The Ingestion of 39 or 64 g·h-1 of Carbohydrate is Equally Effective at Improving Endurance Exercise Performance in Cyclists

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Accepted author manuscript version reprinted, by permission, from International Journal of Sport Nutrition and Exercise Metabolism, 2015, 25 (3), pp. 285-292, https://dx.doi.org/10.1123/ijsnem.2014-0134.

The ingestion of 39 or 64 g·h^{-1} of carbohydrate is equally effective at improving endurance exercise performance in cyclists.

Original Investigation

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Running head (8 words): Carbohydrate and endurance performance: how much is enough?

Abstract word count: 252 (limited to 250)

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Abstract and key words

In an investigator-blind, randomised cross-over design, male well-trained cyclists (n=20) completed four experimental trials. Each trial consisted of a 2h constant load ride (185 ± 25W) followed by a work-matched time trial task (~35min). Three commercially available CHO beverages, plus a control (water), were administered during the 2h ride providing 0, 20, 39 or 64g CHO/h at a fluid intake rate of $1L \cdot h^{-1}$. Performance was assessed by time to complete the time trial task, mean power output sustained, and pacing strategy used. Mean task completion time (min:sec ± SD) for $39g \cdot h^{-1}$ (34:19.5 ± 03:07.1, p=0.006) and $64g \cdot h^{-1}$ (34:11.3 ± 03:08.5 p=0.004) of CHO were significantly faster than control (37:01.9 ± 05:35.0). The mean percentage improvement from control was -6.1% (95% CI: -11.3 to -1.0) and -6.5% (95% CI: -11.7 to -1.4) in the 39 and $64g \cdot h^{-1}$ trials respectively. The $20g \cdot h^{-1}$ (35:17.6 ± 04:16.3) treatment did not reach statistical significance compared to control (p = 0.126) despite a mean improvement of -3.7% (95% CI -8.8 to 1.5%). Mean power output differences mirrored the performance time. There was no interaction between CHO dose and pacing strategy. 39 and $64g \cdot h^{-1}$ of CHO were similarly effective at improving endurance cycling performance compared to a $0g \cdot h^{-1}$ control in our well trained cyclists.

Key words: Carbohydrate, performance, cycling

Introduction

Carbohydrate (CHO) intake during exercise has consistently been shown to improve exercise performance (Smith et al., 2013; Smith et al., 2010) and extend exercise capacity (Galloway & Maughan, 2000; Watson, Shirreffs, & Maughan, 2012). CHO is thought to act in many ways to enhance performance: sparing of muscle glycogen (Bjorkman, Sahlin, Hagenfeldt, & Wahren, 1984; Stellingwerff et al., 2007); enhancing and maintaining elevated CHO oxidation rate; maintenance of blood glucose concentration (Coyle, Coggan, Hemmert, & Ivy, 1986); elevated exogenous CHO oxidation rate (Galloway, Wootton, Murphy, & Maughan, 2001); and central and peripheral neural up-regulation (Carter, Jeukendrup, & Jones, 2004; Chambers, Bridge, & Jones, 2009; Nikolopoulos, Arkinstall, & Hawley, 2004). As a result, CHO feeding strategies are now widely employed in the exercise setting as a means to support athletic performance.

Although the provision of CHO has been shown to improve exercise performance/capacity, the optimal dose of CHO required to maximise athletic performance remains a topic of debate. Currently, guidelines from the ACSM state an optimal dose of CHO during exercise to be within the range of 30 - 60g.h^{-1}. However, significant improvements in performance and exercise capacity have been reported with ingestion rates as low as 22g.h^{-1} (Galloway & Maughan, 2000; Maughan, Bethell, & Leiper, 1996) and as high as >100 g.h^{-1} (Currell & Jeukendrup, 2008) highlighting a beneficial impact of CHO ingestion over a much broader range of feeding rates, when compared with water or placebo solutions. Smith et al (2010) indicated that 15, 30 and 60g.h^{-1} were all 'very likely' to improve power output sustained (7.4, 8.3 and 10.7% respectively) during a 20km TT when compared to a 0g.h^{-1} placebo, with 60g.h^{-1} providing the largest effect. Furthermore, 30g.h^{-1} was 'very unlikely' to further improve performance over 15g.h^{-1} whilst 60g.h^{-1} was 'likely' to improve performance over the 30g·h^{-1} with a mean percentage improvement of only 2.3%. However, following post hoc power calculations, the authors indicated that a sample size of 15 to 22 was required to confidently conclude there were no differences in performances across the three doses. In contrast Watson et al (2012) reported no further improvements in time to exhaustion when feeding a 6% (~47g·h^{-1}) mixed CHO solution when compared to a 4% (~27g.h^{-1}) mixed solution. The absence of an additional improvement with the higher CHO dose is surprising considering the improvements in performance reported with higher ingestion rates (Smith et al., 2010). As such, it seems a range of CHO feeding doses increases performance over a 0g·h^{-1} condition. However, any additional increases in CHO provision above feeding rates of ~30g.h^{-1} do not appear to have a clear significant improvement on performance.

To provide clarity to the optimal dose of CHO for performance additional studies with greater sample sizes have followed up these initial reports. In a recent study Smith et al (2013) expanded on these data and examined fifty five participants spread across four sites. The participants consumed CHO during a 2h submaximal ride followed by a 20km TT task. Each participant completed 4 trials, one placebo and three CHO treatments, between 10 and 120g·h^{-1} (10g·h^{-1} increments) which consisted of a 1:1:1 ratio of glucose, fructose and maltodextrin. Following some statistical modelling of their data the authors reported an optimal dose of 78g·h^{-1} for performances during the TT. However, they reported only a small 1.7% improvement in performance from 30 to 80g·h^{-1}, and a rather trivial 0.7% improvement in performance from 40 to 80g·h^{-1}. In addition, the linear regression model used for the determination of the optimal feeding strategy utilised was not significant. Taken together, these studies suggest increasing amounts of CHO result in diminishing returns with respect to performance gains.

These data, coupled with those of Smith et al (2010) and Watson et al (2012), indicate a divide between the optimal feeding rates and compositions reported by investigators and the subsequent measurable and meaningful improvement in performance obtained from increasing amounts of CHO, particularly in the 30 to 60g.h^{-1} range. Similarly, the range of responses reported across the feeding rates provided in these studies highlights considerable individual variability. Accordingly, the aim of the current study was to determine the dose response relationship between CHO feeding and exercise performance in the 0 to 64g.h-1 range in 20 male cyclists. Furthermore, pacing strategies used during a performance task were investigated to provide insight as to where any changes in performance may be the greatest.

Methods

Twenty well-trained male cyclists were recruited from regional cycling and triathlon clubs. The mean (± SD) characteristics of the participants were: age 34.0 (± 10.2) years, body mass 74.6 (± 7.9) kg, stature 178.3 (± 8.0) cm, peak power output (PPO) 393 (± 36) W, and VO_{2max} 62 (± 9) ml·kg^{-1}·min^{-1}. Participants were required to have been training for >6 h / wk for >3 y. Each individual had the procedures and associated risks explained prior to providing written informed consent to participate in the study, which was approved by the local research ethics committee in accordance with the Declaration of Helsinki.

Design

In an investigator blind, placebo controlled, randomised cross-over study design participants visited the laboratory 6 times (2 preliminary and 4 intervention) over a six week period. They completed one visit per week commencing each trial on the same day at the same time of day on each visit. Following pre-screening, participants completed a preliminary assessment where lactate threshold, VO_{2max}, and peak power output were determined and for the first familiarisation of the performance task to be used in subsequent visits. On the second visit participants completed a full familiarisation trial. The familiarisation trial and four subsequent intervention trials involved a 120 min steady submaximal cycle at 95% lactate threshold (184 ± 25W) followed by a time trial performance task, whereupon the participants were instructed to be complete their set work target as quickly as possible. Water was ingested for the familiarisation trial and consumed at a rate of 1 $L \cdot h^{-1}$. Thereafter, on the intervention trials participants consumed in a random order either: a control (water) 0%, 2%, 3.9% or 6.4% CHO solutions, in random order, at a fluid ingestion rate of 1$L \cdot h^{-1}$. Performance was determined as the time to complete a work matched simulated time trial task designed to last ~30min. Pacing strategy was assessed from taking time splits and average power output sustained for each 10% of work competed during the performance task.

Preliminary testing

On week 1 of 6, following a 10h overnight fast, participants performed a two section incremental cycle test (Lode Excalibur Sport, Netherlands) to determine maximal oxygen uptake (VO_{2max}, lactate threshold, and peak power output. Section 1 commenced at 120W and each stage increased 30W every 3 min until blood lactate increased more than 2mmol·L between stages (lactate threshold defined as the final point before the blood lactate concentration increased distinctly from the baseline concentration (Aunola & Rusko, 1984). In the last 30 s of each stage, heart rate (Polar Electro, Finland) was recorded and a capillary blood sample (fingertip) was obtained for blood lactate concentration analysis by micro-assay (LactatePro LT-1710, ArkRay Inc., Kyoto, Japan). The reliability and validity of this device has been previously determined (Pyne, Boston, Martin, & Logan, 2000). This initial stage was followed by a 10 min recovery period. Individual lactate responses were examined independently by two researchers to ensure validity and consistency of the analysis. The mean ± SD lactate concentration at LT was 2.1 ± 0.4 mmol·L corresponding to an intensity of 52 ± 6% of PPO for LT which is typical of other studies utilising a similar protocol (Neal et al., 2013).

Participants commenced section 2, starting at an intensity of the penultimate stage of section 1, with each stage lasting 1 min and increased by 30 W until volitional exhaustion. The end time and power output of the stage was used to calculate peak power output (PPO) using the following equation (Kuipers, Verstappen, Keizer, Geurten, & Van Kranenburg, 1985):

$$PPO = W_{final} + ([t/60] \cdot PI)$$

Where, W_{final} = the power output of the final completed stage in (watts), t = the time spent in the final uncompleted stage (seconds), 60 = the duration of each stage (seconds) and PI = the increase in power output between each stage (W). Maximal oxygen uptake (VO_{2max}) was also measured during this protocol via an automated online gas analysis machine (Oxycon Pro, Jaeger, Wuerzerberg, Germany). VO_{2max} was determined as the highest average VO_2 captured in a 30 sec period.

Familiarisation and Experimental trials

On arrival to the laboratory participants emptied bladder and bowel prior to nude body mass measurements. Individuals then changed into cycling attire which was kept consistent throughout all trials to reduce thermoregulatory variability. Participants then completed a 2h submaximal ride at 95% LT (185 ± 25 W) during which one of four beverages were consumed: 0% water (familiarisation and control); 2.0%; 3.9%; or 6.4% glucose (single carbohydrate) based commercially available CHO beverage. All beverages were maintained at 10°C and were consumed at a rate of $1L \cdot h^{-1}$ providing 0, 20, 39 and $64g \cdot h^{-1}$ of CHO respectively. The $20g.h^{-1}$ solution contained 37mg of sodium per 100mL and the 39 and $64g \cdot h^{-1}$ solutions both contained 50mg per 100mL. Each beverage was provided with an initial bolus ingestion of 240 mL two minutes prior to the start of exercise. Subsequently, 220mL was consumed every 15 min with the final drink provided at 120min of exercise. Following the 2h ride, a 5min recovery period allowed a toilet break and for the equipment to be set up for the performance task. The performance task was a work target simulated time trial specific to the individual (531 ± 48KJ). A linear factor, 70% W_{max} divided by preferred cadence (rpm^2), was entered into the cycle ergometer. The formula used to determine the work target value was:

$$\text{Work target} = (0.7 \cdot PPO) \cdot 1800$$

The time trial protocol employed has previously been validated and has been shown to be highly reliable (A. Jeukendrup, Saris, Brouns, & Kester, 1996).

155

156 **Data Presentation and Statistical analysis**

157 All data are presented as mean (±SD) unless otherwise stated. Total time to complete the performance task
158 and average power output sustained throughout were compared across all trials. The magnitude of
159 difference from the water control was examined with a one-way ANOVA with Dunnet's post hoc
160 comparisons made. The mean differences between two variables are presented as the mean with associated
161 95% confidence limits and Cohen's size effects (mean difference; confidence intervals; Cohen's size
162 effects). Cohen's sizes effects can be interpreted as 0.2 = small, 0.6 = moderate, 1.2 = large, 2.0 = very
163 large and 4.0 = extremely large. Performance task time and average power output was compared between
164 treatments using repeated measures regression models. The null hypothesis of no differences between any
165 of the treatments groups was tested using ANOVA with all values compared back to the water control
166 condition. A difference from the control of 3.5% in either time to complete the task or mean power output
167 sustained was considered a large and meaningful difference.

168

Results

Performance time and mean power output

Mean task completion time (min:sec ± SD) for 39g·h^{-1} (34:19.5 ± 03:07.1, p<0.01) and 64g·h^{-1} (34:11.3 ± 03:08.5, p<0.01) CHO solutions were significantly faster than control (37:01.9 ± 05:35.0) (Fig 1). Corresponding percentage change from the 0g·h^{-1}condition was similar at 6.1% (95% CI 1 to 11.3%; p=0.02) for the 39g·h^{-1} trial, and 7% (95% CI 1 to 12%, p=0.01) for the 64g·h^{-1} trial (Fig. 2). The 20g·h^{-1} (35:17.6 ± 04:16.3) treatment did not reach statistical significance compared to control (p=0.13) despite a mean improvement of 3.7% (95% CI -1.5 to 8.8%). The Cohen's size effect in comparison to the control was 0.6 (95% CI -0.1 to 1.4), 1.0 (95% CI 0.2 to 1.7), and 1.0 (95% CI 0.3 to 1.8) for 20, 39 and 64g·h^{-1} treatments respectively indicating moderate and large effects on performance improvement.

In conjunction, there was a significant effect of treatment on mean power output sustained during the time trial between the four experimental trials (p<0.01). There were significant increases of 17W (95% CI 5-30; p<0.01) and 19W (95% CI 6-31; p<0.01) in mean power output sustained throughout the 39g·h^{-1} and 64g·h^{-1} treatments, respectively. Corresponding percentage improvements compared to the 0 g·h^{-1} trial were similar at 8% (95% CI 1-15%; p=0.02) for the 39 g·h^{-1} trial, and 9% (95% CI 2-16%; p=0.01) for the 64g·h^{-1} trial. There was no statistical difference reported between the 20g·h^{-1} treatment and the 0g·h^{-1} control (p=0.12) despite a 5.7% (95% CI: -1.2 to 12.6) mean increase in power output sustained. The Cohen's size effect compared to the control was 0.7 (-0.1 to 1.4), 1.1 (0.3 to 1.8), and 1.1 (0.4 to 1.9) for 20, 39 and 64g·h-1 reflecting moderate and large effects respectfully.

Pacing strategy

The assessment of pacing strategy revealed no interaction between time and treatment (p=0.80). This suggests no evidence of any differences in the slopes of the lines between the treatments in the incremental trends of performance time or mean power sustained (Figure 3).

Discussion

This study was designed to determine the optimal dose of CHO to maximise endurance exercise performance. We show that CHO provided at rates of 39 and 64g·h^{-1} were equally effective at improving performance in 20 well trained male participants compared to a 0g·h^{-1} water control. The 20g·h^{-1} treatment did not, on average, show evidence of a significant improvement in participants' performance, despite demonstrating a meaningful mean improvement in both performance task time and mean power output over the 0g·h^{-1} treatment. As such, our data demonstrate that a plateau in performance gain occurs when consuming a single source CHO beverage at rates between 39 to 64g·h^{-1} during endurance tasks lasting less than 3hrs.

Previous studies investigating a dose-response relationship between CHO feeding and endurance exercise performance/capacity have reported somewhat conflicting results. Smith et al (2010) provided evidence of a dose-response relationship when feeding glucose in the range of 15 to 60g·h^{-1}. These authors showed that all trials significantly improved performance of 12 cyclists over the placebo condition, with only the 60g·h^{-1} 'likely' to improve performance over the 15g·h^{-1}. However, the authors highlighted that 15-22 participants would be required to make meaningful comparisons between solutions, leaving no clear picture into the optimal dose of CHO. In a follow up investigation, Smith et al (2013) reported that optimal performance gains with CHO ingestion were likely to occur at rates as high as 78g·h^{-1} when consuming multiple forms of CHO. However, the optimal dose for the greatest improvement in performance was unclear in the 40 to 80g·h^{-1} range and interpretation is limited by the choice of study design. In contrast, Watson et al (2012) observed no further improvement in exercise capacity when 46g·h^{-1} was consumed compared to 31g·h^{-1} during prolonged exercise in cool conditions. We add to these data by demonstrating that the vast majority of the performance gains occur when ingesting 39 g·h^{-1} with greater amounts of CHO ingestion (64 g·h^{-1}) providing negligible additional performance gains. As such, these results support the hypothesis that a ceiling in performance gains exists when consuming CHO above 40g.h^{-1} during exercise < 3 h. However, any mechanistic explanation for the outcome would only be speculative due to the limited measures taken throughout the trial: though increased neural drive through oral sensors in the mouth; better maintenance of blood glucose due to greater exogenous glucose availability; enhanced maintenance of exogenous glucose oxidation; and endogenous glycogen sparing; are all potential explanations.

Consuming 20g·h^{-1} of CHO in the present study had a less easily interpretable outcome. When participants consumed 20g·h^{-1} performance did not significantly improve over the water control, while 39 or 64g·h^{-1} of CHO did not significantly differ compared to 20g·h^{-1}. Other investigations have reported a significant improvement in performance and/or exercise capacity with quite modest (~15g·h^{-1}) amounts of CHO when compared to a 0g·h^{-1} condition (Galloway & Maughan, 2000; Karelis et al., 2010; Maughan et al., 1996; Murray, Seifert, Eddy, Paul, & Halaby, 1989). Consuming 20g·h^{-1} in the present study still produced a mean improvement in performance time of 3.7% compared to 0g.h^{-1}, which corresponds to a ~58s reduction in time trial task time. The variance in response is a likely explanation for lack of statistical significance, but it is noteworthy that there is considerable variation in performance responses in all CHO conditions, not just at the 20g.h^{-1}. Additionally, some individuals (n=2) did not respond positively to any of the CHO ingestion trial, with the control condition being the fastest trial completed. The variability in performances, along with some negative responses to CHO ingestion, highlights the individual nature of CHO feeding as an ergogenic aid.

The range of responses measured in the present study highlights that, for the majority of individuals, there is a ceiling in the performance gains achieved when feeding rates are higher than 40g.h^{-1}. Any additional performance gains reported appear to result in a minimal increase in performance. However, in elite level athletes, there is evidence there is an enhanced ability to utilise CHO and have a subsequent meaningful improvement in performance (Stellingwerff, 2012). In support of this enhanced intake Prof. Louise Burke (personal communication) has recently presented a case study describing a nutritional intervention which enabled an Olympic walker to ingest as much as 90g·h^{-1} of multiple transportable CHO. Thus, when providing feeding recommendations, the degree to which an increase in performance translates into a worthwhile change should be considered.

One potential limitation of the current investigation is that participants completed the trial following an overnight fasted to best control and replicate the metabolic state in which they arrive at the laboratory. Overnight fasting is not the current practice for optimal performance for athletes as liver glycogen is reduced following glycogen breakdown in the liver to maintain blood glucose concentrations overnight. However, the glycogen storage capacity of the liver is enhanced following endurance training therefore reducing the impact an overnight fast has on liver glycogen content. Casey et al (2000) reported athletes

had an overnight liver glycogen content of 386mmol·L^{-1}, which is considerably higher than values reported in healthy untrained individuals (~120 to 210mmol·L^{-1}) (Magnusson, Rothman, Katz, Shulman, & Shulman, 1992; Stadler et al., 2013; Taylor et al., 1996). Therefore, the liver glycogen content of athletes following an overnight fast is unlikely to vastly affect subsequent exercise performance. In studies examining the effect of CHO on performance following a shorter (~3h) fast, where liver glycogen content is unlikely to be compromised, Hulston and Jeukendrup (2009) reported a significant improvement in performance when consuming a CHO beverage compared to water. Additionally, a recent meta-analysis indicated the pre exercise nutritional status of participants (fed or fasted) appears to have no effect on the subsequent exercise performance/capacity achieved (Temesi, Johnson, Raymond, Burdon, & O'Connor, 2011). As such, the findings of this study are still likely to be applicable to those looking to perform in the fed state.

The current investigation only measured performance responses up to feeding rates of 64g·h^{-1} and we are therefore unable to determine responses to higher feeding rates. The upper feeding rate was based on research showing a maximal absorption rate of ~1g·min^{-1} of a single source CHO solution (A. E. Jeukendrup et al., 1999). Nevertheless, we cannot be certain that CHO feeding rates above 64g·h^{-1} does not significantly alter subsequent performances as others have reported (Currell & Jeukendrup, 2008; Smith et al., 2013). The lack of any further substantial improvement in performance with rates >39g.h^{-1} in the present study, in addition to reports of a negative impact on performance with higher rates of CHO ingestion, suggests that performance is unlikely to improve with higher rates of single source CHO ingestion during exercise < 3h. Future studies should focus on utilising measures and techniques to try and ascertain explanations as to why some feeding rates are more beneficial than others, and which factors contribute to individual variability in response.

Conclusions

The 39g·h^{-1} and 64g·h^{-1} CHO solutions were equally effective in improving the cycling performance of 20 well trained male cyclists over a 0g·h^{-1} water placebo following a 2 h submaximal ride. For most well trained individuals, an optimal feeding rate for maximising the ergogenic effect of CHO for endurance performance is likely to occur at around 40g·h^{-1}. There is a wide range of responses to all rates of CHO

ingested highlighting the individual nature of the responses observed in individuals using CHO to aid performance. However, the results of this study highlight that most individuals will respond most positively to CHO ingestion rates around 39 and 64g.h^{-1}.

Novelty statement

The vast majority of performance improvement with CHO ingestion occurred when ingesting 39 g·h^{-1}, with any additional CHO intake (64 g·h^{-1}) providing a minimal additional performance gain. As such, both 39 and 64g·h^{-1} of carbohydrate, ingested during 2 hours of endurance exercise, are equally effective at improving subsequent TT task performance in comparison to a water control.

Practical application

Cyclists performing tasks lasting between 2-3 hours should consider consuming around 40-60g·h^{-1} of single source carbohydrate and increase their intake within this range depending on individual comfort and experience.

Acknowledgements

The study was designed by MLN, AMH, CL, KDT and SDRG; data were collected and analysed by MN, and SDRG; data interpretation and manuscript preparation were undertaken by MLN, AMH, CL, KDT and SDRG. All authors approved the final version of the paper. A special thanks to Gillian Dreczkowski for her assistance throughout the study.

Funding Source

This research was funded by GlaxoSmithKline Nutritional Healthcare.

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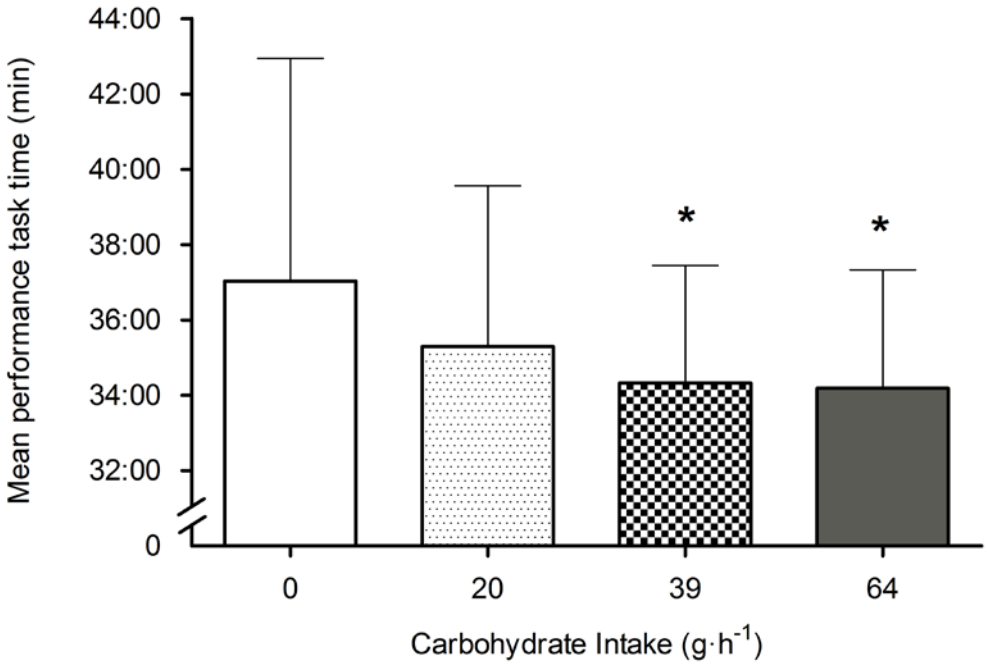
401

402 **Figure 1**



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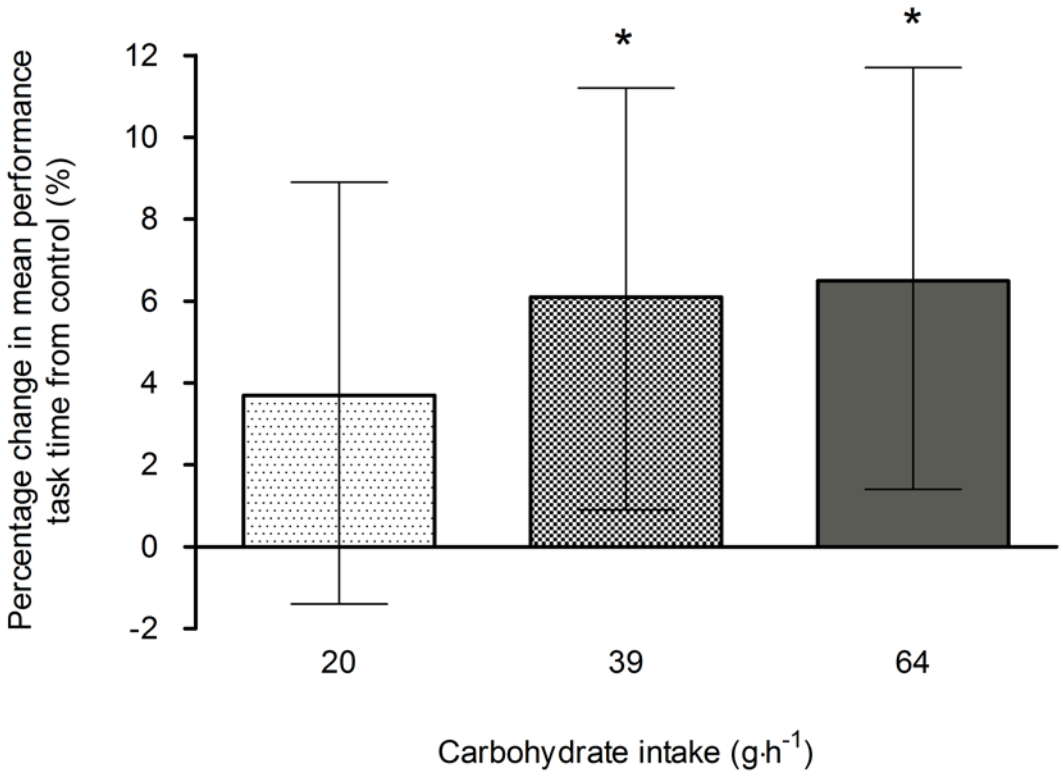
404 **Figure 2**



405

406 **Figure 3**

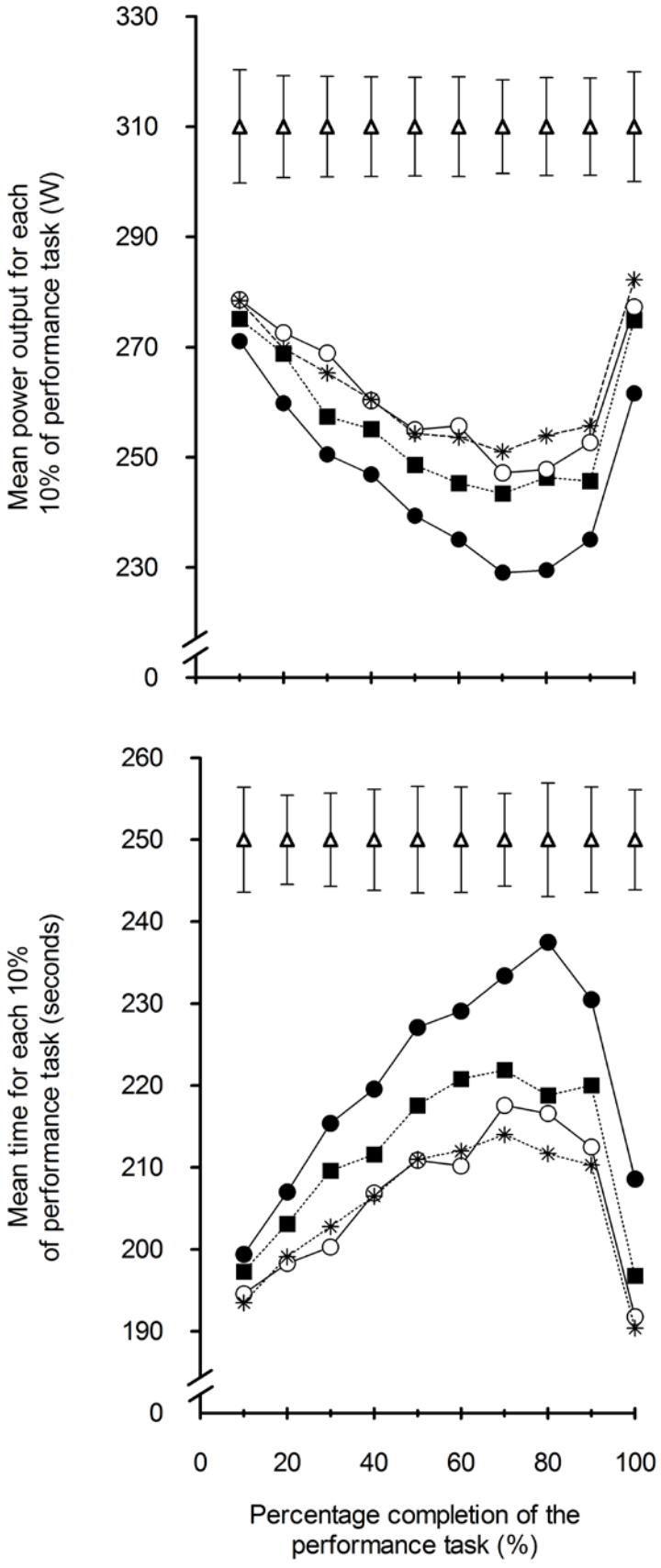


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Figure 1. Mean performance task time when 0, 20, 39, and 64 $g \cdot h^{-1}$ of carbohydrate were consumed with an arbitrary finish line denoting the fasting mean time. Data presented as mean ± standard deviation. Statistical significance is ($*p < 0.05$).

Figure 2. Percentage change in mean performance task time from the 0 $g \cdot h^{-1}$ treatment for 20, 39, and 64 $g \cdot h^{-1}$ carbohydrate ingestion rates. The percentage change in performance task time was significantly greater in the 39 $g \cdot h^{-1}$ and 64 $g \cdot h^{-1}$ trials when compared to 0 $g \cdot h^{-1}$ ($*p < 0.05$). Data presented as mean ± 95% confidence intervals.

Figure 3. Mean power output (A) and time to complete each 10% of the performance task (B) when 0 $g \cdot h^{-1}$ (-●-), 20 $g \cdot h^{-1}$ (-■-), 39 $g \cdot h^{-1}$ (-o-), and 64 $g \cdot h^{-1}$ (-*-) of carbohydrate was consumed. Data presented as means with the pooled standard error of the mean (open triangle) on an arbitrary value of 310 (Power) and 250 (Time) for ease of viewing.