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Carbohydrate supplementation during cycling exercise

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ABSTRACT

CARBOHYDRATE SUPPLEMENTATION DURING CYCLING EXERCISE

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Enhancing cycling exercise performance through means of carbohydrate supplementation suggests that a blend of multiple transportable carbohydrate (CHO) sources supplemented at a feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$ will provide optimal performance and attenuate gastrointestinal discomfort during exercise. **PURPOSE:** To determine if the literature suggested feeding rate ($78 \text{ g}\cdot\text{h}^{-1}$) applies to variable and relatively high-intensity cycling exercise and to determine if a unique high molecular weight starch fraction (Vitargo®; Swecarb, Sweden) provides an advantage over the literature ideal (multiple transportable CHO). **METHODS:** Six competitive male cyclists and triathletes (mean age 25.6 ± 4.4 years; mean weight 77.56 ± 7.3 kg; mean $\text{VO}_{2\text{max}}$ $59.57 \pm 8.47 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) volunteered in the randomized double-blind study. Each participant completed three randomized, 90-min cycling time trials with various stages (3 distinct flats and 3 distinct mountains) while ingesting the following CHO solutions: 1:1:1 maltodextrin-fructose-glucose at $117 \text{ g}\cdot\text{h}^{-1}$ (HDMD), 1:1:1 maltodextrin-fructose-glucose at $78 \text{ g}\cdot\text{h}^{-1}$ (LDMD), or a single-source high molecular weight starch fraction (Vitargo) at $117 \text{ g}\cdot\text{h}^{-1}$ (HDV.) Each CHO solution had an identical electrolyte composition ($18 \text{ mmol}\cdot\text{L}^{-1}$ Na, $3 \text{ mmol}\cdot\text{L}^{-1}$ K, and $11 \text{ mmol}\cdot\text{L}^{-1}$ Cl). **RESULTS:** Independent of CHO type, power (W) was significantly greater

during the final flat stage ($p = .01$) compared to the first two flat stages and significantly greater during the first mountain stage ($p = .01$) compared to the final two mountain stages. However, power (W) was not significantly different between CHO supplement types across the stages. Independent of CHO type, respiratory exchange ratio (RER) was significantly different across all flat stages ($p = .01$). However, RER was not significantly different between CHO supplement types across the flat stages. **CONCLUSION:** During variable-intensity cycling, there does not appear to be a performance or metabolic advantage to supplementing multiple transportable CHO at $78 \text{ g}\cdot\text{h}^{-1}$ compared to the same multiple transportable CHO blend at a feeding rate $117 \text{ g}\cdot\text{h}^{-1}$. Additionally, there does not appear to be disadvantage to supplementing with a single-source high molecular weight starch fraction (Vitargo), despite the literature suggestion of using CHO solutions that have multiple transportable CHO sources.

Keywords: multiple transportable carbohydrate; carbohydrate ingestion rate; cycling

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CARBOHYDRATE SUPPLEMENTATION DURING
CYCLING EXERCISE

BY

BILL JULIAN
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A THESIS SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

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DEPARTMENT OF KINESIOLOGY AND PHYSICAL EDUCATION

Thesis Director:
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INTRODUCTION

Recreational and competitive participation in endurance sports continues to grow, and commercially available sports drinks and carbohydrate (CHO) supplements are widely used during these events. Runners, cyclists, swimmers, and triathletes often seek a competitive advantage from CHO supplementation during competition to provide additional muscle fuel and enhance endurance performance. Research into the effectiveness of supplemental CHO during endurance exercise has resulted in the formation of a wide variety of sports drinks and CHO supplements.

The majority of recent research exploring the effects of CHO supplementation during endurance exercise has focused on the specific CHO type and ideal feeding amount that leads to maximal performance. Many authors have found that a combination of multiple transportable CHO sources (maltodextrin-glucose-fructose) leads to higher exogenous oxidation rates when compared to single CHO drinks (glucose). Using tracer techniques, research has revealed that peak oxidation rates are around $1.5 \text{ g}\cdot\text{min}^{-1}$ when a combination of multiple transportable CHO is ingested during moderate-intensity cycling (60-65% $\text{VO}_{2\text{max}}$, 50-55% W_{max}) and rarely exceed $1 \text{ g}\cdot\text{min}^{-1}$ when a single-source CHO is ingested (Jentjens, Achten, & Jeukendrup, 2004; Jentjens, Venables, & Jeukendrup, 2004; Jeukendrup, Jentjens, & Venables, 2003; Wallis, Rowlands, Shaw, Jentjens, & Jeukendrup, 2005).

The ingestion of multiple transportable CHO during cycling exercise has also been shown to increase endurance performance over single CHO drinks. Currell and Jeukendrup (2008) investigated the effects of ingesting a glucose and fructose beverage compared to a glucose

beverage on endurance cycling performance. Participants were required to cycle at 55% W_{\max} for two hours. Immediately upon completion, participants were asked to complete an amount of work equal to about 60 minutes of cycling at 75% W_{\max} as fast as possible. When the combination of glucose and fructose was ingested, it resulted in 8% quicker time to completion during the time trial compared with a CHO beverage containing glucose alone. In addition, mean power output during the time trial was significantly higher when participants consumed the combination of glucose and fructose compared to glucose alone, 275 ± 10 W and 254 ± 8 W, respectively.

In contrast, there is one particular CHO source that does not fit into the traditional maltodextrin or sugar categories and appears to have unique advantages over maltodextrin-based CHO supplements. Recent studies done on a soluble, high molecular weight starch extract (Vitargo®; Swecarb, Sweden) have demonstrated unique advantages over lower molecular weight maltodextrin-based CHO. Initial research used gastric aspiration to compare the gastric emptying rates between the two CHO sources (Leiper, Aulin, & Soderlund, 2000). By measuring the time it took to empty half of a 500 mL 13.5% solution of fluid from the stomach, the authors found that Vitargo® left the stomach almost twice as fast as the maltodextrin, 17 minutes and 32 minutes, respectively (Leiper et al., 2000). In addition to significant differences in gastric emptying, authors have also found significant differences in muscle glycogen resynthesis rates following exhaustive running and cycling. Quadriceps (vastus lateralis) muscle biopsies taken two hours postexercise showed 68% greater glycogen content following the ingestion of Vitargo® compared to maltodextrin (Aulin, Soderlund, & Hultman, 2000). A more recent study completed by Stephens, Roig, Armstrong, and Greenhaff (2008) measured work output during a

15-min maximal endurance bout of cycling exercise following exhaustive cycling. The authors reported significantly greater work output during the subsequent bout following the ingestion of Vitargo® compared to maltodextrin, 164.1 kJ and 137.5 kJ, respectively. The authors speculated that the observed greater recovery performance with Vitargo® was due to more rapid muscle glycogen repletion.

From a practical point of view, the amount of CHO that should be supplemented to attain optimal performance is important. A recent study by Smith et al. (2013) investigated the relationship between CHO dose and 20 km time trial performance following a two-hour constant-load ride at 95% of the workload that elicited a $4 \text{ mmol}\cdot\text{L}^{-1}$ blood lactate concentration in recreationally trained male cyclists and triathletes. Using the literature-suggested blend of multiple transportable CHO, the authors had participants supplement a 1:1:1 blend of glucose, fructose, and maltodextrin plus electrolytes at varying doses ($0\text{-}120 \text{ g}\cdot\text{h}^{-1}$) to determine the ideal CHO ingestion rate to maximize cycling performance and reduce the instance of stomach discomfort. By evaluating the relationship between time trial performance and CHO intake, the authors concluded the optimal CHO ingestion rate for a 1:1:1 blend of maltodextrin, fructose, and glucose plus electrolytes is around $78 \text{ g}\cdot\text{h}^{-1}$ (Smith et al., 2013).

Purpose

The primary purpose of this study was to determine if the literature-based suggested feeding rate ($78 \text{ g}\cdot\text{h}^{-1}$) applies to variable and relatively high-intensity cycling exercise in multiple transportable CHO. The secondary aim of this study was to determine if a unique high molecular weight starch fraction (Vitargo®) provides an advantage over the literature-based ideal (multiple transportable CHO) when fed at a dose 1.5x greater than literature-suggested $78 \text{ g}\cdot\text{h}^{-1}$.

METHODS

Experimental Procedures

The participants were required to make a total of five visits to the research lab separated by one week. The first visit consisted of baseline testing including body composition analysis, maximal oxygen consumption (VO_{2max}), and functional threshold (FTH) testing. The second visit consisted of further baseline testing including a lactate threshold (LT) test and a familiarization (FAM) ride used to acclimatize participants to the computer-programmed cycling course and testing protocol. Participants were allowed to hydrate with water and fuel ad libitum during the entire FAM ride. These visits lasted approximately two hours.

The remaining visits consisted of three randomized 90-min time trials while ingesting one of three experimental CHO solutions: high-dose maltodextrin with sugars (HDMD), low-dose maltodextrin with sugars (LDMD), or high-dose Vitargo (HDV). A number of variables were collected during the testing, including heart rate (HR), CHO and fat oxidation rates, oxygen consumption (VO_2), respiratory exchange ratio (RER), gastrointestinal (GI) fullness, and multiple cycling performance metrics including power, speed, cadence, pedal force, and distance. Both the lead researchers and participants were blinded to the CHO supplement being consumed during each trial using blinding codes and opaque mixing bottles. These visits lasted approximately three hours and each trial was separated by one week.

Participants

Six male competitive endurance athletes from the local cycling community volunteered to participate in the study, including four road cyclists (categories 1-3) and two triathletes (one collegiate and one professional). These athletes were recruited via flyers handed out at local bicycle and endurance retailers (Appendix A). Mean and SD age, height, and body weight were 25.6 ± 4.4 yrs, $1.83 \pm .04$ m, and 77.56 ± 7.3 kg, respectively. Mean and SD VO_{2max} , LT, and FTH were 59.57 ± 8.47 mLs \cdot kg $^{-1}\cdot$ min $^{-1}$, 241.33 ± 47.15 W, and 279 ± 41.95 W, respectively. Each participant read and signed an informed consent form that was approved by the Institutional Review Board at Northern Illinois University (Appendix B), medical health history questionnaire (Appendix C), and physical activity readiness questionnaire (Appendix D) prior to completing any testing. Participants were limited to experienced male cyclists and triathletes (minimum 3 years) between the ages of 18-35 years with a VO_{2max} no less than 50 mLs \cdot kg $^{-1}\cdot$ min $^{-1}$.

Protocol

The first laboratory visit consisted of three baseline tests in the following order. Body composition was measured by direct/segmental/multi-frequency bioelectrical impedance analysis (InBody 520, InBody Co., Cerritos, CA). VO_{2max} was measured using a continually increasing power output protocol following a 10-min warm-up. The workload started at 100 W and increased incrementally every minute by 25 W until volitional fatigue. A true VO_{2max} was determined from attaining at least two of the four following criteria as described by the American College of Sports Medicine (ACSM, 2006), blood lactate greater than 8 mM,

respiratory exchange ratio (RER) greater than 1.2, terminal heart rate (HR) within five beats of age predicted HR max, and a leveling off of VO_2 (ACSM, 2006). After a 15-min recovery period the participants completed a 30-min FTH test. Functional threshold is defined as the highest power a cyclist can maintain in a quasi-steady state ride for approximately 60 minutes (Allen & Coggan, 2010). The method used for determining FTH consisted of an athlete completing a 30-min time trial at their highest sustainable power pace, 95% of their best 20-min average power achieved was considered the athlete's FTH.

The second laboratory visit consisted of one additional baseline test followed by a FAM ride. Participants first completed the LT test to determine the workload that would elicit the onset of blood lactate accumulation (OBLA). After a 10-min warm-up the workload started at 75 W and increased by 25 W every 4 minutes. Blood samples were collected in the final 30 seconds of each stage and analyzed for blood lactate (Lactate Plus; Nova Biomedical, Waltham, MA). The test was terminated after participants' blood lactate recorded a value above $4 \text{ mmol}\cdot\text{L}^{-1}$ and was $1 \text{ mmol}\cdot\text{L}^{-1}$ higher than the previous stage. Lactate Threshold was defined as the stage just prior to the rise in blood lactate greater than $1 \text{ mmol}\cdot\text{L}^{-1}$ (Weltman, 1995). After a 15-min recovery, the participants then completed a practice trial of the full 90-min cycling course. This allowed participants to practice the electronic gearing system, develop an understanding of the course, and formulate a potential pacing strategy. The $\text{VO}_{2\text{max}}$, LT, FTH, and FAM ride were all performed on the participants' own bikes mounted to a stationary trainer (Cyclus2, RBM elektronik-automation GmbH, Leipzig, Germany).

The final three visits consisted of the experimental CHO supplement trials. Participants reported to the laboratory in the morning after an overnight fast, maintaining a consistent diet

and exercise routine 48 hours prior verified by their dietary food log (Appendix H) and physical activity recall (Appendix F). After submitting their dietary food log and physical activity recall, each participant was prepped with a heart rate monitor (Polar) and a muscle oxygen sensor (MOXY), which was measured continuously throughout the trial. Participants were then asked to void their bladder and upon return began a 15-min warm-up at 50% of W_{\max} . Once the warm-up was complete, participants began the 90-min computerized cycling time trial protocol. Participants were instructed to maintain maximal power and speed for the entire trial and cover as much distance as possible over the 90 minutes. The course included 3 distinct flat (FT) and 3 distinct mountain (MT) stages intended to simulate the variation experienced during a real road race and to create a controlled environment for data analysis. All participants received pacing updates throughout the trial including distance traveled, time elapsed, and time left.

During each of the experimental CHO trials participants received one of three CHO solutions in randomized order: high dose maltodextrin (HDMD), low dose maltodextrin (LDMD), or high dose Vitargo (HDV). The maltodextrin (MD) solutions consisted of a 1:1:1 blend of maltodextrin, fructose, and glucose with electrolytes ($18 \text{ mmol}\cdot\text{L}^{-1} \text{ Na}$, $3 \text{ mmol}\cdot\text{L}^{-1} \text{ K}$, and $11 \text{ mmol}\cdot\text{L}^{-1} \text{ Cl}$). The Vitargo solution contained a sole carbohydrate source (Vitargo®; Swecarb, Sweden) with the same electrolyte blend. The low dose maltodextrin drink was administered at the literature suggested feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$, while the high dose maltodextrin and Vitargo drinks were administered at a rate 1.5x greater, $117 \text{ g}\cdot\text{h}^{-1}$. The drinks were administered in 250 mL aliquots at the start of exercise (minute 0), minute 30, and minute 60. All three experimental drinks were matched for taste (tropical fruit flavor) and color (red). The supplements were pre-mixed by a research assistant on the morning of or the night prior to

testing and stored in a refrigerator until testing began. Participants were allowed to drink water ad libitum each trial during the entire ride. The amount of water consumed during each trial was measured and recorded.

Metabolic measurements (VO_2 , VCO_2 , RER) were collected at the start of exercise (0-10 min) and during each flat stage, FT1 (25-30 min), FT2 (55-60 min), and FT3 (85-90 min) using a COSMED metabolic cart (COSMED USA Inc., Chicago, IL). Stomach fullness was recorded at the end of each flat stage using a scale described in a recent paper exploring exogenous carbohydrate oxidation during ultraendurance exercise (Jeukendrup et al., 2005). Performance variables including power, speed, cadence, pedal force, and distance were collected continuously throughout the ride via the Cyclus2.

Statistical Analysis

Descriptive and summary variable data are presented as means \pm SD. For the comparisons between each experimental CHO for the entire 90-min trial, ANOVA was used to analyze the three treatment trials (JMP, SAS Version 12.0, Cary, NC). Within each 90-min trial, there were two major areas of interest (3 flat stages and 3 mountain stages). For each of the stages, a 3x3 repeated-measure ANOVA mix model (one repeated measure, three mountain or flat stages; one between measure, the three CHO treatments) was used to determine how the repeated workload challenges and each CHO supplement may have affected the performances across these areas of interest. When the ANOVA model identified a significant difference ($p < .05$) across a given fixed variable, orthogonal post hoc comparisons were performed to identify the precise comparison area. To identify the relationship between the within factors, least-squares means were manually computed between the different flat and mountain stages. For the between factors, a Tukey post hoc was used to identify differences between CHO treatments. Gastrointestinal (GI) fullness was measured using a 10-point scale (Appendix G), ranging from 1 (“not full at all”) to 10 (“the fullest I’ve ever been”). Any fullness value of 5 or greater was classified as significant.

RESULTS

A total of ten athletes volunteered to participate in the study. One road cyclist who did not meet the age requirement volunteered as a pilot participant, one mountain bike racer did not meet the minimum VO_{2max} criteria, and two triathletes dropped out after the start of initial baseline testing because of scheduling conflicts. Therefore, a total of six participants completed the full set of baseline tests and met all the requirements of study inclusion criteria.

A VO_{2max} greater than $50 \text{ mLs}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ was required to participate in this study and the participant average was $59.57 \pm 8.47 \text{ mLs}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. There was not a minimum requirement for LT; however, average watts achieved at LT was $241.33 \text{ W} \pm 47.15$. These data indicate our study participants to be considered highly trained according to their baseline testing results (see Table 1).

Table 1

Participant characteristics

Demographics (n=6)	M \pm SD
Age (yr)	25.60 \pm 4.4
Height (m)	1.83 \pm .04
Weight (kg)	77.56 \pm 7.3
Body Fat (%)	14.12 \pm 3.04
VO_{2max} ($\text{mLs}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	59.57 \pm 8.47
VO_{2max} (W)	420.83 \pm 51.03
LT (W)	241.33 \pm 47.15
LT (% of W_{max})	56.96 \pm 5.9

Note. VO_{2max} , maximal oxygen consumption; LT, lactate threshold

The average FTH for the participant's was 279 ± 42 W, which represents the group's overall predicted 60-min power output value. On average, the participants' FTH power represents $66.2\% \pm 3.4\%$ of their W_{\max} achieved during the $VO_{2\max}$ test. As a result, the average FTH power (W) per unit of body weight (kg) was 3.63 ± 0.72 W/kg. Each individual participant's FTH data are presented in Table 2.

Table 2

Functional threshold (FTH) data

Athlete Type	Power (W)	% of W_{\max}	FTH W/kg	Cadence (rpm)
Cat-3 cyclist	201	61.9	2.72	101
Cat-2 cyclist	318	70.7	4.66	89
NCAA triathlete	270	67.5	3.10	93
PRO triathlete	283	62.9	3.53	102
Cat-1 cyclist	295	65.6	3.53	88
Cat-1 cyclist	308	68.4	4.27	100
Mean	279	66.2	3.63	96
SD	42.0	3.4	0.72	6.3

Note. W_{\max} , maximal watts

One of the most unique aspects of this study was the ability to use the Cyclus2 to create a 90-min course designed to replicate true cycling race demands. Prior to data collection, participants created their own athlete profile (height, weight, age) and bike profile (weight, crank length, front chain ring configuration, rear cluster gearing). Together this provided a real-time measurement of transmission (meters / pedal stroke) and the overall distance covered. In contrast to other ergometers that can slip under high wattages, the elastic suspension and non-slip transmission of the Cyclus2 provides a more accurate power reading under extreme conditions (i.e., hill climbs). Figure 1 highlights the variety of challenges participants encountered during

the entire 90-min time trial including small and moderate hill climbs, short down-hill recovery sections, three major mountain stages, and three major flat stages.

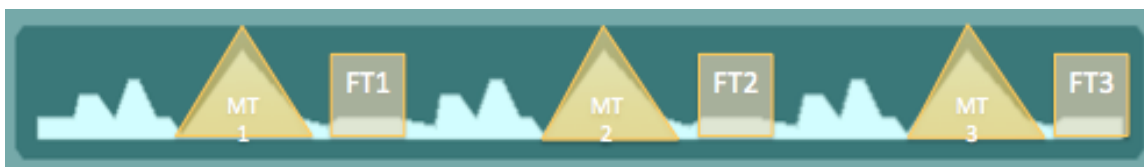


Figure 1. Timeline view of entire 90-min time trial highlighting changes in grade.

It is very important to point out that Figure 1 is not a true visual representation of the cycling challenges of the entire time trial, rather a representation of the change in percent grade over the course of the 90 minutes. For example, each mountain (MT) stage began at 0% grade and continually climbed to a peak of 9% before descending back to 0%; thus each mountain stage was a continuous uphill climb. Using the complete ride data, Figure 2 highlights the actual overall performance for one subject, which includes the actual distance traveled horizontally in kilometers and the vertical net gain in meters. In the sample subject data presented, over the entire 90 minutes, this cyclist covered approximately 44 km (27.3 miles) with an overall net vertical gain of 695 meters (1,765 feet). Thus, highlighting the true challenge of the cycling course.

Average power output during the entire 90-min time trial for high-dose maltodextrin (HDMD), low-dose maltodextrin (LDMD), and high-dose Vitargo (HDV) was 242.7 ± 49.9 W, 242.3 ± 52.2 W, and 239.2 ± 45.0 W, respectively, and was not statistically different between CHO types $F(2,10) = .45, p = .64$. Average speed during the entire 90-min time trial for high-dose maltodextrin, low-dose maltodextrin, and high-dose Vitargo was $29.8 \text{ km}\cdot\text{h}^{-1}$, $29.8 \text{ km}\cdot\text{h}^{-1}$,

and $29.6 \text{ km}\cdot\text{h}^{-1}$, respectively, and was not statistically different between CHO types $F(2,10) = .31, p = .73$. Average distance traveled during the entire 90-min time trial for high-dose maltodextrin, low-dose maltodextrin, and high-dose Vitargo was 44.9 km, 44.9 km, and 44.6 km, respectively, and was not statistically different between CHO types $F(2,10) = .34, p = .72$.

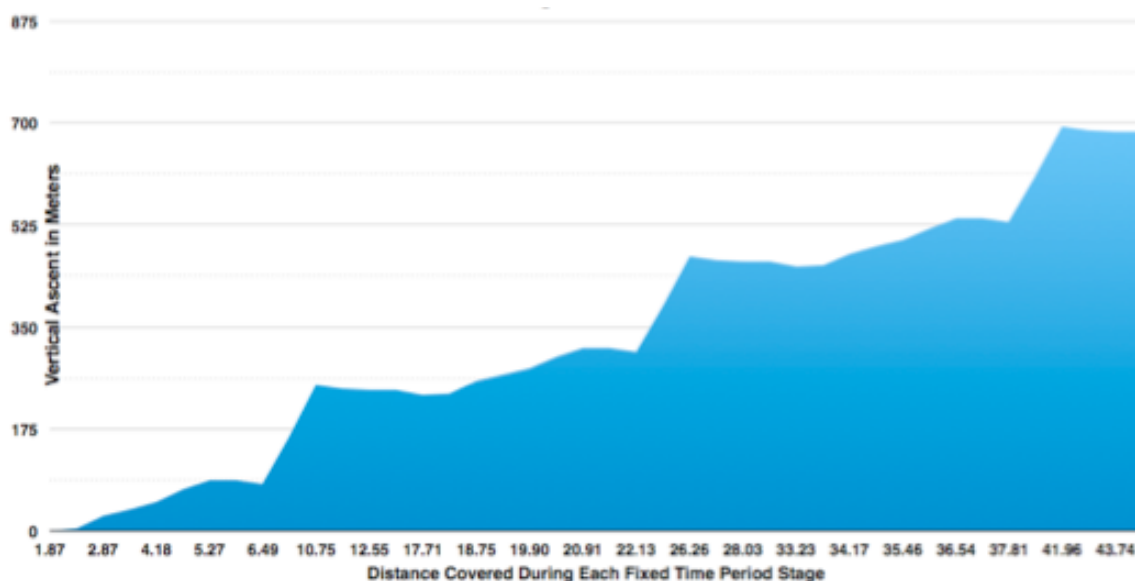


Figure 2. Example distance summary and vertical gain profile for one subject.

Within each 90-min time trial, the two major areas of interest were the three flat stages (25-30 min, 55-60 min, 85-90 min) and the three mountain stages (12-22 min, 42-52 min, 72-82 min). Each flat stage lasted for five minutes at 0% grade. Independent of CHO type, the average power during the final flat stage (FT3) was $293.7 \pm 61.3 \text{ W}$, which was significantly greater than FT1 ($p = .01$) and FT2 ($p = .01$), $272.7 \pm 52.6 \text{ W}$ and $263.7 \pm 58.8 \text{ W}$, respectively. The average power output for FT1 was greater than FT2; however, the difference was not statistically significant. Figure 3 highlights the differences in power between the three flat stages independent of CHO type.

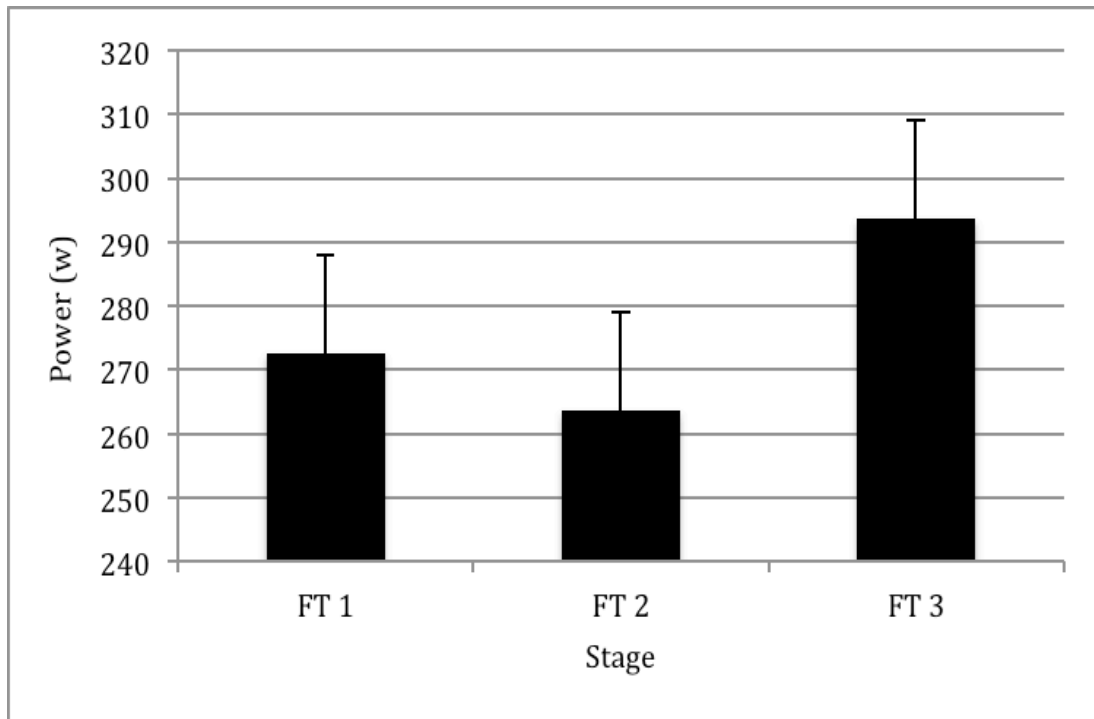


Figure 3. Average power across each flat stage, independent of CHO supplement type, $F(4,26) = 20.25$, $p = .0001$)

Relative to CHO supplement type, there was a tendency for the participants to sustain the greatest power across all three flat stages during the HDMD trial. However, there were no statistically significant differences in power between any of the CHO types across the flat stages $F(2,13) = .05$, $p = .94$. In addition, there was no significant interaction between flat stage and CHO type $F(4,26) = .42$, $p = .79$. Refer to Table 3 for the average power sustained for each CHO type across the three flat stages.

Table 3

Average power across the flat stages for each CHO supplement type

Stage (time)	HDMD	LDMD	HDV
FT1 (25-30 min)	277.0 ± 54.6	269.4 ± 57.6	271.8 ± 57.5
FT2 (55-60 min)	271.8 ± 56.8	262.8 ± 63.8	256.6 ± 68.4
FT3 (85-90 min)	302.2 ± 62.5	286.2 ± 70.3	293.6 ± 63.9

Data shown as mean ± SD

CHO, carbohydrate; FT, flat; HDMD, high-dose maltodextrin; LDMD, low-dose maltodextrin; HDV, high-dose Vitargo

Each mountain stage lasted a total of ten minutes starting with a steady 5-min climb from 0 – 9% grade, immediately followed by an equally steady 5-min decline back to 0% grade.

Independent of CHO type, the average power during the first mountain stage (MT1) was 254.3 ± 53.3 W, which was significantly greater than MT2 ($p = .01$) and MT3 ($p = .01$), 240.6 ± 48.0 W and 234.2 ± 48.0 W, respectively. The average power output during MT2 was greater than MT3; however, the difference was not statistically significant. Figure 4 highlights the differences in power between the mountain stages independent of CHO type.

Relative to CHO supplement type, there was a tendency for the participants to sustain the greatest power across the three mountain stages during the HDMD trial. However, there were no statistically significant differences in power between any of the CHO types across the mountain stages $F(2,13) = .06$, $p = .93$. In addition, there was no significant interaction between mountain stage and CHO type $F(4,26) = 1.13$, $p = .36$. Refer to Table 4 for the average power sustained for each CHO type across the three mountain stages.

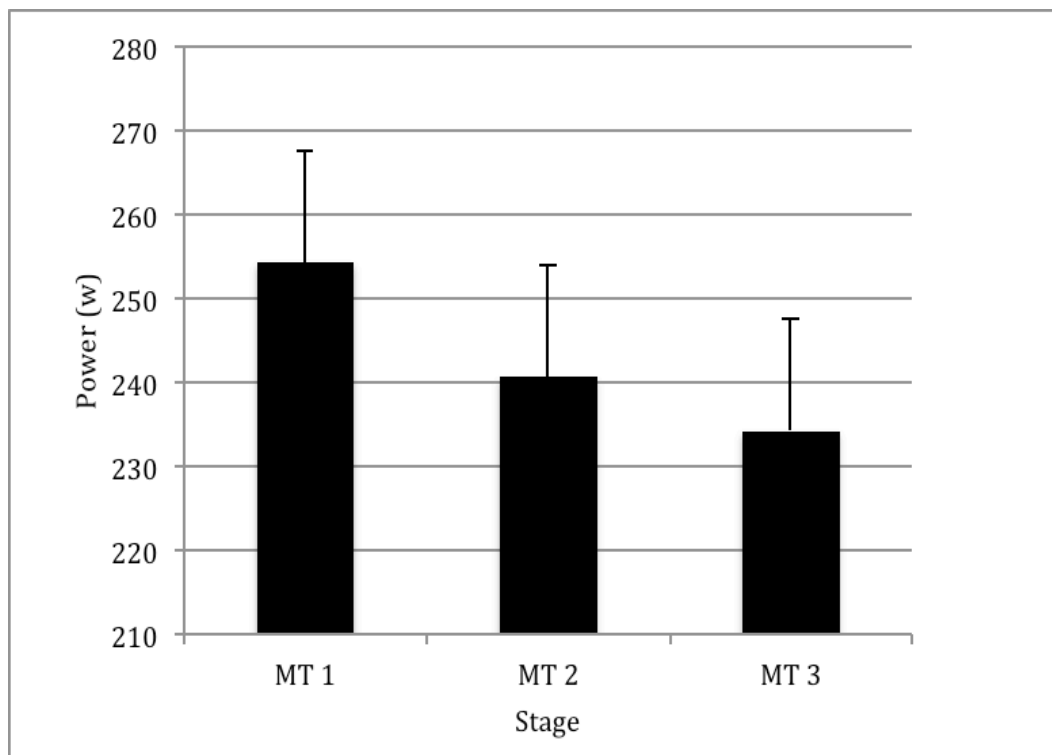


Figure 4. Average power (W) across each mountain stage, independent of CHO supplement type, $F(4,26) = 19.57$, $p = .0001$)

Table 4
Average power across the mountain stages for each CHO supplement type

Stage (time)	HDMD	LDMD	HDV
MT1 (25-30 min)	259.2 ± 55.2	247.7 ± 62.2	256.3 ± 53.7
MT2 (55-60 min)	245.8 ± 50.1	240.2 ± 51.5	235.9 ± 52.7
MT3 (85-90 min)	244.1 ± 51.1	231.0 ± 51.2	227.2 ± 50.4

Data shown as mean ± SD

Note. CHO, carbohydrate; MT, mountain; HDMD, high-dose maltodextrin; LDMD, low-dose maltodextrin; HDV, high-dose Vitargo

Independent of CHO type, VO_2 during the last flat stage (FT3) was 52.4 ± 7.7 mLs· kg^{-1} ·min $^{-1}$, which was significantly higher than the VO_2 during FT1 ($p = .01$) and FT2 ($p = .01$), 50.1 ± 7.0 mLs· kg^{-1} ·min $^{-1}$ and 49.6 ± 7.8 mLs· kg^{-1} ·min $^{-1}$, respectively. However, there were no significant differences in VO_2 between CHO types across the flat stages $F(2,15) = .10$, $p = .90$.

In addition, there was no significant interaction between CHO type and flat stage $F(4,30) = .22$, $p = .92$. Refer to Table 5 for VO_2 differences between the CHO types across the flat stages.

Table 5

VO_2 ($mLs \cdot kg^{-1} \cdot min^{-1}$) comparisons between each CHO supplement type

Stage (time)	HDMD	LDMD	HDV
BL (0-10 min)	48.99 ± 3.92	49.06 ± 4.25	48.19 ± 3.15
FT1 (25-30 min)	50.69 ± 3.04	50.35 ± 3.55	49.56 ± 2.46
FT2 (55-60 min)	50.61 ± 3.51	49.89 ± 3.65	48.44 ± 2.84
FT3 (85-90 min)	53.75 ± 3.41	52.40 ± 3.91	51.00 ± 2.34

Data shown as mean ± SE

VO_2 , oxygen consumption; CHO, carbohydrate; BL, baseline; FT, flat; HDMD, high-dose maltodextrin; LDMD, low-dose maltodextrin; HDV, high-dose Vitargo

Independent of CHO type, there was a significant difference in RER between all three flat stages. The average RER for FT1 was $.92 \pm .06$, which was significantly greater than FT2 ($p = .05$). The average RER for FT2 was $.91 \pm .06$, which was significantly lower than FT3 ($p = .01$). The average RER for FT3 was $.95 \pm .06$, which was significantly greater than FT1 ($p = .01$). However, there were no significant differences in RER between any of the CHO types across the flat stages $F(2,15) = .02$, $p = .97$. In addition, there was no significant interaction between CHO type and flat stage $F(4,30) = .23$, $p = .91$. Refer to Table 6 for differences in RER between the CHO types across the flat stages.

Table 6

RER (VCO_2/VO_2) comparisons between each CHO supplement type

Stage (time)	HDMD	LDMD	HDV
BL (0-10 min)	.94 ± .02	.95 ± .02	.95 ± .02
FT1 (25-30 min)	.93 ± .03	.93 ± .02	.92 ± .03
FT2 (55-60 min)	.92 ± .03	.91 ± .02	.91 ± .03
FT3 (85-90 min)	.95 ± .03	.94 ± .03	.95 ± .02

Data shown as mean ± SE

VCO_2 , carbon dioxide production; VO_2 , oxygen consumption; CHO, carbohydrate; BL, baseline; FT, flat; HDMD, high-dose maltodextrin; LDMD, low-dose maltodextrin; HDV, high-dose Vitargo

Participants were asked to rate their perceived GI fullness at the end of every flat stage (30 min, 60 min, and 90 min). Any reported value of 5 or greater on the 10-point scale was classified as significant. Participants reported more instances of GI fullness under the high dose treatments, 3 trials for HDMD and 4 trials for HDV. The number of complete 90-min time trials with a report of significant GI fullness at anytime during the trial are compared across CHO types in Table 7.

Table 7

Gastrointestinal fullness perception during each CHO supplement type

CHO type	HDMD	LDMD	HDV
Trials with sig fullness (#)	3	0	4

Participants were allowed to drink water ad libitum throughout the entire time trial under each CHO treatment. The amount of water consumed was recorded during each trial and the average for each CHO treatment is presented in Table 8. There were no statistically significant

differences between CHO treatments $F(2) = .025$, $p = .77$; however, there was a tendency for participants to consume the most water during the HDV trial.

Table 8

Water consumed ad libitum during each CHO treatment

CHO type	HDMD	LDMD	HDV
Water intake (mL)	658.3	612.5	760.0

DISCUSSION

The primary goal of this study was to create a real-life cycling experience that closely resembles what athletes encounter when competing on the road and determine if the current literature-suggested feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$ provides the greatest performance advantage when supplementing with a combination of multiple transportable CHO. Previous studies have measured CHO burn rates during cycling exercise using fixed intensities (60-64% $\text{VO}_{2\text{max}}$) for prolonged periods of time with little power variation (50-55% W_{max}) throughout the trial (Jeukendrup et al., 2003; Jentjens, Achten, Jeukendrup, 2004; Jentjens, Moseley, et al., 2004; Jentjens, Venables, & Jeukendrup, 2004; Wallis et al., 2005). Our current study found significant performance and metabolic differences between various stages within each trial at intensities (81-88% $\text{VO}_{2\text{max}}$) and workloads (63-70% W_{max}) higher than previous studies and theoretically closer to real-life competition, thus achieving the goal of creating a more realistic competitive cycling experience for our participants.

In addition to $\text{VO}_{2\text{max}}$ and LT, FTH is a strong predictor of an athlete's endurance performance ability. In terms of competitive road racing, an athlete's FTH relative to one's total body weight can be a strong indicator of an individual's ability to sustain power when facing challenging sections of a race course (i.e., hill climbs). Because of the participant differences in FTH per unit of body weight (W/kg), certain participants were better equipped for the mountain stages and conversely others were better equipped for the flat stages, thus leading to potential differences in overall race strategies. Participants with higher FTH values relative to their body weight (W/kg) may have been able to sustain power better during the mountain stages, whereas

participants with lower FTH values relative to their body weight (W/kg) may have been able to produce more power during the flat stages.

Based on the performance data collected over the various flat and mountain stages, there was a clear decline in power over the course of the entire 90-min time trial with evidence of a strong final effort during the final 5 minutes (FT3), as would be expected in a real time-trial race. The participants produced significantly higher power during the final flat stage compared to the first two flat stages (+7.2% and +10.2%), thus highlighting the overall group strategy to finish strong. In addition to significantly higher power during FT3, data also reveal significantly higher VO_2 ($p = .01$) and RER ($p = .01$) values compared to FT1 and FT2. These higher metabolic values are expected to align with higher work rates. Interestingly, despite an average VO_2 significantly higher during FT3, RER failed to reach baseline (0-10 min) values during which VO_2 was significantly lower (-9%), thus providing a strong indication of a reduction in CHO availability and utilization during the later stages of the time trial.

In contrast to the flat stages, an extreme climbing force was required for each mountain stage, which participants failed to maintain over the course of the time trial. The significant decline in power (-5.4%) from MT1 to MT2 and even greater decline (-7.9%) from MT1 to MT3 shows the decreased ability to produce power during each subsequent mountain stage, identifying clear neuromuscular fatigue and a probable reduction in fuel availability. However, because of the extreme physical demands of the mountain stages, metabolic measurements were not collected. Thus, the confirming VO_2 and RER data are not available.

Although we did not find any significant differences between CHO types on any of the cycling performance or metabolic variables, there was a tendency for the high-dose maltodextrin

(HDMD) CHO solution to provide the greatest performance and metabolic advantage for our participants. While supplementing the high-dose maltodextrin solution, participants were able to maintain a non-significant ($p = .64$) higher average power (242.7 W) during the entire 90-min trial and experienced the smallest decline in power (-5.8%) from MT1 to MT3 (see Table 4). In addition to better power during the mountain stages, while supplementing the HDMD solution, participants experienced the largest improvement in power (8.3%) from FT1 to FT3 (see Table 3). Thus, we would expect to see higher VO_2 and RER values under conditions of greater work; while supplementing the high-dose maltodextrin solution, participants were able to maintain a non-significant ($p = .92$) higher VO_2 and a non-significant ($p = .91$) higher RER value compared to the other CHO drinks across all three flats stages. Altogether, the higher power and RER recorded during the HDMD trials may suggest that at higher exercise intensities and work rates there may be greater energy demand, primarily being fueled through CHO oxidation, and that supplementing with multiple transportable CHO at a rate of $117 \text{ g}\cdot\text{h}^{-1}$ may provide more adequate fueling than the literature suggestion of $78 \text{ g}\cdot\text{h}^{-1}$.

The secondary goal of this study was to determine if a unique high molecular weight single-source starch fraction (Vitargo®; Swecarb, Sweden) provides a greater performance and metabolic advantage than a combination of multiple transportable CHO. Based on previous research highlighting quicker gastric emptying (Leiper et al., 2000) and faster glycogen refueling (Aulin et al., 2000), we expected this single-source CHO to provide a performance advantage greater than or equal to that of the maltodextrin-based solutions by delivering CHO to the working muscle faster. As previously mentioned, we found no significant differences between CHO types on any of the cycling performance variables, so it could be concluded that the high-

dose Vitargo solution provided an equal performance advantage to the both maltodextrin groups. However, in practical terms, the high-dose Vitargo solution had a tendency to provide the least performance advantage compared to the maltodextrin groups. For our participants, while supplementing with HDV, participants averaged the lowest power output (239.2 W) over the entire 90-min trial and experienced the greatest decline in power from MT1 to MT3 (-11.3%). In addition, participants also recorded non-significant lower VO_2 (see Table 3) and RER (see Table 4) values across the flat stages during this CHO treatment.

In addition to lower power, VO_2 , and RER values, participants also reported more frequent significant GI fullness while supplementing the high-dose Vitargo solution (see Table 7). Interestingly, under the same treatment condition, participants also had a tendency to drink more water (see Table 8). The GI fullness and bloating may have impacted performance and the ability to maintain pedal force and cadence in the latter stages of the trial, thus explaining the greatest decline in power between the first and last mountain stages. GI distress is more commonly reported in CHO supplements that contain a single type of CHO compared to those that contain multiple types of CHO (Jentjens, Achten, & Jeukendrup, 2004; Wallis et al., 2005). Wallis et al. (2005) found that participants ingesting a single CHO in the form of maltodextrin reported four times as many instances of GI distress compared to a combination of maltodextrin and fructose during 150 minutes of cycling at 64% $\text{VO}_{2\text{max}}$. Furthermore, Jentjens, Achten, and Jeukendrup (2004) found that during 150 minutes of cycling at 62% $\text{VO}_{2\text{max}}$ participants who ingested a single CHO in the form of glucose reported more severe GI discomfort than participants ingesting an isocaloric amount of glucose + sucrose + fructose. In this particular study, two participants were unable to completely finish the last glucose drink as they felt it

would make them sick and another participant vomited after 120 minutes of exercise (Jentjens, Achten, & Jeukendrup, 2004).

We hypothesized that previous reports of quicker gastric emptying (Leiper et al., 2000) would lead to fewer reports of GI fullness in the Vitargo® treatments. However, we found participants reported the most significant GI fullness under the HDV supplementation treatment. Unique to all previous research on Vitargo®, this is the first study ever to include the addition of electrolytes to this unique high molecular weight starch fraction. The addition of the electrolyte blend (18 mmol·L⁻¹ Na, 3 mmol·L⁻¹ K, and 11 mmol·L⁻¹ Cl) to the Vitargo® solution in this study may have impacted the amount of water pulled into the gut, thus changing the osmolality and ultimately slowing the absorption rate compared to the previous Vitargo® solutions that did not contain electrolytes. Although it could have been simply a dosing issue, changing the electrolyte composition may potentially have an impact on the rate at which this traditionally faster, low-osmolality CHO leaves the stomach. Being able to deliver the additional CHO needed to support potentially higher oxidation rates at higher exercise intensities without experiencing GI fullness could create a superior format for fueling during competitive endurance activities that require large amounts of supplemental CHO to keep up with high burn rates. Further research needs to be done looking into the potential endurance drink benefits of this unique high molecular weight starch fraction using different electrolyte compositions and feeding rates.

The limited number of participants (6) in this study made it difficult to find significant differences between CHO types in cycling performance measures and metabolic variables. A larger sample size, with similar trends, may have provided the statistical power needed to separate the high-dose maltodextrin-based CHO solution as superior. If so, this would have been

a very interesting finding in relation to CHO feeding rates during endurance exercise. The literature-suggested feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$ may not apply to exercise intensities above 65% $\text{VO}_{2\text{max}}$ because of the greater reliance on CHO as a fuel source at higher workloads. Further research needs to be conducted using similar realistic cycling protocols to determine if the literature-suggested CHO feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$ applies to various exercise modalities at higher relative intensities and work rates.

CONCLUSION

Under the current cycling protocol and CHO supplementation conditions, there does not appear to be a performance or metabolic advantage to supplementing multiple transportable CHO at $78 \text{ g}\cdot\text{h}^{-1}$ compared to the same multiple transportable CHO blend at a feeding rate of $117 \text{ g}\cdot\text{h}^{-1}$. Additionally, there does not appear to be a disadvantage to supplementing with a single-source high molecular weight starch fraction (Vitargo®) instead of the literature-suggested CHO solution with multiple transportable CHO sources. Future research should focus on the differences in oxidation rates at varying workout intensities between different CHO sources and continue to explore ways to create real-life road cycling protocols while maintaining a controlled laboratory environment for data collection.

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APPENDIX A
RECRUITING FLYER

Subject's Needed

For Cycling Study

www.enllc.us • en.llc@me.com • 630-303-3686



Study Description

Exercising Nutritionally, LLC, a medical research company, is studying the effects of a new form of carbohydrate supplementation on cycling performance in highly trained cyclists or triathletes. The CHO supplement used in this study has been reported in previous research to improve muscle glycogen storage by 68% while improving gastric emptying 2.3 times faster.

This study will allow each cyclist to see directly how well oxygen is delivered to working muscle, how much blood is ejected from the heart per beat, hormonal & substrate responses, and a detailed cycling analysis showing muscle type activation patterns during cycling.

Pre Evaluation Subject Requirements

- ▶ Males between 18-35 yrs old
- ▶ Minimum 3 yrs competitive cycling or triathlon race experience
- ▶ Be able to dedicate, 3-4 hrs per week for 4 weeks

When: Now through October 30

Where: EN, LLC @ Central Park Business Complex, 4225 Naperville Road, Lisle, IL

Results: Each volunteer will receive a true VO2 max test, advanced body comp, lactate threshold and functional threshold including direct muscle oxygenation measures and cardio output measure, & a post study results report.

Contact: www.enllc.us • en.llc@me.com • 630-303-3686

APPENDIX B
INFORMED CONSENT FORM

Informed Consent Form

I agree to participate in the research project titled, “Carbohydrate Supplementation during Prolonged Cycling Exercise”, being conducted by Bill Julian, under the direction of Dr. Amanda Salacinski and Craig Broeder, of Northern Illinois University. I have been informed that the purpose of the study is to determine if a high molecular weight carbohydrate sports drink provides an advantage over a maltodextrin based sports drink during a simulated cycling road race. This study is not a formal medical health screening and it is not intended to diagnose, or treat, any type of medical condition.

I understand that if I agree to participate in this study, I will be asked to attend five sessions, and to do the following: Complete a body composition analysis using an InBody 520 bioelectrical impedance analysis scale (not to be performed on individuals with implanted electrical devices such as pacemakers). Complete a maximal oxygen consumption ($VO_{2\max}$) test followed by a functional threshold (FTH) test to further validate my fitness level. Attend a familiarization session to become familiar with the testing protocol and equipment. Participate in one standard testing protocol outlined below, on three separate occasions, which will be separated by one week. During the three occasions I will be asked to perform the cycling protocol while supplementing one of three carbohydrate drinks. Before each carbohydrate supplement trial I will be required to turn in a dietary food log and complete a physical activity recall to ensure consistent diet and exercise regimen before each trial. The order of the protocols CON, SGL, and MLT will be randomly chosen.

Total time of participation: 4-5 weeks

Number of protocols for data collection: 1 (Performed on three separate occasions separated by 1 week)

Baseline Session: Body Composition, $VO_{2\max}$, Functional Threshold: 2 hours

Familiarization Session: 120 minute simulated cycling road race while supplementing water: 3 hours

Testing protocol: 120 minute simulated cycling road race while supplementing one of three experimental carbohydrate solutions

Time for each testing protocol session: 3 hours

Baseline session (Exercising Nutritionally)	Time Allotment
--	-----------------------

Complete Informed Consent Form and Medical Health History Questionnaire	
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Complete Physical Activity Readiness Questionnaire (PAR-Q)	
--	--

Complete Body Composition Assessment (InBody 520)	
---	--

Complete $VO_{2\max}$ and Functional Threshold (cycling protocol)	2 Hours
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Familiarization Session (Exercising Nutritionally)	Time Allotment
---	-----------------------

Turn in dietary recall log	
----------------------------	--

Completion of 7 day recall of physical activity
 Perform the cycling protocol while supplementing water 3 Hours

Testing Session 1 (Exercising Nutritionally) **Time Allotment**

Turn in dietary recall log
 Completion of 7 day recall of physical activity
 Perform protocol under first set of randomized conditions 3 Hours

Testing Session 2 (Exercising Nutritionally) **Time Allotment**

Turn in dietary recall log
 Completion of 7 day recall of physical activity
 Perform protocol under second set of randomized conditions 3 Hours

Testing Session 3 (Exercising Nutritionally) **Time Allotment**

Turn in dietary recall log
 Completion of 7 day recall of physical activity
 Perform protocol under third set of randomized conditions 3 Hours

I understand that I have been requested to refrain from consuming any supplements or stimulants within 2 hours of testing, including but not limited to caffeine, ephedrine, synephrine, and yohimbe.

I have been informed that potential discomforts and risks I could experience during this study include those associated with intense cycling exercise including moderate to severe muscular fatigue. An indwelling catheter will be inserted 20 minutes before the testing protocol sessions and will be removed immediately after test completion for a total of 3 catheter placements. I may experience mild discomfort when the indwelling catheter is inserted but I understand this is much more tolerable compared to repeated lancet finger pricks. The possible risks associated with blood collection include infection and contamination. To reduce this risk, the catheters will be inserted by Dr. Craig Broeder, who has over 24 years experience in exercise physiology and exercise testing. I may also experience gastrointestinal (GI) discomfort from the carbohydrate drinks. This is often a common variable of interest in carbohydrate supplement studies and a mild degree of GI distress may be experienced.

I verify that I am between 18-35 years old with no known food allergies.

I understand that all information gathered during this experiment will be kept confidential by being assigned a code number that will be the only identifying information on the recording form and will be kept in a locked file cabinet in the sole possession of the researcher. A master list of code numbers, cellular telephone numbers, and names will be kept separate from all other data collected and will be stored in a locked cabinet and a password protected laptop only accessible to the researchers. I also understand that once the data analysis has been completed the master

list will be destroyed. The data obtained from me may be used in classroom settings and for professional development, but will have no way of revealing my identity.

I realize that Northern Illinois policy does not provide for compensation for, nor does the University carry insurance to cover injury or illness incurred as a result of participation in University sponsored research projects. I also have the right to stop at any time during the testing without penalty.

I understand that my consent to participate in this project does not constitute a waiver of any legal rights or redress I might have as a result of my participation, and I acknowledge that I have received a copy of this consent form.

Print Name

Signature

Date

Witness Print Name

Witness Signature

Date

APPENDIX C

MEDICAL HEALTH HISTORY QUESTIONNAIRE

Name: _____

Medical History Questionnaire

Please answer the following questions to the best of your knowledge by checking yes, no, or unknown.
This questionnaire is completely confidential.

Assess your health by marking each question either Yes, No, or Unknown

PART 1: KNOWN DISEASES

Do you currently have:

- Cardiovascular disease, peripheral vascular disease, and/or cerebrovascular disease?
- Asthma?
- Interstitial lung disease?
- Cystic fibrosis?
- Chronic Obstructive Pulmonary Disease (COPD)?
- Diabetes (Type 1 or 2)?
- Any thyroid disorder?
- Renal or liver disease?

PART II: SIGNS AND SYMPTOMS

- Do you experience pain and/or discomfort in the chest, neck, jaw, arms, or other areas during mild exercise?
- Do you feel short of breath at rest, with typical daily activities, or with mild exercise?
- Do you feel short of breath while lying down flat?
- Are you awoken in the middle of the night due to feeling short of breath and/or severe coughing/wheezing?
- Do you often feel dizzy at rest or with mild exercise?
- Have you experienced ankle edema (swollen ankles)?
- Do you suffer from muscle cramping, burning, numbness, or fatigue in your calf muscles at rest or with mild exercise?
- Do you have a known heart murmur?
- Do you have unusual fatigue with typical, daily activities?
- Have you ever experienced heart palpitations or tachycardia?
- Have you ever experienced fainting during exercise?

PART III: CORONARY ARTERY DISEASE RISK FACTORS

- Do you have a close blood relative who has had a heart attack or heart surgery before the age of 55 (Dad, Brother) or age 65 (sister, mother)?
- Do you smoke, or did you just quit smoking within the past 6 months?

___ For the last 3 months, do you get less than 30 minutes of moderate-intense exercise, less than 3 days per week?

___ Are you at least 20lbs overweight?

___ Is your blood pressure over 140/90 mmHG, or are you on blood pressure medication?

___ Is your blood cholesterol greater than or equal to 200 mg/dl, or are you on cholesterol medication?

___ Is your fasting glucose greater than or equal to 100 mg/dl?

___ Are you over the age of 45?

PART IV: Specific to Protocol

___ Do you have musculoskeletal problems that limit what/how you exercise?

___ Do you have any known pathological concerns of the knee, hip, or ankle joint?

___ Do you have any known food allergies?

___ Have you ever experienced intense stomach pains with the consumption of water during exercise?

___ Have you ever experienced intense stomach pains with the ingestion of carbohydrates or sports drinks during exercise?

___ Have you ever developed a strong urge to urinate with the consumption of fluids during exercise?

___ Have you ever experienced myoglobinuria (very very dark urine typically following heavy exertion)?

APPENDIX D

PAR-Q PHYSICAL ACTIVITY QUESTIONNAIRE

Physical Activity Readiness Questionnaire (British Columbia Ministry of Health, 1978)

Physical Activity Readiness Questionnaire (PAR-Q)*

NAME OF PARTICIPANT _____
DATE _____

PAR Q & YOU

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read them carefully and check (✓) the YES or NO opposite the question if it applies to you.

YES NO

1 Has your doctor ever said you have heart trouble?

2 Do you frequently have pains in your heart and chest?

3 Do you often feel faint or have spells of severe dizziness?

4 Has a doctor ever said your blood pressure was too high?

5 Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?

6 Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?

7 Are you over the age of 65 and not accustomed to vigorous exercise?

If You Answered

YES to one or more questions

If you have not recently done so, consult with your personal physician by telephone or in person BEFORE increasing your physical activity and/or taking a fitness appraisal. Tell your physician what questions you answered YES to on PAR-Q or present your PAR-Q copy.

programs

After medical evaluation, seek advice from your physician as to your suitability for:

- unrestricted physical activity starting off easily and progressing gradually.
- restricted or supervised activity to meet your specific needs, at least on an initial basis.

Check in your community for special programs or services.

NO to all questions

If you answered PAR-Q accurately, you have reasonable assurance of your present suitability for:

- A GRADUATED EXERCISE PROGRAM – a gradual increase in proper exercise promotes good fitness development while minimizing or eliminating discomfort.
- A FITNESS APPRAISAL – the Canadian Standardized Test of Fitness (CSTF)

postpone

If you have a temporary minor illness, such as a common cold.

• Developed by the British Columbia Ministry of Health. Conceptualized and critiqued by the Multidisciplinary Advisory Board on Exercise (MABE).
Reference PAR-Q Validation Report, British Columbia Ministry of Health, May, 1978.
• Produced by the British Columbia Ministry of Health and the Department of National Health & Welfare.

APPENDIX E
DATA COLLECTION SHEET

DATA SUMMARY SHEET

PARTICIPANT _____ LT: _____

VO2 MAX: _____ FTH: _____

FAM TRIAL 1 TRIAL 2 TRIAL 3

Measure Time	VO2	VCO2	RER	EE	% Fat	% CHO	RPE	GI Distress	Glucose	Lactate	Insulin
0-5											
5-10											
25-30											
55-60											
85-90											
115-120											

Measure Time	Q	SV	HR	SVR	SBP	DBP	MAP
0-10							
25-30							
55-60							
85-90							
115-120							

APPENDIX F

SEVEN-DAY PHYSICAL ACTIVITY RECALL

Seven Day Recall of Physical Activity adopted from Sallis, Haskell, Wood, Fortmann, Rogers, Blair, & Paffenbarger, 1985.

Physical Activity Recall Items

Now we would like to know about your physical activity during the past 7 days. But first, let me ask you about your sleep habits.

1. One the average, how many hours did you sleep each night during the last five weekday nights (Sunday-Thursday)? _____ hours
2. One the average, how many hours did you sleep each night last Friday and Saturday nights? _____ Hours

Now I am going to ask you about your physical activity during the past 7 days, that is, the last 5 weekdays, and last weekend, Saturday and Sunday. We are not going to talk about light activities such as slow walking, light homework, or un strenuous sports such as bowling, archery, or softball. Please look at the list below which shows some examples of what we consider moderate, hard, and very hard activities:

Moderate Activity

Occupational tasks: 1) delivering the mail or walking on patrol; 2) house painting; and 3) truck driving (making deliveries, lifting and carrying heavy objects).

Household activities: 1) raking the lawn; 2) sweeping and mopping; 3) mowing the lawn with a power mower; and 4) cleaning the windows.

Sports activities (actual playing time): 1) volleyball; 2) Ping-Pong; 3) brisk walking for pleasure or to work (3 m/h) or 20 minutes of walking; 4) golf that involves carrying clubs; and 5) calisthenic exercises.

Hard Activity

Occupational tasks: 1) heavy carpentry; and 2) construction work, doing physical labor

Household activities: 1) scrubbing floors

Sports activities (actual playing time): 1) tennis doubles; and 2) disco, square, or fold dancing

Very Hard Activity

Occupational tasks: 1) very hard physical labor, digging or chopping with heavy tools; 2) carrying heavy loads such as bricks or lumber.

Sports activities (actual playing time): 1) jogging or swimming; 2) singles tennis; 3) racquetball; and 4) soccer.

3. First, let's consider moderate activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these moderate activities or other like them? Please tell me to the nearest half hour. _____ Hours

4. Last Saturday and Sunday, how many hours did you spend on moderate activities and what did you do? Hours

5. Now let's look at hard activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these hard activities or other like them? Please tell me to the nearest half hour. _____ Hours

6. Last Saturday and Sunday, how many hours did you spend on hard activities and what did you do? _____Hours

7. Now let's look at very hard activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these very hard activities or other like them? Please tell me to the nearest half hour. _____Hours

8. Last Saturday and Sunday, how many hours did you spend on very hard activities and what did you do? _____Hours

9. Compared with your physical activity over the past 3 months, was last week's physical activity more, less, or about the same?

Please circle: More Less About the same

APPENDIX G

GASTROINTESTINAL FULLNESS SCALE

Rating - Description

0 – NOT FULL AT ALL

1

2 – SOMEWHAT FULL

3

4 – FULL

5

6 – VERY FULL

7

8 – EXTREMELY FULL

9

10 – MAXIMAL FULLNESS

APPENDIX H

DIETARY FOOD LOG



**American
Heart
Association®**
Learn and Live

Date: _____

Food Diary

Time / Meal	Food / Beverage (type and amount)	Calories	Notes
Breakfast			
Snack			
Lunch			
Snack			
Dinner			
Snack			
TOTAL Calories: _____			

APPENDIX I
REVIEW OF LITERATURE

REVIEW OF LITERATURE

The diets of athletes and physically active individuals can have a large impact on exercise performance. Carbohydrates (CHO) contribute most of the energy released to support exercise, and the relative contribution of CHO increases as relative workload increases (Brooks, Fahey, & Baldwin, 2005). The body stores CHO in the form of glycogen, which is found mainly in the liver and skeletal muscle. Muscle glycogen is a readily available energy source and the rate at which glycogen is used is highly dependent on exercise intensity (Jeukendrup & Gleeson, 2004). At low exercise intensities, fat can contribute much of the energy demand from oxidative phosphorylation of acetyl-CoA. As exercise intensity increases, the oxidation of CHO and muscle glycogen increases significantly. Glycogen that is broken down in the muscle serves as an immediate fuel source. The glucose is not released into the systemic circulation because muscle lacks the enzyme (glucose-6-phosphatase) that removes a phosphate group from glucose-6-phosphate (Jeukendrup & Gleeson, 2004). The glucose-6-phosphate will continue to be broken down further for energy. Therefore, the breakdown of glycogen (glycogenolysis) in the muscle serves as immediate muscle fuel.

The role of liver glycogen is slightly different from muscle glycogen. The liver is responsible for the maintenance and regulation of blood glucose. Glycogen broken down in the liver is released into the systemic blood circulation to help maintain a constant level of blood glucose (euglycemia) (Jeukendrup & Gleeson, 2004). Thus, the liver plays an important role in preventing excessive drops in blood glucose (hypoglycemia) during exercise. In addition to releasing glucose from glycogen breakdown, the liver is also capable of producing glucose from

other substrates through a process called gluconeogenesis (Brooks et al., 2005). Lactate, glycerol, pyruvate, alanine, glutamine, and other amino acids can be used to synthesize glucose in the liver under conditions of low CHO availability (Brooks et al., 2005). This may happen late in exercise when CHO stores start to deplete and an alternative fuel source is required to maintain physical performance.

The effectiveness of carbohydrate supplements in enhancing performance during extended bouts of aerobic exercise is well documented. There is a convincing amount of evidence that suggests carbohydrate feeding during prolonged exercise can improve endurance capacity and delay fatigue. Most of the effect of CHO feedings on performance has been ascribed to maintenance of euglycemia and high rates of CHO oxidation in contracting skeletal muscle late in exercise when endogenous CHO stores are low (Coggan & Coyle, 1991). Hypoglycemia has been suggested as a mechanism of fatigue during prolonged exercise events, and CHO feedings during prolonged endurance exercise improve performance by maintaining blood glucose (Fahey et al., 1991). Coyle, Coggan, Hemmert, and Ivy (1986) mention that highly trained endurance athletes are capable of oxidizing CHO at relatively high rates from sources other than muscle glycogen during the latter stages of prolonged strenuous exercise and that this postpones fatigue. In addition to maintenance of blood glucose, CHO administration during exercise also results in a proportional slowing of muscle glycogen depletion (Coyle et al., 1983).

In 1987 Coggan and Coyle compared the effects of glucose polymer ingestion and intravenous glucose infusion during an extended bout of cycling in seven trained cyclists. The participants exercised at 70% maximal oxygen uptake (VO_{2max}) until fatigue during an initial bout of exercise. After the completion of the initial bout of exercise participants received either

intravenous infusion of a 20% dextrose solution, carbohydrate ingestion of a 50% solution (85% glucose polymers-15% sucrose), or an artificially flavored placebo drink. Twenty minutes following the first bout the participants attempted to perform additional exercise at the same intensity until they again fatigued. Both glucose ingestion and glucose infusion increased plasma glucose and respiratory exchange ratio (RER) beyond that of the placebo. Exercise time to fatigue during the second bout of exercise was significantly greater in the glucose infusion trial compared to the glucose ingestion trial, 43 min and 26 min, respectively. Additionally, time to fatigue was significantly greater in the glucose ingestion trial compared to placebo, 26 min and 10 min, respectively (Coggan & Coyle, 1987). The authors concluded that fatigue appears to be due primarily from an inadequate supply of carbohydrate to the exercising musculature, which can be reversed by increasing plasma glucose. Although it seems impractical to intravenously infuse glucose during competition, a carbohydrate solution that provides adequate maintenance of blood glucose can also be effective.

A variety of CHO supplements are commercially available and may be as simple as a single type of CHO or be composed of advanced formulations with multiple types of CHO in a unique and specific formula. Popular CHO components in sports drinks include simple sugars such as glucose, fructose, sucrose, and dextrose; complex starches or glucose polymers such as maltodextrin or amylopectin; and some even include substrates such as lactate and pyruvate. The practice of consuming sports drinks during exercise has become a habit during many sports and now CHO drinks are deeply embedded in the culture of endurance sports (Jeukendrup, 2004). A number of studies have addressed the effectiveness of different CHO in sports drinks and which of them provides the most benefit during prolonged exercise (Currell & Jeukendrup, 2008; Fahey

et al., 1991; Jentjens, Achten, & Jeukendrup, 2004; Rowlands, Wallis, Shaw, Jentjens, & Jeukendrup, 2005; Wallis, Rowlands, Shaw, Jentjens, & Jeukendrup, 2005). The purpose of this review is to help identify the ideal components of CHO supplement drinks and their impact on performance during prolonged aerobic exercise.

The effectiveness of different forms of supplemental CHO is often assessed by the rate at which the carbohydrate is oxidized. Oxidation rate is a measurement of the amount of ingested CHO that is utilized for fuel by contracting muscle. The greater contribution of exogenous (external) fuel sources spares endogenous (internal) sources such as muscle and liver glycogen and it is believed that greater contribution of exogenous fuel sources may increase endurance capacity (Jeukendrup & Gleeson, 2004). The contribution of exogenous substrate can be measured using stable or radioactive isotopic tracers. The technique requires ingested CHO to be labeled, which then can be measured in expired gas after the CHO has been oxidized (Jeukendrup & Gleeson, 2004). The more the ingested CHO has been oxidized, the more of the label (tracer) will be recovered in the expired air (Jeukendrup & Gleeson, 2004). Knowing the amount of tracer ingested, the amount of tracer in the expired gas, and the total CO₂ production enables researchers to calculate exogenous glucose oxidation.

Exogenous CHO oxidation is often limited to less than what is consumed by an endurance athlete during exercise. The possible sites of physiological limitation include muscle uptake and oxidation, release of glucose from liver, uptake of glucose from the duodenum in the intestine, enzymatic hydrolysis of di- and polysaccharides, and gastric emptying (Rowlands et al., 2005). Different authors will argue which one of these events most likely restricts exogenous CHO oxidation depending on the type of carbohydrate. According to Rowlands et al. (2005),

glucose oxidation during moderate intensity cycling is limited to 1.0-1.1 g/min, probably by events in the duodenum or liver. It has been suggested that ingestion of multiple carbohydrates combined in a single drink may enhance intestinal absorption and lead to higher exogenous CHO oxidation compared to ingestion of an isocaloric amount of a single CHO (Wallis et al., 2005). As a result, using a CHO supplement with only one type of CHO may be taxing to any single delivery system. Azevedo, Tietz, Two-Feathers, Paull, and Chapman (2007) suggest that the ideal sports drink contains several different energy substrates because the absorption of any single substrate is limited by competition for its unique intestinal transporter site. Including several substrates in a sports drink might accelerate the rate of energy absorption due to the utilization of various independent transport systems and is therefore the best way to provide energy during prolonged exercise.

Higher oxidation rates for combined carbohydrates have been seen in a number of recent studies. Jentjens et al. (2004) found that using a mixture of glucose + sucrose + fructose compared to an equal amount of glucose during cycling for 150 minutes at 62% VO_{2max} resulted in higher peak exogenous oxidation rates, $1.70 \text{ g}\cdot\text{min}^{-1}$ and $1.18 \text{ g}\cdot\text{min}^{-1}$, respectively. Similar results were found when a combination of maltodextrin and fructose was compared to an equal amount of maltodextrin. A study completed by Wallis et al. (2005) reported that during 150 minutes of cycling at 64% VO_{2max} , participants who ingested a combination of maltodextrin and fructose had exogenous CHO oxidation rates 40% higher than ingestion of an isoenergetic amount of maltodextrin. The authors concluded that mean peak oxidation rates were higher when participants consumed large amounts of maltodextrin and fructose compared to maltodextrin alone, $1.5 \text{ g}\cdot\text{min}^{-1}$ and $1.06 \text{ g}\cdot\text{min}^{-1}$, respectively (Wallis et al., 2005).

It has been suggested that higher exogenous CHO oxidation rates may lead to increased performance (Currell & Jeukendrup, 2008). Since multiple transportable CHO have been shown to have higher exogenous oxidation rates compared to single CHO drinks; then the assumption that these drinks would also increase endurance performance led to further investigation. A study completed by Currell and Jeukendrup (2008) investigated the effects of ingesting a glucose and fructose beverage compared with a glucose beverage on endurance cycling performance. Participants were required to cycle at 55% maximal watts (W_{\max}) for two hours while ingesting CHO every 15 minutes. Immediately upon completion participants were asked to complete an amount of work equal to about 60 minutes of cycling at 75% W_{\max} as fast as possible. The ingestion of the combination of glucose and fructose resulted in 8% quicker time to completion during the time trial compared with a CHO beverage containing glucose alone, 3641 seconds and 4022 seconds, respectively. In addition, mean power output during the time trial was significantly higher during consumption of the multiple CHO drink, 254 ± 8 W for glucose and 275 ± 10 W for glucose and fructose.

GI distress is often a main variable of interest in CHO supplementation studies, especially when large amounts of fuel are supplemented. The underlying mechanisms of GI problems have been proposed to result from many factors, including decreased splanchnic blood flow and oxygen delivery, dehydration, electrolyte changes, changes in blood viscosity, hormonal changes, gastric emptying, gut transit time, absorption in the gut, dietary intake, CHO malabsorption, and mechanical stress due to vertical movement of the internal organs associated with running (Peters et al., 1993). Although the exact mechanisms of GI distress may not be fully understood, severe GI distress is often reported as nausea, bloated feeling, urge to vomit, and

vomiting (Jentjens et al., 2004). More recent investigations have insisted GI distress and stomach-related problems may be caused by gradual increase in gastric volume over an exercise period where consistent CHO feedings are given throughout the trial. An increase in stomach volume occurs when the rate of intake (CHO and fluid) exceeds the rate of gastric emptying (Jentjens et al., 2004). The rate of gastric emptying is regulated by a number of factors including nutrient state (liquid or solid), volume, concentration, and osmolality (Jentjens et al., 2004). The type of CHO ingested may also affect gastric emptying and CHO absorption. It has been suggested that glucose polymer solutions may enhance the rate of gastric emptying over simple sugars (Mitchell et al., 1988).

In 2006 Lang, Gisolfi, and Lambert reported that CHO absorption either decreases or does not change with exercise. The discrepancy in these results could be attributed to experimental conditions, the type of CHO used, exercise intensity and mode, and the method used to measure CHO absorption. Leiper, Prentice, Wrightson, and Maughan (2001) measured the gastric emptying of a 500 mL CHO-electrolyte drink (Gatorade) during a soccer match and compared it to walking at a much lower intensity. They reported that during the first 15 minutes of exercise, the amount of fluid emptied from the stomach was significantly lower in the soccer trial compared to the walking trial. However, no significant differences were found after the first 15 minutes of exercise. A sports drink that spends less time in the stomach may provide less GI discomfort during prolonged exercise.

Similar to results seen with exogenous CHO oxidation rates, GI distress is more often reported in CHO supplements that contain a single type of CHO compared to those that contain multiple types of CHO. In a study completed by Wallis et al. (2005), participants ingesting a

single CHO in the form of maltodextrin reported four times as many instances of GI distress compared to a combination of maltodextrin and fructose during 150 minutes of cycling at 64% VO_{2max} . Furthermore, a similar study conducted by Jentjens et al. (2004) found that during 150 minutes of cycling at 62% VO_{2max} participants who ingested a single CHO in the form of glucose reported more severe GI discomfort than participants ingesting an isocaloric amount of a mixture of glucose + sucrose + fructose. In addition, two participants were unable to completely finish the last glucose drink as they felt it would make them sick and another participant vomited after 120 minutes of exercise (Jentjens et al., 2004).

From a practical point of view, the amount of CHO that needs to be ingested to attain optimal performance is important. The optimal amount is likely to be the amount that results in maximal exogenous oxidation rates without causing gastrointestinal (GI) distress (Jeukendrup, 2004). A recent study by Smith, Pascoe, Passe, Ruby, Stewart, Baker, Zachwieja (2013) investigated the relationship between CHO dose and 20 km time trial performance following a two-hour constant load ride at 95% of the workload that elicited a $4 \text{ mmol}\cdot\text{L}^{-1}$ blood lactate concentration in recreationally trained male cyclists and triathletes. Using the literature-suggested blend of multiple transportable CHO, the authors had participants supplement a 1:1:1 blend of glucose, fructose, and maltodextrin plus electrolytes at varying doses ($0\text{-}120 \text{ g}\cdot\text{h}^{-1}$) to determine the ideal CHO ingestion rate to maximize cycling performance and reduce the instance of stomach discomfort. By evaluating the relationship between time trial performance and CHO intake, the authors concluded the optimal CHO ingestion rate for a 1:1:1 blend of maltodextrin, fructose, and glucose is around $78 \text{ g}\cdot\text{h}^{-1}$ (Smith et al., 2013).

Much of the research indicates that using multiple types of CHO combined would make the ideal sports drink for use during prolonged exercise. Utilizing multiple CHO should lead to higher exogenous CHO oxidation as well as less GI distress. However, recent research done on a unique glucose polymer has shown numerous advantages over cheaper and more commercially available maltodextrin. A study completed by Leiper, Aulin, & Soderlund (2000) used a gastric aspiration technique to measure gastric emptying of a high molecular weight amylopectin-based glucose polymer (Vitargo) and a low molecular weight polysaccharide-based maize starch (maltodextrin). By measuring the time it took to empty half of a 500 mL, 13.5% solution of fluid from the stomach, the authors found that the Vitargo left the stomach almost twice as fast as the maltodextrin, 17 minutes and 32 minutes, respectively. The amount of time a drink spends in the stomach could play a major role in substrate availability during exercise, as gastric emptying has been proposed as a limiting physiological factor to exogenous CHO oxidation. If gastric emptying and CHO absorption are affected by exercise intensity and type of CHO ingested, then Vitargo may have an advantage over other substrate and CHO supplements during exercise. Not only may Vitargo lead to quicker substrate availability but it may also reduce the chances of developing GI distress.

Aulin, Soderlund, and Hultman (2000) measured muscle glycogen resynthesis using a muscle biopsy of the vastus lateralis after glycogen depleting leg exercise. The exercise consisted of 60 minutes of running, 60 minutes of submaximal cycling, and a short series of sprints on the cycle to exhaustion. The authors reported that two hours after exercise along with the consumption of 300 g of an isoenergetic solution, the mean muscle glycogen contents were significantly higher in the Vitargo group compared to the maltodextrin group, 153.3 mmol

glycosyl units and 118.1 mmol glycosyl units, respectively (Aulin et al., 2000). Mean muscle glycogen contents were further elevated after four hours of recovery with no differences between groups. This is most likely attributed to the difference in the amount of CHO delivered to the intestine and the subsequent amount available for glycogen resynthesis.

A more recent study completed by Stephens, Roig, Armstrong, and Greenhaff (2008) measured cycling performance during a subsequent bout of exercise after glycogen depleting exercise and CHO ingestion. The authors had participants complete a protocol that previously demonstrated almost complete depletion of leg muscle glycogen followed by ingestion of 100 g of either Vitargo or maltodextrin. During two hours of supine rest, blood glucose and serum insulin were measured every 10 minutes. Both variables were significantly higher during the first 40 minutes following ingestion of the CHO solutions in the Vitargo group. Work output for each participant during a 15-min all-out cycling time trial was then performed after the two-hour supine rest period. Work outputs following the consumption of the CHO solutions were 10% greater and all participants had a significant increase in work output in the Vitargo trial compared to the maltodextrin trial, 164.1 kJ and 149.4 kJ, respectively.

Very few studies that examine the effects of CHO supplementation on cycling performance use cycling protocols that recreate a real-life road cycling experience. Most studies use fixed intensities (60-65% of VO_{2max}) and have little power output variance during the majority of the ride. These studies also tend to use workloads that fall short of those seen during cycling competition (i.e. 50-55% W_{max}). Creating a cycling protocol that closely resembles real-life road cycling, using variable intensities and relatively high work rates, may be more appropriate in determining the actual energy demands and the ideal CHO supplement

requirements during cycling exercise. The literature-suggested feeding rate of $78 \text{ g}\cdot\text{h}^{-1}$ may not provide enough fuel to maintain optimal performance under these conditions.

In addition, exploring the effects that a unique single-source high molecular weight starch fraction (Vitargo) has on exogenous oxidation rates during a high-intensity, real-life cycling protocol compared to a blend of maltodextrin and sugar may help us understand the limiting factors behind exogenous CHO oxidation rates. The accelerated gastric emptying of Vitargo may be better at maintaining blood glucose concentrations, ultimately improving exogenous CHO oxidation rates, and thus leading to better performance.

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