25-km Race and a Marathon. *Int. J. Sports Med*, *10*, S22-S25.

26. Romijn, J. A., Coyle, E. F., Sidossis, L. S., Gastaldelli, A., Horowitz, J. F., Endert, E., & Wolfe, R. R. (1993). Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *American Journal of Physiology-Endocrinology And Metabolism*, *265*(3), E380-E391.

27. Rowlands, D. S., Swift, M., Ros, M., & Green, J. G. (2012). Composite versus single transportable carbohydrate solution enhances race and laboratory cycling performance. *Applied Physiology, Nutrition, and Metabolism*, *37*(3), 425-436.

28. Shi, X. I. A. O. C. A. I., Schedl, H. P., Summers, R. M., Lambert, G. P., Chang, R. T., Xia, T. I. N. G., & Gisolfi, C. V. (1997). Fructose transport mechanisms in humans. *Gastroenterology*, *113*(4), 1171-1179.

29. Smith, J. W., Pascoe, D. D., Passe, D. H., Ruby, B. C., Stewart, L. K., Baker, L. B., & Zachwieja, J. J. (2013). Curvilinear dose–response relationship of carbohydrate (0–120 g· h− 1) and performance. *Medicine & Science in Sports & Exercise*, *45*(2), 336-341.

30. Smith, J. W., Zachwieja, J. J., Péronnet, F., Passe, D. H., Massicotte, D., Lavoie, C., & Pascoe, D. D. (2010). Fuel selection and cycling endurance performance with ingestion of 13c-glucose: evidence for a carbohydrate dose-response. *journal of applied physiology*.49.

31. Stellingwerff, T., & Cox, G. R. (2014). Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations. *Applied Physiology, Nutrition, and Metabolism*, *39*(9), 998-1011.

32. Triplett, D., Doyle, J. A., Rupp, J. C., & Benardot, D. (2010). An isocaloric glucose-fructose beverage's effect on simulated 100-km cycling performance compared with a glucose-only beverage. *International journal of sport nutrition and exercise metabolism*, *20*(2), 122-131.

33. Wagenmakers, A. J., Brouns, F. R. E. D., Saris, W. H., & Halliday, D. A. V. I. D. (1993). Oxidation rates of orally ingested carbohydrates during prolonged exercise in men. *Journal of Applied Physiology*, *75*(6), 2774-2780.

34. Wallis, G. A., Rowlands, D. S., Shaw, C. H. R. I. S. T. O. P. H. E. R., Jentjens, R. L., & Jeukendrup, A. E. (2005). Oxidation of combined ingestion of maltodextrins and fructose during exercise. *Medicine and Science in Sports and Exercise*, *37*(3), 426-432.

35. Wilson P, Ingraham S. Glucose-fructose likely improves gastrointestinal comfort and endurance running performance relative to glucose-only. *Scandinavian Journal Of Medicine & Science In Sports* [serial online]. December 2015;25(6):e613-e620. Available from: SPORTDiscus with Full Text, Ipswich, MA.