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Effects of Carbohydrate Mouth Rinsing Plus Ingestion On Cycling Time Trial Performance

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ABSTRACT

Due to limited glycogen stores, carbohydrate (CHO) consumption during exercise is effective at improving performance in endurance events lasting longer than 90 minutes in duration. Recent research has established that CHO mouth rinsing may improve performance over shorter durations, independent of actual consumption. However, research is lacking in determining if an extended period of mouth rinsing has any additive benefit in conjunction with typical CHO beverage consumption over longer competition durations, where CHO ingestion/consumption is likely warranted. **PURPOSE**: Determine the effects of CHO mouth rinsing combined with consumption compared to CHO consumption alone on cycling performance. **METHODS**: Following an initial graded exercise test to determine VO_2max, 5 male cyclists completed two cycling performance trials in a randomized, double-blind, crossover design. In order to determine any added benefit of an extended CHO mouth rinse period prior to consumption, trials consisted of two drinking conditions: 1) placebo (PLA) mouth rinse plus CHO consumption and 2) CHO mouth rinse plus CHO consumption. For the mouth rinsing, a 25 mL solution (PLA: Gatorade Zero; CHO: Gatorade) was swished for 5 seconds before spitting out. Mouth rinsing was always followed up by actual consumption of 1.5 ml/kg of CHO beverage (Gatorade). Performance trials consisted of an initial 1-hour cycling bout at a workload corresponding to 60% VO2max on an electronically braked cycle ergometer

(Wahoo Kickr). During this 1-hour segment, a 30-second sprint was performed every 10 minutes, for a total of 6 sprint efforts. The mouth rinsing/consumption protocol was performed prior to each sprint interval. Following the 1-hour bout with intermittent sprints, a 20 km time trial was performed using the simulation mode setting on the cycle ergometer. The same mouth rinsing/consumption protocol was performed every 4 km during the time trial. A two-way (condition x time) repeated measures ANOVA was used to determine effects on sprint power output and rating of perceived exertion (RPE) during the 1-hour segment as well as 20 km time trial performance. **RESULTS**: There were no main effects for condition or interactions for any of the performance variables measured. Averages values ± SD for the 6 sprint segments during the 1-hour bout were as follows: sprint power (watts, CHO: 425 ± 80, PLA: 437 ± 48), heart rate (bpm, CHO: 157 ± 12, PLA: 157 ± 8), RPE (CHO: 16.7 ± 3.3, PLA: 17.3 ± 2.4). Further, 20 km time trial performance did not differ between conditions (CHO: 43.1 ± 3.8 min, PLA: 42.8 ± 3.6 min). **CONCLUSION**: In this limited sample, it does not appear that an extended CHO mouth rinsing period has any additive benefit to typical CHO consumption. This would suggest that any receptors thought to be stimulated through mouth rinsing are already stimulated adequately with normal CHO beverage consumption.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Carbohydrate (CHO) availability has long been understood as an important determinant of performance in high intensity exercise (>75% VO2max) where CHO is believed to be the predominant substrate being utilized (3). With the depletion of muscle glycogen being associated with reduced power output and increased event times among other detrimental effects (4), ingestion of exogenous CHO (both before and during events) has demonstrated effectiveness at improving performance, particularly with longer-duration events of at least 60 minutes (19, 25).

Since the seminal article in 2004 (5), studies demonstrating the effectiveness of CHO mouth rinsing have become much more common (8, 14, 29). This is of particular interest in events under 60 minutes where CHO ingestion is unlikely to offer significant performance benefits given that glycogen depletion is less likely, as well as for athletes who are prone to gastro-intestinal distress during high intensity exercise. CHO rinsing is unique in its ability to offer performance benefits despite expectorating the solution, which differentiates it from CHO ingestion in that there is no significant substrate delivery to working muscle. Thus, it has been theorized that the presence of carbohydrate in the mouth promotes a central effect during exercise (14, 15). This increase in central drive is what allows CHO rinsing to offer performance benefits such as increased power output (5, 8), increased time to exhaustion (21, 23, 29), as well as reduced time trial times (14, 20).

While the benefits of CHO ingestion during longer durations of exercise has been well established and CHO mouth rinsing alone has shown recent promise, there are few studies comparing CHO rinsing with CHO ingestion. One study published in 2010 concluded that, when comparing the effects of CHO rinsing and ingestion of a 6% CHO solution in endurance-trained triathletes, rinsing with the CHO solution for 5 seconds was able to improve 60 minute cycling time trial times by 3.9%, whereas ingesting the solution provided no significant effect on performance (20). These findings seem to indicate that typical drinking/ingestion patterns may not offer the same benefits as an exaggerated 5 second rinse, particularly in shorter duration events (<60 minutes) where CHO depletion is not likely a problem. A second study published in 2017 came to a different result, concluding that CHO ingestion improved performance in repeated 15 second cycling sprints by 2.8%, whereas rinsing the solution for 10 seconds in-between sprints offered no significant benefits (16). However, the differences in methodology and outcomes of interest in these two studies makes it difficult to draw meaningful comparisons.

While these studies offer insight into CHO rinsing compared against CHO ingestion, there are fewer studies that look at combining the two. One study published in 2011 is unique in that it compared CHO rinsing alone to CHO rinsing and ingestion (22). Subjects were given a bolus of a 6.4% carbohydrate-electrolyte beverage 30 minutes before, immediately before, and at regular intervals during a 60 minute running bout. Subjects in the rinse-only trial were instructed to rinse the solution for 5 seconds before expectorating, with the rinse and ingest trial performing the same 5 second rinse before ingesting it. Runners in the rinse and ingest trial covered 2.3% more distance, with the rinse-only group only covering 0.7% more distance. However, this study did not examine how ingestion alone compared to rinse plus ingestion.

The findings of these various studies raise an interesting question of whether the combination of CHO rinse with ingestion can be utilized to further enhance performance. Given that CHO ingestion is likely to be warranted regardless in longer duration events of at least 60-90 minutes, the question really becomes whether or not athletes are drinking in an optimal way. In other words, could an exaggerated CHO rinsing period prior to ingestion further augment performance. Thus, the purpose of this study is to investigate the effects of CHO mouth rinsing combined with ingestion compared to CHO ingestion alone on endurance performance.

REVIEW OF LITERATURE

Review of Carbohydrate Ingestion

In the area of optimizing endurance performance, the question of ideal carbohydrate intake can often be a heated topic among athletes and professionals alike. Carbohydrate (CHO) is capable of generating more ATP per volume of oxygen compared to fat, but depletion of liver and muscle CHO stores is associated with fatigue, reduced work, and impaired concentration (26). This decrease in performance as a result of reduced CHO availability is appropriately referred to by many athletes as "hitting the wall" or "bonking." Because of this, an appropriate fueling strategy for both before and during a long distance event is essential for maintaining performance.

Dosing and Timing

It is important for an endurance athlete to consume adequate amounts of energy both before and during a competitive event. Research has concluded that endurance and ultra-endurance athletes on average do not consume enough energy in the form of calories from food and drink (19). This results in a negative energy and fluid balance during the race, which in turn could impair performance. The American College of Sports Medicine (ACSM) recommends that moderate exercise of 1 hour per day (h/day) requires 5-7grams per kilogram of bodyweight per day of CHO (g/kg/day), with moderate to high intensity exercise lasting 1-3h/day requiring 6-10g/kg/day. More extreme endurance athletes training 4-5h/day may require up to 8-12g/kg/day (24).

Before Competition

A common strategy to increase CHO availability is known as "Carbohydrate-loading," which involves a period of 36-48 hours before an event of high CHO consumption (70% of total energy) accompanied with little to no physical activity (19). This results in a supercompensation of muscle and liver glycogen stores leading up to the event, thus increasing total CHO availability. Recent studies have also demonstrated that complete physical inactivity followed by consuming 10-12g/kg/day for 24 hours achieves similar levels of supercompensation (26). Additionally, it is recommended to consume 1-4g/kg 1-4 hours before an event as a final top-off of glycogen stores (7, 26). While these strategies won't allow for greater speeds, they will allow the athlete to maintain their usual race pace for a much longer period of time due to the increased CHO availability.

During Competition

For events lasting less than 60 minutes, ingestion of CHO during the event is not necessary (4, 13, 26). However, for longer events it is recommended to consume CHO during the event to maintain performance. For events lasting 1-2.5 hours, consuming 30-60g per hour of CHO (g/hr) is commonly recommended (4, 13). For events lasting longer than 2.5 hours, higher intakes as tolerated up to 90g/hr is associated with improved performance (13). The most common way to achieve this is with a 6-8% CHO solution beverage (the concentration typically found in sports beverages) consumed every 10-15 minutes (26).

Effects on Performance

It has been well established that consumption of CHO is associated with improvements to performance, particularly with longer events. A recent review concluded that, when compared against an equivalent volume of water or placebo, CHO beverages (5.0-6.9% concentration) likely improve running performance when consumed during events lasting 110 minutes or longer (28). It was also concluded that CHO feedings are less tolerated during maximal runs lasting 60-90 minutes due to increases in gastrointestinal (GI) distress.

These findings are further supported by a meta-analysis which concluded the performance effects of carbohydrate range from clear improvements of 6% to clear impairments of 2% (25). The best supplement derived from their analysis provided ~0.7grams per kilogram of bodyweight per hour (g/kg/hr) of glucose, ~0.2g/kg/hr of fructose, and ~0.2g/kg/hr of protein, and offered an explanation that different varieties of carbohydrate may aid in maximizing rates of carbohydrate oxidation. The single best source of carbohydrate when consumed at a high rate was found to be glucose, with fructose showing the greatest performance decrements. In addition to fructose possibly increasing GI distress in certain individuals, it was suggested that the conversion of fructose to glucose may not be fast enough to maintain needed oxidation rates during later stages of exercise. It was also concluded that a greater frequency of bolus ingestion offers greater benefits, possibly due to (1) reduced GI distress, (2) changes in metabolism due to changes in insulin response, or (3) ongoing stimulation of carbohydrate receptors in the mouth. A longer fast before the consumption of carbohydrate was also associated with greater benefits from carbohydrate, due to reduced glycogen stores. Given these findings, it would appear that consumption of a typical commercial sports beverage every 10 minutes, containing a variety of simple sugars in a concentration of 6-8% total carbohydrate would be able to most easily and economically accommodate these needs for athletes looking to improve performance in events lasting at least 60-120 minutes.

Carbohydrate Mouth Rinsing

While a recent systematic review published in 2019 concluded that carbohydrate mouth rinsing has the potential to increase mean power output in cycling trials (2), the large variety of methodological differences seen in much of the literature makes it difficult to compare their findings. Table 1 summarizes the characteristics of the literature on carbohydrate mouth rinsing that was investigated for this review. While this summary shows the apparent efficacy of carbohydrate mouth rinsing for improving endurance performance, it also illustrates the wide range of variables that might account for the differences in the magnitude of outcomes (training status of subjects, type of carbohydrate used, mode of exercise, exercise intensity, carbohydrate concentration, rinsing frequency, rinsing duration, fasting status of subjects, and the control).

Mechanisms

The exact mechanisms for how carbohydrate mouth rinsing can increase performance measures such as power output and endurance is unknown. Expectorating the solution precludes significant substrate delivery to working muscle, thus it has been theorized the presence of carbohydrate in the mouth promotes a central effect during exercise (14, 15). The first study to make a connection between a central response from carbohydrate rinsing and endurance performance was published in 2009 (6). It was found that mouth rinsing with a 6.4% carbohydrate solution was associated with improvements in 1 hour cycling time trial performance compared to an artificially sweetened placebo (62.6 ± 4.7 minutes and 64.6 ± 4.9 minutes respectively). Functional magnetic resonance imaging also revealed increased activation of the frontal operculum, orbitofrontal cortex, anterior cingulate cortex, and striatum, which are regions of the brain believed to be involved with reward and motor control. These regions of the brain were similarly stimulated for both glucose and maltodextrin, but were found to be unresponsive to a noncaloric sweetener (saccharin), suggesting a specific responsiveness to the presence of carbohydrate.

Another study that investigated the effects of various taste stimuli on brain activation (Caffeine, citric acid, guanosine monophosphate, saccharin, sucrose, and sodium chloride) found that more brain activation occurs following a 12 hour fast compared to a fed state, with the greatest activation occurring in response to the presence of sucrose (11). These findings suggest that the improvements in exercise performance that are seen when carbohydrate is present in the mouth are due to the stimulation of these brain regions. However, the existence of specialized oral receptors that respond to carbohydrate has yet to be identified in humans.

Concentration

The specific concentration of carbohydrate in solution appears to have little to no effect on performance improvements. One study found that 90 minute self-paced running performance was significantly improved with a 6% carbohydrate solution (14.6 ± 1.7km) compared to placebo (13.9 ± 1.7km) (29). Increasing the solution to 12% saw no additional benefit in distance covered (14.9 ± 1.6km). The solution was administered after the warm-up and then at 15, 30 and 45 minutes of performance trial for a total of 4 rinses. The subjects were active in a competitive sports team (soccer, rugby, field hockey) but were not specifically endurance trained.

Another study found that 1 hour cycle time trial performance was improved with mouth rinsing a 7% maltodextrin solution (57.5 ± 4.5 minutes) compared to placebo (59.5 ± 4.9 minutes) (14). Increasing the solution to 14% saw no additional benefits (57.4 ± 4.1 minutes). Scores for Gastrointestinal discomfort indicated very little GI discomfort during exercise. The solution was administered every 12.5% of the total work for a total of 8 rinses. The subjects were competitive male cyclists who were accustomed to competitions lasting for at least 1 hour.

There have also been some studies that investigated a wider range of concentrations. A paper published in 2016 investigating three different concentrations found no statistically significant differences in 20km cycling time trial both for completion time and for mean power output (17). Rinsing was performed every 2.5km for 5 seconds, averaging 5.7 ± 0.59 minutes between rinses. Completion times were 40.2 ± 4.0, 40.1 ± 3.9, 40.1 ± 4.4, and 39.3 ± 4.2 minutes for placebo, 3%, 6%, and 12% concentration respectively. Likewise, mean power output was 205 ± 22, 206 ± 25, 210 ± 24, and 205 ± 23 W for placebo, 3%, 6%, and 12% respectively. The author concluded that the recreationally trained subjects (average VO2max 47 ± 5 mL/kg/min) is the most likely reason for the lack of performance benefits at any concentration. However, it is also possible that their larger volume of rinse (50mL as opposed to an almost universally used 25mL) could also be part of it. A study published in 2013 concluded that the act of mouth rinsing 25mL of water for 5 seconds increases cycling time trial times when compared against a non-rinse control (69.4 ± 13.81 minutes and 67.6 ± 12.68 minutes respectively), possibly due to a reduction of focus of focus and impairment of breathing rhythm (10). It is possible that the larger bolus of liquid might be more difficult to rinse with and thus exaggerate this effect.

Another study published in 2015 investigating three different concentrations found that there was no statistically significant difference in 1 hour cycling time trial performance for a 4% (62.8 ± 4.0), 6% (63.4 ± 3.4), and 8% (63.0 ± 4.0) CHO solution compared with placebo (62.0 ± 3.0) (12). However, measures of thirst and subjective feelings in the CHO conditions, but not the placebo condition, were significantly elevated by the end of the trial. Rinsing was performed for 5s upon completion of every 12.5% of the trial. Some limitations of this study, however, include (1) Dropouts resulted in their sample size becoming smaller than average for a study like this, and (2) The relatively short fasting period before the trial (3 hours). The fasting period is worth bringing attention to because carbohydrate rinsing has been demonstrated to have either no benefit (1), or a less significant benefit (9, 18) when in a fed state. While there is enough data to suggest a possible lack of a dose-response relationship, more research is needed in order to determine the minimum concentration that is necessary in order to elicit an effective response.

Rinsing Frequency

Research comparing different frequencies of mouth rinsing is lacking. In a review article published in 2015, it was concluded that the performance benefits of a CHO mouth rinse can be achieved through frequent (every 5-10 minutes) contact between the oral cavity and a source of carbohydrate, independent of a sweet taste (4). However, no one study that was reviewed investigated different rinsing frequencies. Considering the wide variety of methodological differences between carbohydrate rinse studies it is difficult to draw meaningful conclusions between separate studies on this variable alone.

Given the transient nature of the performance benefits from carbohydrate rinsing, rinsing more frequently could be warranted in order to maximize the contact time of oral receptors. However, a study published in 2013 concluded that the act of mouth rinsing reduces cycling time trial performance by as much as 3%, possibly by reducing focus on the task at hand and impairing breathing rhythm (10). Because of this, an argument could also be made for rinsing less frequently in order to minimize this effect. Research comparing different rinsing frequencies is warranted in order to shed light on whether or not rinsing frequency impacts the efficacy of the intervention.

Rinsing Duration

The vast majority of studies performed on carbohydrate rinsing have adopted a 5 second rinsing duration (1, 5, 20, 21, 27). The most common reason this duration is chosen is for the ease of replicating methodology that has demonstrated effectiveness, but there are other more practical reasons for adopting a 5 second duration as opposed to a longer one such as 10 seconds. The first reason is a 5 second rinsing duration is more likely to be adopted in ecological settings compared to longer durations (12). The second reason is to minimize the detrimental loss of power output resulting from rinsing a liquid in one's mouth (10). While longer rinse durations would likely provide greater stimulation of oral receptors from increased exposure, the longer period of reduced focus could potentially result in a net reduction in power output.

A study published in 2014 sheds some light on the question of whether a 5 second rinse or a 10s rinse is more practical (23). Utilizing 11 recreationally trained cyclists, their training protocol involved 3 simulated cycling time trials of cycling for maximal distance over 30 minutes. During the 3 experimental trials, participants were given either a tasteless 6.4% maltodextrin solution, or a water placebo. The two maltodextrin trials were differentiated by rinsing duration, with one rinsing for 5 seconds and the other rinsing for 10 seconds. Mouth rinsing was performed every 6 minutes of the total protocol before expectorating. Total distance cycled for the 10 second (20.4 ± 2.3 km) and 5 second (20.16 ± 2.2) maltodextrin trials both showed a marked improvement in distance cycled compared to placebo (19.2 ± 2.2km), but only the 10 second trial did so to the point of statistical significance. 10 out of the 11 cyclists cycled a greater distance in the 5 second rinse compared to placebo, and 8 cyclists in the 10 second trial cycled a greater distance compared to the 5 second trial. While these results would appear to suggest a 10 second rinse being superior than a 5 second rinse, it is only a marginal difference when comparing the means. Because of this, a 5 second rinse may be more practical for competitive events as an athlete would be able to get most of the benefits while having a less pronounced effect on breathing rhythm and focus.

Carbohydrate Mouth Rinsing (vs Ingestion)

Research comparing carbohydrate rinsing to carbohydrate ingestion is lacking, making it difficult to draw meaningful conclusions. A more complete breakdown of the studies investigating carbohydrate rinsing compared to ingestion can be found in Table 1. One study found that mouth rinsing, but not ingestion, of carbohydrate improves 60 minute cycle time trial performance in endurance trained triathletes (20). Twelve subjects were asked to complete four experimental trials: (1) Placebo rinse, (2) Carbohydrate ingestion (3) Placebo ingestion, and (4) Carbohydrate ingestion, with each test separated by at least 48h. Subjects were fasted for 3 hours before each trial. The exercise protocol comprised a 5 minute warmup at 100W on a cycle ergometer, followed by completing a set amount of work (equal to 60 minutes of cycling at 75% W_{max}) as fast as possible. The total rinsed/ingested amount of solution was set at 14mL/kg body weight that was equally distributed over the entire trial. During the mouth rinse trials, subjects were asked to rinse the solution in their mouth for 5 seconds and before expectorating. Before and after the warm-up, subjects received 2 and 1.5mL/kg of solution respectively and received another 1.5mL/kg after every 12.5% of total work completed. The carbohydrate-electrolyte solution was a commercial-branded beverage (Gatorade), with the placebo solution containing the exact same ingredients except the carbohydrate was replaced with a non-caloric sweetener (Aspartame). Carbohydrate rinsing was found to improve time trial time by 3.9% compared to the placebo rinse (61.7 ± 5.1 vs 64.1 ± 6.5 minutes respectively), with carbohydrate ingestion showing no significant difference compared to placebo ingestion (63.2 ± 6.9 vs 62.5 ± 6.8 minutes respectively). Power output was also found to increase with CES rinsing (265 ± 30.6 W) compared with PLA rinse (256 ± 34.3 W). Despite increased power output with carbohydrate rinsing, there was no differences in RPE, suggesting subjects were able to work harder at the same perceived intensity.

Another study investigated the effects of carbohydrate ingestion and mouth rinses on repeated sprint performance in recreationally active individuals (16). Fourteen subjects were asked to complete four experimental trials: (1) Carbohydrate rinse, (2) Carbohydrate ingestion, (3) Placebo rinse, and (4) Placebo ingestion, with each trial separated by at least seven days. Subjects were fasted for 10 hours before each trial. The exercise protocol comprised a 5 minute warmup, followed by a series of five maximal 15 second sprints interspersed with 4 minutes of active recovery at 50 W. Ten seconds before each sprint, subjects were instructed to increase their cadence and maximally increased their cadence 6 seconds prior. There was no resistance during this 10 second phase before each sprint to allow subjects to reach maximal cadence. At the beginning of each sprint, 0.075 kg/kg body mass of resistance was applied. The total protocol lasted for 22 minutes and 15 seconds. Throughout each trial, subjects received a total of six beverages, which were administered immediately before the 5 minute warmup and 45 seconds before each sprint. During the mouth rinse trials, subjects were instructed to rinse the solution for 10 seconds before expectorating. During ingestion trials, subjects were instructed to ingest the entire bolus as fast as possible. Each beverage consisted of a 50 mL solution containing either 10% carbohydrate or a sugar-free similarly flavored placebo. The carbohydrate solution consisted of a sugar and dextrose mixture similar to that of commercially available sports beverages, with the placebo being an artificially flavored zero-calorie solution. When performing five 15 second maximal cycling sprints interspersed with 4 minutes of active recovery, Mean power output and total work were found to be significantly greater with CHO Ingestion (659.3 ± 103.0 W, 9849.8 ± 1598.8 joules) compared with CHO Rinse (645.8 ± 99.7 W, 9447.5 ± 1684.9 joules). Fatigue index was also significantly attenuated with CHO Ingestion (15.3 ± 8.6 W/s) compared with CHO Rinse (17.7 ± 10.4 W/s). This study is quite different from other studies investigating carbohydrate rinsing in that it measured power output and work during repeated cycling sprints, compared to much more common protocols utilizing endurance cycling or running. This makes the findings difficult to compare to other literature. What's intriguing about these findings is that carbohydrate ingestion offered any benefits at all given the relatively short total time of the entire protocol, where glycogen depletion is believed to not normally be a limiting factor. This might be due to the relatively long fasting period of 10 hours causing enough glycogen depletion to allow for benefits to be seen despite the relatively short testing period.

A third study investigated the effects of carbohydrate mouth rinsing on a 60 minute running trial compared with rinsing and ingestion of the same carbohydrate (22). Ten subjects were asked to complete three trials: (1) Carbohydrate rinse + ingestion, (2) Placebo rinse + ingestion, or (3) Carbohydrate rinse without ingestion. The exercise protocol comprised a 5 minute warmup followed by a running trial where subjects were instructed to run as far as they can in 60 minutes. Subjects would run on a treadmill that dynamically adjusted speed based on their position on the belt. In the two ingestion trials, runners ingested the equivalent of 8 mL/kg body mass of solution 30 minutes before the 1 hour run. Runners also ingested 25 mL immediately before the run, and then the equivalent of 2 mL/kg at 15 minute intervals during the run. Runners were also instructed to rinse the last mouthful of solution for 5 seconds before ingestion to maintain a similar mouth contact time with the rinse-only trial. During the rinse-only trials, the 25 mL of the same carbohydrate beverage was administered at the same time points (30 minutes before, immediately before, and every 15 minutes during the trial), with subjects instructed to rinse the solution for 5 seconds before expectorating. The carbohydrate solution used was a commercially available 6.4% carbohydrate-electrolyte beverage, with the placebo containing identical formulation except the carbohydrate was replaced with artificial sweetener (Aspartame). It was found that rinsing and ingesting a 6.4% carbohydrate-electrolyte solution caused subjects to cover more distance compared with placebo (14,515 ± 756 vs. 14,190 ± 800 m respectively), and also covered more distance compared to just rinsing the solution (14,283 ± 758 m). Additionally, there was no significant difference between the CHO rinse trial and placebo ingestion, suggesting that only rinse and ingestion of a carbohydrate-electrolyte solution provides meaningful endurance benefits.

With one study concluding that carbohydrate rinsing is superior to ingestion, one study concluding that ingestion is superior to rinsing, and a third study concluding the combination of the two to be superior, this makes it difficult to form a meaningful conclusion as to the efficacy of carbohydrate rinsing when compared with carbohydrate ingestion. This is further compounded by the fact that each study utilized very different methodology. While it is possible that carbohydrate mouth rinsing has some degree of efficacy compared to ingestion, more research is necessary to provide a more complete picture as to the precise magnitude.

Conclusion

In conclusion, there appears to be a solid case for the efficacy of carbohydrate mouth rinsing for improving endurance exercise performance. While the wide degree of variation in methodology of currently available literature makes it difficult to draw meaningful conclusions, the most common magnitude of improvement was in the range of 2-4% for endurance trained and competitive athletes, although some studies have shown improvements as high as 6-8% in recreationally trained athletes. While some studies have found success with relatively high concentrations of carbohydrate (10-16% CHO), a concentration of 6-8% has been demonstrated to be not only just as effective but also much more practical due to matching the concentrations found in commercially available sports drinks.

Regarding rinsing duration, a duration of 5 seconds is by far the most common to be utilized in literature while also appearing to be more than adequate for ensuring efficacy. While a rinse duration of 10 seconds has been demonstrated to possibly be more effective, the difference is minor at best. Because of this, it was concluded that a 5 second duration is still more practical due to being more likely to be adopted into wider use. For rinsing frequency, little to no literature investigating this variable exists. However, frequencies of 5-10 minutes are common in the currently available literature and appear to be sufficient for incurring performance benefits. The question of whether or not a higher frequency would result in greater benefits is yet to be investigated, and future research on this is warranted.

Another important factor is the effectiveness of carbohydrate rinsing compared to traditional carbohydrate ingestion. Studies comparing the two are very limited, and the few that are available draw different conclusions. While carbohydrate rinsing might offer some degree of improvement relative to ingestion, more research is needed in order to determine the precise magnitude and direction.

METHODS

General Design

The present study employed a double-blind, randomized, crossover design. The study consisted of two 20 km cycling time trials that followed 60 minutes of steady state cycling at 60% VO2max. The trials consisted of 1) placebo rinse plus CHO ingestion and 2) CHO rinse plus CHO ingestion. This study was approved by the Stephen F. Austin Institutional Review Board, and all subjects provided informed consent before participating.

Subjects

Subjects were apparently healthy, recreationally active men and women between the ages of 18-65 were recruited for the study. Cyclists and individuals who routinely exercised on cycle ergometers were preferentially recruited. Inclusion criteria for subjects was as follows: 1) Subjects must have been participating in a regular routine of moderate-intensity aerobic exercise for at least 300 minutes per week, vigorous-activity aerobic exercise for at least 150 minutes per week, or an equivalent combination of moderate and vigorous activity for at least 3 months; 2) Subjects must have been habitually consuming a mixed diet for at least 3 months; 3) Subjects must have been weight stable for at least 1 month. Exclusion criteria for subjects were: 1) Known disease or signs/symptoms of disease, 2) Participating in a diet or weight loss program, 3) Regular low-carbohydrate intake, 4) Ingesting dietary supplements or medications known to impact exercise performance within the previous 2 weeks, with the exception of caffeine, protein, and carbohydrate supplements, 5) Injury that would preclude participation in exercise.

Pre-Experimental Protocol

On their first visit to the laboratory, each subject had their height, weight, and body composition assessed. Body composition was acquired using a GE Lunar Dual Energy X-Ray Absorptiometry (DEXA) machine. Afterwards, they performed a maximal, incremental test to exhaustion on an electronically braked bike (Wahoo KICKR, Wahoo Fitness, Atlanta, GA, USA). During the maximal test, subjects inspired air through a two-way valve attached to a custom-built Parvo Medics TrueOne 2400 metabolic cart that was calibrated against a known air sample, with heartrate measured using a Wahoo heart rate sensor (Parvo Medics, Salt Lake City, UT, USA; Wahoo TICKR, Wahoo Fitness, Atlanta, GA, USA). VO2max was defined as the highest oxygen uptake subjects achieved during sampling periods, with the results of the max test being used to establish work rates for each subject in subsequent trials. The Wahoo bike was set to ergometer mode throughout the maximal test, meaning the power output was set and the ergometer electronically adjusted resistance based on the cyclists cadence.

Fifteen minutes following the VO2max test, subjects then completed a familiarization trial involving cycling for 5km with the bike set to simulation mode in order to allow the subject to get comfortable with freely changing gears for modifying resistance and speed. Simulation mode mimics real over ground cycling where the subject’s cadence and gearing selection dictate speed. During this trial, subjects were asked to pedal at a pace they could maintain for 20km. This served as familiarization for the time trial simulation portions of the experimental protocol.

Experimental Protocol

Subjects arrived to the lab following a 10 hour fast, having abstained from coffee, alcohol, tobacco, and exercise in the previous 24 hours. Upon arrival, subjects were weighed and fitted with a heart rate monitor. The bike was set to ergometer mode in order to apply resistance to the bike to maintain a set work rate. Subjects first performed a 10 minute warmup at 70W with a self-selected cadence. Following the warmup, subjects were instructed to rinse a 25mL solution (placebo or CHO) before ingesting 1.5mL/kg body weight of a CHO beverage (ingestion always CHO). After ingesting the CHO beverage, subjects were instructed to perform six 10 minute cycling bouts at a power output deemed to elicit 60% VO2 max interspersed with six 30 second all-out sprints. One minute before each sprint, the subject performed another rinse followed by CHO ingestion and was asked to rate their perceived exertion using the 6- to 20-point Borg scale prior to the sprint. All sprints were conducted in simulation mode in the same gearing ratio throughout all attempts and trials. Subjects were giving 1 minute of easy spinning following each sprint following the start of the next 10 minute steady state effort.

Upon completion, the subject rested for 10 minutes, and the bike was set to simulation mode to allow subjects to pedal at a self-selected gear and cadence as was previously done in their familiarization time trial. After resting, the subject performed another rinse followed by CHO ingestion and immediately began a time trial of cycling a set distance (20km) as quickly as possible. At set intervals during the time-trial (every 20% of time trial completed in order to ensure a similar drinking frequency as the previous exercise bout), the subject performed another mouth rinse and CHO ingestion, and was asked to rate their perceived exertion using the 6- to 20-point Borg scale.

Care was given to minimize potential external stimuli or disruption. During each trial, no interaction occurred between the subject and test proctor except for administration of the mouth rinse and Borg scale. No encouragement was given to subjects, and other than being able to see distance covered they were kept unaware of information related to their performance (time, speed, cadence, heart rate) during each trial. Individuals not involved in the study were excluded from the laboratory to minimize disruption.

Rinsing Protocol

At regular intervals during each exercise bout, subjects were given a 25mL bolus of either 6.4% carbohydrate (CHO) or a taste-matched non-caloric placebo (PLA). The subjects were instructed to rinse the fluid in their mouth for 5 seconds before expectorating the solution. Afterwards, the subjects were given a second 1.5mL/kg body weight bolus of the same 6.4% CHO beverage to be immediately ingested. For the initial intermittent sprint session, subjects rinsed and ingested 30 seconds before beginning exercise and rinsed and ingested again 30 seconds before each sprint, allowing for 10 minutes between each bolus. For the 20km time trial, subjects rinsed and ingested 30 seconds before beginning exercise and rinsed and ingested again every 20% of trial completion, which allowed for a similar frequency of around ~10 minutes between each bolus.

The rationale for ingesting CHO solution in both trials is due to the fact that in performances lasting longer than 90 minutes, CHO is likely essential and of benefit. Our purpose of determining whether or not an exaggerated 5 second rinse of the beverage prior to ingestion was achieved by the prior CHO or placebo rinse conditions that were employed. The subjects were kept blind to the composition of their rinse treatments until the completion of the study.

Dietary Procedures

During the 24 hour period before their first visit to the lab, subjects were asked to record their diet and were asked to replicate the same diet before all subsequent visits as well as avoid exercise in the 24 hour period before each test. Subjects were advised to eat a mixed diet rich in carbohydrate during their last meal the evening before the test.

Statistical Analysis

A dependent sample t-test was used to determine differences between trials in average power during the 6 sprint efforts as well as the time to complete the 20k trial. Power across the sprint efforts was analyzed by a 2-way (trial x time) repeated measures ANOVA.

RESULTS

A total of 5 subjects participated in the study. Subject demographics can be found in Table 1. The mean values across the 6 sprint efforts are displayed as follows: power (Figure 1), cadence (Figure 2), heart rate (Figure 3), speed (Figure 4), RPE (Figure 5). There was no main effect for condition or condition by time interaction for power cadence, heart rate, or speed across the 6 sprints. There was a condition by time interaction for RPE (Figure 6), with the CHO condition having slightly lower RPE only for the first sprint interval. Average performance data for all six sprint efforts can be found in Table 2, and performance data across the entire 60-min cycling bout can be found in Table 3. A paired sample t-test revealed no significant differences between conditions for any of the tested parameters.

The mean values for each 4km of the 20km the time trial are displayed as follows: time splits (Figure 6), power (Figure 7), cadence (Figure 8), heart rate (Figure 9), speed (Figure 10), RPE (Figure 11). There were no main effects for condition or condition by distance interaction for any of the tested variables. Average performance data across the 20km time trial can be found in Table 4. Again, paired sample t-tests revealed no significant differences between conditions for any of the tested parameters.

DISCUSSION

The aim of the present study was to investigate the effects of CHO mouth rinsing combined with ingestion compared to CHO ingestion alone on endurance performance. Key findings of the study were there was no main effects for condition or interaction for any of the performance variables measured.

CHO mouth rinsing offering performance benefits in the area of endurance exercise is supported by previous data (5, 8, 21, 23, 29), and it has been theorized that the presence of CHO in the mouth has a stimulatory effect during exercise that allows it to offer performance benefits despite no significant substrate delivery to working muscle (14, 15). The present study aimed to investigate whether combining CHO mouth rinsing with traditional ingestion could offer additional benefits over rinsing or ingestion alone. As a more novel area of research, the corresponding data is limited. To our knowledge, only two studies have compared CHO rinsing with CHO ingestion (16, 20), and only one study has looked into combining the two (22). Additionally, all three of these studies come to different conclusions, with one concluding rinsing is superior to ingestion (20), one concluding that ingestion was superior to rinsing (16), and the third study concluding the combination of the two to be superior (22). Because of the differences in methodology and outcomes, it becomes difficult to draw meaningful comparisons from this varied body of knowledge.

In Pottier et al., (20) it was concluded that rinsing with a CHO solution for 5 seconds was able to improve 60 minute cycling time trial times in endurance-trained triathletes, whereas ingesting the solution provided no significant effect on performance. Conversely, Krings et al., (16) came to the opposite conclusion, where CHO ingestion was able to improve performance in repeated 15-second cycling sprints, whereas rinsing for 10 seconds between sprints offered no benefit. While they differ significantly from the present study in that they do not investigate combining CHO rinsing with ingestion, these studies are at least able to offer some insight that there may be variables that result in CHO rinsing providing benefits where ingestion cannot and vice versa. Such variables could be differences in training status, the duration of exercise, the type of exercise, rinsing duration, individual variability, etc.

As it is the only study to our knowledge that investigated combining CHO rinsing with ingestion, Rollo et al. (22) is similar enough to the present study where some comparison of findings are able to be made. It was concluded that rinsing plus ingestion of a CHO solution provided additional benefit over CHO rinsing alone. A slightly larger dose of CHO was administered than the present study, a difference of 0.5mL/kg, however it was administered at a lower frequency of every 15 minutes. While the present study consumed an additional 1mL/kg body weight for every hour of exercise, the primary reason for differences in total CHO consumed is due to differences in exercise duration. However, rather than utilizing a no-rinse CHO ingestion trial in the present study, we selected a placebo rinse as a control, and found no differences with the CHO rinse condition. This indicates that the Rollo findings may have been influenced by a placebo effect, and there really are no additive benefits of an exaggerated rinsing period prior to ingestion. A possible explanation for the findings in the present study is that any receptors thought the be stimulated through mouth rinsing are already adequately stimulated with normal CHO beverage consumption, and any additional stimulation provided by an exaggerated rinse done before ingestion is either minimal or even unnecessary.

Given the current findings, the present study is not without limitation. One limitation was the small sample size (n=5). A larger sample may help to clarify the effect of CHO rinsing plus ingestion on endurance performance. Another limitation was the lack of a no-rinse condition, as our control condition involved a placebo rinse followed by CHO ingestion. There is data to indicate that the act of mouth rinsing alone may reduce performance due to loss of focus or impaired breathing rhythm (10), thus having a no-rinse trial to compare with would help to verify whether or not this had an impact on our findings.

Future research could include more subject populations, as it has been speculated that training status has an impact on the ability to benefit from CHO rinsing. More attention should also be placed on the various factors in the exercise prescription (intensity, duration, etc) and also the administration of the CHO solution (frequency, concentration, rinse duration, dose, etc). Lastly, future research should incorporate a no-rinse condition to ensure that any benefit thought to be gained from a CHO rinse would actually provide a net benefit over only ingestion.

Despite some limitations, this is the first study to assess the effects of an exaggerated CHO mouth rinse prior to CHO ingestion while using a placebo rinse as a control. Our findings indicate that an exaggerated rinsing period prior to ingestion does not appear to offer any additive benefit compared to typical CHO ingestion patterns, suggesting that normal drinking techniques are adequate when CHO ingestion is warranted.

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Table 1. Demographic, body composition, and VO2max values obtained from initial fitness screening of individuals.

Variables	Average
Age (years)	38.0 ± 12.6
Weight (lbs)	158.3 ± 24.8
Height (in)	68.4 ± 5.1
BMI (kg/m^2)	24.0 ± 4.7
Body Fat %	22.56 ± 6.4
VO2max (ml/kg/min)	43.8 ± 10.0

All values represent mean ± SD.

Table 2. Average performance variables of all sprint efforts.

Variables	Carbohydrate	Placebo	p-value
Average Power (watts)	425.0 ± 80.3	437.2 ± 47.7	0.570
Average Cadence (rpm)	99.9 ± 12.8	102.0 ± 11.5	0.197
Average Heart Rate (bpm)	157.4 ± 12.3	157.4 ± 8.4	0.999
Average Speed (km/h)	37.7 ± 2.9	38.0 ± 1.8	0.668
Average RPE (6-20)	16.7 ± 3.3	17.3 ± 2.4	0.347

All values represent mean ± SD. p-values from dependent t-test comparing conditions.

Table 3. Average performance variables of the 60-min cycling bout

Variables	Carbohydrate	Placebo	p-value
Total Distance (km)	29.7 ± 3.9	28.6 ± 5.4	0.466
Average Power (watts)	137.0 ± 26.8	138.0 ± 25.6	0.217
Average Cadence (rpm)	74.8 ± 10.7	73.6 ± 12.9	0.798
Average Heart Rate (bpm)	143.9 ± 13.1	143.5 ± 8.9	0.849
Average Speed (km/h)	28.3 ± 3.7	27.2 ± 5.2	0.468

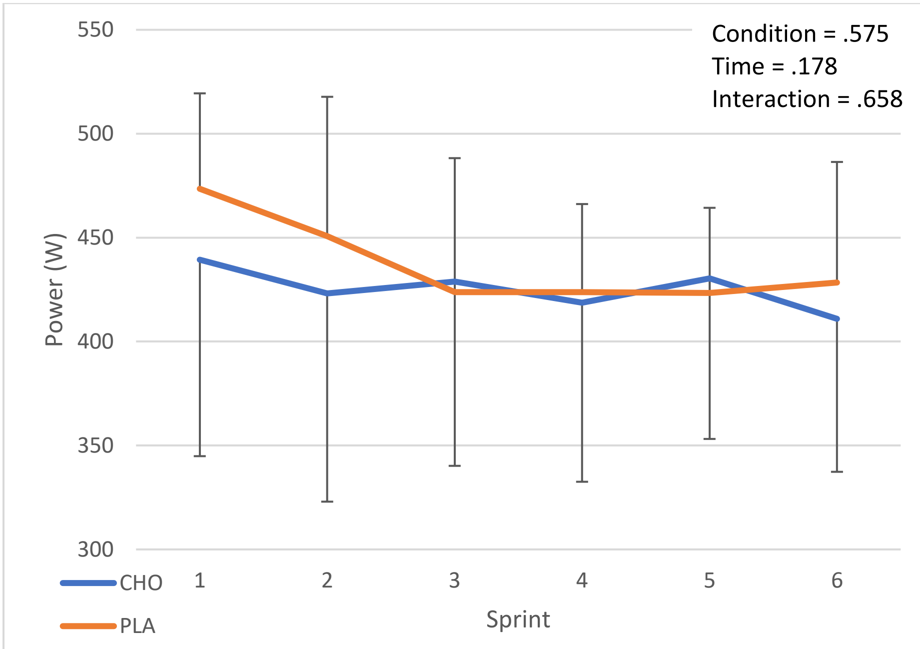
All values represent mean ± SD. p-values from dependent t-test comparing conditions.

Table 4. Average performance variables of the 20km time trial

Variables	Carbohydrate	Placebo	p-value
Total Time (min)	43.1 ± 3.8	42.8 ± 3.6	0.464
Average Power (watts)	163.3 ± 40.1	166.7 ± 41.5	0.405
Average Cadence (rpm)	77.2 ± 12.5	75.4 ± 14.6	0.315
Average Heart Rate (bpm)	160.3 ± 9.2	159.3 ± 10.4	0.442
Average Speed (km/h)	28.0 ± 2.5	28.3 ± 2.5	0.444
Average RPE (6-20)	15.8 ± 1.9	16.1 ± 1.2	0.537

All values represent mean ± SD. p-values from dependent t-test comparing conditions.

Figure 1.



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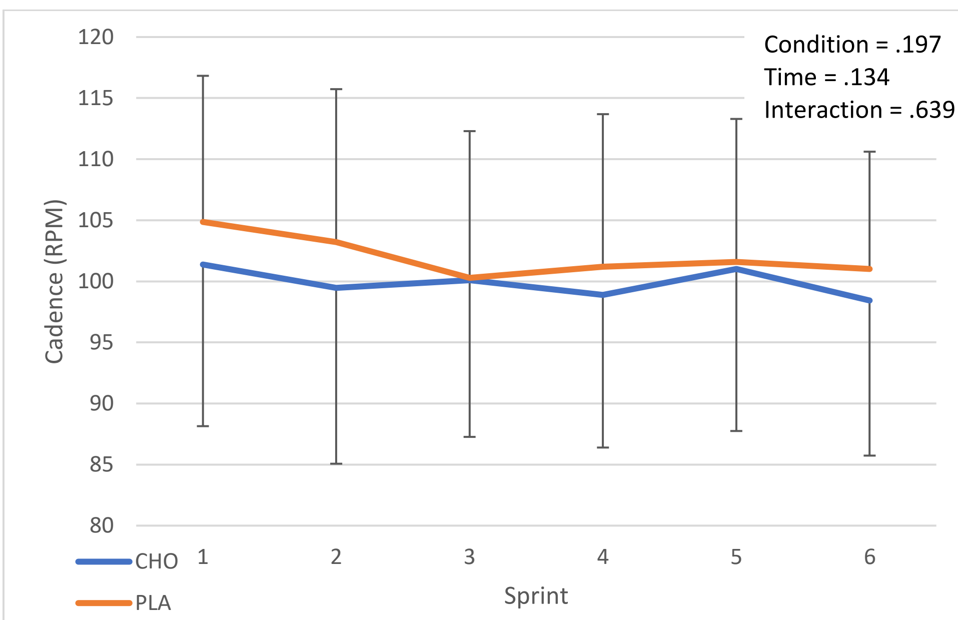

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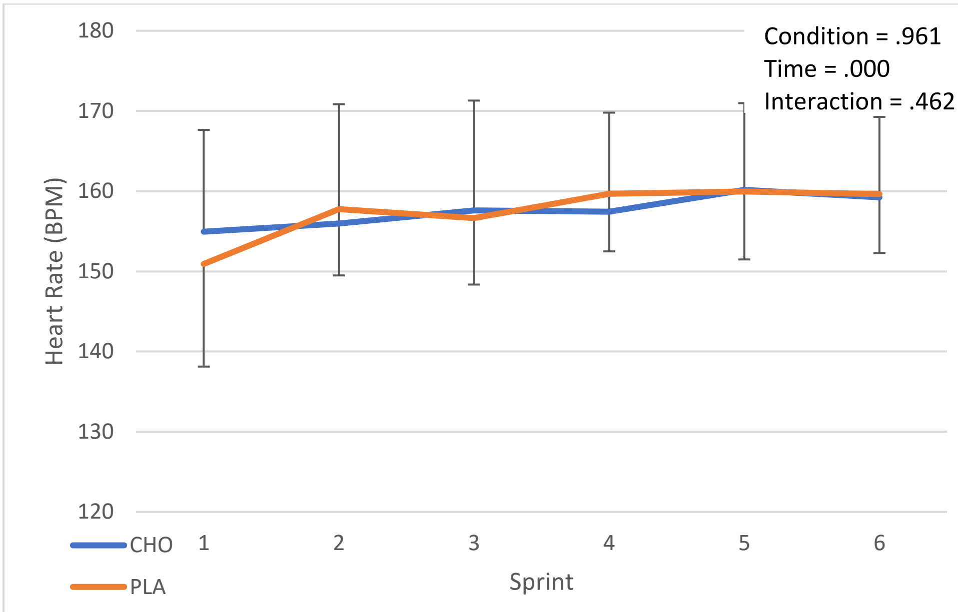

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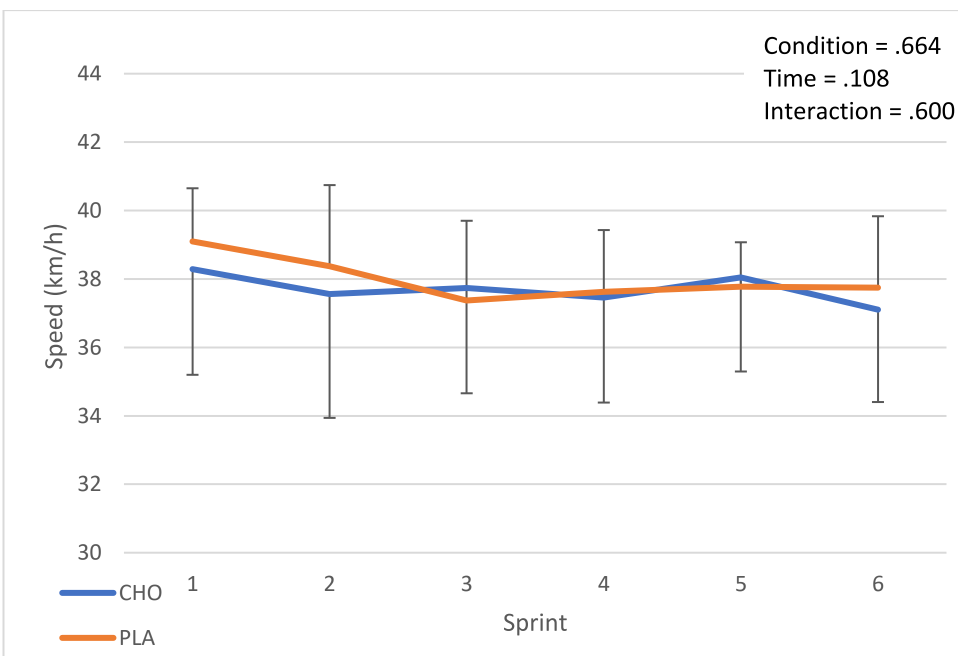

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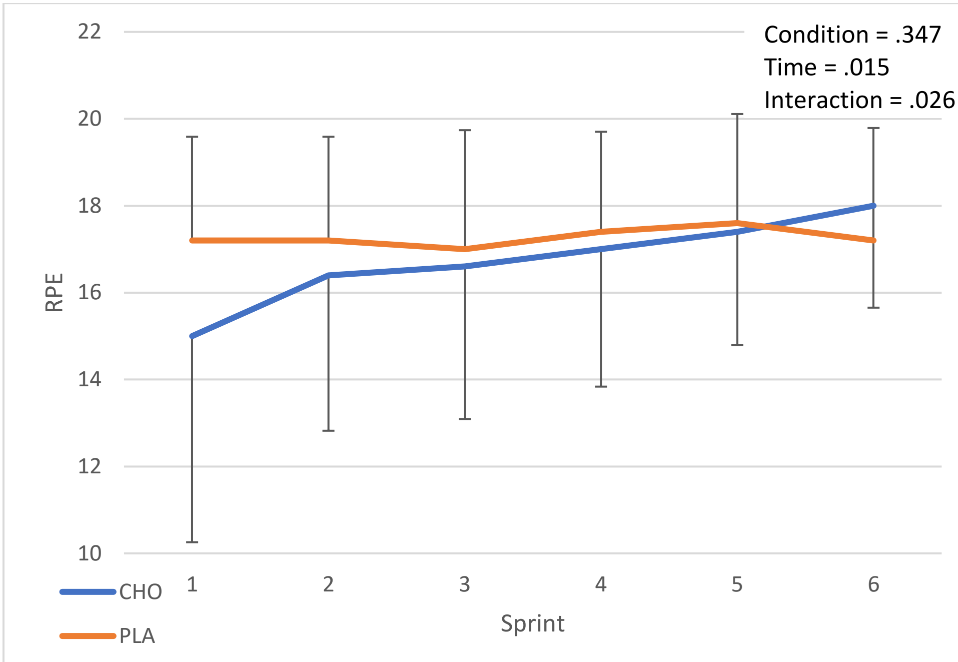

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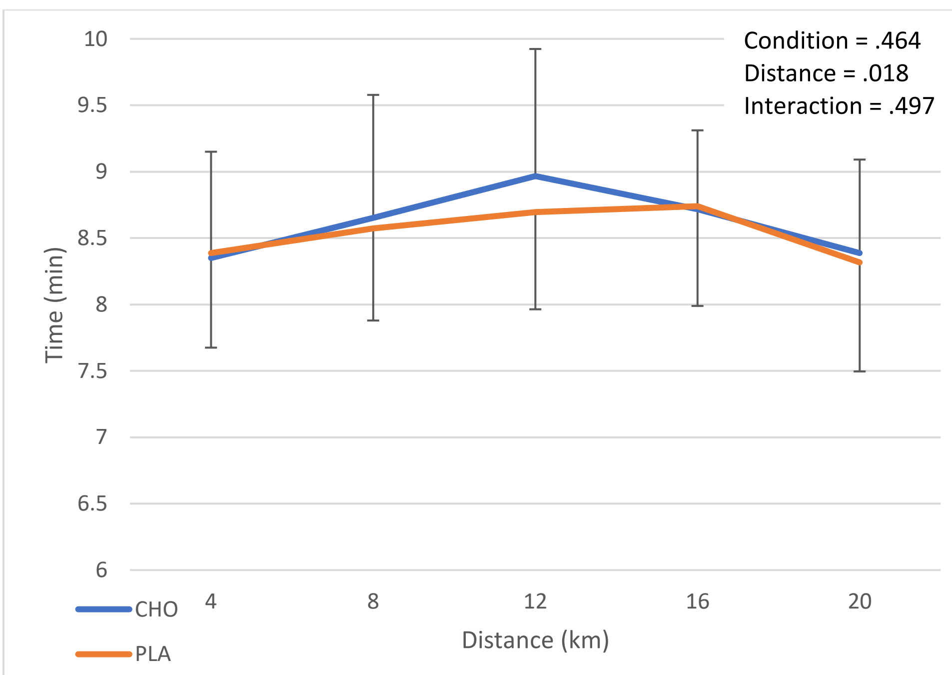

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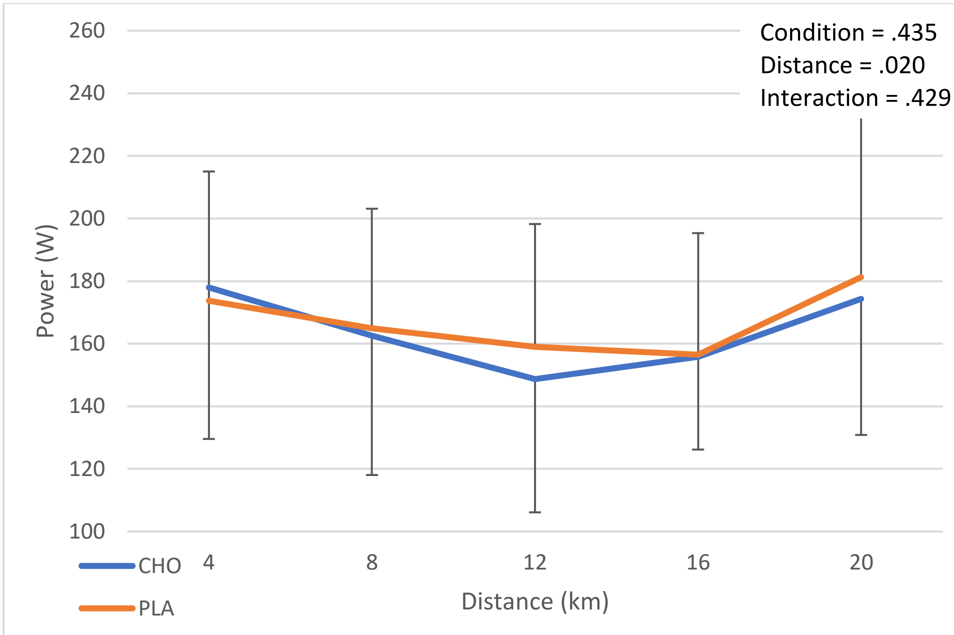

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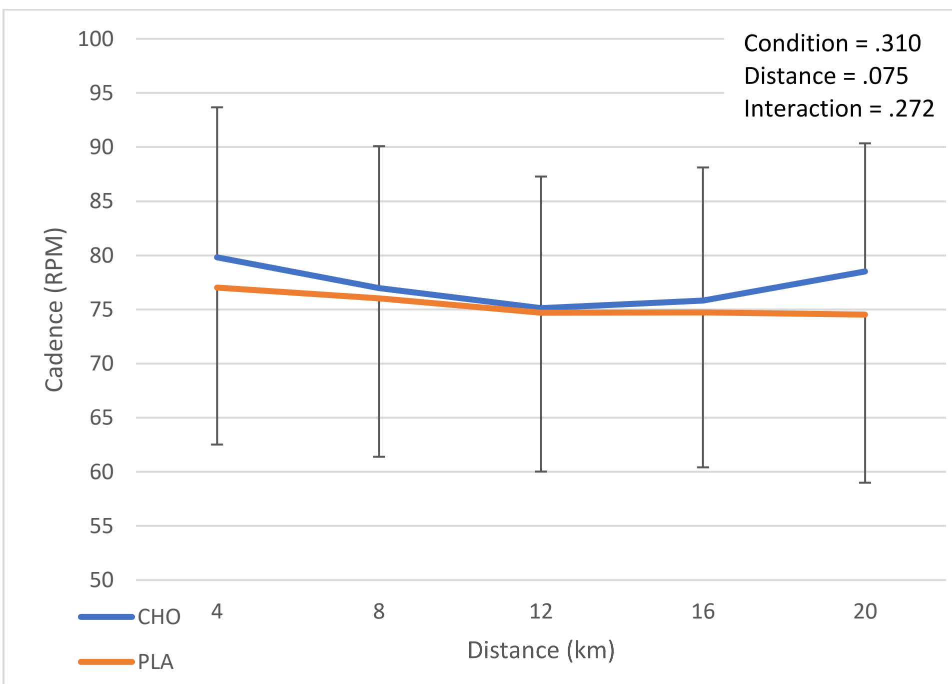

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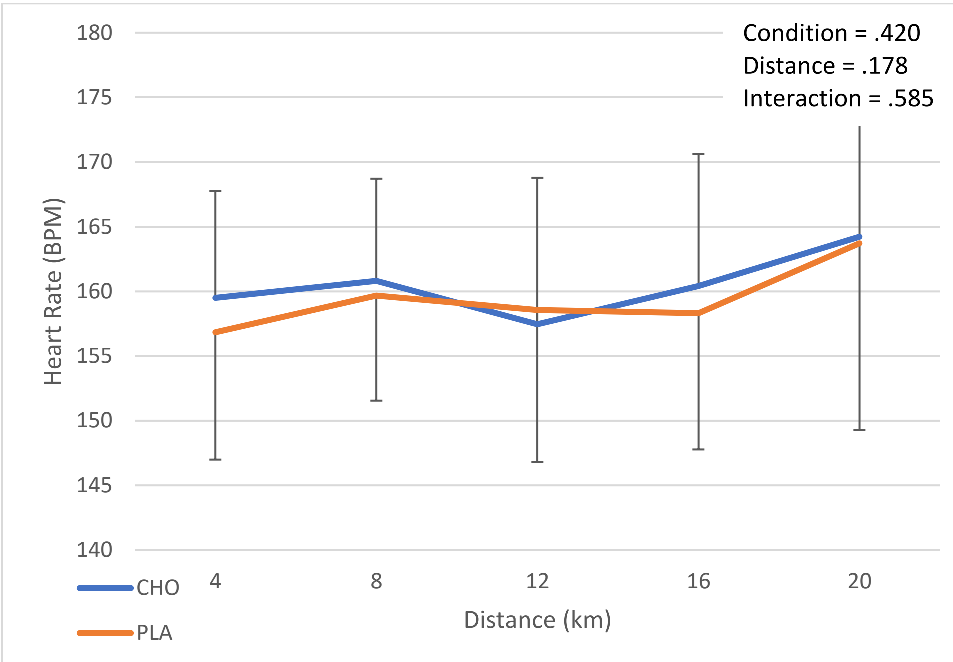

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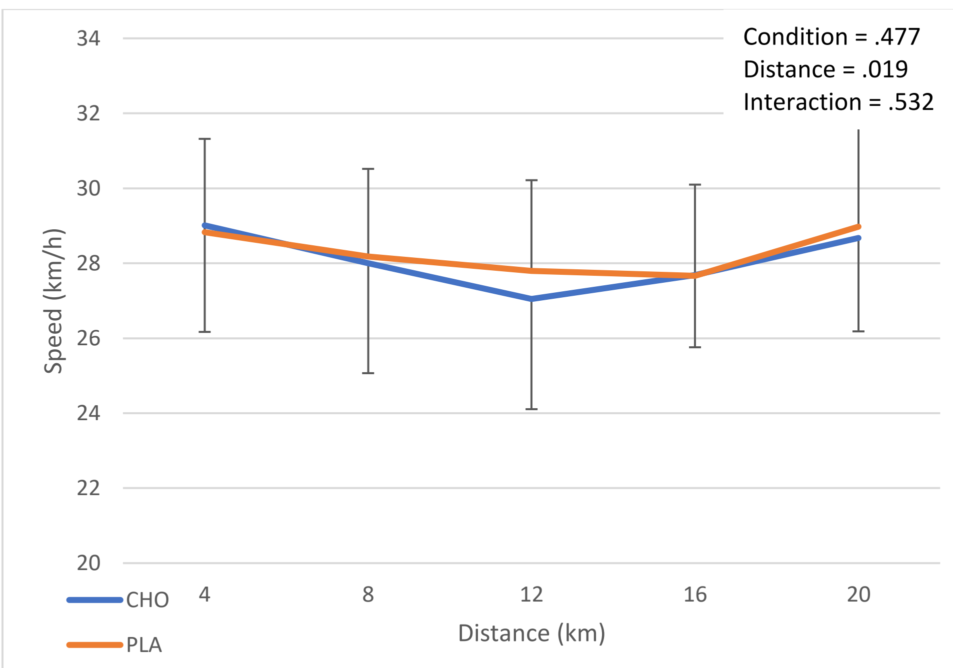

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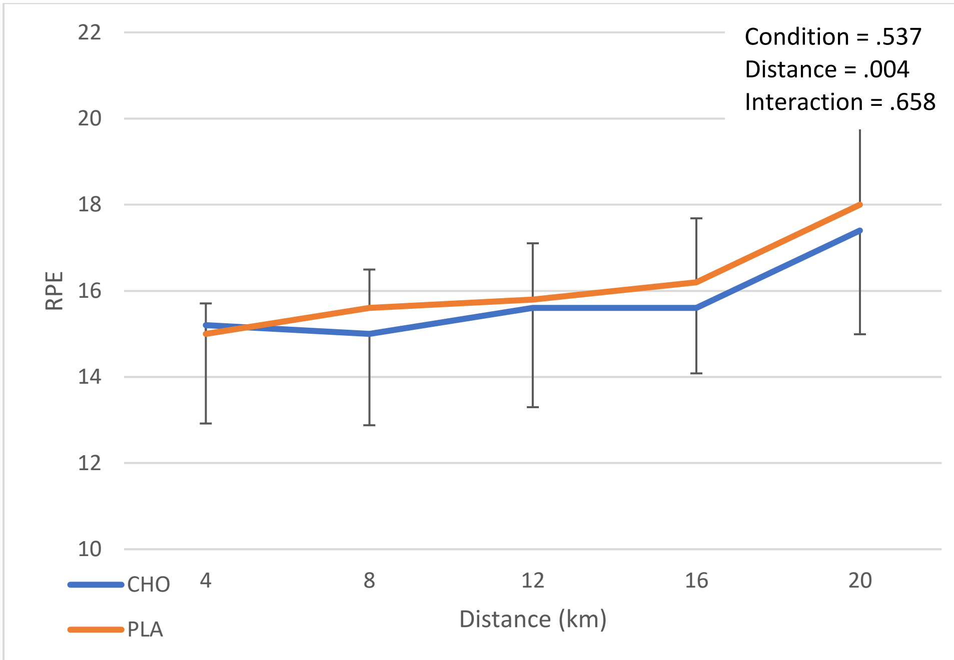

Condition = .537
Distance = .004
Interaction = .658
22
20
18
16
14
12
10
RPE
4
8
12
16
20
Distance (km)
CHO
PLA

Figure 1. Average power output during 6, 30-second intermittent cycling sprint efforts over the course of 1-hour (sprint every 10 minutes) steady state ride at 60% VO2max for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 2. Average cadence output during 6, 30-second intermittent cycling sprint efforts over the course of 1-hour (sprint every 10 minutes) steady state ride at 60% VO2max for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 3. Average heart rate during 6, 30-second intermittent cycling sprint efforts over the course of 1-hour (sprint every 10 minutes) steady state ride at 60% VO2max for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 4. Average speed during 6, 30-second intermittent cycling sprint efforts over the course of 1-hour (sprint every 10 minutes) steady state ride at 60% VO2max for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 5. Average perceived exertion during 6, 30-second intermittent cycling sprint efforts over the course of 1-hour (sprint every 10 minutes) steady state ride at 60% VO2max for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 6. Time splits for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 7. Average power for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 8. Average cadence for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 9. Average heart rate for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 10. Average speed for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

Figure 11. Average perceived exertion for each 4 km segment of 20 km time trial for CHO and PLA mouth rinsing conditions. All values represented as mean ± SD.

VITA

After graduating from Houston Christian High School in May of 2011, Henry Gebhardt enrolled at Stephen F. Austin State University in Nacogdoches, Texas. He received a Bachelor of Science in Kinesiology with an emphasis in Fitness and Human Performance in December of 2018. The following semester he enrolled in the Graduate School of Stephen F. Austin State University where he was employed as a graduate teaching and research assistant for the Kinesiology and Health Science Department.

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