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Effect of carbohydrate intake on pacing in endurance cycling

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Effect of Carbohydrate Intake on Pacing in Endurance Cycling

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by Morgan Ann Price

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Accepted by the faculty of the Department of Kinesiology, James Madison University, in partial fulfillment of the requirements for the Honors Program.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at the JMU Honors Symposium on April 24, 2015.

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Effect of Carbohydrate Intake on Pacing in Endurance Cycling

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I would like to dedicate this to my loving family and friends who have supported me throughout this wonderful journey. I would also like to dedicate this to my professor and advisor, Dr. Saunders. I could not have done it without all of your guidance and support.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

LIST OF FIGURES

Figures

LIST OF TABLES

Tables

ABSTRACT

PURPOSE: To study the influences of carbohydrate intake (CHO) on pacing in endurance cycling, as well as the effects of wearing metabolic headgear (HG) on power output. METHODS: Eight male endurance trained cyclists completed 120 min of constant load cycling at 55% W_{max}, immediately followed by a simulated 30 km time trial, on two occasions. On one occasion, subjects consumed a CHO solution at regular intervals throughout the trial, while a placebo (PL) was consumed during the other trial (in a randomly counterbalanced design). For statistical analysis, the 30 km time trial was divided into 4 segments (S1 = 0-7.5 km, S2 = 7.5-15 km, S3 = 15-22.5 km, and S4 = 22.5-30 km), with each segment immediately preceded by a beverage feeding. Further, each of these segments was sub-divided into early (EP) and late phases (LP). Power output (PO) was averaged for three-minute periods in each phase. In addition, PO was calculated for two five-minute periods during the time trial, when HG was worn (starting at 12 km) and not worn (starting at 20 km). RESULTS: In the 30 km time trial (both CHO and PL conditions), PO decreased significantly between S1 (240 ± 13) and S2 (227 ± 11) (p = 0.019), and decreased further during S3 (216 ± 11) (p = 0.017). Subsequently, PO increased between S3 and S4 (234 ± 12) (p = 0.001), resulting in values in S4 which were not significantly different from S1 (p = 0.302). CHO ingestion resulted in significantly greater PO during the trial, versus PL (242 ± 10 W vs 217 ± 14 W; p = 0.044). In the CHO trial, PO did not decrease significantly across the four time segments (p>0.05), whereas in the PL trial PO decreased significantly from S1 to S2 (p = 0.008) and from S2 to S3 (p = 0.009), followed by a subsequent increase in PO between S3 and S4 (p = 0.001). PO was not significantly different between the early and late phase following beverage consumption (230 ± 12 W vs 229 ± 12 W; p = 0.709). There was no significant effect of HG on PO (HG = 216 ± 10 W, no HG = 221 ± 11 W;

p = 0.299). CONCLUSION: CHO ingestion improved endurance performance and influenced pacing in a general manner, by preventing decreases in PO over the first three quarters of the time trial. However, the ergogenic effects of CHO were not systematically different between early and late periods following each feeding. In addition, wearing headgear to measure metabolic measurements during exercise did not affect PO.

CHAPTER I: INTRODUCTION

Various pacing strategies are utilized by endurance athletes, and may have an influence on optimal performance levels. The specific pacing strategy chosen by an athlete can be affected by the distance or demands of the event, how the individual feels that particular day, the context of the endurance event (whether it is a high-level competition or not), as well as many other factors. Pacing strategies include all-out, negative, positive, even, and variable pacing (1). An all-out pacing strategy is where peak velocity is reached early in the event, and the athlete holds that pace for as long as possible (1). Negative pacing is when the athlete starts the event conservatively, and then increases the pace over time, and positive pacing is when an athlete starts the event quickly, and then decreases their speed over time (1). Even-paced strategies include a steady speed that the athlete holds for the entire event with minimum variations, whereas a variable-paced strategy consists of the athlete purposely varying their power output throughout the event (1).

Many studies have concluded that events lasting longer than 4-5 minutes require a more even-paced strategy in order for optimal performance results, compared to variable and all-out pacing (3, 4, 10, 14, 18, 24, 31). For example, high-level ultra-marathoners exhibited minimal variations in their running speed, keeping their starting pace for longer periods of time than lower-level performers (24). Studies of shorter events, lasting only a few minutes (such as cycling time trials of 1000m and 1500m) have reported that the all-out strategy works best (3, 14, 19). Most studies of shorter events (between 1-5 minutes) have shown that faster starts result in better performance times (2, 4, 18, 23) possibly due to a greater amount of aerobic contribution to energy turnover which increases the time until the anaerobic contribution is depleted, thus increasing the time to exhaustion (23). Although there are inconsistent results regarding optimal

pacing methods, it generally appears that an all-out pacing strategy works best for shorter events, whereas an even-paced strategy results in the greatest performance results for longer distances. However, the selection of optimal pacing strategies for a particular event remains controversial, as they can be affected by numerous factors, such as changes or fatigue in the muscle (1, 15), body temperature (15), brain responses to feedback (1, 4), the distance to be performed (1, 26), carbohydrate availability (15), or a combination of these mechanisms.

Carbohydrate ingestion is known to improve endurance performance but little is known on its potential effect on pacing strategies. Carbohydrate ingestion before and during prolonged exercise (≥2 hrs) has been shown to benefit performance by improving the time to fatigue (8, 11, 12, 20), increasing average power output (13, 29), and increasing running speeds (27). Supplementing subjects with carbohydrate during exercise increases the amount of accessible carbohydrate towards the end of exercise (6, 11, 20, 21, 28) and limits the usage of endogenous stores of glucose (20, 22, 28), possibly maintaining glycogen levels in the liver and muscle (6, 20, 28, 30), which all are important for maximizing the availability of carbohydrate as a fuel. Recent studies have shown that combinations of glucose and fructose may improve performance to a greater extent than solutions containing only glucose (13, 20). Glucose and fructose are absorbed from the intestines via different transporters, allowing increased total carbohydrate absorption, and resulting in increased exogenous carbohydrate oxidation (13, 20, 28). Because the ergogenic effects of carbohydrate are at least partially related to their influence on energy metabolism (i.e. blood glucose levels, and carbohydrate availability for the muscle), it is possible that an absorption-related lag-time may exist between carbohydrate feedings and their effect on power output. Therefore, carbohydrate ingestion may have a time-related effect on pacing during endurance exercise.

11

Carbohydrate intake has also been shown to enhance power output and performance during shorter, higher-intensity bouts of endurance exercise (≥1hr) (7, 9, 16, 17, 25). These performance improvements have been observed, even when carbohydrate is rinsed in the mouth, and not swallowed (7, 8, 9, 17, 25). Chambers and colleagues (9) reported that subjects who rinsed with either glucose or maltodextrin solutions (independent of sweetness), improved their cycling performance by maintaining a higher power output for longer periods without having an increase in perceived exertion. These investigators provided evidence that oral receptors detect carbohydrate solutions in the mouth, activating the orbitofrontal cortex and striatum reward regions, communicating to the brain to continue the high intensity exercise (9). Carter *et al.* (7) discovered similar results when comparing cyclists who rinsed with either maltodextrin solution or water, and found significant improvements in performance time and power output in the carbohydrate trials (7). As demonstrated by the prior studies, there is growing evidence that carbohydrate may affect performance via its influence on the central nervous system. These benefits occur almost immediately after exposure to carbohydrate, but the longevity of these effects have not been investigated. Therefore, it is conceivable that carbohydrate ingestion may produce a short-lived effect on power output, causing feeding-related changes in pacing during endurance exercise.

Few studies have looked at pacing strategies in true endurance settings (>2 hours), nor have any studies directly investigated whether carbohydrate intake alters pacing during exercise. Thus the purpose of the current study is to examine the effects of carbohydrate ingestion during endurance cycling on pacing. Power output will be examined throughout endurance cycling, and compared between 'immediate' (immediately after beverage intake) and 'delayed' (10-15 min following beverage intake) time-periods in both carbohydrate and placebo trials. A secondary

12

purpose of this project is to determine if the experimental equipment that is worn to measure physiological measurements during cycling trials influences power output. We hypothesize that there will be increased power output averages during the early periods of the segments in the 30 km time trial and decreased averages at time points where the metabolic head gear was worn.

CHAPTER II: MATERIALS AND METHODS

Data collection for this experiment was completed as part of a prior study which addressed a separate research question related to carbohydrate ingestion. All testing was completed after informed consent was obtained from subjects, and all experimental procedures were approved by the Institutional Review Board of James Madison University. The findings from the original study were recently published by Baur and colleagues (5), and detailed methodology can be obtained from this source.

Subjects

8 male endurance trained cyclists were recruited to participate in the study. Subjects' cardiorespiratory fitness (VO_{2max}) was measured via an incremental exercise test to exhaustion on a cycle ergometer. Power output at VO_{2max} (W_{max}) was determined, and used to set workloads for subsequent testing (described below) (5).

Experimental Trials

As described by Baur *et al*. (5) the study consisted of four experimental trials including a placebo trial and three carbohydrate beverage trials. For the purpose of the current project, only data obtained from the placebo trial and a single carbohydrate trial (described below) were utilized. Each experimental trial was performed on a cycle ergometer and consisted of 120 min of constant load cycling at 55% of the subjects' W_{max}. Immediately following the 120 min of constant-load cycling, subjects completed a simulated 30 km time trial. Power output was recorded throughout the 30 km trials (5).

Treatments

As described by Baur *et al.* (5), subjects consumed a 150 mL bolus of beverage every 15 minutes in the constant-load cycling section of the trial, and in the 30 km time trial subjects drank the 150 mL bolus at three different segments (7.5, 15, and 22.5 km). The two treatments used in the study included:

1) Placebo trial (PL) - a non-caloric, artificially sweetened placebo.

2) Carbohydrate trial (CHO) - a 12% (2:1 ratio) glucose+fructose solution. The average carbohydrate ingestion rates were 1.03 grams of glucose per minute and 0.52 grams of fructose per minute.

Each beverage also included 470 mg/L of sodium chloride and 200 mg/L of potassium chloride.

Physiological Measurements

During the 30 km time trial, a metabolic apparatus (including headgear with a mouth piece similar to the end of a snorkel) was worn for five minutes at the 20 km point of the 30 km time trial to obtain measurements such as VO_2, respiratory exchange ratio, and ventilation as described by Baur *et al.* (5).

Power Output Analyses

Alterations in power output during specific segments of the 30 km time trials were compared between treatments. The 30 km time trial was divided into four segments (S1 = 0-7.5 km, S2 = 7.5-15 km, S3 = 15-22.5 km, and S4 = 22.5-30 km), with each segment immediately preceded by a beverage feeding. Each of the four segments were further divided into early and late phases. The early period included the 3 minutes immediately following each feeding and the

late period included the 3 minutes prior to the next feeding. This segmentation allowed us to compare average power output over a 3 minute period during time-periods that occurred immediately (early) and ~10-15 minutes (late) following each beverage feeding. In addition, power output was averaged for a 5 minute period in which the metabolic apparatus was worn (starting at 12 km), and when it was not worn (starting at 20 km). This permitted us to determine the influence of the apparatus on power output.

Statistical Analysis

The Statistical Package for Social Sciences (SPSS) Version 21 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. A three-factor repeated-measures analysis of variance (RMANOVA) was implemented to determine the independent and interactive effects of treatment (CHO and PL), segment (S1, S2, S3, S4), and timing post-feeding (early, late) on power output. Separate two-factor RMANOVAs were also performed to examine the effects of trial segment (S1, S2, S3, S4), and timing post-feeding (early, late) on power output within each treatment (PL and CHO).

Changes in power output between early and late phases were calculated (within treatment and trial segment). A two-factor ANOVA (treatment, trial segment) was then performed on these change scores to determine how differences in power output between early-late phases were influenced between treatments. The potential influence of metabolic headgear on power output was investigated using a two-factor ANOVA (headgear condition, treatment).

All reported values are mean±SE. An alpha level of $p < 0.05$ was used to determine statistical significant for all analyses.

CHAPTER III

Introduction

There are several pacing patterns that athletes can adopt during their sporting events to enhance performance, including all-out, negative, positive, even, or variable pacing (1). The optimal pacing strategy for athletic performance is dependent upon the duration of the event (1, 27), muscle fatigue (1, 16), body temperature (16), brain responses to feedback (1, 4), and carbohydrate availability (16), and different pacing strategies are chosen by different athletes. Prior studies have generally concluded that longer events (>4-5 minutes) require athletes to use an even-paced strategy (3, 4, 11, 15, 19, 25, 33), where a relatively consistent speed is held throughout the full event (1). By contrast, shorter events ($\leq$2 minutes) tend to prompt an all-out pacing strategy (3, 15, 20), where the athlete reaches peak velocity early in the event (1), in order to elicit the best performance results.

Carbohydrate ingestion before and during prolonged exercise ($\geq$2hrs) has been shown to improve endurance performance. The ingested carbohydrate provides additional energy for muscle contraction, reducing the utilization of liver, and possibly muscle, glycogen (6, 21, 29, 31). This increases the availability of carbohydrate accessible towards the end of exercise (6, 12, 21, 22, 29). Because these influences on energy metabolism are dependent upon digestion/absorption of ingested carbohydrate, there may be absorption-related lag-time between the carbohydrate feedings and their effect on power output, hypothetically resulting in changes in pacing during exercise.

Carbohydrate intake during shorter bouts of endurance exercise ($\geq$1hr) has also been shown to increase power output and improve performance (8, 17, 18). These ergogenic effects are believed to be related to effects on the central nervous system (8, 9, 10, 18, 26). Receptors in

the mouth sense the carbohydrate, activating brain divisions related to motor control (9, 10, 30) and feelings of reward (10, 21), pleasure (21), and motivation (8, 9) which may lead to increased power output and/or reduced perceived exertion (10). With carbohydrate intake influencing the central nervous system, there could be immediate short-lived effects on power output immediately following carbohydrate feedings, which could also potentially alter pacing during exercise.

Although there is strong evidence in the literature supporting the ergogenic effects of carbohydrate ingestion, it is currently unclear whether these effects are due to systematic increases in power output, or due to short-term alterations in pacing due to factors such as those described above. Therefore the current study examined the effects of carbohydrate intake on pacing in endurance cycling, with a specific emphasis on changes in power output in the periods following carbohydrate feedings. As a secondary objective, we also examined whether the metabolic headgear commonly worn during exercise studies influenced power output during cycling.

Methods

Data collection for this experiment was completed as part of a prior study which addressed a separate research question related to carbohydrate ingestion. The findings from the original study were recently published by Baur and colleagues (5), and detailed methodology can be obtained from this source.

Subjects

8 male endurance trained cyclists completed an incremental exercise test to exhaustion on a cycle ergometer and VO_{2max} was measured in order to determine their power output at VO_{2max} (W_{max}) which was used to set workloads for further testing (5).

Experimental Trials

Four experimental trials were conducted in the prior study (Baur *et al*.) including a placebo trial and three carbohydrate beverage trials. For the purpose of the current study, only data obtained from the placebo trial and a single carbohydrate trial were utilized. Each trial was performed on a cycle ergometer and consisted of 120 min of constant load cycling at 55% of the subject's W_{max}, immediately followed by a simulated 30 km time trial (5). Power output was measured in the 30 km time trials (5).

Treatments

As described by Baur *et al*. (5), subjects consumed a 150 mL bolus of beverage every 15 minutes in the constant-load cycling section and in the 30 km time trial at three different segments (7.5, 15, and 22.5 km). The two treatments used in the current study were a non-caloric, artificially sweetened placebo in the placebo trial (PL) and a 12% (2:1 ratio) glucose+fructose solution in the carbohydrate trial (CHO). For the CHO trial, carbohydrate ingestion rates were 1.03 grams of glucose per minute and 0.52 grams of fructose per minute. Both beverages also included 470 mg/L of sodium chloride and 200 mg/L of potassium chloride (5).

Physiological Measurements

During the 30 km time trial, a metabolic apparatus (including headgear with a mouth piece similar to the end of a snorkel) was worn for five minutes at the 20 km point of the 30 km time trial to obtain measurements such as VO_2, respiratory exchange ratio, and ventilation as described by Baur *et al*. (5).

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Alterations in power output during specific segments of the 30 km time trials were compared between treatments. The 30 km time trial was divided into four segments (S1 = 0-7.5 km, S2 = 7.5-15 km, S3 = 15-22.5 km, and S4 = 22.5-30 km), with each segment immediately preceded by a beverage feeding. Each of the four segments were further divided into early and late phases. The early period included the 3 minutes immediately following each feeding and the late period included the 3 minutes prior to the next feeding. This segmentation allowed us to compare average power output over a 3 minute period during time-periods that occurred immediately (early) and ~10-15 minutes (late) following each beverage feeding. In addition, power output was averaged for a 5 minute period in which the metabolic apparatus was worn (starting at 12 km), and when it was not worn (starting at 20 km). This permitted us to determine the influence of the apparatus on power output.

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The Statistical Package for Social Sciences (SPSS) Version 21 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. A three-factor repeated-measures analysis of variance (RMANOVA) was implemented to determine the independent and interactive effects of treatment (CHO and PL), segment (S1, S2, S3, S4), and timing post-feeding (early, late) on power output. Separate two-factor RMANOVAs were also performed to examine the effects of trial segment (S1, S2, S3, S4), and timing post-feeding (early, late) on power output within each treatment (PL and CHO).

Changes in power output between early and late phases were calculated (within treatment and trial segment). A two-factor ANOVA (treatment, trial segment) was then performed on these

change scores to determine how differences in power output between early-late phases were influenced between treatments. The potential influence of metabolic headgear on power output was investigated using a two-factor ANOVA (headgear condition, treatment).

All reported values are mean±SE. An alpha level of $p<0.05$ was used to determine statistical significant for all analyses.

Results

Influences of Trial Segment and Carbohydrate Intake on Power Output

Trial segment had a significant effect on power output ($p = 0.000$). As shown in Figure 1, power output decreased significantly between S1 and S2 ($p = 0.019$), and exhibited a further decrease between S2 and S3 ($p = 0.017$). Subsequently, power output increased between S3 and S4 ($p = 0.001$), resulting in power values in S4 which were not significantly different from S1 ($p = 0.302$).

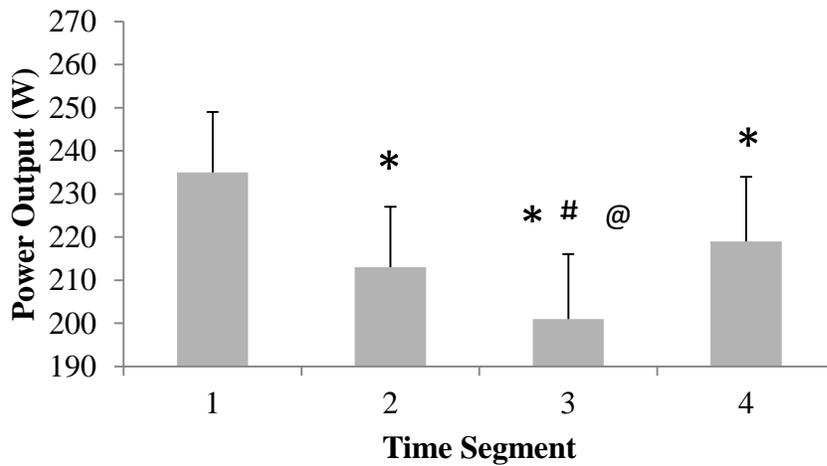Figure 1 – Changes in Power Output during the 30 km Trial
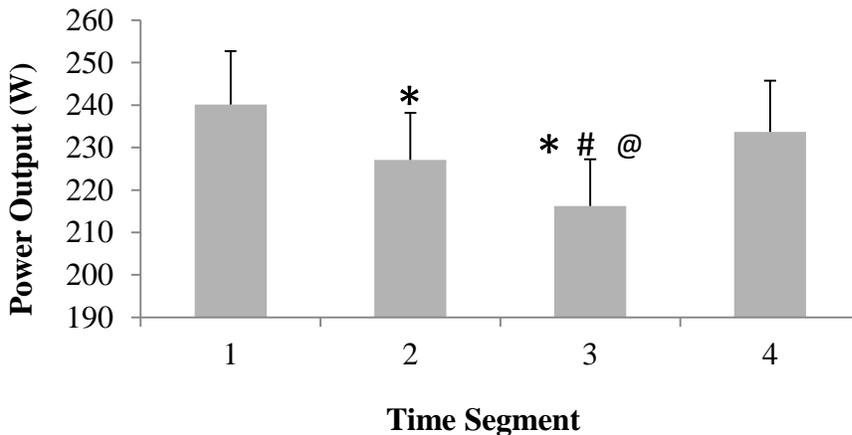
* = decreased versus 1 ($p < 0.05$); # = decreased versus 2 ($p < 0.05$);
@ = decreased versus 4 ($p < 0.05$)

Average power output during the 30 km time trial was significantly greater ($p = 0.044$) in the CHO trial (242 ± 10 W) versus PL (217 ± 14 W). In addition, CHO altered the aforementioned changes in power output observed between time segments. In the PL trial (shown in Figure 2A), power output decreased significantly between S1 and S2 ($p = 0.008$), and declined further between S2 and S3 ($p = 0.009$). Although power increased between S3 and S4 ($p = 0.001$), the values in S4 remained lower than S1 ($p = 0.019$). In the CHO trial (shown in Figure 2B), power output did not decrease significantly across the four time segments ($p > 0.05$), and power output in S4 was greater than S3 ($p = 0.008$).

Figure 2 – Changes in Power Output during the 30 km Time Trial

A – PL

B – CHO

* = decreased versus 1 ($p < 0.05$); # = decreased versus 2 ($p < 0.05$);
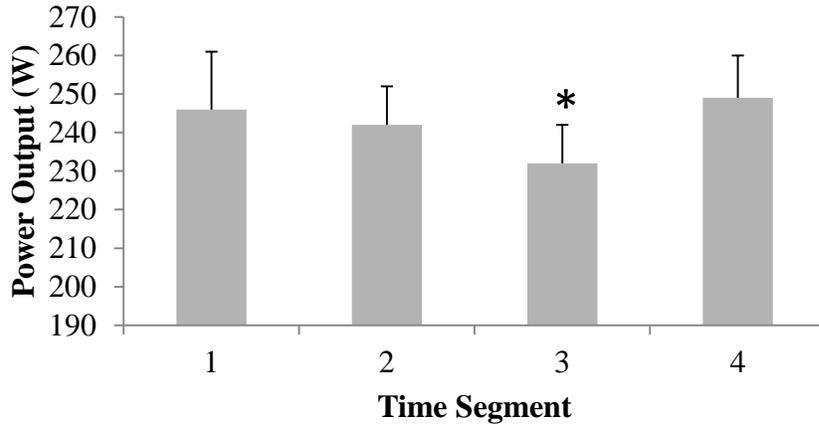@ = decreased versus 4 ($p < 0.05$)

Influence of Feeding Timing on Changes in Power Output

Mean power output was not significantly different between the early phase (230 ± 12 W) and late phase (229 ± 12 W) following beverage consumption ($p = 0.709$). In addition, changes in power output between early-late phases were not significantly influenced by treatment ($p = 0.154$), or interactions in treatment*trial segment ($p = 0.189$). Data are presented in Table 1 below.

Table 1 – Influence of Feeding Timing on Mean Power Output

Treatment	Phase	Mean Power Output (Watts)			
		Segment 1	Segment 2	Segment 3	Segment 4
PL	Early	233±16	218±14	204±15	208±16
	Late	237±15	207±14	198±15	229±17
CHO	Early	245±15	248±11	237±9	246±11
	Late	246±14	235±10	227±11	251±12

Influence of Metabolic Headgear on Power Output

Average power output was not significantly different (p = 0.299) between headgear (216 ± 10 W) and no-headgear (221 ± 11 W) conditions. In addition, there was no treatment*headgear interaction effect on power output (p = 0.857).

Discussion

Many studies have examined the effects of carbohydrate intake on performance during prolonged endurance exercise (9, 12, 13, 14, 22, 23, 28, 29, 30, 31). Numerous studies have also investigated pacing strategies during exercise, and have generally reported that all-out strategies are most effective in short-duration events (2, 3, 4, 15, 19, 20, 24), and even-paced strategies are most effective in long-duration events (3, 4, 11, 15, 25, 33). To our knowledge, the present study was the first to examine the potential effects of carbohydrate intake on short-term changes in pacing during an endurance event. Power output was also compared between time periods in which metabolic headgear was worn and when it was not worn. The main findings of this present study were that, a) carbohydrate ingestion influenced pacing in a general manner, by preventing decreases in power output that otherwise occurred over the duration of the time trial, b) differences in power output between carbohydrate and placebo trials were not systematically different between early and late periods following each feeding, and c) wearing headgear to measure metabolic measurements during exercise did not have a significant effect on power output during cycling.

In the present study, mean power output was significantly higher during the carbohydrate trials compared to the placebo trials, demonstrating that carbohydrate ingestion improved endurance performance. These findings support prior studies which have examined the effects of carbohydrate intake consumed during prolonged and shorter-endurance exercise (≥1 hr) (8, 9, 10,

12, 13, 14, 17, 18, 21, 22, 26, 28, 29, 30, 31), suggesting that carbohydrate ingestion improves time to fatigue (9, 12, 13, 21), running speeds (28), and average power output during cycling (8, 14, 17, 30). Recent studies have suggested that carbohydrate intake improves performance by preserving carbohydrate energy for the final stages of exercise (6, 12, 21, 22, 29, 30), due to increased rates of exogenous fuel utilization (23, 29, 30), sparing of liver glycogen (29, 30), and the possible sparing of muscle glycogen (6, 7, 29, 31). Other studies have indicated that oral receptors detect carbohydrate solutions in the mouth, activating divisions of the brain associated with reward (10, 21), motor control (9, 10, 30), pleasure (21), and/or motivation (8, 9), thus improving performance via influences on the central nervous system.

The primary purpose of the present study was to investigate the influence of carbohydrate intake on pacing during endurance cycling. As illustrated in Figures 2A and 2B, ingesting carbohydrate prevented the significant decline in power output observed in the placebo trial between S1 and S3. It is important to note that the 30 km time trial was preceded by 2 hours of constant load cycling at 55% of W_{max}, which likely resulted in substantial depletion of endogenous carbohydrate reserves, and muscular fatigue prior to the onset of the time-trial. The observation that carbohydrate intake preserved power output throughout the trial is consistent with the concept that carbohydrate ingestion increased total carbohydrate availability in the late stages of exercise, as discussed previously. This idea is also supported by published data from the original study (Baur *et al*.), which reported higher RER values in the CHO trial at the end of constant-load cycling (0.89 ± 0.02 vs 0.84 ± 0.03), and during the 30 km time trial (0.89 ± 0.02 vs 0.84 ± 0.02).

Differences in power output between treatments were quite similar between early-late periods across each of the trial segments, with no evidence of a systematic early-late effect from

the carbohydrate feedings. This suggests that there was no absorption-related lag-time effect between carbohydrate ingestion and its influence on power output (in which case, the ergogenic effects of CHO would be greater in the late-period). In addition, it also indicates that there was not a short-lived, immediate effect on the central nervous system elicited by the carbohydrate ingestion, which would have resulted in enhanced power output from CHO in the early-period. However, because carbohydrate feedings were provided every 7.5 km during the trial (approximately 10-15 min, depending on rider speed), we cannot rule out effects on the central nervous system which may have persisted between each feeding period – which could also hypothetically result in the maintenance in power output observed in the present study. This may also suggest that both a central nervous system and a metabolic effect were occurring (oral receptor effect followed by a metabolic effect).

In both the carbohydrate and placebo trials, there was a significant increase in power output between segments 3 and 4. This pacing pattern, characterized by a tendency for power output to be high at the start of the trial, decline throughout, and then increase near the end, is known as the "end spurt" (1, 4, 11, 32, 34). Tucker *et al.* (34) reported that in 5000m and 10,000m world-record running events, competitors tended to follow a fast, slow, fast pacing pattern, where an end spurt is observed near the end of the race. Tucker *et al.* (34) suggested that the end spurt signifies that the athlete has a 'reserve capacity,' and whatever caused the athlete to slow down in the middle segments of the race can be overcome in the final segments when the reserve is utilized (34). Chambers and colleagues (10) termed the same pacing pattern a "sprint finish" and suggested (in agreement with the present findings) that when cyclists were provided carbohydrate during exercise, they were able to uphold consistent power outputs throughout the exercise, especially in the final periods (10). Corbett and associates (11), reported no evidence of

an end spurt pacing pattern in cyclists, but this study was conducted on much shorter events (3 km and 4 km track races). In the present study, the basic pacing strategy utilized by cyclists did not appear to be affected by carbohydrate intake, as an end spurt was present in both the carbohydrate and placebo trials.

This present study was also the first to examine the potential effects of wearing metabolic headgear on power output during endurance cycling. No significant differences in power output were observed between time segments in which the headgear was worn (5 min at 12 km, 216 ± 10 W) and when it was not worn (5 min at 20 km, 221 ± 11 W). Although it is potentially reassuring to conclude that the metabolic headgear has no effect on performance, it should be noted that the time periods in which headgear were worn in the present study were not counterbalanced between treatments. This is particularly relevant in the present study, based on the aforementioned tendency for power output to decline between segments 2 and 3 (where the headgear measurements were recorded). It is therefore possible that an interactive effect between time-segments (2 versus 3) and conditions (headgear or no headgear) may have masked a possible effect of the headgear. For example, it is possible that feelings of discomfort or claustrophobia from the mask could adversely affect a subject's concentration, resulting in a negative effect on performance. Conversely, subjects could inadvertently increase their power output when headgear is worn, due to being more conscious of being 'measured' during these time periods. Therefore, further studies should be conducted to systematically examine the effects of wearing headgear on power output during cycling.

In conclusion, the primary findings from this study were that carbohydrate ingestion improved performance during endurance cycling compared to a placebo solution, by preventing declines in power output over a 30 km time trial (which immediately followed 2 hours of

submaximal cycling). However, carbohydrate intake had no impact on short-term changes in

power output between feedings. In addition, wearing metabolic headgear during cycling had no

significant effect on power output, although this last issue requires further systematic

investigation.

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