American Journal of Sports Science and Medicine, 2017, Vol. 5, No. 3, 53-56
Available online at http://pubs.sciepub.com/ajssm/5/3/3

DOI:10.12691/ajssm-5-3-3

Ingestion of Caffeine and Carbohydrate Increases Average Power Output during a 10 mile Time Trial in Both Male and Female Cyclists

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Abstract Previous researchers observed that elite male cyclists' performance improves with combined ingestion of caffeine and carbohydrate. We carried out this study to determine if similar outcomes would be observed in a group of cyclists varying widely in age and racing experience as well as gender. We administered carbohydrate with or without the addition of 6 mg/kg body weight caffeine in a counterbalanced blind manner to ten trained male and female cyclists in the fed state one hour prior to 20 minutes of steady-state (SS) cycling at 60% VO_{2max} power followed by a simulated 10-mile time trial (TT). Ventilation (VE), rate of oxygen consumption (VO_2), respiratory exchange ratio (RER), and rate of perceived exertion (RPE) were measured during the SS, whereas completion time, average power output, heart rate (HR) and RPE were measured during the TT. The addition of caffeine resulted in a significant reduction in completion time (1.9%) and increased the average power output (5.0%), as well as significantly higher heart rates during the TT (2.9%). We observed no significant differences in VE, VO_2, RER, RPE, and HR during the SS between treatments. Our data shows that the ingestion of 6 mg/kg of caffeine in combination with a 7.5% carbohydrate solution in male and female cyclists in the fed state improves short duration time trial performance as measured by completion time and average power output. These findings can be of great value to cyclists across a wide range of age and experience.

Keywords: *cycling performance, ergogenic aid, short term*

Cite This Article: Ryan D. Mitchell, and Amada Podczerwinski, "Ingestion of Caffeine and Carbohydrate Increases Average Power Output during a 10 mile Time Trial in Both Male and Female Cyclists." *American Journal of Sports Science and Medicine*, vol. 5, no. 3 (2017): 53-56. doi: 10.12691/ajssm-5-3-3.

1. Introduction

Multiple researchers have examined the effects of carbohydrate and caffeine on long-duration (greater than one hour) cycling, with time to exhaustion as the primary measure. Researchers of only two studies, however, focused on the effects of carbohydrate and caffeine on short-duration (one hour or less), high intensity cycling and actually measured performance. [1,2] Kovacs et al. examined the effects of the addition of caffeine to a carbohydrate solution on one hour time trial performance of male cyclists in the fed state. The addition of caffeine resulted in a dose dependent reduction in performance time and increase in power output, relative to a carbohydrate solution alone. And, relative to a water placebo, researchers found that carbohydrate had no significant effect on performance time or power. [1]

Carbohydrates are the body's primary fuel during high intensity exercise, which makes them a staple nutrient in an athlete's diet. Researchers, however, have found that carbohydrate ingestion before and during cycling [2] or running [3] will only improve performance when the subject is in a fasting state and has no significant impact when the subject is in a fed state [1,4,5,6,7]. In the fed state, the most important role of carbohydrate ingestion during exercise (especially in short duration, high intensity exercise) may be to maintain blood glucose in support of the central nervous system (CNS). The mechanism for the improvement of performance in short duration cycling in the fasting state is particularly unclear. To determine a potential mechanism, Carter et al. studied the effects of a carbohydrate mouth rinse compared to a water rinse on one hour time trial performance of cyclists in the fasting state. [8] The researchers found that cyclists power output increased with the carbohydrate mouth rinse, suggesting that carbohydrates increase the central drive or motivation via carbohydrate receptors in the mouth.

Caffeine is a widely used stimulant that has been utilized by researchers and athletes as an ergogenic aid to improve both long and short duration performance via a number of possible mechanisms, including antagonism of adenosine, increased fatty acid oxidation, inhibition of cAMP breakdown, increased post-exercise glycogen accumulation, mobilization of intracellular calcium, and via reductions in the perception of effort. [9,10,11] In the study by Kovacs et al., caffeinated carbohydrate ingestion before and after a one hour time trial did not appear to enhance muscle substrate metabolism and the researchers concluded that the performance enhancing effects were more likely due to CNS effects on perceptions of effort.

[1] In a study of male cyclists and triathletes who consumed carbohydrate before and during 120 minutes of steady state cycling followed by a 7 kJ/kg time trial, Cox et al. reported that caffeine ingested both before and during exercise significantly improves TT performance. Substrate utilization, however, was not enhanced relative to placebo control as measured by respiratory exchange ratios (RER), even though pre-ingestion of caffeine resulted in elevated plasma free fatty acids. Cyclists rating of perceived exertion (RPE) at the end of 120 minute steady state cycling was lower with caffeine ingestion compared with placebo. [12] These results are consistent with an earlier study by Cox et al. that found no significant differences in RER of subjects during 30 minutes of isokinetic variable-resistance cycling, yet subjects who consumed 6 mg/kg of caffeine performed more total work compared to placebo controls under conditions of the same RPE during the work period. [13]

In a more recent study of short-term cycling performance completed on elite male cyclists in the fed state, Acker-Hewitt et al. examined the interactive effects of carbohydrates and caffeine during 20 minute steady state cycling followed by a simulated 20 km time trial. [7] In this study, researchers demonstrated that the ingestion of caffeine combined with carbohydrate improved cyclists power output and completion time of the time trial whereas no significant changes occurred when carbohydrate and caffeine were ingested separately relative to an unsweetened placebo control. The researchers observed elevated RER levels during the steady state when subjects consumed caffeine in combination with carbohydrate relative to the placebo control, yet the RER levels were equally elevated for the caffeine only and carbohydrate only treatments. Taken together, however, with the observation of elevated blood glucose after the steady state and time trial only when cyclists ingested the carbohydrate and caffeine combination, Acker-Hewitt et al. suggested that the mechanism for improved TT performance may be related to alterations in substrate metabolism due to the caffeine and carbohydrate combination. [7] Unlike studies by Kovacs et al. [1] and Cox et al. [12], Acker-Hewitt et al. observed no changes in RPE amongst any of the treatments. [7]

One limitation of the above studies to making their results generalizable is the utilization of subjects within a narrow age range and use of only elite cyclists, as in cyclists from a collegiate cycling team. [1] While focused study populations may prevent dilution of study results, the designs nonetheless restrict the ability of researchers to extrapolate the results to the cycling community at large that includes cyclists from across a wide range of age, experience and ability. Few studies have included any females in their studies of caffeine and cycling performance [11]. In the study presented here, we examined the effects of ingesting caffeine combined with carbohydrate compared to carbohydrate alone utilizing a similar performance protocol to the Acker-Hewitt et al. study. [7] We, however, completed the study on a group of cyclists from across a wide age range with varying levels of competitive experience, and measured performance variables during a 20 minute steady state effort followed by a 10 mile time trial (a common race distance in amateur cycling). We sought to determine if the caffeine and carbohydrate combination is effective at improving cycling performance relative to ingesting carbohydrate alone, and to determine if substrate utilization and perception of effort is altered by the treatment condition.

2. Materials and Methods

Subjects: Four female and six male cyclists who trained at a minimum of 20-30 miles, 2-3 days a week on a bike volunteered to participate in the study. The mean age of the subjects was 39.4 +/- 12.0 years. The experience level of the cyclists ranged from those with no racing experience to those with extensive amateur racing level experience. All subjects had experience with cycling on a bicycle trainer stand and regularly engaged in high intensity exercise.

Study Design: We conducted the study in a counterbalanced blind manner.

VO_{2max} Power Test: We determined the VO_{2max} power of each subject using a bicycle ergometer (CompuTrainer) to determine power and a COSMED Quark CPET to determine VO_{2max}. We maintained the laboratory at ~70°F and 50% humidity, and used a fan to cool cyclists during testing. We fit each subject with a COSMED heart rate monitor strap, and instructed each to warm up for ten minutes on the CompuTrainer at a self-selected load after which the CompuTrainer was calibrated. While the subject was warming up, we also calibrated the CPET to facilitate accurate VO_{2max} determination. After the calibrations, we fit the cyclist's with a COSMED exercise mask. We used a ramp protocol for VO_{2max} power determination in which we incrementally increased power by 50 W per two minutes until subjects could no longer maintain 90 rpm, or three of the criterion for VO_{2max} had been met: RER (vCO_2/vO_2) greater than or equal 1.10, heart rate greater than 95% of age predicted maximum, and plateau in rate of oxygen uptake (VO_2). We considered a plateau in VO_2 when the VO_2 value did not change more than 2 ml/min/kg over the course of a minute. For analysis of VO_{2max}, we used 15 second averaging of the CPET raw data. We determined VO_{2max} by averaging four consecutive data points at the plateau of each cyclist's data. VO_{2max} power was defined as the highest power output at VO_{2max}. These data were utilized during the 20 minute steady state (SS) ride, where subjects rode at 60% of their VO_{2max} power.

Trials: Each subject performed six trials on the CompuTrainer consisting of a 20 minute SS (at 60% VO_{2max}) ride followed by a simulated 10-mile time trial (TT); each trial was separated by one week. We designed the first two trials to familiarize the subjects with the protocol. We matched subjects based on gender, VO_{2max} power, and age to determine which experimental trials they started with in a randomized manner, either two of carbohydrates only (CHO) or two of caffeine combined with carbohydrate (CHO+CAF). During the trials, there was no interaction of the subjects with the researchers except for assessing RPE, and no encouragement was given to the subjects. The performance repeatability of the time trial protocol followed here was reported to have a coefficient of variation of 1.44% across three consecutive placebo time trials in the study of male elite cyclists by Acker-Hewitt et al. [7].

During the SS, we determined each subjects' RPE using the Borg RPE scale and recorded their heart rate (HR) at minutes 8 and 20. We obtained the average ventilation (VE), average respiratory exchange ratio (RER), and average rate of oxygen consumption (VO_2) for each subject utilizing the CPET unit and analyzed these data between minutes 5 and 8 of the SS. During the TT, we recorded RPE and HR for each subject when they reached mile 9.98. For each subject, we also recorded their overall RPE, completion time and average power output for the TT.

Dietary procedures: We instructed subjects to avoid caffeine and alcohol 24 hours before their trials, as well as limit their physical activity 48 hours prior. We collected a 24 hour food diary and 72 hour activity log and instructed each subject to repeat the same food consumption pattern before each trial, including a self-selected meal the night before consumed within 12 hours of beginning each trial. Similarly, subjects were instructed to maintain the same level of physical activity before each trial. Two hours prior to the SS trial, we administered a 500 calorie meal to each subject consisting of juice (Dole orange or orange pineapple) and a Power Bar or Cliff Bar to assure that each subject received 90-100 g of carbohydrate, 8-12 g of protein, and 4-8 g of fat. One hour before the SS, subjects drank a 7.5% carbohydrate/electrolyte solution (Gatorade), 250 mL with (CHO+CAF) or without (CHO) the addition of 6 mg/kg body weight caffeine (TerraVita). Immediately preceding and following the SS, 375 mL of the 7.5% carbohydrate/electrolyte solution was given to the subject. After consuming the third drink, subjects proceeded immediately into the 10 mile TT.

Statistical Analysis: All results are reported as mean +/- standard deviation. A paired t-test was utilized in analyzing each set of measurements, with statistical significance set at the $p<.05$ level.

No conflicts of interest existed that could have inappropriately influenced the study.

3. Results

The subjects in the study had an average VO_{2max} of 54.8 ±6.3 mL/min/kg and VO_{2max} power of 315.0 ± 50.4 Watts. We observed a significant decrease in both the average completion time and an increase in average power output during the simulated 10 mile time trial when subjects consumed caffeine in combination with carbohydrate compared to the trials in which the subjects consumed carbohydrate alone (Table 1).

Table 1. 10 Mile Time Trial Completion Time and Average Power Output

	Carbohydrate Only	Carbohydrate plus Caffeine	p-value	Percent Difference
Average Power (watts)	244.9 ± 43.0	257.2 ± 44.1	0.002	5.0% increase
Completion Time (minutes)	27.1 ± 1.9	26.6 ± 1.8	0.022	1.9 % decrease

Average power and completion time are significant to $p<.05$.

We also observed that the HR of subjects taken at the end of the TT was significantly higher when subjects consumed caffeine and carbohydrate compared to carbohydrate alone (Table 2). The RPE of riders at mile 9.98 of the TT was not significantly altered by the addition of caffeine to carbohydrate. We observed no significant changes in HR, VE, VO_2, RER, and RPE during the steady state.

Table 2. 20 Minute Steady State (SS) and 10 Mile Time Trial (TT) Data: ventilation (VE), oxygen uptake (VO_2), respiratory exchange ratio (RER), rate of perceived exertion (RPE), and heart rate (HR)

	Carbohydrate Only	Carbohydrate and Caffeine
VE (L/min)	72.1 ± 10.5	75.0 ± 9.9
VO_2 (mL/min/kg)	39.78 ± 4.33	40.92 ± 3.46
RER	0.90 ± 0.02	0.90 ± 0.02
RPE min 8	12 ± 1	12 ± 1
HR min 8 (bpm)	137 ± 8	138 ± 8
RPE min 20	13 ± 1	12 ± 1
HR min 20 bpm)	140 ± 10	141 ± 9
RPE mile 9.98	18 ± 1	19 ± 1
HR mile 9.98 (bpm)*	172 ± 11	177 ± 8
RPE overall	17 ± 1	18 ± 1

*The HR difference observed at mile 9.98 was significant to $p<.05$.

4. Discussion

The reduction in completion time and increased power output during the time trials in which the subjects consumed caffeine in combination with carbohydrate versus carbohydrate alone is consistent with previous findings in male cyclists for a one hour time trial [1] and a 20 km time trial following 20 minutes of steady state cycling. [7] In a study of ten elite male cyclists, relative to carbohydrate only treatment, Acker-Hewitt et al. [7] observed a similar reduction in the completion time of the TT whereas we observed a higher increase in average power output (albeit for a 10 mile TT in this study versus a 12.4 mile TT in the Acker-Hewitt et al. study). [7] The higher HR observed during the time trial when subjects consumed caffeine along with carbohydrate is consistent with the findings by Kovacs et al. [1], but was not observed in the study by Acker-Hewitt et al. [7] Kovacs et al. suggested that the higher heart rates observed with the addition of caffeine, however, may have been related to the higher work output of the subjects during the TT protocol utilized in their study. [1] The elevated HR observed in this study may simply be related to the stimulating effect of caffeine and the increased power output of riders during the CAF + CHO trials. The lack of change in RPE when subjects consumed caffeine in addition to carbohydrate observed during the time trial portion of the study reported here is consistent with the findings reported by the previous studies [1,7].

The observation of no significant differences in VO_2 and VE during 20 minutes of steady state cycling between the treatments is surprising given what is known about caffeine. Caffeine has been shown to increase ventilation in individuals across a wide range of cardiorespiratory fitness levels. [14] The findings, however, are consistent with the findings of Acker-Hewitt et al. who reported no differences in VO_2 and VE during the steady state of subjects who received caffeine and carbohydrate versus carbohydrate alone. [7] Our finding of no difference in RER during the SS between treatments is consistent with the results of Acker-Hewitt et al. who reported no difference in RER of subjects who ingested caffeine combined with carbohydrate versus carbohydrate alone. In the Acker-Hewitt et al. study, significantly higher RER values during 20 minute steady state cycling were observed in subjects receiving caffeine and carbohydrate compared to an artificially sweetened placebo, yet the RER values were equally high with the caffeine only and carbohydrate only treatments. [7] Kovacs et al. observed no difference in plasma free fatty acid levels and plasma glycerol during a cycling time trial in subjects that consumed caffeine and carbohydrate in combination versus carbohydrate alone. [1] Cox et al. reported no differences in RER and no differences in the rates of carbohydrate and fat oxidation in cyclists during 120 minute steady state cycling at 70% peak O_2 uptake in subjects who ingested 6 mg/kg body weight of caffeine in a 6% carbohydrate drink versus those who ingested the carbohydrate drink without caffeine. They did, however, find that subjects had a lower RPE under these conditions. [12] Collectively, the results from the study reported here and those of previous researchers suggests that during short duration (< one hour) steady state cycling, the addition of caffeine to a carbohydrate solution compared to a carbohydrate only solution does not result in consistent and discernable differences in substrate utilization of subjects in the fed state. Our findings of no change in RPE during 20 minutes of steady state cycling nor at the end of the 10 mile TT are consistent with the findings of Acker-Hewitt et al., [1] and hence do not support an alternative mechanism for increased TT performance resulting from combined caffeine and carbohydrate ingestion and cyclists with a decreased perception of effort as suggested by Cox et al. [12].

5. Conclusions

Cyclists, in the fed state, across a wide range of age and competitive experience can improve their 10 mile time trial performance by consuming 6 mg/kg body weight of caffeine added to a 7.5% carbohydrate solution. Specifically, the completion time improves 30 seconds on average with a significant increase in the average power output. In the future, studies with larger population sizes may help to clarify the factors by which caffeine combined with carbohydrate improves cycling performance. While consumption of caffeine has become popular in its use by endurance athletes, athletes and cyclists should be aware of the rules regarding caffeine use in cycling. For example, the NCAA currently bans the use of caffeine [15]; the International Olympic Committee (IOC) restricts caffeine use to urinary caffeine levels of <12 ug/ml, above which may trigger a doping suspension [10]; whereas the World Anti-Doping Agency (WADA) places caffeine in its monitoring program but does not prohibit the use of caffeine. [16] Cyclists may also want to check with their regional cycling governing bodies regarding any restrictions on caffeine use. Cox et al. found that when 6 mg/kg of caffeine is administered one hour before cycling at steady state followed by a time trial, the urinary levels of male triathletes and cyclists were well below 12 ug/ml. [12].

Acknowledgements

The authors wish to acknowledge the assistance of Rachelle Valenzuela (an undergraduate Health Sciences major at The Sage Colleges) with data collection and analysis.

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