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# Low vs. High Glycemic Index Carbohydrate Gel Ingestion During Simulated 64-km Cycling Time Trial Performance

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**Abstract.** Earnest, C.P., S. Lancaster, C. Rasmussen, C. Kerksick, A. Lucia, M. Greenwood, A. Almada, P. Cowan, and R. Kreider. Low vs. high glycemic index carbohydrate gel ingestion during simulated 64-km cycling time trial performance. *J. Strength Cond. Res. 18(3):466–472. 2004.*—We examined the effect of low and high glycemic index (GI) carbohydrate (CHO) feedings during a simulated 64-km cycling time trial (TT) in nine subjects ([mean ± *SEM*], age = 30 ± 1 years; weight = 77.0 ± 2.6 kg). Each rider completed three randomized, double blind, counterbalanced, crossover rides, where riders ingested 15 g of low GI (honey; GI = 35) and high GI (dextrose; GI = 100) CHO every 16 km. Our results showed no differences between groups for the time to complete the entire TT (honey = 128 minutes, 42 seconds ± 3.6 minutes; dextrose = 128 minutes, 18 seconds ± 3.8 minutes; placebo = 131 minutes, 18 seconds ± 3.9 minutes). However, an analysis of total time alone may not portray an accurate picture of TT performance under CHO-supplemented conditions. For example, when the CHO data were collapsed, the CHO condition (128 minutes, 30 seconds) proved faster than placebo condition (131 minutes, 18 seconds; $p < 0.02$). Furthermore, examining the percent differences and 95% confidence intervals (CI) shows the two CHO conditions to be generally faster, as the majority of the CI lies in the positive range: placebo vs. dextrose (2.36% [95% CI; −0.69, 4.64]) and honey (1.98% [95% CI; −0.30, 5.02]). Dextrose vs. honey was 0.39% (95% CI; −3.39, 4.15). Within treatment analysis also showed that subjects generated more watts (W) over the last 16 km vs. preceding segments for dextrose ($p < 0.002$) and honey ($p < 0.0004$) treatments. When the final 16-km W was expressed as a percentage of pretest maximal W, the dextrose treatment was greater than placebo ($p < 0.05$). A strong trend was noted for the honey condition ($p < 0.06$), despite no differences in heart rate (HR) or rate of perceived exertion (RPE). Our results show a trend for improvement in time and wattage over the last 16 km of a 64-km simulated TT regardless of glycemic index.

Key Words. glycemic index, carbohydrate, exercise, time trial, cycling

## Introduction

Contemporary research findings suggest that cyclists ingest carbohydrate (CHO) during prolonged exercise as a means of improving performance. However, CHO ingestion may not be necessary for all events, depending on the length and intensity of the event in question. For example, CHO use during cycling time trial (TT) studies has produced equivocal results (3, 8, 18). Some authors suggest that CHO ingestion during shorter events might influence performance via a placebo effect (4). A distinction not often addressed is that the times necessary to complete a TT are often separated by small differences. This is especially true for accomplished riders, where small differences can make a very real difference between winning and losing.

This scenario can be demonstrated by examining the top five riders' performances during the longest TT of the 2001 Tour de France. During this 61-km race, the difference between the top five riders was only 1.8–3.1%. The difference between 1st and 2nd was only 1.8%. As another example, the separation between 1st (Jan Ullrich) and 4th (no medal) during the 2001 World TT Championships (40 km) was only 25 seconds. Thus, an examination of these subtle performance differences and any factors affecting them are important, as recent mathematical modeling studies suggest that CHO and electrolyte solutions may improve 40-km TT performance by 32 to 42 seconds depending on the ability of the rider (19). The length and time of the event needs to be considered when comparing TT studies; shorter TT events lasting 20–40 km (30–60 minutes) may be affected differently than longer TT efforts (90–120 minutes). In this regard, three common themes emerge from the literature regarding CHO use. These are (a) the glycemic index of the CHO (11), (b) the rate of gastric emptying of the CHO alone or when combined with other macronutrient sources (13), and (c) the maintenance of blood glucose concentration during a TT event (10, 18).

The glycemic index ranks foods according to their glycemic relationship as compared to a standard CHO source (i.e., white bread or glucose) that is assigned a value of 100 (17). Specifically, high glycemic index foods enter the blood stream rapidly and low glycemic index foods enter more slowly. Research has also shown that mixed macronutrient combinations, such as those containing fat and CHO, yield lower glucose excursions than CHO alone

(13). Perhaps the most important factor affecting performance is the observation that studies showing an improvement in performance couple a pre-exercise feeding with immediate and continued CHO ingestion during the ride (9, 18). This implies that maintaining blood glucose concentration during the ride is a distinguishing feature for CHO supplementation during prolonged exercise.

Another important factor is that a TT is performed at high intensity, which is synonymous with a more rapid utilization of muscle glycogen (24, 25). Related to this observation is that exercise intensity over the final portion of a TT will most likely occur at or above the lactate or ventilatory threshold. This has been shown in professional cyclists during the Tour de France, where riders spend a significant percentage of their time at or above intensities associated with the second ventilatory threshold ($VT_2 > 85–90\%\ \dot{V}O_2max$) (24). Overall, this set of circumstances increases CHO dependence, which inevitably goes up even if power output is maintained, because of the $\dot{V}O_2$ slow component. This occurs due to the recruitment of more inefficient type II fibers, which compensate for fatiguing type I fibers, which become glycogen depleted with prolonged exercise (36). Therefore, cyclists must be able to distinguish whether CHO ingestion in conjunction with a TT is necessary. The primary aim of our trial was to examine the relationship between regular CHO feedings and the time to complete a 64-km TT.

## METHODS

### Experimental Approach to the Problem

We chose to use a simulated TT to examine the efficacy of CHO supplementation for several reasons. First, mathematical modeling suggests that TT improvements while ingesting CHO are small (19). Because frontal surface area, air resistance, aerodynamic equipment, and aerodynamic position all affect TT performance (19), we sought to remove these confounders via simulation by using a mechanically braked ergometer. Second, changes in wind direction and climatic conditions can also affect TT performance, thus creating inconsistencies in data collection. Third, we also examined various blood parameters and wattage output every 16 km during the TT, which was best accomplished in a laboratory setting.

During the course of this study, we chose to examine all dependent variables at baseline (time 0) and each 16-km segment of the TT course (i.e., 16 km, 32 km, 48 km, and 64 km) for two reasons. First, it is rare that a TT is performed in a "steady-state" manner. During actual race conditions, cyclists typically ride at a moderate-high intensity pace for the first portion of the race and then attempt to increase power output during the latter portion of the event. Second, because of the first phenomenon, an increase in power output (i.e., intensity) places greater reliance on muscle glycogen stores. As glycogen stores become depleted, the benefits of exogenous CHO oxidation may prove beneficial at the end of a TT effort.

As a secondary consideration, we sought to compare a high glycemic index gel similar to those commercially sold to athletes vs. a low glycemic index CHO gel using regular honey.

### Subjects

Nine endurance-trained amateur male subjects actively participating in local cycling races volunteered to participate in this trial. Subjects ranged in experience from category II to III cyclists and competitive triathletes. The United States Cycling Association categorizes amateur riders into 5 categories, with category V being the lowest and category I being the highest. All subjects were actively training in their preseason preparatory phase and not currently involved in competitions. Mean ± *SEM* rider characteristics are age = 30 ± 1 year; height = 169.9 ± 4.6 cm, and weight = 77.0 ± 2.6 kg. The maximal wattage exhibited by these riders was 329 ± 20 W. Participants were screened in advance to ensure that they were not taking any nutritional supplements that might affect CHO metabolism. Prior to entry into the study, all subjects signed an informed consent statement approved by the Human Subjects Review Board at the University of Memphis. This board ensures that each university-based trial is carried out ethically and in accordance with the Declaration of Helsinki.

### Experimental Design

Before data collection began, all subjects participated in a 2-week familiarization period. During this time each subject practiced the study protocol and became familiar with bike setup. Subsequently, each subject was tested to determine maximal exercise performance in watts (W) using their own bikes on a mechanically braked training ergometer (Computrainer, Seattle, WA). Each subject then participated in three simulated 64-km TT in which subjects ingested either a low–glycemic-index CHO (honey), high–glycemic-index CHO (dextrose), or artificially flavored placebo gel supplement. Independent analysis of the honey showed the gel constituency to be 38.5% fructose, 31.0% glucose, 17.1% water, 7.2% maltose, 4.2% trisaccharides/other carbohydrates, 1.5% sucrose, and 0.5% proteins. A previous investigation by our group showed the same dextrose and honey used for this trial to have glycemic indexes of 100 and 35, respectively (30). Treatment was administered in a randomized, double-blind, counter-balanced, crossover manner separated by 7 days.

So as to best replicate race performance, subjects were asked to treat each trial as a race and to prepare accordingly. Subjects were also asked to complete a 4-day nutritional diet log replicating their usual 4-day prerace diet. Prior to each trial, subjects were asked to consume the same meals so as to best duplicate pretrial macronutrient intake. On the day of each trial, each subject consumed a high-CHO meal of their choosing approximately 4 hours prior to performing the TT. Furthermore, all subjects were asked to duplicate their training loads from week to week so that they were well rested and ready to perform at their best effort.

### Maximal Power Output Testing

We tested all subjects for maximal power output using the Computrainer. This test required that each subject's bicycle be attached to the Computrainer unit according to manufacturer calibration procedures. Briefly, subjects warmed up for 5 minutes at a self-selected workload. We calibrated the unit by having the subjects pedal until they reached 25 miles per hour. After the subject achieved the required speed, he stopped pedaling, allowing the wheel to coast to a stop. When the wheel stopped, a rolling resistance was measured, recorded, and reproduced for each endurance capacity trial thereafter. We performed each calibration procedure 2 more times to ensure accu-

racy. Subjects then performed an incremental maximal exercise test to exhaustion. The cycling workloads began at 150 W and increased 50 W each minute to 300 W. Workloads were increased 25 W each minute thereafter until subjects could no longer maintain a cadence of at least 65 revolutions per minute.

### 64-km Time Trial Testing

Before each TT, subjects reported to the lab, where they were weighed and allowed to warm up at a self-selected tension. We positioned fans on the athletes to simulate the cooling effects of air convection experienced while riding. Subjects were also asked to emulate an "aerodynamic" position by using either aerodynamic bars or the handlebar drops. Each subject maintained this position throughout the trial; however, we allowed riders to alter their body positions by switching between the two. We anticipated no difference in performance due to allowing this alteration in position because research conducted indoors and under laboratory conditions has demonstrated no difference in energy cost between hand placement on the handlebar drops and the brake hoods (32). However, we are unaware of any data detailing differences using aero bars while under laboratory conditions.

Once the warm-up phase was completed, each subject ingested 15 g of 1 of 3 gels (placebo, dextrose, or honey) administered in generic packets, along with 250 ml of water. We instructed each subject to ride the TT as hard as possible in order to complete the trial in the shortest amount of time possible. During the TT, subjects ingested 15 g of the designated CHO gel with 250 ml of water every 16 km and an additional 250 ml of water every 3.2 km. We recorded average power output, heart rate (HR), rate of perceived exertion (RPE), and the time to complete the segment during each 16 km of the TT course. We obtained blood samples during this time to examine blood glucose and insulin concentrations.

### Blood Samples

We collected approximately 400 μl of arterialized-venous blood at baseline and every 16 km from a prewarmed clean finger. Baseline samples were collected approximately 4 hours following the subjects' preride meal and prior to warm-up or the ingestion of their first gel packet. The blood was collected in Monoject EDTA (K3) Samplette capillary whole blood collectors (Sherwood Medical, St. Louis, MO). We centrifuged each sample using an Adams Physicians Compact Centrifuge (Clay Adams, Division of Beckton Dickson & Co., Parsipanny, NJ) and then transferred the serum from each sample into two labeled Costar microcentrifuge tubes (Corning Incorporated, Corning, NY). We analyzed all blood samples in the Exercise Biochemistry Laboratory (EBL) using standard spectrophotometric and enzymatic immunoassay procedures. The quantitative, enzymatic determination of blood glucose was determined using Sigma Diagnostics Glucose Trinder reagent No. 315 (Sigma Diagnostics, St. Louis, MO). We assayed all glucose samples in duplicate using a Spectronic 21D spectrophotometer (Milton Roy Company Analytical Products Division, Rochester, NY). The quantitative measurement of insulin in plasma was determined in duplicate using the DSL-10-1600 ACTIVE Insulin Enzyme-Linked Immunosorbent Assay (ELISA) Kit (Diagnostic Systems Laboratories, Inc., Webster, TX). For insulin, the intraassay variance ranged from 3.0–5.3% (mean ± *SD* = 4.4 ± 0.8). The interassay variance was less than 8.4%. The mean $r^2$ values for the standard curve were always $> 0.98$ with an average of 0.99.

### Statistical Analyses

Dependent variables for this investigation included cumulative time to complete the 64-km course, time to complete each 16-km segment, average wattage during the entire 64 km, average wattage during each 16-km segment, glucose and insulin concentrations, and average HR and RPE for each 16-km segment. We used a 3 (treatment condition) × 5 (time; baseline and distance segments) repeated measures analysis of variance (ANOVA) with a Fisher least significant difference (LSD) post hoc analysis to assess glucose and insulin concentration. We used a 3 × 4 repeated measures ANOVA with a Fisher LSD post hoc analysis to examine average wattage output during each segment, average time to complete each segment, and the average HR and RPE for each distance segment.

In order to gain an appreciation for trends in our data, we examined changes in glucose and insulin concentrations from baseline, as well as the percentage of maximum wattage capacity used by each participant during each segment of the TT. Lastly, the variable that we felt held the most practical significance to the athlete was time to completion of the 64-km TT. As we anticipated that there might be a marginal difference gained from CHO ingestion, we compared not only the mean differences, but also the percent difference between each treatment condition for total time to complete the TT, relative to the placebo condition.

Data for the percent difference was expressed as the mean and percentage difference of each variable, accompanied by 95% confidence intervals (95% CI) in order to better examine trends that would make any perceived benefits clearer and more applicable to the athlete (14). We realize that this is not a traditional approach to statistical analysis. However, we believe that the examination of confidence intervals is important because they give an estimated range of values that are likely to occur in a given set of data. The choice of 95% confidence limits represents the lower and upper boundary values of our confidence interval, or those values that define the range of confidence that our data cover. If this latter analysis ranged between 1.5% and 3%, and our aforementioned analysis showed no difference between CHO treatments, we collapsed all CHO data into 1 group. We compared the combined CHO group against the placebo treatment, because mathematical modeling suggests that this would be the benefit attained by ingesting CHO during a 40-km TT (19). We used Statview 5.0 (Cary, NC) to analyze our data. Statistical significance was set at $p \leq 0.05$, and the results are presented as mean ± *SEM*.

## RESULTS

Overall, our repeated measure ANOVA showed a significant effect for the time to complete each 16-km segment ($p < 0.0006$), average W maintained for each 16-km segment ($p < 0.0001$), and the percentage of maximal W attained during each 16-km segment ($p < 0.0001$) during this trial. We also found significant effects for changes in glucose concentration ($p < 0.01$), HR ($p < 0.0001$), and RPE ($p < 0.0001$). We observed no statistical effect for insulin or insulin change. The within group time effects

**TABLE 1.** Data represent mean ± *SEM* for total time and the wattage obtained for the final 16 km of the simulated time trial. Statistical power and effect size vs. the placebo group are provided.

| | Total Time (min) | Statistical Power* | ES* |
|---|---|---|---|
| Placebo | 131.3 ± 3.9 | – | – |
| Dextrose | 128.3 ± 3.8 | 0.08 | 0.77 |
| Honey | 128.8 ± 3.5 | 0.08 | 0.76 |
| | Wattage over last 16 km (W) | | |
| Placebo | 174.8 ± 11 | – | – |
| Dextrose | 218.7 ± 20 | 0.49 | 2.19 |
| Honey | 209.6 ± 16 | 0.48 | 1.74 |

* Power and effect size (ES) are compared to the placebo treatment.

and between group treatment effects are outlined below. We observed no differences in 4-day dietary patterns or training patterns during the week before and the meal intake 4 hours immediately before each trial.

### Time per Segment

When we examined the total time to complete the 64-km TT, we observed no between group treatment effects for the time to complete the entire 64-km or any 16-km time segment. Specifically, the time to complete the entire 64-km TT was 131 minutes, 18 seconds for the placebo treatment; 128 minutes, 42 seconds for the honey treatment; and 128 minutes, 24 seconds for the dextrose treatment. Compared to the placebo treatment, the honey and dextrose treatments produced times to completion that were 2 minutes, 36 seconds and 2 minutes, 54 seconds faster, respectively. We have presented the statistical power and effect size for total time for CHO treatments vs. the placebo treatment in Table 1. Because this met our criteria for a 1.5–3.0% time difference, we collapsed the data from the two CHO treatments. When this was done, CHO supplementation (128 minutes, 30 seconds) was significantly faster than placebo (131 minutes, 18 seconds; $p < 0.02$).

Expressed as a percentage difference vs. the placebo, the dextrose treatment was 2.4% faster (95% CI; −0.69, 4.64), and the honey treatment was 2.0% faster than the placebo treatment (95% CI; −0.30, 5.02). The percent difference between the dextrose and honey treatment was 0.39% (95% CI; −3.39, 4.15). In the analysis of the within group effects for the time to complete each distance segment, we did observe a significant time effect for the placebo group ($p < 0.03$; Figure 1). The post hoc analysis showed that, under placebo conditions, riding time was significantly longer (i.e., slower) over the last two distance segments during the two latter stages of the TT, where the 48-km ($p < 0.02$) and 64-km ($p < 0.006$) segments took longer to complete.

### Watts per Segment

Average wattage for the entire 64-km TT was 162.3 ± 10.6 W for the placebo treatment, 176.3 ± 12.4 W for the honey treatment, and 178.3 ± 12.8 W for the dextrose treatment. However, we observed no between group treatment differences for the average wattage produced by the riders over the TT course. When expressed as a percentage of maximal wattage, both the dextrose and honey treatments were generally greater than the placebo group. However, only the dextrose group reached a level during the last 16-km segment that was significantly greater than the placebo group ($p < 0.05$), whereas the honey condition exhibited a strong trend for being greater than placebo conditions ($p < 0.06$). Data for percentage of maximal watts over the last 16-km segment are dextrose, 67%; honey, 63%; and placebo, 53%.

When we examined each treatment condition for within group time effects, our results showed that the dextrose ($p < 0.002$) and honey conditions ($p < 0.0004$) were significant. Further post hoc analysis showed that under CHO treatment conditions both groups were able to produce a greater average W during the last 16-km TT segment (i.e., 48–64 km) than the W observed at 16 km ($p < 0.0001$), 32 km ($p < 0.0001$), and 48 km ($p < 0.0001$; Figure 2). We have presented the statistical power and effect size for wattage during the final 16 km for the CHO treatments versus the placebo treatment in Table 1. No within group time treatment effects were observed for the placebo condition.

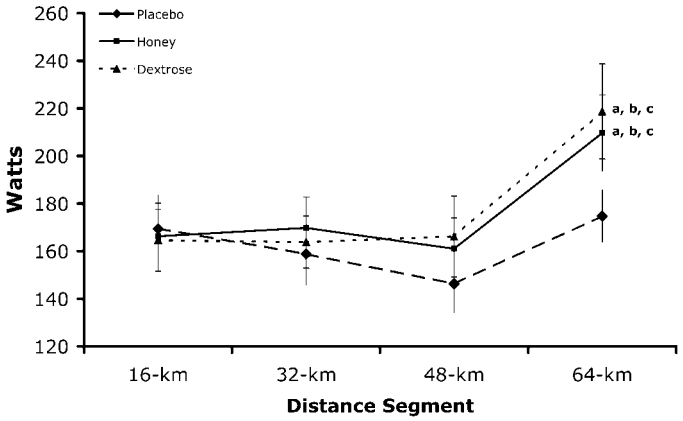


**FIGURE 1.** Data represent average time to complete each 16-km segment of a 64-km time trial. Data are mean ± *SEM*. Significance is represented as (a) time is longer (i.e., slower) than the 0–16-km time segment; (b) time is longer (i.e., slower) than the 16–32-km time segment.

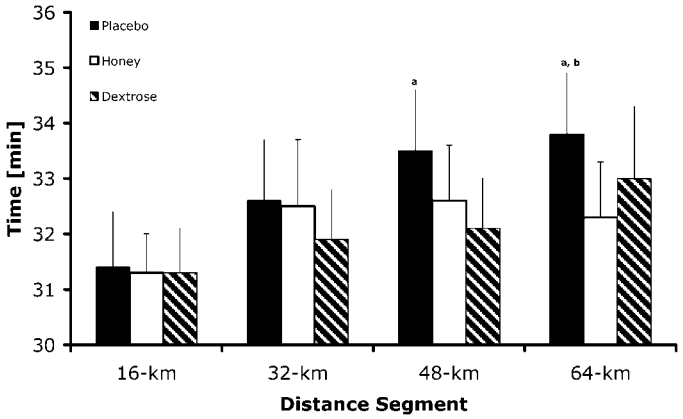


**FIGURE 2.** Data represent average wattage produced during each 16-km segment of a 64-km time trial. Data are mean ± *SEM*. Significance is represented as (a) wattage is greater than the 0–16-km time segment; (b) wattage is greater than the 16–32-km time segment; (c) wattage is greater than the 32–48-km time segment. The notations (d; $p < 0.05$) and (e; $p < 0.06$) represent W greater than placebo W relative to pretrial maximal W testing.

**TABLE 2.** Blood glucose and insulin concentrations, heart rate, and rate of preceived exertion for study subjects during simulated 64-km time trial performance. Values are mean ± *SEM*.

| | Baseline | 16-km segment | 32-km segment | 48-km segment | 64-km segment |
|---|---|---|---|---|---|
| Glucose (mmol·L$^{-1}$) | | | | | |
| Placebo | 5.7 ± 0.3 | 5.6 ± 0.5 | 5.6 ± 0.4 | 5.1 ± 0.2 | 5.3 ± 0.4 |
| Delta | NA | −0.1 ± 0.3 | −0.1 ± 0.5 | −0.6 ± 0.4 | −0.4 ± 4.3 |
| Honey | 6.3 ± 0.4 | 6.7 ± 0.8 | 6.3 ± 1.0 | 5.5 ± 0.3 | 5.3 ± 0.4 |
| Delta | NA | 0.4 ± 0.5 | 0.0 ± 0.7 | −0.8 ± 0.3 | −0.9 ± 0.7 |
| Dextrose | 6.3 ± 0.2 | 6.1 ± 0.3 | 5.7 ± 0.3 | 5.3 ± 0.3* | 5.7 ± 0.8 |
| Delta | NA | −0.2 ± 0.3 | −0.6 ± 0.3** | −0.9 ± 0.3**, *** | −0.6 ± 0.3** |
| Insulin (pmol·L$^{-1}$) | | | | | |
| Placebo | 41.3 ± 2.9 | 35.2 ± 2.9 | 36.0 ± 2.9 | 40.8 ± 3.6 | 37.5 ± 3.2 |
| Delta | NA | −6.2 ± 2.2 | −5.3 ± 2.9 | −0.6 ± 3.6 | −3.8 ± 2.9 |
| Honey | 40.1 ± 3.2 | 40.4 ± 2.7 | 50.6 ± 13.6 | 45.6 ± 9.3 | 38.0 ± 2.9 |
| Delta | NA | 0.3 ± 2.9 | 10.5 ± 11.5 | 5.5 ± 6.5 | −1.7 ± 2.9 |
| Dextrose | 40.0 ± 1.0 | 38.2 ± 1.9 | 36.4 ± 2.9 | 34.5 ± 2.2 | 32.1 ± 2.2 |
| Delta | NA | −2.0 ± 2.2 | −3.87 ± 2.9 | −5.67 ± 2.2 | −8.1 ± 2.2 |
| Heart Rate (b·min$^{-1}$) | | | | | |
| Placebo | n/a | 156.1 ± 5.3 | 154.9 ± 5.0 | 154.6 ± 4.2 | 170.6 ± 6.4** |
| Honey | n/a | 156.7 ± 5.0 | 155.6 ± 4.2 | 151.3 ± 5.4 | 171.1 ± 5.2** |
| Dextrose | n/a | 154.6 ± 4.3 | 156.6 ± 4.1 | 157.1 ± 5.2 | 178.3 ± 7.2** |
| RPE† | | | | | |
| Placebo | n/a | 14.0 ± 0.2 | 14.8 ± 0.3 | 15.3 ± 0.4 | 18.4 ± 0.2** |
| Honey | n/a | 14.3 ± 0.2 | 15.1 ± 0.4 | 15.3 ± 0.4 | 18.8 ± 0.5** |
| Dextrose | n/a | 14.3 ± 0.2 | 14.8 ± 0.4 | 15.7 ± 0.5 | 18.6 ± 0.8** |

* Significantly different from baseline segment ($p < 0.01$).
† RPE = rate of perceived exertion; NA = not available.
** Significantly different from baseline segment ($p < 0.05$).
*** Significantly different from 16-km segment ($p < 0.05$).

### Blood Glucose

During the TT, we did not observe any significant between group treatment differences for blood glucose concentration ($p = 0.9$). However, the dextrose treatment demonstrated a significant within group time effect ($p < 0.01$), where blood glucose concentration was significantly lower at the end of 48 km versus those concentrations at the 16-km mark ($p < 0.001$; Table 2).

Delta scores for glucose concentrations also demonstrated a significant time effect ($p < 0.01$), with a specific time effect noted for the dextrose treatment ($p < 0.005$). Further analysis showed that blood glucose concentration was significantly lower than baseline at 32 km ($p < 0.05$), 48 km ($p < 0.05$), and 64 km ($p < 0.05$). Change of glucose concentration at 48 km was also lower than at 16 km ($p < 0.05$; Table 2).

### HR and RPE

No between group treatment differences were noted for any variable. However, within group time analysis showed significant time effects for the dextrose ($p < 0.0001$), honey ($p < 0.0001$), and placebo ($p < 0.04$) treatments. Post hoc analysis further showed that during all treatment conditions riders performed the final distance segment (64 km) at a higher HR than each previous distance segment ($p < 0.002$; Table 2). The same effects were also noted for RPE (Table 2).

## DISCUSSION

The primary finding from our study is that the riders ingesting low- and high-glycemic CHO were capable of completing the last 16 km of a simulated 64-km TT faster than under placebo conditions. Specifically, riders ingesting CHO in the form of dextrose and honey finished the 64-km TT approximately 3 minutes and 2.5 minutes faster than under placebo (non-CHO) conditions, respectively. Interestingly, the glycemic index of the CHO source did not affect the outcome of this trial. The overall improvement in time was matched by a significant increase in power wattage output and percentage of pretest maximal power wattage over the last 16-km distance during each CHO treatment condition. This was not true of the placebo condition. For the dextrose treatment condition, the percentage of pretest maximal wattage generated by the riders over the last 16 km was statistically greater than the placebo treatment condition ($p < 0.05$). While the honey treatment condition did not produce a statistically significant effect, it is our opinion that the observed statistical alpha level obtained versus the placebo treatment (i.e., $p < 0.06$) demonstrates a strong trend for power improvement accompanying honey ingestion. This additional power output and time to complete the final 16 km was accomplished with no difference in HR or RPE.

While our analysis did not show a significant CHO treatment effect for total time performance, we cannot exclude the possibility of a positive CHO effect for the average competitive athlete. Several points should be considered concerning this issue. When we examined our data as a percentage of difference relative to the placebo group, both dextrose (2.4% [95% CI; −0.69, 4.64]) and honey (2.0% [95% CI; −0.30, 5.02]) CHO treatments yielded faster TT results than the placebo treatment. Furthermore, an examination of the confidence intervals, which defines the range of confidence that our data cover, suggests that the range of the true effect for each CHO treatment was positive (i.e., faster) for the average sub-

ject. Specifically, the magnitude of the outcome and the span of the confidence intervals suggest that a cyclist ingesting either form of CHO would improve performance. This was further illustrated when both CHO treatment groups were collapsed into one CHO group, showing that a significant treatment effect may be found when using a continual CHO ingestion schema.

The concept of continual CHO feeding is important during exercise, because this form of CHO ingestion appears to increase exercise performance when the duration of exercise is greater than 45 minutes (6, 18). When one considers this length of performance time, research supports the idea that maintaining blood glucose is associated with an increased rate of exogenous CHO oxidation and the possible sparing of liver glycogen (6, 21). Though it has been postulated that CHO feedings will spare muscle glycogen, this phenomenon is not well established (6, 20, 29, 34, 35). Another interesting finding from our trial is that a lower glycemic-index CHO source performed as well as a higher glycemic source.

The practice of continued CHO feeding during exercise is important because CHO oxidation rises through the first 75–90 minutes of exercise and then plateaus (12, 16, 23). This practice appears to be important as CHO supplemented riders in our trial showed an improvement in performance. Another reason that continual feedings are important is that research comparing the effects of CHO ingestion throughout exercise vs. an equal amount of CHO ingested late in exercise has shown that continuous ingestion improved performance relative to control conditions, despite similar increases in plasma glucose and insulin concentrations during late exercise feedings (28). The observation that CHO feeding during exercise increases muscle glucose uptake compared to control conditions provides a physiologic basis for performance improvement (28). Thus, the continued ingestion of CHO during exercise is important, as increased exogenous CHO uptake will be sustained throughout the event, resulting from the maintenance of blood glucose concentration.

One of the reasons that repetitive CHO feeding schedules should be adopted is because continued CHO ingestion accelerates the rate of gastric emptying and delivery of CHO to the intestine (29, 31). This may be important given the absorption characteristics and glycemic index of the CHO sources used in our trial. As evidenced in our trial, both the dextrose and honey treatments exhibited similar times to complete 64 km, ranging from approximately 2.5–3 minutes faster than placebo conditions. This is of particular interest given our previous documentation of honey's low glycemic index (30). A matter that is not so clear from the literature relates to the glycemic index of the CHO ingested: high–glycemic-index CHO is recommended for maintaining and improving performance. However, this potential disparity may be illuminated when one considers that the honey used during our trial was composed of equal percentages of glucose and fructose, both of which have distinguishing oxidation characteristics when examined alone and in combination.

Studies examining the isoenergetic ingestion of fructose and glucose oxidation characteristics show that a lower rate of oxidation can be observed for fructose than for glucose (15, 26, 27). Although other researchers have had similar findings (1, 2, 7, 12), combining the two CHO sources into a single feeding could produce a much different result. For example, a study performed by Adopo et al. (1) used 13C labeling in subjects ingesting 50 g each of glucose and fructose. When ingested simultaneously, the amount of CHO oxidized was similar to the amount observed when 50 g of glucose or fructose was ingested separately and 21% larger than when 100 g of glucose was ingested (1). The authors of this trial suggest that these findings may be due to the different routes of absorption and metabolism, which would in turn result in less competition for CHO oxidation (1). These observations may also partially explain the similarity in TT performance observed during our current trial.

## PRACTICAL APPLICATIONS

Though our data do not statistically support an overall improvement in TT performance times with CHO supplementation, we feel that the trend for improvement was noticeable. Specifically, the data in our study show a strong trend for improvement with CHO supplementation where time, power output, and percentage of pretest maximal wattage all improved during continual CHO feedings over the last 16 km. All these improvements occurred despite almost identical HR and perceived exertion indices during all treatment conditions. As for the wattage generated over the last 16 km, the dextrose treatment condition was the only one to achieve statistical significance when examined as a percentage of pretrial maximum wattage output. However, the honey treatment condition demonstrated a strong trend for achieving statistical significance ($p < 0.06$), a matter that has been debated in statistical circles and one that might be clarified in a similar trial using a greater sample size (5, 22).

Given the strong trends present in our data and the observation that our collapsed data analysis shows a significant time improvement with CHO supplementation, which is in agreement with other reports (9, 11, 33), we believe that our findings demonstrate practical significance to the competitive cyclist seeking to improve TT performance regardless of glycemic index. Furthermore, we utilized a crossover design, which attempted to standardize meal patterns and weekly training volume before testing in order to examine the effects of low– and high–glycemic-index CHO gels on 64-km cycling performance. Though we found a trend for TT improvement, our data were not statistically significant between treatment conditions.

In conclusion, we believe that the reader must consider several observations associated with this trial. These include consistent statistically significant within CHO treatment findings suggesting an improvement in performance with continual CHO feedings during a 64-km TT effort. However, the small subtleties associated with overall time differences may not be fully elucidated because of the small sample size used in this trial. We therefore recommend that similar investigations be performed with larger samples and that particular attention be given to the latter stages of the TT, because some riders may increase power output during the final portions of this type of event. It further appears that honey can serve as an effective mixed CHO gel source.

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