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# The independent and combined effects of carbohydrate and caffeine ingestion on cycling performance

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The Independent and Combined Effects of Carbohydrate and Caffeine Ingestion on  
Cycling Performance

Tiffany L. Acker

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

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## Abstract

**Purpose:** The purpose of this study was to determine the independent and combined effects of carbohydrate and caffeine ingestion on performance and physiological parameters during high-intensity aerobic cycling (~60 minutes). **Methods:** Ten cyclists ( $28 \pm 3$  yr,  $73.2 \pm 1.9$  kg) performed 20 minutes of steady-state cycling (60%  $W_{\max}$ ) followed by a simulated 20-km time trial (TT) under the following four treatment conditions: placebo (PLA), carbohydrate (CHO), caffeine (CAF), and a combination of CHO and CAF (CHO-CAF). One hour prior to exercise subjects ingested a placebo/caffeine capsule. Beverages (250 ml) were consumed immediately prior to the 20-min steady-state, immediately prior to the 20-km TT, and at the 20-min mark during the time trial. Subjects completed the treatment trials in a semi-randomized, double-blind, placebo fashion and trials were separated by  $\geq 5$  days. **Results:** CHO-CAF improved 20-km TT performance by 3.4% (93 sec) compared to PLA ( $p \leq 0.05$ ), whereas no differences were detected among CHO, CAF, and PLA. Similarly, CHO-CAF improved mean power output by 5% during the 20-km TT compared to the PLA trial. RER was elevated under all treatment conditions compared to PLA. Further, blood glucose was elevated in CHO-CAF compared to PLA post steady-state and post TT. Treatment conditions did not differentially impact VE,  $VO_2$ , pre-exercise MVC, post-exercise MVC, RPE, and blood lactate. **Conclusions:** CAF and CHO improve 20-km time trial performance when taken together but not when taken independently. This appears to be possibly facilitated by peripheral (MVC) and metabolic modifications (RER + blood glucose).

Regardless of the mechanism, these data suggest that cyclists should ingest CHO and CAF together to improve high-intensity time trial performance, while in the fed state.

Key Words: Carbohydrate, Caffeine, Performance, Cycling



## CHAPTER ONE - INTRODUCTION

Cyclists are consistently searching for methods to improve performance (e.g. nutrition, pharmacology, training etc). Carbohydrate ingestion proximate to the start of exercise or during exercise is one such method (Jeukendrup, 2008). Although the benefits of a high carbohydrate diet have been studied for many years (Krogh and Lindhard, 1920), it was not until the late 1970s and early 1980s that supplementation of carbohydrates during exercise was systematically investigated in humans (Ivy, 1979, Bonen, 1981, and Coyle, 1983). Caffeine is another supplement commonly used by cyclists, prior to or during exercise, to improve high-intensity and/or prolonged cycling performance (Graham, 2001). Similar to that of carbohydrates, scientific support for the purported ergogenic effects of caffeine began to emerge in the late 1970's (Costill, 1978), although evidence for caffeine-induced gains in muscle function can be traced back to 1907 (Rivers and Webber, 1907). Researchers have more recently examined the combined effects of carbohydrates and caffeine on performance. Wemple (1997) was the first to test the combined effects of carbohydrate and caffeine, a study in which no differences in time to exhaustion (85%  $VO_{2max}$ ) were reported between a caffeinated carbohydrate electrolyte beverage and a non-caffeinated carbohydrate electrolyte beverage, after cycling for three hours. One year later, Kovacs (1998) reported that one-hour time trial performance improved when moderate doses of caffeine were added to a carbohydrate-electrolyte beverage. However, Jacobson (2001), like Wemple (1997), found that the addition of caffeine to a carbohydrate supplement proved ineffective when comparing it to carbohydrate alone, thus refuting the notion that carbohydrate and caffeine simply elicit additive performance gains.

Ivy (1979) performed initial observations of the effects that carbohydrates have on extended-duration work capacity, and it is now paradigmatic that prolonged cycling performance is enhanced with the provision of carbohydrates (Coyle, 1983; Bjorkman, 1984; Fielding, 1985; Coyle, 1986; Murray, 1987; Coggan and Coyle, 1988; Murray, 1991; Wright, 1991; Zachweija, 1992, Bacharach, 1994; Langenfield, 1994; Maughan, 1996; Angus, 2000; Febbraio, 2000; Carter, 2003; Hulston and Jeukendrup, 2009). More recently, the performance benefits of carbohydrate ingestion during cycling exercise have been extended to include higher intensity cycling ( $\leq 60$  minutes) (Anantaraman, 1995; Below, 1995; Carter, 2003; Carter, 2004a).

Caffeine, a drug commonly found in many foods and beverages, is consumed by approximately 90% of the adult population (Burke, 2008). Caffeine is also heavily used in the world of sport as an ergogenic substance. Costill (1978) provided the first scientific documentation of these benefits by demonstrating that of cycling time was extended 15 minutes when subjects consumed caffeinated coffee compared to decaffeinated coffee. The authors suggested that the gains in performance were likely accomplished through augmented lipolysis and enhanced neural transmission. It was not until 1991 that caffeine's effects on high-intensity cycling were examined. Graham and Spriet (1991) reported that caffeine ingestion one hour prior to cycling (85% of  $VO_{2max}$ ) extended cycling time by 20 minutes. High-intensity time trial performance has also been shown to benefit from caffeine ingestion (4.7%), demonstrating that the physiological impact of caffeine translates to a wide variety of performance conditions.

Naturally, it is common practice for cyclists to combine known ergogenic aids, such as carbohydrates and caffeine, to optimize performance. Surprisingly, evidence

based information on the efficacy of combining carbohydrates and caffeine are limited to only ten studies. However, the majority of these studies addressed the effects during prolonged cycling rather than during high-intensity aerobic cycling. Only one study has researched the combination of carbohydrate and caffeine ingestion during high-intensity aerobic cycling (Kovacs, 1998). Kovacs (1998) reported that time trial performance was enhanced when moderate amounts of caffeine were added to a carbohydrate-electrolyte solution compared to a placebo. The absence of a caffeine only trial makes it impossible to ascertain the individual and combined source-contributions to the enhanced performance. While researchers in the past have examined carbohydrates and caffeine for independent effects, they have failed to compare those results to the effect that carbohydrates and caffeine have on performance when combined. It is logical to expect that the combination of carbohydrates and caffeine will elicit larger performance gains than either substance individually. However, it is important to consider that 1) the precise physiological mechanisms that facilitate these improvements in performance are largely unknown and 2) as individuals near their physiological capacity, additional supplements must elicit 'diminished returns'. For these reasons it may not be appropriate to make assumptions about the performance manifestation of individual supplements taken together.

### **Purpose of the Study**

To determine the independent and combined effects of caffeine and carbohydrate ingestion on performance and physiological responses to these treatments during high-intensity aerobic cycling (~60 minutes)

## **Aims and Hypotheses**

*Aim 1-* To determine if carbohydrate ingestion improves performance during high-intensity aerobic cycling (~60 minutes)

*Hypothesis 1-* Carbohydrate ingestion will improve performance compared to a placebo

*Aim 2-* To determine if caffeine ingestion improves performance during high-intensity aerobic cycling (~60 minutes)

*Hypothesis 2-* Caffeine ingestion will improve performance compared to a placebo

*Aim 3-* To determine if carbohydrate and caffeine ingestion together improve high-intensity aerobic cycling performance (~60 minutes) compared to carbohydrate alone and caffeine alone

*Hypothesis 3-* The combination of carbohydrate and caffeine will improve performance more than carbohydrates alone and caffeine alone, and the ergogenic effects of carbohydrate and caffeine combined will be additive.

## **Significance**

Of the nine studies examining the combined effects of carbohydrate and caffeine, not one has examined both carbohydrate and caffeine independently to determine the type of effect these two supplements have when combined. Knowing this information may help determine the physiological mechanisms underlying the improvement in performance with these two supplements. Further, while acknowledging that important information has been gained from previous studies, a major shortcoming of the literature

is that the findings have limited generalizability to real-world scenarios. For instance, numerous studies have researched caffeine's effect on prolonged endurance and high-intensity aerobic cycling, most of which have assessed time to exhaustion or a steady-state followed by one of the following performance assessments: 1) amount of work (kJ/kg) completed or 2) the distance traveled in a given amount of time. Burke (2008) recently suggested that future research should examine the efficacy of caffeine in real-world scenarios. This includes the use of time trials, rather than work capacity-scenarios, while athletes follow their typical nutritional habits. Many of the recent studies examining carbohydrate ingestion during high-intensity aerobic cycling exercise ( $\leq 60$  minutes) have used time to exhaustion or time trials similar to those used in caffeine studies. The present study will test the effects of supplementation on a simulated time trial while allowing the subjects to follow their typical nutritional habits.

## **CHAPTER TWO- LITERATURE REVIEW**

### **Objectives**

The objectives of this chapter are to: 1) provide an overview of the impact that carbohydrate ingestion has on cycling performance, 2) provide an overview of the impact that caffeine ingestion has on cycling performance, 3) provide an overview of the impact that the combination of carbohydrates and caffeine ingestion has on cycling performance, and 4) provide an overview of potential physiological mechanisms for improved performance with a focus on high-intensity cycling exercise.

### **Carbohydrate and Exercise Performance**

A substantial amount of research has been conducted on the performance impact of carbohydrate provision during both prolonged ( $\geq 90$  min, Table 2.1) and high-intensity cycling ( $\leq 60$  min, Table 2.2). Seventeen out of 21 studies show that performance improves when carbohydrates are ingested during exercise lasting greater than 90 minutes (Table 2.1), and there is growing support for the benefits of carbohydrate during ~1-hour cycling (higher intensity) (Anantaraman, 1995; Below, 1995; Carter, 2003; Carter, 2004a).

There have been several proposed mechanisms underlying the improvement in performance when carbohydrates are supplemented during high-intensity aerobic exercise. El-Sayed (1997) suggested that the increase in total carbohydrate oxidation rates was the possible mechanism; however, Jeukendrup (1997) and Maresh (2001) reported the amount of exogenous carbohydrate was too small for such improvements or was not available for oxidation during the first hour of exercise. Carter (2004a) reported

that time trial performance lasting approximately one hour was improved by 3% when carbohydrate was simply rinsed in the mouth for five seconds, without swallowing. This equaled the improvement Jeukendrup (1997) demonstrated in subjects who ingested carbohydrates during a similar protocol. Therefore, Carter (2004a) proposed that the intricate interplay between mouth receptors and the brain was responsible for the gains in performance suggesting that the mechanism for improved performance with carbohydrate may not only be mediated by altered fuel metabolism but also a central response.

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
Ivy, 1979	7 M and 2 F Trained Cyclists	4 trials- 1- FAM, 1- caffeine (250 mg 60min prior and divided does every 15 min during exercise), 1- CHO (total of 90g), and 1- P	Total work (2 hrs)	$\leftrightarrow$
Coyle, 1983	9 M and 1 F Experienced Cyclists	3 trials- 1- FAM, 1- P and 1- CHO 20 min into exercise- 1.0 g/kg (50% solution), then at 60, 90, and 120 min 0.25 g/kg (6% solution) was ingested	TTE (74% $VO_{2max}$ )	CHO $\uparrow$ TTE by an average of 23 min
Bjorkman, 1984	8 Well-Trained M	3 trials- 1- P, 1- 7% solution glucose, 1- 7% solution fructose, all beverages were 250 ml and ingested every 20 min	TTE (68% $VO_{2max}$ )	Glucose $\uparrow$ TTE vs. fructose and P. Fructose $\downarrow$ TTE.
Fielding, 1985	9 M	3 trials- 1- P, 1- CHO doses every 30 min- 22g/h (F), 1- CHO every 60 min- 11g/h (D), separated by at least 5 days	Cycled for 4 hrs each 30 min were as follows: 20 min (50% $VO_{2max}$ ), 10 min intermittent exercise (30s sprint, 2 min rest), final sprint TTE	Final sprint performance was improved by 40 seconds during F vs. P. $\leftrightarrow$ between F and D or D and P.
Coyle, 1986	7 Endurance Trained M Cyclists	2 trials- 1- P, 1- CHO given 20 min into exercise 2.0g/kg (50% solution), then every 20 min 0.4 g/kg (10% solution), P beverage given at same time points	TTE below LT (70-74% $VO_{2max}$ )	CHO $\uparrow$ TTE by 33%. Improvements in performance ranged from 21 min to 149 min, average improvement was 1 hr.



**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Flynn, 1987</b>	8 Well-Trained Cyclists	4 trials- 1- P, 1- fructose (5 g/100ml) and maltodextrin (5 g/100ml), 1- maltodextrin (7.7 g/100ml) and high fructose corn syrup (2.3 g/100ml), 1- maltodextrin (3 g/100ml) and glucose (2 g/100ml), subjects consumed a 150 ml beverage every 24 min	48 hrs prior to each trial, 60 min (70% $VO_{2max}$ ), then consumed high CHO diet, Total work (2 hrs)	↔
<b>Murray, 1987</b>	13 M	5 trials- 1- FAM, 1- P, 1- 5% CHO solution, 1- 6% CHO solution, 1- 7% CHO solution, each beverage (2 ml/kg) was consumed at designated rest periods, at least 7 days separated the trials	15 min (55% $VO_{2max}$ ), 15 min (65% $VO_{2max}$ ), 3 min rest, 2 min (55% $VO_{2max}$ ), 15 min (65% $VO_{2max}$ ), 3 min rest, 2 min (55% $VO_{2max}$ ), 15 min (65% $VO_{2max}$ ), 3 min rest, 2 min (55% $VO_{2max}$ ), 240 revs (Performance ride 1), 5 min rest, 2 min (55% $VO_{2max}$ ), 15 min (65% $VO_{2max}$ ), 15 min rest, 2 min (55% $VO_{2max}$ ), 480 revs (Performance ride 2)	↔ in treatments during Performance ride 1. There was a difference in Performance ride 2. The 6% and 7% CHO solutions were faster than P, ↔ between solutions.
<b>Coggan and Coyle, 1988</b>	7 Endurance Trained Cyclists	3 trials- 1- FAM, 1- P, 1- 50% CHO solution (1 g/kg) 10 min into exercise and 20% solution (0.6 g/kg) every 30 min after, trials separated by 1 wk	TTE alternated every 15 min (60% $VO_{2max}$ and 85% $VO_{2max}$ )	CHO ↑TTF and total work production vs. P by 18% and 19% respectively.

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Mitchell, 1989</b>	10 Highly Trained M Cyclists	5 trials- 1- P, 1- 6% CHO solution (37g), 1- 12% CHO solution (74g), 1- 18% CHO solution (111g), 1- 12% CHO during intermittent exercise (74g), separated by at least 1 wk	4 trials- 105 SS (70% $VO_{2max}$ ) followed by total work (15 min), 5 <sup>th</sup> trial- 7- 15 min intervals with 3 min rest (70% $VO_{2max}$ )	12% CHO $\uparrow$ total work compared to P. $\leftrightarrow$ between the CHO trials.
<b>Murray, 1991</b>	8 M and 2 F	6 trials- 2- FAM, 1- P, 1- CHO 6% (26g per hr), CHO 12% (52g per hr), CHO 18% (78g per hr), beverages started at 12 min in exercise and thereafter every 15 min, 7-10 days separated trials	2 hr (50, 65 or 75% of $VO_{2max}$ ) followed by 4.8-km TT	CHO 6% and CHO 18% improved performance in the TT vs. P. $\leftrightarrow$ between all CHO trials.
<b>Wright, 1991</b>	8 M and 1 F Experienced Cyclists	5 trials- 1- FAM, 1- P before, P during (PP), 1- CHO before, P during (CP), 1- P before, CHO during (PC), 1- CHO before, CHO during (CC), before meal- 5 g/kg of CHO 3 hrs prior, during- after 20 min of exercise and every 20 min thereafter 0.2 g/kg (8% solution), separated by at least 7 days	TTE (70% $VO_{2max}$ )	CP, PC, and CC all $\uparrow$ TTE vs. P by 17%, 32%, and 44% respectively. Total work output was $\uparrow$ in CP, PC, and CC vs. P by 19%, 34%, and 46% respectively.

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
Zachweija, 1992	8 M Cyclists	4 trials- 1- No CHO, no carbonation, 1- no CHO, carbonated, 1- CHO, no carbonation, 1- CHO, carbonated, CHO drinks 10% solution- 6% glucose, 4% fructose	105 min SS (70% $VO_{2max}$ ) followed by 15 min TT	$\leftrightarrow$ in average power output between all performance trials. When fed CHO, subjects worked at a greater intensity with CHO vs. without CHO.
Yaspelkis, 1993	7 Well-Trained M Cyclists	3 trials- 1- P, 1- 10% CHO solution (54 total g), 1- solid CHO (50 total g)	TTE intervals (45% $VO_{2max}$ and 75% $VO_{2max}$ )	10% CHO solution and solid CHO improved TTE by 31 min and 22 min respectively.
Bacharach, 1994	12 Trained M Cyclists	3 trials- 1- P, 1- 6.4% CHO solution with electrolytes, 1- 10% CHO solution without electrolytes, 3 ml/kg ingested at 0 min and every 20 min after during exercise, separated by 1 wk	2 hrs (65% $VO_{2max}$ ) followed by 500 rev sprint ride	10% CHO solution and 6.4% CHO solution improved performance vs. P by 12 sec and 9.1 sec respectively, and 10% CHO solution improved performance compared to 6.4% CHO solution by 2.9 sec.
Langenfeld, 1994	14 Trained Cyclists	2 trials- 1- P, 1- CHO (5% maltodextrin, 2% fructose) (0.25 g/kg), beverages given every 10 miles, separated by 1 wk	80-mile TT	CHO ingestion improved performance time in the 80-mile time trial by 5% vs. P.
Madsen, 1996	9 Well-Trained M	3 trials- 1- P, 1- 5% CHO solution, 1- 5% CHO + BCAA (18g), all beverage amounts and times: 600 ml prior, 250 ml after 15 min, 350 ml after 35 min, and then 350 ml every min, separated by 1 wk	100-km TT	$\leftrightarrow$

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min)  
(Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Maughan, 1996</b>	12 M	5 trials- 1- FAM, 1- no fluid, 1- water (W), 1- isotonic glucose solution (I) (200 mmol/l), 1- hypotonic glucose and electrolyte solution (H) (90 mmol/l), immediately prior to exercise 100 ml of fluid was given and continued every 10 min	TTE ( $70\% \text{VO}_{2\text{max}}$ )	TTE was $\uparrow$ in W, I, and H vs. P. Trial I had a longer TTE than W. $\leftrightarrow$ in the other treatments.
<b>Jeukendrup, 1998</b>	7 Endurance Trained M Cyclists	4 trials- 1- P, 1- CHO, 1- CHO + MCT, 1- MCT, all CHO beverages 10% solution, 170g-total, all MCT 5%, 85g-total, 8 ml/kg during min1 of exercise, every 15 min 2ml/kg, separated by $\geq 5$ days	120 min SS ( $60\% \text{VO}_{2\text{max}}$ ) followed by 15min TT	$\leftrightarrow$
<b>Angus, 2000</b>	8 Endurance Trained M Cyclists	3 trials- 1- P, 1- 6% CHO solution, 1- 6% CHO solution + 4.3% MCT, beverages given at start of exercise and every 15 min until completed (250ml), separated by at least 1 wk	35 kJ/kg TT	When CHO alone was ingested, performance was improved by 7% vs. P and CHO + MCT improved performance by 5%. $\leftrightarrow$ between CHO and CHO+ MCT.

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Febbraio, 2000</b>	7 Trained M	4 trials- 1- P before, P during (PP), 1- P before, CHO during (PC), 1- CHO before, P during (CP), 1- CHO before, CHO during (CC), CHO beverage 30 min before 2 g/kg in 25.7% CES, CHO beverage during (at onset and every 15 min) 2 g/kg in 6.4% CES separated by at least 7 days	120 min SS (63% $W_{max}$ ) followed by 7 kJ/kg TT	Time to complete the TT was $\downarrow$ during CC and PC vs. PP. $\leftrightarrow$ between CP and PP.
<b>Yeo, 2000</b>	8 Trained M Cyclists	3 trials- 1-water, 1-glucose, 1- glucose + caffeine	120 min (55% $W_{max}$ )	CHO co-ingested with caffeine results in higher exogenous CHO oxidation than CHO alone.
<b>Carter, 2003</b>	8 Endurance Trained M	3 trials- 1- FAM, 1- P, 1- CHO (6.4% maltodextrin solution), drank 8 ml/kg of fluid prior to exercise (in CHO trial 0.51 g/kg was added), beverages 3 ml/kg every 15 min	TTF (60% $VO_{2max}$ )	CHO $\uparrow$ TTF by 14.5% vs. P.

**Table 2.1: Carbohydrate ingestion and prolonged cycling performance ( $\geq 90$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Hulston and Jeukendrup, 2009</b>	10 Endurance Trained M Cyclists	3 trials- 1- water, 1- P- same color and taste as CHO, 1- 6% CES, ingested 600 ml at onset of exercise and 150 ml every 15 min for each beverage, told subjects P and CHO were both CHO separated by 7 days	120 min SS (61% $VO_{2max}$ ) followed by 847 kJ TT	CHO improved performance time vs. water and P by 11.3% and 10.6% respectively. Average power output was improved with CHO vs. water and P.

MCT = medium-chain triglyceride, BCAA = branched-chain amino acids, rev = revolutions, FAM = familiarization, P = placebo, hr = hour, min = minute, ml = milliliter, g = gram, kJ = kilojoules, kg = kilogram, SS = steady-state, CHO = carbohydrate, W = watts, TT = time trial, TTE = time to exhaustion, TTF = time to fatigue,  $\uparrow$  = increase,  $\downarrow$  = decrease,  $\leftrightarrow$  = no difference

**Table 2.2: Carbohydrate ingestion and high-intensity cycling performance ( $\leq 60$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Bonen, 1981</b>	31 M	4 conditions- 1- 8 subjects exercised with no CHO, 1- 7 subjects exercised with CHO ingested 15-17 min prior to exercise, 1- 8 subjects exercise with CHO during exercise between min 3 and 5, 1- control no exercise with CHO ingestion (20% CHO solution containing 1.5 g/kg)	TTE (80% $VO_{2max}$ ) after fasting for 36-44 hrs and glycogen depletion ride	$\leftrightarrow$
<b>Powers, 1990</b>	9 Trained Cyclists	3 trials- 1- P without electrolytes (31 mosmol/kg), 1- P with electrolytes (48 mosmol/kg), 1- CHO (7% solution, 231 mosmol/kg), beverages were given prior and every 15 min after	TTE (85% $VO_{2max}$ )	$\leftrightarrow$
<b>Anantaraman, 1995</b>	3 M and 2 F	3 trials- 1- P before, P during (PP), 1- glucose before, P during (GP), 1- glucose before, glucose during (GG), CHO beverages contained 30 g/ 300 ml (10%), all beverages given 2 min prior, at 15, 30, and 45 min into exercise, separated by at least 1 wk	Total work (1 hr)	Power output was averaged every 10 min. $\leftrightarrow$ in the 10 min power outputs except between 40-50 min where GP had a greater power output vs. PP and 50-60 min where GG had a greater power output vs. PP and GP. Total work in GP and GG was greater compared to PP.

**Table 2.2: Carbohydrate ingestion and high-intensity cycling performance ( $\leq 60$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Below, 1995</b>	8 Endurance Trained M	4 trials- 1- Fluid (water) (200 ml total) SF, 1- CHO Large Volume (CLV) 6% solution (1330ml-total), 1- Fluid (water) (1330ml-total) (F), 1- CHO Small Volume 40% maltodextrin solution (200ml-total) (CSV), all treatments C contained electrolytes, beverages/pill consumed prior to, at 15, 25, and 35 min of trial, separated by at least 72 hr	Cycled for 50 min in warm environment 5% above their LT, followed by 10 min TT	CLV and F had faster times in the 10 min TT than SF and CSV. CLV and CSV (CHO) improved in the TT compared to F and SF. Fluid and CHO did not have a synergistic affect both improved performance by ~6%.
<b>Jeukendrup, 1997</b>	17 M and 2 F Endurance Trained Cyclists	3 trials- 1- FAM (only 3 subjects who were unfamiliar with protocol), 1- P, 1- CHO (7.6% CES or 76 g/l), 8 ml/kg of P and CHO prior to exercise, 2 ml/kg at 25, 50, 75% of work was completed	1 hr TT	CHO improved performance TT by 2.3%.



**Table 2.2: Carbohydrate ingestion and high-intensity cycling performance ( $\leq 60$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Clark, 2000</b>	41 M and 2 F Competitive Endurance Cyclists	Each subject completed 4 trials, all performed a water trial (W), split into 2 groups- P and CHO, within each group there were 3 trials run- 1-told CHO, 1- told P, 1- not told, beverages 16 ml/kg (CHO beverage 7.6%), drank 30 min prior 8 ml/kg, and 2 min prior, 10-km, 20-km, 30-km was 2 ml/kg, at least 3 days separated trials	40-km TT	A difference in time to completion when subjects ingested CHO or were told they ingested CHO when they ingested P.
<b>McConell, 2000</b>	13 Well-Trained M Cyclists and Triathletes	3 trials- 1- FAM, 1- P, 1- CHO (6% solution ~81 g/h total), 7 ml/kg of beverage consumed prior to exercise, 3.5 ml/kg consumed every 15 min	TTE (83% $VO_{2max}$ )	↔
<b>Carter, 2003</b>	8 Endurance Trained M	3 trials- 1- FAM, 1- P, 1- CHO (6.4% maltodextrin solution), drank 8 ml/kg of fluid prior to exercise (in CHO trial 0.51 g/kg was added), beverages 3 ml/kg every 15 min	TTF (73% $VO_{2max}$ )	CHO $\uparrow$ TTF by 13.5% vs. P.

**Table 2.2: Carbohydrate ingestion and high-intensity cycling performance ( $\leq 60$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Carter, 2004a</b>	7 M and 2 F Endurance Cyclists	3 trials- 1- FAM, 1- P, 1- CHO (6.4% maltodextrin), 25 ml of beverages given for every 12.5% of TT completed, subjects rinsed fluid in mouth for 5 sec and then spit it out, separated by 7 days	914kJ TT	Performance time was faster when subjects rinsed mouth with CHO vs. P by 3%. Power output was $\uparrow$ in CHO vs. P.
<b>Carter, 2004b</b>	6 Endurance Trained M	3 trials- 1- FAM, 1- P (saline), 1- CHO ( $[6,6^2\text{H}_2]$ -glucose), subjects were given a consist infusion, separated by 7 days	1 hr TT	$\leftrightarrow$
<b>Desbrow, 2004</b>	9 Well-Trained M Cyclists	3 trials- 1- FAM (only if new to protocol), 1- P, 1- CHO (6% CES), 8 ml/kg of beverage during warm-up, 2 ml/kg between 20-30%, 50-60%, and 70-80% of work completed, separated by at least 4 days	14 kJ/kg TT	$\leftrightarrow$
<b>Jeukendrup, 2008</b>	12 Endurance Trained M Cyclists	4 trials- 1- FAM, 2- P, 1- CHO (6% CES), beverages were 4 ml/kg 5 min prior to exercise, 1.4 ml/kg at 25, 50, and 75% completion of TT	Cycled for given amount of work (~450kJ or 16km)	$\leftrightarrow$

**Table 2.2: Carbohydrate ingestion and high-intensity cycling performance ( $\leq 60$  min) (Continued)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Beelen, 2009</b>	14 Endurance Trained M	3 trials- 1- FAM, 1- P, 1- CHO (6.4% maltodextrin solution), at the start and for every 12.5% of TT completed, subjects rinsed fluid in mouth for 5 sec and then spit it out, subjects ate 2 hrs prior to all trials, separated by at least 7 days	1053kJ TT	$\leftrightarrow$
<b>Chambers, 2009</b>	8 Endurance Trained M Cyclists	3 trials- 1- FAM, 1- 6.4% glucose solution, 1- 6.4% maltodextrin solution , 1- P, subjects only completed 2 of the 3 treatment trials, 25ml of mouth rinse given at the start and after every 12.5% of the TT completed, fMRI to determine activation of the brain	914 kJ TT	Glucose improved performance time by 1.2 min and power output by 2.0% compared to P. Maltodextrin improved performance time by 2 min and power output by 3.1% compared to P.

CES = carbohydrate-electrolyte solution, TT = time trial, kJ = kilojoules, hr = hour, CHO = carbohydrate, min = minute, kg = kilogram, ml = milliliters,  $\leftrightarrow$  = no difference,  $\uparrow$  = increase, TTF = time to fatigue

## **Caffeine and Exercise Performance**

The ergogenic effects of caffeine taken prior to and during exercise are well documented (Table 2.3 and Table 2.4), so much so that both the International Olympic Committee (IOC) and the National Collegiate Athletic Association (NCAA) have established maximum urinary caffeine allowances (Graham and Spriet, 1996). Similar to the carbohydrate literature, much of the early work focused on caffeine's effect on prolonged exercise (Costill, 1978 and Ivy, 1979). Costill (1978) reported that time to exhaustion (80%  $VO_{2max}$ ) was extended following pre-exercise caffeine ingestion. Ivy (1979) also reported that caffeine ingestion increased the total work accomplished during a two-hour ride.

The potential advantages of caffeine for high-intensity cycling were largely ignored until more recently (Graham and Spriet, 1991). Graham and Spriet (1991) reported that caffeine increased time to exhaustion (85%  $VO_{2max}$ ) by 20 minutes compared to the placebo. Of the 14 studies that have investigated the effects of caffeine on high-intensity aerobic cycling, 13 have reported significant improvements in performance, whether it was time to exhaustion or time trial performance (Table 2.4). Jenkins (2008) was the first to incorporate a time trial element in a high-intensity aerobic cycling study. Although there was only a 15-minute warm-up followed by a 15-minute time trial, 2 mg/kg BW improved time trial performance by 3.9% and 3 mg/kg BW improved time trial performance by 2.9%. However, they found that 1 mg/kg BW had no effect on performance. McNaughton (2008) was the first to use a 60-minute time trial where the objective was to cover as much ground as possible during that time. When

caffeine was ingested prior to the 60-minute time trial, subjects rode significantly farther (28.11 km) compared to a control (26.69 km) and to a placebo (27.0 km).

The physiological explanation for the marked improvement in performance when caffeine is ingested is still not completely understood. Costill (1978) suggested the improvement in performance could be attributed to an increase in lipolysis and neural transmissions. In 1980 Essig (1980) proposed that because there was an increase in fat oxidation, muscle glycogen was spared presumably delaying metabolic fatigue. However, many studies have been published signifying muscle glycogen is not spared during exercise when caffeine is ingested (Jackman, 1996; Chesley, 1998; Greer, 2000; Graham, 2000; Laurent, 2000). It was reported the breakdown of glycogen was enhanced by 40% in hind-limb fast-twitch muscles of rats (Vergauwen, 1997). Cole (1996) reported that decreased perception of effort could be a possible mechanism behind the improvement in performance with caffeine because subjects produced a greater total work output when caffeine was ingested compared to a placebo when riding at the same Ratings of Perceived Exertion (RPE). Although most studies have found that blood glucose is unaltered, there have been six studies reporting an increase in blood glucose when caffeine is ingested prior to exercise (Trice, 1995; Raguso, 1996; Graham and Spriet, 1995; Spriet, 1992; Engels, 1992; Graham, 2000). Graham (2000) reported that after 60 minutes of cycling (70%  $\text{VO}_{2\text{max}}$ ), blood glucose was significantly elevated. Eleven caffeine studies have been published that have reported significant elevations in blood lactate. Graham (2000) also reported that blood lactate was significantly elevated during 60 minutes of cycling (70%  $\text{VO}_{2\text{max}}$ ). Caffeine has been shown to affect the central nervous system by way of its role as an adenosine receptor antagonist mainly due

to the ability of caffeine to cross the blood-brain barrier (Biaggioni, 1991; Davis, 2003; Kalmar, 2004).

Many studies examining the effects of caffeine on prolonged (Table 2.3) or high-intensity aerobic performance (Table 2.4) have assessed performance with time to exhaustion. If a time trial is present in the study, it follows a long ride or is based on distance covered/work completed in a given amount of time. Although these two time trial protocols have some carry-over to real-life situations, they are not ideal from an application viewpoint. Therefore, a simulated time trial where the basis is who can complete the given distance in the fastest time possible may be the most applicable to real-life situations.

**Table 2.3: Caffeine effects on prolonged cycling endurance performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Costill, 1978</b>	7 M and 2 F Competitive Cyclist	2 trials- 1- P, 1- caffeine 330 mg	TTE (80% $VO_{2max}$ )	Caffeine $\uparrow$ TTE by 14 min. Mean caffeine time = 90 min
<b>Ivy, 1979</b>	7 M and 2 F Trained Cyclists	4 trials- 1- FAM, 1- caffeine (250 mg 60min prior and divided does every 15 min during exercise), 1- CHO (total of 90g), and 1- P	Total work (2 hr)	Caffeine ingestion improved work production compared to P (7.4%) and CHO (5.3%). Oxygen consumption was greater in the caffeine trial.
<b>Spriet, 1992</b>	8 Subjects	2 trials- 1- P, 1- caffeine 9 mg/kg	TTE (80% $VO_{2max}$ )	Caffeine $\uparrow$ TTE by 20 min. Mean caffeine time = 96 min.
<b>Wemple, 1997</b>	4 M and 2 F Highly Active	4 trials- 1- resting P, 1- exercising P, 1- resting caffeine, 1- exercising caffeine, caffeine $\sim 8.7$ mg/kg	3 hr ( 60% $VO_{2max}$ ) TTE (85% $VO_{2max}$ )	$\leftrightarrow$
<b>Van Soeren and Graham, 1998</b>	6 Recreational M	8 trials- 1- FAM (30 min), 1- P no WD, 1- caffeine no WD, 1- P 2 days WD, 1- caffeine 2 days WD, 1- P 4 days WD, 1- caffeine 4 days WD, 1- P repeat (single blinded), caffeine dose= 6 mg/kg, at least 10 days separated the trials	TTE (80-85% $VO_{2max}$ )	TTE was $\uparrow$ with caffeine vs. placebo regardless of withdrawal period.

**Table 2.3: (Continued) Caffeine effects on prolonged cycling endurance performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Cox, 2002</b>	12 Highly Trained M Cyclists or Triathletes	4 trials- 1-caffeine 60 min before (6 mg/kg), 1- 6X1 mg/kg BW every 20 min, 1- Coca-Cola in latter stages, 1-P (CHO given in all trials 6.3% solution)	120 min SS (70% $VO_{2peak}$ ) followed by 7 kJ/kg BW TT	Caffeine administered 60 min prior (3.4%), caffeine during exercise (3.1%), and Coca-Cola during exercise (3.1%) all trials containing caffeine improved performance vs. P.
<b>Conway, 2003</b>	9 Well-Trained Cyclists	4 trials- 1 FAM, 1- P 1hr prior and 45 min into exercise, 1- caffeine 1 hr prior to exercise (one 6 mg/kg BW) and P 45 min into exercise, 1- caffeine 1hr prior to exercise and 45 min into exercise (both 3 mg/kg BW)	90 min SS (68% $VO_{2max}$ ) followed by a 30 min TT	↔
<b>Slivka, 2008</b>	9 Recreational M Cyclists	Subjects were only allowed to eat 1 standardized meal 2 days prior to trials and drink water, 4 trials- 1-P, 1- caffeine only, 1- CHO only, 1-combined caffeine and CHO, 2 hr of cycling @ 50% $VO_{2max}$ 24 hr prior to trial, during trial- caffeine and CHO was given every 30 min	2 hr (50% $VO_{2max}$ ) followed by 20-km TT	↔
<b>Walker, 2008</b>	9 Endurance Trained M Cyclists	3 trials- 1- FAM (shortened), 1- P, 1- caffeine, caffeine dose= 6 mg/kg	90 min SS (70% $VO_{2max}$ ) followed by 30 min TT	Caffeine improved performance by 4.3% in the TT.

CHO = carbohydrates, min = minutes, hr = hours, FAM = familiarization, P = placebo, TT = time trial, WD = withdrawal, mg = milligram, kg = kilogram, SS = steady-state, TTE = time to exhaustion, ↔ = no difference, ↑ = increase



**Table 2.4: Caffeine effects on high-intensity cycling performance ( $\leq 60$  minutes)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Graham and Spriet, 1991</b>	6 M and 1 F Well-Trained Distance runners	4 trials- 1- P running, 1- P cycling, 1- caffeine running, 1- caffeine cycling (caffeine dose= 9 mg/kg)	TTE (85% $VO_{2max}$ )	Ingestion of caffeine improved running and cycling TTE vs. P. Mean caffeine running time = 71 min vs. 49 min without caffeine. Mean caffeine cycling time = 59 min vs. 39 min without caffeine.
<b>Fulco, 1994</b>	8 M	6 trials- 1- P at sea level, 1- P 1 hr at 4300m, 1- P 2 wks at 4300m, 1- caffeine at sea level, 1- caffeine 1hr at 4300m, 1- caffeine 2 wks at 4300m, caffeine dose= 4 mg/kg	TTE (80% $VO_{2max}$ )	$\leftrightarrow$ on performance at sea level and when chronically exposed to altitude. Caffeine increased TTE by 54% when acutely exposed to altitude (1 hr).
<b>Pasman, 1995</b>	9 Well-Trained Subjects	4 trials- 1- P, 1- caffeine 5 mg/kg, 1- caffeine 9 mg/kg, 1- caffeine 13 mg/kg, completed in 4 consecutive wks	TTE (80% $W_{max}$ )	Caffeine $\uparrow$ TTE in all trials vs. P by 27%. $\leftrightarrow$ between different dosages of caffeine.
<b>Cole, 1996</b>	10 Recreational M	6 Trials- 3-P, 3- caffeine (6mg/kg)	Cycled at Borg's RPE of 9 first 10 min, 12 next 10 min, and 15 last 10 min	Caffeine $\uparrow$ total work during the 30 min by 12.6% vs. P.
<b>Bell, 1998</b>	12 Recreational M	5 trials- 1 FAM, 1- P, 1- caffeine (5 mg/kg), 1- ephedrine (1 mg/kg), 1- caffeine and ephedrine (same dose for each) caffeine and ephedrine was administered 90 min prior to exercise, minimum of 1 wk separated trials	TTE (85% $VO_{2peak}$ )	$\leftrightarrow$

**Table 2.4: (Continued) Caffeine effects on high-intensity cycling performance ( $\leq 60$  minutes)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Denadai and Denadai, 1998</b>	8 Untrained M	4 trials- 1- P 10% above AT, 1- P 10% below AT, 1- caffeine 10% above AT, and 1- caffeine 10% below AT, caffeine dose 5 mg/kg 60 min prior to exercise	TTE (10% above and 10% below AT)	Caffeine ingestion improved TTE by 15 min when intensity was 10% below lactate threshold vs. P. $\leftrightarrow$ for trials above AT.
<b>Graham, 2000</b>	10 Healthy M	3 trials- 1-FAM, 1-P, 1-caffeine (6 mg/kg), 60 min prior to exercise	1hr (70% $VO_{2max}$ )	Caffeine has minimal effects on metabolism. Blood glucose and lactate $\uparrow$ .
<b>Greer, 2000</b>	8 Active M	4 trials- 1- FAM (not to exhaustion), 1- P, 1-theophylline (4.5 mg/kg), 1- caffeine (6 mg/kg)	TTE (80-85% $VO_{2max}$ )	Caffeine improved performance vs. P by 22% and theophylline improved performance by 14%. $\leftrightarrow$ between caffeine and theophylline.
<b>Ryu, 2001</b>	5 M Rugby Players	Caffeine dose 5 mg/kg	45 min SS (60% $VO_{2max}$ ) followed by TTE (80% $VO_{2max}$ )	Caffeine improved TTE in both rats and humans.

**Table 2.4: (Continued) Caffeine effects on high-intensity cycling performance ( $\leq 60$  minutes)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Bell and McLellan, 2002</b>	15 M and 6 F Active	8 trials- 2 FAM (lasting 1 hr), 1- P ingested 1 hr prior, 1- P ingested 3 hr prior, 1- P ingested 6 hr prior, 1- caffeine ingested 1 hr prior, 1- caffeine ingested 3 hr prior, 1- caffeine ingested 6 hr prior, caffeine dose= 5 mg/kg, each trial separated by at least 2 wks (Gatorade was consumed 1 hr prior to all trials)	TTE (80% $VO_{2max}$ )	Caffeine $\uparrow$ TTE in all trials vs. P except in users when caffeine was ingested 6 hr prior to exercise. Caffeine's effect was greater in non-users compared to users.
<b>Bell and McLellan, 2003</b>	9 Recreational Cyclists	6 trials- 2 FAM, 1- caffeine AM and PM, 1- placebo AM and PM, 1- caffeine AM, placebo PM, 1- placebo AM, caffeine PM, AM and PM rides were 5 hr apart, all caffeine doses 5 mg/kg, each trial was separated 1 wk	TTE (80% $VO_{2max}$ )	Caffeine $\uparrow$ TTE vs. P except when caffeine was ingested in the AM and the P ingested in the PM.
<b>Jenkins, 2008</b>	13 M Cyclists	5 trials- 1 FAM, 1- P, 1- 1 mg/kg BW caffeine, 1- 2 mg/kg BW caffeine, 1- 3mg/kg BW caffeine	15 min SS ( $VO_{2peak}$ ), 4 min recovery, 15 min $VO_{2peak}$ test	The 2 mg/kg of caffeine had a 4% improvement in performance vs. P. 3 mg/kg of caffeine had 3% improvement over P. 1 mg/kg had $\leftrightarrow$ on performance.
<b>McNaughton, 2008</b>	8 Trained Cyclists M	3 trials- 1- control, 1- P, 1- caffeine, caffeine dose= 6 mg/kg	1 hr TT	Caffeine improved distance covered vs. the control and P by 1.42 km and 1.11 km respectively.

**Table 2.4: (Continued) Caffeine effects on high-intensity cycling performance ( $\leq 60$  minutes)**

Author	Subjects	Design	Performance Criterion	Findings
Ivy, 2009	6 M and 6 F Trained Cyclists	2 trials- 1- P, 1- energy drink (500ml, 160 mg caffeine, 40 min prior to exercise), separated by 1 wk	1hr TT	The energy drink improved performance vs. P by 4.7%.

AT = anaerobic threshold, wk = week, P = placebo, min = minute, hr = hour, mg = milligram, kg = kilogram, FAM = familiarization, SS = steady-state, TT = time trial, TTE = time to exhaustion,  $\leftrightarrow$  = no difference,  $\uparrow$  = increase

### **Combined Carbohydrates and Caffeine and Exercise Performance**

The performance gains that can be achieved by ingesting carbohydrate and caffeine are well established, but surprisingly, only a few studies have assessed the combined effects (Table 2.5 and Table 2.6), most of which examined prolonged cycling (>90 minutes) (Table 2.5). To our knowledge, only one study has tested the combined effects of carbohydrate and caffeine on high-intensity cycling performance (Kovacs, 1998). Kovacs (1998) found that when caffeine was added to a carbohydrate-electrolyte solution, performance was improved in a time trial lasting about one hour. Two of the three caffeinated carbohydrate-electrolyte solutions (CES with varying amounts of caffeine) improved performance when compared to the carbohydrate-electrolyte solution. As a consequence of not including a caffeine-only trial, the respective contributions from carbohydrate and caffeine alone compared to the combined effects could not be discerned.

**Table 2.5: Caffeine and Carbohydrate effects on prolonged endurance performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Wemple, 1997</b>	4 M and 2 F Highly Active	4 trials- 1- resting P, 1- exercising P, 1- resting caffeine, 1- exercising caffeine, caffeine $\sim 8.7$ mg/kg	3 hr ( 60% $VO_{2max}$ ) TTE (85% $VO_{2max}$ )	$\leftrightarrow$
<b>Jacobson, 2001</b>	8 Highly Trained M Cyclists and Triathletes	4 trials- 1- CHO only, 1- CHO + caffeine, 1- Fat only, and 1-Fat + caffeine (meals and caffeine were consumed 55 min prior to the warm-up)	120 min SS (70% $VO_{2max}$ ), 3 min rest followed by a 7 kJ/kg BW TT	Less time needed to complete the TT when CHO was ingested vs. fat ingestion. $\leftrightarrow$ in performance time when caffeine was added to CHO or fat.
<b>Cox, 2002</b>	12 Highly Trained M Cyclists or Triathletes	4 trials- 1-caffeine 60 min before (6 mg/kg), 1- 6X1 mg/kg BW every 20 min, 1- Coca-Cola in latter stages, 1-P (CHO given in all trials 6.3% solution)	120 min SS (70% $VO_{2peak}$ ) followed by 7 kJ/kg BW TT	Caffeine administered 60 min prior (3.4%), caffeine during exercise (3.1%), and Coca-Cola during exercise (3.1%) all improved performance over P.
<b>Cox, 2002</b>	8 Highly Trained M Cyclists or Triathletes (different than Study A)	4 trials- 1-decaf cola-flavored drink (6% CHO), 1- caffeinated cola-flavored drink (6% CHO), 1-decaf cola-flavored drink (11% CHO), 1- caffeinated cola-flavored drink Coke (11% CHO)	120 min SS (70% $VO_{2peak}$ ) followed by 7 kJ/kg BW TT	TT performance was improved 3.3% with the Coke trial vs. the decaf. TT performance was improved when trial had caffeine by 2.2% vs. without.
<b>Hunter, 2002</b>	8 Endurance Trained, Competitive M Cyclists	4 trials- 1 FAM, 1- P, 1- CHO only, 1- caffeine and CHO	100-km TT with 5 x 1-km and 4 x 4-km high-intensity bouts	$\leftrightarrow$

**Table 2.5: (Continued) Caffeine and Carbohydrate effects on prolonged endurance performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Cureton, 2007</b>	16 Highly Trained Cyclists (studied at two independent laboratories)	4 trials- 1-FAM, 1-P, 1-non-caffeinated sports beverage, 1-caffeinated sports beverage- separated by at least 5 days	Total 135 min: first 120 min, 15 min intervals (60% and 75% of $VO_{2max}$ ) followed by 15 min TT	Caffeinated sports beverage had an improvement in performance during the final 15 min of exercise vs. the non-caffeinated sports beverage and P by 15 % and 23% respectively. $\leftrightarrow$ between non-caffeinated sports beverage and P.
<b>Hogervorst, 2008</b>	24 Recreational M Cyclists	4 trials- 1- FAM, 1- P beverage, 1-caffeinated performance bar (100 mg of caffeine), 1- non-caffeinated performance bar, all trials separated by at least 1 wk, prior to exercise, 55 min, and 115 min bar and beverage supplied again, water given every 20 min	150 min SS (60% $VO_{2max}$ ) followed by TTE (75% $VO_{2max}$ )	The caffeinated bar improved TTE vs. the CHO bar and P beverage by 27% and 84% respectively. The CHO bar improved TTE over P by 44%.
<b>Hulston and Jeukendrup, 2008</b>	10 Endurance Trained Cyclist	4 trials- 1-FAM, 1-P, 1-CHO only, 1-CHO/caffeine, unfed prior to study. Caffeine given during not prior. separated by at least 7 days	105 min SS ( $VO_{2max}$ 62%) followed by 45 min TT	Performance during TT was improved in CHO by 4.4% and CHO/caffeine by 9.0% vs. P and CHO/caffeine 4.6% improved performance vs. CHO.

**Table 2.5: (Continued) Caffeine and Carbohydrate effects on prolonged endurance performance ( $\geq 90$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Slivka, 2008</b>	9 Recreational M Cyclists	Subjects were only allowed to eat 1 standardized meal 2 days prior to trials and drink water, 4 trials- 1-P, 1- caffeine only, 1- CHO only, 1- combined caffeine and CHO, 2 hr of cycling @ 50% $VO_{2max}$ 24 hr prior to trial, during trial- caffeine and CHO was given every 30 min	2 hr (50% $VO_{2max}$ ) followed by 20-km TT	CHO only improved average watts vs. P. $\leftrightarrow$ between trials in time.
<b>Desbrow, 2009</b>	9 Trained M Cyclist or Triathletes	4 trials- 2-FAM, 1-P, 1-1.5 mg/kg BW caffeine, and 1-3 mg/kg BW caffeine- separated by at least 7 days, Fed prior and during study. Glucose beverage immediately prior to exercise (8 ml/kg, 8% solution). Glucose beverage every 20 min in SS (5 ml/kg, 8% solution)	120 min SS (70% $VO_{2peak}$ ) followed by 7 kJ/kg BW TT	$\leftrightarrow$

min = minutes, FAM = familiarization, P = placebo, CHO = carbohydrate, TT = time trial, SS = steady-state, decaf = decaffeinated, kJ = kilojoules, kg = kilogram, BW = body weight, mg = milligram, wk = week, ml = milliliter, TTE = time to exhaustion,  $\leftrightarrow$  = no difference,  $\uparrow$  = increase



**Table 2.6: Caffeine and Carbohydrate effects on high-intensity cycling performance ( $\leq 60$  min)**

Author	Subjects	Design	Performance Criterion	Findings
<b>Kovacs, 1998</b>	15 Well-Trained M	5 trials- 1-P, 1-CES 68.8 g CHO, 1- CES + 150 mg/L of caffeine, 1- CES + 225 mg/L of caffeine, 1-CES + 320 mg/L of caffeine. All trials separated by 7 days.	1 hr TT	TT performance was improved with CES-225 and CES-320 compared with CES-150, CES, and P. CES-150 had an improvement in time vs. P. CES and P had $\leftrightarrow$ and CES-320 had no further improvement than CES-225.

CHO = carbohydrate, CES = CHO-electrolyte solution, mg = milligram, TT = time trial, min = minute, P = placebo, L = liter,  $\leftrightarrow$  = no difference

**Summary**

Carbohydrates when ingested during exercise can be used to improve prolonged and high-intensity cycling exercise. Caffeine can also be used to improve prolonged and high-intensity cycling exercise. However, few studies have examined the impact of caffeine on simulated real-life events, particularly when the intensity is high. Only one study to date has examined the effects of combining carbohydrates and caffeine on high-intensity aerobic cycling exercise; however, the independent and combined effects of carbohydrates and caffeine were not determined. The current project was therefore designed to address the independent and combined effects of carbohydrate and caffeine ingestion on high-intensity cycling performance.

## CHAPTER THREE- METHODOLOGY

### Subjects

Twelve male cyclists from James Madison University and the Harrisonburg community volunteered to participate in this study. Over the course of the study, two subjects dropped out due to scheduling conflicts. Statistical analysis was performed on the remaining 10 subjects. Subject characteristics are provided in Table 3.1.

**Table 3.1: Subject Characteristics**

	Height (cm)	Weight (kg)	Age (yr)	VO <sub>2max</sub> (ml/kg/min)	W <sub>max</sub>
<b>Mean ± SD</b>	178 ± 6	73.2 ± 5.9	28 ± 8	65.5 ± 9.2	320.0 ± 52.1

Subjects were provided with written and oral information about the experimental procedures and potential risks prior to written consent (Appendix I). Subjects also completed a Pre-Participation Screening Questionnaire to minimize the risk of an adverse cardiovascular event (Appendix II). In addition, subjects completed a caffeine questionnaire to determine the amount of caffeine consumed on a weekly basis (Appendix III). All procedures were approved by the James Madison University Institutional Review Board prior to any testing.

### Testing Procedures

#### *Maximal Exercise Test*

Subjects performed an incremental exercise test to exhaustion on a bicycle ergometer (Velotron, Racermate, Inc.) to determine maximal oxygen consumption (VO<sub>2max</sub>). Testing began with the subjects riding at a self-selected pace, described as a

“comfortable but not an easy pace for a 60-minute ride.” After the initial workload was selected, workload was increased by 25 watts (W) every two minutes until the subject reached volitional exhaustion. Breath-by-breath gas exchange analysis was averaged over one-minute. Peak power at  $\text{VO}_{2\text{max}}$  ( $W_{\text{max}}$ ) was defined as the highest sustainable (30 seconds) power output during the maximal exercise test.  $W_{\text{max}}$  was used to prescribe exercise intensities for the 20-minute steady-state in subsequent trials. A SensorMedics Spectra (Yorba Linda, CA) metabolic cart continuously monitored oxygen uptake. A Polar (Lake Success, NY) heart rate monitor was used to determine heart rate during each test.

### *Protocols*

Each subject performed six trials with 5-14 days separating each trial. The first two trials were familiarization trials with the final four trials serving as the treatment trials. Testing of the four treatment conditions was performed in a semi-randomized (the initial trial was always the placebo trial), double-blind, placebo fashion. All trials were performed at ambient room temperature (70-72°F). The subjects were asked to void their bladder prior to all trials. An Essential Home fan, set on ‘medium’ speed, was placed 2 meters from the handlebars of the ergometer for cooling purposes during the trial. Subjects were asked to approach each time trial as a competitive event.

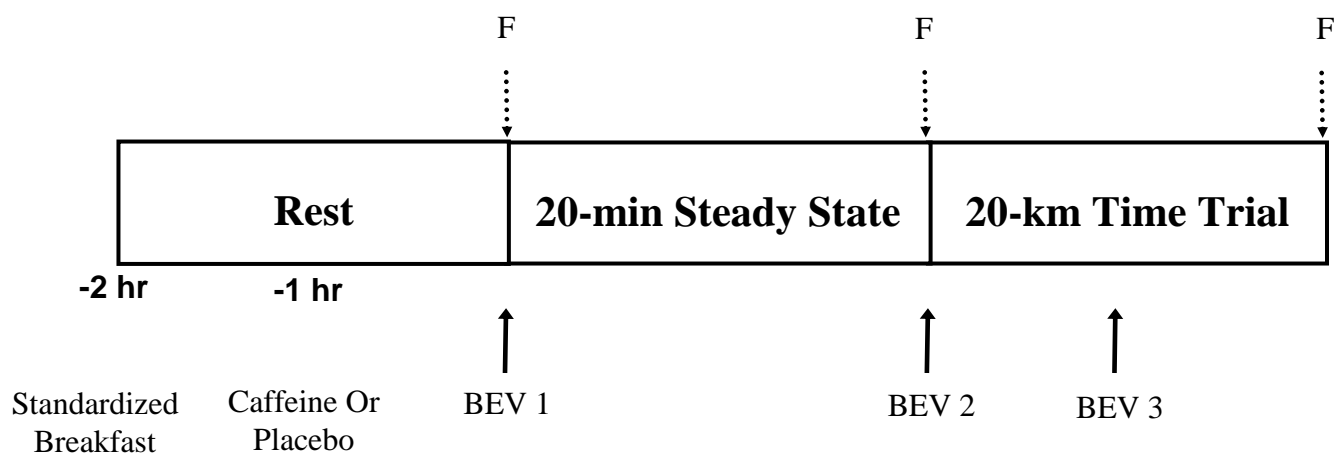
The four treatments were as follows: 1) *placebo trial*- placebo pill administered 60 minutes prior to exercise and artificially sweetened water (250 ml) administered at three time points, 2) *carbohydrate only trial*- a placebo pill administered 60 minutes prior to exercise and a carbohydrate beverage containing 20 g of CHO in an 8% solution (250

ml) administered at three time points, 3) *caffeine only trial*- 6-mg/kg BW dose of caffeine in pill form administered 60 minutes prior to exercise and a placebo beverage containing artificially sweetened water (250 ml) administered at three time points, and 4) *caffeine and carbohydrate trial*- 6-mg/kg BW dose of caffeine in pill form administered 60 minutes prior to exercise and a carbohydrate beverage containing 20 g of CHO in an 8% solution (250 ml) administered at three time points. The first two familiarization trials were performed under identical conditions to the placebo trial.

A general study design is displayed in Figure 3.1. Two hours prior to exercise, subjects consumed a standardized breakfast at home. One hour prior to the start of exercise, subjects reported to the laboratory and were administered a caffeine or placebo pill. Ten minutes prior to exercise, finger-stick blood samples were obtained (0.5 ml). Immediately prior to exercise, a muscle function test was performed to determine isometric peak torque of the quadriceps during a leg-extension test (MVC). Following the muscle function assessment, subjects were positioned on the bicycle ergometer (Velotron, Racermate, Inc.) whereupon the first of three treatment beverages were administered – either artificially sweetened water or an 8% carbohydrate solution (250 ml). A 20-minute steady-state exercise was then performed at 60%  $W_{max}$ . During the 20-minute steady-state ride, expired gases were obtained for five minutes (min 3:00 to min 8:00). The final three minutes of gas collection was aggregated to represent a mean for  $VO_2$ , VE, and RER. With 30 seconds remaining during gas collection (7:30), heart rate was recorded and Ratings of Perceived Exertion were obtained using the Borg RPE scale; this was repeated with 30 seconds remaining in the steady-state exercise (19:30). Immediately following the steady-state ride, a finger-stick blood sample was obtained.

Following blood sampling, the 2<sup>nd</sup> of three treatment beverages was administered and subjects began the simulated 20-km time trial (TT). The final treatment beverage was administered 20 minutes into the TT. Subjects received no encouragement or feedback during this portion of the trial and were only allowed to monitor the remaining distance, percent grade of the course, and gearing. With 0.05 km left, heart rate and RPE were recorded. Immediately following the TT, a finger-stick blood sample was obtained. Two minutes following the 20-km TT, post-exercise MVC was determined.

**Figure 3.1: General Trial Design**



F = finger-stick blood sample; BEV = beverage consumption

### **Dependent Measurements**

#### *Exercise Performance*

A simulated 20-km TT was selected as the performance criterion. Performance time was also recorded for the final 5 km of the trial to provide a late-exercise

assessment. Power output (watts) was also recorded throughout the 20-km TT and mean power output was calculated for the final 5-km segment.

#### *Skeletal Muscle Function*

Isometric Peak Torque (MVC). Peak torque of the knee extensors (knee joint angle: 70°) was assessed immediately before and after exercise. Subjects were seated in a modified chair and instructed to push as hard as possible against a fixed shin pad that was connected to a force transducer. Testing was performed on a custom-built muscle function device designed by Dr. Gordon Warren. Participants performed three 5-second repetitions with 60-seconds of rest prior to and following exercise. Peak force was recorded in Newtons. The average of the three measurements was used for analysis.

#### Physiological Responses during Exercise

##### *Metabolic Measurements*

Metabolic measurements were recorded for five minutes during the steady-state segment of the trial using a SensorMedics Spectra metabolic cart. The final three minutes of gas collections was aggregated to represent a mean for *oxygen uptake* ( $\text{VO}_2$ ), *expired ventilation* (VE), and *respiratory exchange ratio* (RER; indicates relative contributions of fat and carbohydrate oxidation to total energy expenditure).

### *Blood Glucose and Blood Lactate*

Finger-stick blood samples (~0.5 ml) were obtained at the previously mentioned time points to determine blood glucose and lactate levels using an automated analyzer (YSI 2300 STAT glucose/lactate analyzer).

### *Heart Rate*

Heart rate was recorded at the previously mentioned time points using a Polar heart rate monitor. In addition, average heart rate was calculated for the 20-km TT.

### *Ratings of Perceived Exertion (RPE)*

Subjective ratings of exertion was obtained by having the subjects indicate their corresponding level of exertion (rated numerically from 6-20) on a Borg RPE scale. RPE was at the previously mentioned time points. Subjects received instructions regarding how to utilize the RPE scale during the familiarization trials, consisting of the following: *“Please describe your current level of exertion using the following scale. This level should represent your overall perception of effort, and not localized to a specific group of muscles, etc. For reference, a 6 would represent your effort when you are resting or watching TV, while a 20 would represent the highest level of exertion you are capable of producing during exercise.”*

### **Dietary and Exercise Controls**

Subjects were instructed to refrain from heavy exercise for 48-hours prior to each trial. In addition, subjects kept dietary records for 24-hours preceding each trial, and they



were instructed to maintain consistent dietary habits before each subsequent trial (Appendix IV). Subjects also recorded all physical activity performed during the 72-hours prior to each trial and were instructed to maintain consistent exercise habits between each of these trials (Appendix V). Subjects were also asked to refrain from alcohol and caffeine ingestion for 24-hours prior to each trial. Subjects were instructed to eat a self-selected meal no less than 12 hours prior to the start of each trials (i.e. dinner on the evening prior to testing). After this time, subjects followed standardized dietary protocols, including the following:

- 1) No food or beverage intake between dinner and bedtime on the evening prior to the trial (water was consumed *ad libitum*).
- 2) On the morning of the exercise trials, subjects consumed a standardized breakfast two hours prior to the trial. The meal was provided by the researchers, consisted of approximately 500 kcal, and comprised of 90-100 g carbohydrate, 8-12 g protein, and 4-8 g fat. In order to account for personal tastes, subjects selected from one of a few choices, and the meal of choice was repeated across all trials for each subject. Subjects consumed 8 oz of orange juice or apple juice with this meal. These dietary restrictions ensured that there were no differences in nutrient intake between the intervention periods, other than the treatments provided by the researchers.

### **Statistical Analyses**

20-km TT, average power output (Watts) in both the 20-km TT and the final 5-km, HR, RPE, RER, MVC, blood glucose, and blood lactate were assessed using a

repeated measures ANOVA with treatment as a within-subjects factor. Our planned comparisons were all treatment conditions compared to placebo. A *priori* level of significance was set at  $p < 0.05$ . Where statistical significance was detected, pairwise comparisons were performed using Bonferroni post-hoc analysis. In the case of *a priori* ‘planned’ comparisons (20-km time trial performance), post-hoc analyses were performed if  $p < 0.1$ . Non-parametric statistics were applied to the following skewed (e.g. variation from normal distribution) variables: time to complete the final 5-km of the TT,  $\text{VO}_2$ , VE, RPE recorded mid steady-state and post steady-state, and post TT glucose, and post TT lactate (Friedman Test). If significance or trend toward significance was detected, a Wilcoxon Signed Rank Test was used to determine pairwise comparisons. The level of significance was adjusted for multiple comparisons which was 0.05 divided by the number comparison (6) and set to  $p < 0.008$ . Pre-MVC was assessed using a One-Sample T-Test to determine significance relative to placebo. Level of significance was adjusted for multiple comparisons and set to  $p < 0.017$ . All data is reported as means  $\pm$  SE.

## CHAPTER FOUR- MANUSCRIPT

THE INDEPENDENT AND COMBINED EFFECTS OF CARBOHYDRATE AND  
CAFFEINE INGESTION ON CYCLING PERFORMANCE

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Running Head: Carbohydrate, caffeine, and cycling time trial performance

### Abstract

**Purpose:** The purpose of this study was to determine the independent and combined effects of carbohydrate and caffeine ingestion on performance and physiological parameters during high-intensity aerobic cycling (~60 minutes). **Methods:** Ten cyclists ( $28 \pm 3$  yr,  $73.2 \pm 1.9$  kg) performed 20 minutes of steady-state cycling (60%  $W_{\max}$ ) followed by a simulated 20-km time trial (TT) under the following four treatment conditions: placebo (PLA), carbohydrate (CHO), caffeine (CAF), and a combination of CHO and CAF (CHO-CAF). One hour prior to exercise subjects ingested a placebo/caffeine capsule. Beverages (250 ml) were consumed immediately prior to the 20-min steady-state, immediately prior to the 20-km TT, and at the 20-min mark during the time trial. Subjects completed the treatment trials in a semi-randomized, double-blind, placebo fashion and trials were separated by  $\geq 5$  days. **Results:** CHO-CAF improved 20-km TT performance by 3.4% (93 sec) compared to PLA ( $p \leq 0.05$ ), whereas no differences were detected among CHO, CAF, and PLA. Similarly, CHO-CAF improved mean power output by 5% during the 20-km TT compared to the PLA trial. RER was elevated under all treatment conditions compared to PLA. Further, blood glucose was elevated in CHO-CAF compared to PLA post steady-state and post TT. Treatment conditions did not differentially impact VE,  $VO_2$ , pre-exercise MVC, post-exercise MVC, RPE, and blood lactate. **Conclusions:** CAF and CHO improve 20-km time trial performance when taken together but not when taken independently. This appears to be possibly facilitated by peripheral (MVC) and metabolic modifications (RER + blood glucose).

Regardless of the mechanism, these data suggest that cyclists should ingest CHO and CAF together to improve high-intensity time trial performance, while in the fed state.

Key Words: Carbohydrate, Caffeine, Performance, Cycling

## Introduction

Cyclists are consistently searching for methods to improve performance (e.g. nutrition, pharmacology, training etc). One such method is the ingestion of carbohydrates before and/or during exercise. Surprisingly, it was not until the late 1970s and early 1980s that carbohydrate supplementation during exercise was systematically investigated (Ivy, 1979; Bonen, 1981; Coyle, 1983; Bjorkman, 1984). Since then, carbohydrate has been shown to improve performance during prolonged and high-intensity cycling (Coyle, 1986; Langenfeld, 1994; Hulston and Jeukendrup, 2009; Below, 1995; Jeukendrup, 1997; Carter, 2004a). Another method utilized to improve both prolonged and high-intensity cycling performance is caffeine ingestion. Similar to that of carbohydrates, scientific support for the purported ergogenic effects of caffeine began to emerge in the late 1970's (Costill, 1978), although evidence for caffeine-induced gains in muscle function can be traced back to 1907 (Rivers and Webber, 1907). Researchers have more recently examined the combined effects of carbohydrates and caffeine on performance and the results are equivocal. Wemple (1997) was the first to test the combined effects of carbohydrate and caffeine, a study in which no differences in time to exhaustion (85%  $\text{VO}_{2\text{max}}$ ) were reported between a caffeinated carbohydrate electrolyte beverage and a non-caffeinated carbohydrate electrolyte beverage, after cycling for three hours. Conversely, Kovacs (1998) reported that one-hour time trial performance improved when moderate doses of caffeine were added to a carbohydrate-electrolyte beverage.

The ergogenic effects of carbohydrate ingestion during high-intensity cycling (~60 minutes) remain a source of contention. Approximately half of the literature

supports the performance benefits of carbohydrate ingestion, while the other half does not (Coyle, 1986; Flynn, 1987; Carter, 2004a; Carter, 2004b). In the case of those studies demonstrating improvements in performance, there seems to be a lack of mechanistic understanding. Proposed mechanisms include augmented carbohydrate oxidation rates and the intricate interplay between mouth receptors and the brain (central mechanism) (El-Sayed, 1997; Carter, 2004a). With regard to central mechanisms, Carter (2004a) reported that time trial performance of approximately one hour improved by 3% when a carbohydrate solution was rinsed in the mouth for five seconds. Two investigations were recently conducted using protocols similar to that of Carter (2004a). One of these studies demonstrated a 2% gain in cycling time trial performance (60 min) with the carbohydrate mouth rinse compared to placebo (Chambers, 2009) while the other reported null findings (Beelen, 2009).

Caffeine is widely used as an ergogenic substance for athletes. Ingestion of caffeine, typically 60 minutes prior to exercise, is known to have positive effects on high-intensity cycling exercise (~60 minutes) (Graham and Spriet, 1991; Pasman, 1995; Bell and McLellan, 2002; Jenkins, 2008). When the effects of caffeine ingestion during cycling were first reported, the authors suggested that the improvements may be facilitated by elevated rates of lipolysis and an increase in the impulse of neural transmissions (Costill, 1978). Essig (1980) extended Costill's hypothesis and suggested that muscle glycogen was being spared as a result of an increase in fat oxidation. However, a sizable collection of studies have since concluded that muscle glycogen is not spared during exercise when caffeine is ingested (Jackman, 1996; Chesley, 1998; Greer, 2000; Graham, 2000; Laurent, 2000). It is also suggested that caffeine may affect



performance due to its ability to cross the blood-brain barrier, which in turn allows it to act as an adenosine receptor antagonist (Biaggioni, 1991; Davis, 2003; Kalmar, 2004).

Naturally, it is common practice for cyclists to combine known ergogenic aids (stacking), such as carbohydrates and caffeine. The performance gains that can be achieved by ingesting carbohydrate and caffeine are well established, but surprisingly, only a few studies have assessed the combined effects (Wemple, 1997; Kovacs, 1998; Jacobson, 2001; Cox, 2002; Hunter, 2002; Cureton, 2007; Hogervorst, 2008; Hulston and Jeukendrup, 2008; Slivka, 2008; Desbrow, 2009). Nine out of these ten studies have examined the combined effects of carbohydrate and caffeine on prolonged cycling (> 90 minutes), and to our knowledge, only one study has examined this in the context of high-intensity cycling performance (Kovacs, 1998). Kovacs (1998) demonstrated that one-hour time trial performance improved when caffeine was added to a carbohydrate-electrolyte solution. However, as a consequence of not including a caffeine-only trial, the respective contributions from carbohydrate and caffeine alone compared to the combined effects could not be discerned.

Therefore, the primary purpose of the present study was to determine the independent and combined effects of carbohydrate and caffeine ingestion on high-intensity cycling (~60 minutes) performance as well as physiological responses to these treatments. It was hypothesized that performance would be improved by supplementing with carbohydrate alone and caffeine alone. It was also hypothesized that by combining the two supplements, there would be more of an improvement than either supplement alone which would be additive.

## Methods

### Subjects

Twelve male cyclists from James Madison University and the Harrisonburg community volunteered to participate in this study. Over the course of the study, two subjects dropped out due to scheduling conflicts. Statistical analysis was performed on the remaining 10 subjects. Subject characteristics are provided in Table 1.

**Table 4.1: Subject Characteristics**

	Height (cm)	Weight (kg)	Age (yr)	VO <sub>2max</sub> (ml/kg/min)	W <sub>max</sub>
<b>Mean ± SD</b>	178 ± 6	73.2 ± 5.9	28 ± 8	65.5 ± 9.2	320.0 ± 52.1

Subjects were provided with written and oral information about the experimental procedures and potential risks prior to written consent. Subjects also completed a Pre-Participation Screening Questionnaire to minimize the risk of an adverse cardiovascular event. In addition, subjects completed a caffeine questionnaire to determine the amount of caffeine consumed on a weekly basis. All procedures were approved by the James Madison University Institutional Review Board prior to any testing.

### Testing Procedures

#### *Maximal Exercise Test*

Subjects performed an incremental exercise test to exhaustion on a bicycle ergometer (Velotron, Racermate, Inc.) to determine maximal oxygen consumption (VO<sub>2max</sub>). Testing began with the subjects riding at a self-selected pace, described as a “comfortable but not an easy pace for a 60-minute ride.” After the initial workload was

selected, workload was increased by 25 watts (W) every two minutes until the subject reached volitional exhaustion. Breath-by-breath gas exchange analysis was averaged over one-minute. Peak power at  $\text{VO}_{2\text{max}}$  ( $W_{\text{max}}$ ) was defined as the highest sustainable (30 seconds) power output during the maximal exercise test.  $W_{\text{max}}$  was used to prescribe exercise intensities for the 20-minute steady-state in subsequent trials. A SensorMedics Spectra (Yorba Linda, CA) metabolic cart continuously monitored oxygen uptake. A Polar (Lake Success, NY) heart rate monitor was used to determine heart rate during each test.

### *Protocols*

Each subject performed six trials with 5-14 days separating each trial. The first two trials were familiarization trials with the final four trials serving as the treatment trials. Testing of the four treatment conditions was performed in a semi-randomized (the initial trial was always the placebo trial), double-blind, placebo fashion. All trials were performed at ambient room temperature (70-72°F). The subjects were asked to void their bladder prior to all trials. An Essential Home fan, set on 'medium' speed, was placed 2 meters from the handlebars of the ergometer for cooling purposes during the trial. Subjects were asked to approach each time trial as a competitive event.

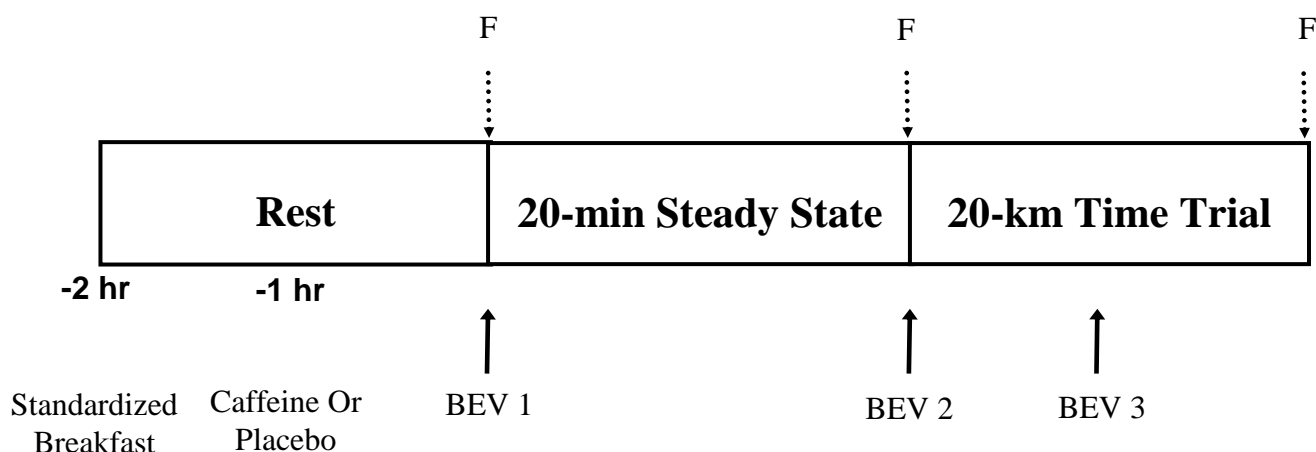
The four treatments were as follows: 1) *placebo trial*- placebo pill administered 60 minutes prior to exercise and artificially sweetened water (250 ml) administered at three time points, 2) *carbohydrate only trial*- a placebo pill administered 60 minutes prior to exercise and a carbohydrate beverage containing 20 g of CHO in an 8% solution (250 ml) administered at three time points, 3) *caffeine only trial*- 6-mg/kg BW dose of caffeine

in pill form administered 60 minutes prior to exercise and a placebo beverage containing artificially sweetened water (250 ml) administered at three time points, and 4) *caffeine and carbohydrate trial*- 6-mg/kg BW dose of caffeine in pill form administered 60 minutes prior to exercise and a carbohydrate beverage containing 20 g of CHO in an 8% solution (250 ml) administered at three time points. The first two familiarization trials were performed under identical conditions to the placebo trial.

A general study design is displayed in Figure 4.1. Two hours prior to exercise, subjects consumed a standardized breakfast at home. One hour prior to the start of exercise, subjects reported to the laboratory and were administered a caffeine or placebo pill. Ten minutes prior to exercise, finger-stick blood samples were obtained (0.5 ml). Immediately prior to exercise, a muscle function test was performed to determine isometric peak torque of the quadriceps during a leg extension test (MVC). Following the muscle function assessment, subjects were positioned on the bicycle ergometer (Velotron, Racermate, Inc.) whereupon the first of three treatment beverages were administered – either artificially sweetened water or an 8% carbohydrate solution (250 ml). A 20-minute steady-state exercise was then performed at 60%  $W_{max}$ . During the 20-minute steady-state ride, expired gases were obtained for five minutes (min 3:00 to min 8:00). The final three minutes of gas collection was aggregated to represent a mean for  $VO_2$ , VE, and RER. With 30 seconds remaining in the gas collection phase (7:30), heart rate was recorded and Ratings of Perceived Exertion were obtained using the Borg RPE scale; this was repeated with 30 seconds remaining in the steady-state exercise (19:30). Immediately following the steady-state ride, a finger-stick blood sample was obtained. Following blood sampling, the second of three treatment beverages was administered and

subjects began the simulated 20-km TT. The final treatment beverage was administered 20 minutes into the TT. Subjects received no encouragement or feedback during this portion of the trial and were only allowed to monitor the remaining distance, percent grade of the course, and gearing. With 0.05 km left, heart rate and RPE were recorded. Immediately following the TT, a finger-stick blood sample was obtained. Two minutes following the 20-km TT, post-exercise MVC was determined.

**Figure 4.1: General Trial Design**



F = finger-stick blood sample; BEV = beverage consumption

### **Dependent Measurements**

#### *Exercise Performance*

A simulated 20-km TT was selected as the performance criterion. Performance time was also recorded for the final 5 km of the trial to provide a late-exercise assessment. Power output (watts) was also recorded throughout the 20-km TT and mean power output was calculated for the final 5-km segment.

### *Skeletal Muscle Function*

Isometric Peak Torque (MVC). Peak torque of the knee extensors (knee joint angle: 70°) was assessed immediately before and after exercise. Subjects were seated in a modified chair and instructed to push as hard as possible against a fixed shin pad that was connected to a force transducer. Testing was performed on a custom-built muscle function device designed by Dr. Gordon Warren. Participants performed three 5-second repetitions with 60-seconds of rest prior to and following exercise. Peak force was recorded in Newtons. The average of the three measurements was used for analysis.

### Physiological Responses during Exercise

#### *Metabolic Measurements*

Metabolic measurements were recorded for five minutes during the steady-state segment of the trial using a SensorMedics Spectra metabolic cart. The final three minutes of gas collections was aggregated to represent a mean for *oxygen uptake* ( $\text{VO}_2$ ), *expired ventilation* (VE), and *respiratory exchange ratio* (RER; indicates relative contributions of fat and carbohydrate oxidation to total energy expenditure).

#### *Blood Glucose and Blood Lactate*

Finger-stick blood samples (~0.5 ml) were obtained at the previously mentioned time points to determine blood glucose and lactate levels using an automated analyzer (YSI 2300 STAT glucose/lactate analyzer).

### *Heart Rate*

Heart rate was recorded at the previously mentioned time points using a Polar heart rate monitor. In addition, average heart rate was calculated for the 20-km TT.

### *Ratings of Perceived Exertion (RPE)*

Subjective ratings of exertion was obtained by having the subjects indicate their corresponding level of exertion (rated numerically from 6-20) on a Borg RPE scale. RPE was at the previously mentioned time points. Subjects received instructions regarding how to utilize the RPE scale during the familiarization trials, consisting of the following: *“Please describe your current level of exertion using the following scale. This level should represent your overall perception of effort, and not localized to a specific group of muscles, etc. For reference, a 6 would represent your effort when you are resting or watching TV, while a 20 would represent the highest level of exertion you are capable of producing during exercise.”*

### **Dietary and Exercise Controls**

Subjects were instructed to refrain from heavy exercise for 48-hours prior to each trial. In addition, subjects kept dietary records for 24-hours preceding each trial, and they were instructed to maintain consistent dietary habits before each subsequent trial. Subjects also recorded all physical activity performed during the 72-hours prior to each trial and were instructed to maintain consistent exercise habits between each of these trials. Subjects were also asked to refrain from alcohol and caffeine ingestion for 24-hours prior to each trial. Subjects were instructed to eat a self-selected meal no less than

12 hours prior to the start of each trials (i.e. dinner on the evening prior to testing). After this time, subjects followed standardized dietary protocols, including the following:

- 1) No food or beverage intake between dinner and bedtime on the evening prior to the trial (water was consumed *ad libitum*).
- 2) On the morning of the exercise trials, subjects consumed a standardized breakfast two hours prior to the trial. The meal was provided by the researchers, consisted of approximately 500 kcal, and comprised of 90-100 g carbohydrate, 8-12 g protein, and 4-8 g fat. In order to account for personal tastes, subjects selected from one of a few choices, and the meal of choice was repeated across all trials for each subject. Subjects consumed 8 oz of orange juice or apple juice with this meal. These dietary restrictions ensured that there were no differences in nutrient intake between the intervention periods, other than the treatments provided by the researchers.

### **Statistical Analyses**

20-km TT, average power output (Watts) in both the 20-km TT and the final 5-km, HR, RPE, RER, MVC, blood glucose, and blood lactate were assessed using a repeated measures ANOVA with treatment as a within-subjects factor. *A priori* level of significance was set at  $p < 0.05$ . Where statistical significance was detected, pairwise comparisons were performed using Bonferroni post-hoc analysis. In the case of *a priori* 'planned' comparisons (20-km time trial performance), post-hoc analyses were performed if  $p < 0.1$ . Non-parametric statistics were applied to the following skewed (e.g. variation from normal distribution) variables: time to complete the final 5-km of the TT,



VO<sub>2</sub>, VE, RPE recorded mid steady-state and post steady-state, and post TT glucose, and post TT lactate (Friedman Test). If significance or trend toward significance was detected, a Wilcoxon Signed Rank Test was used to determine pairwise comparisons. The level of significance was adjusted for multiple comparisons which was 0.05 divided by the number comparison (6) and set to  $p < 0.008$ . Pre-MVC was assessed using a One-Sample T-Test to determine significance relative to placebo. Level of significance was adjusted for multiple comparisons and set to  $p < 0.017$ . All data is reported as means  $\pm$  SE.

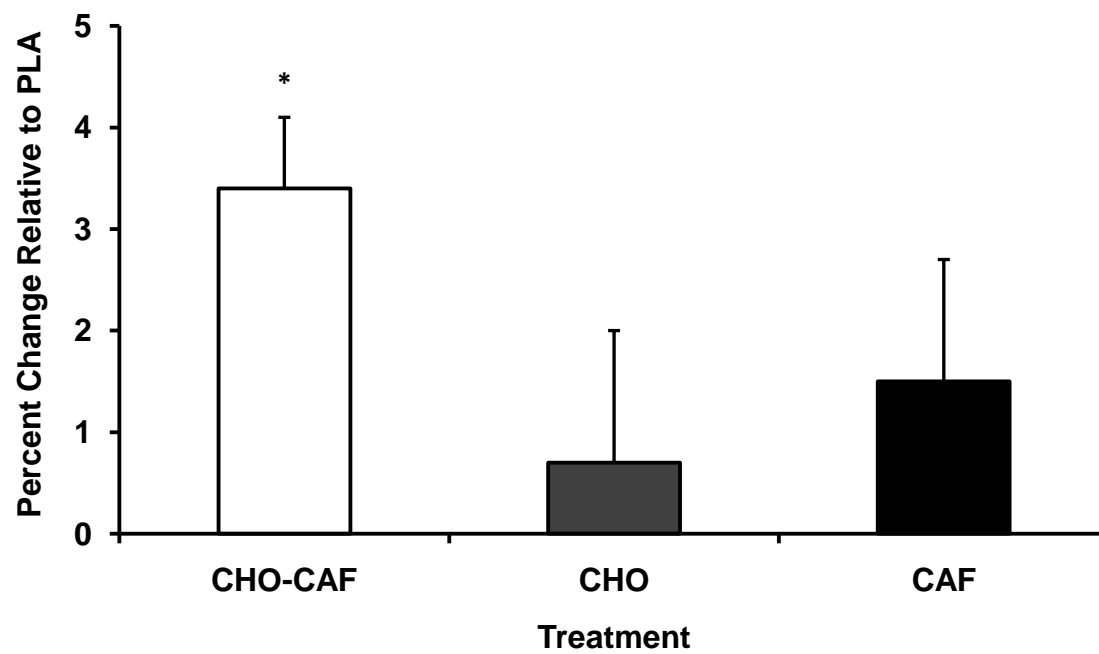
## Results

### 20-km Performance

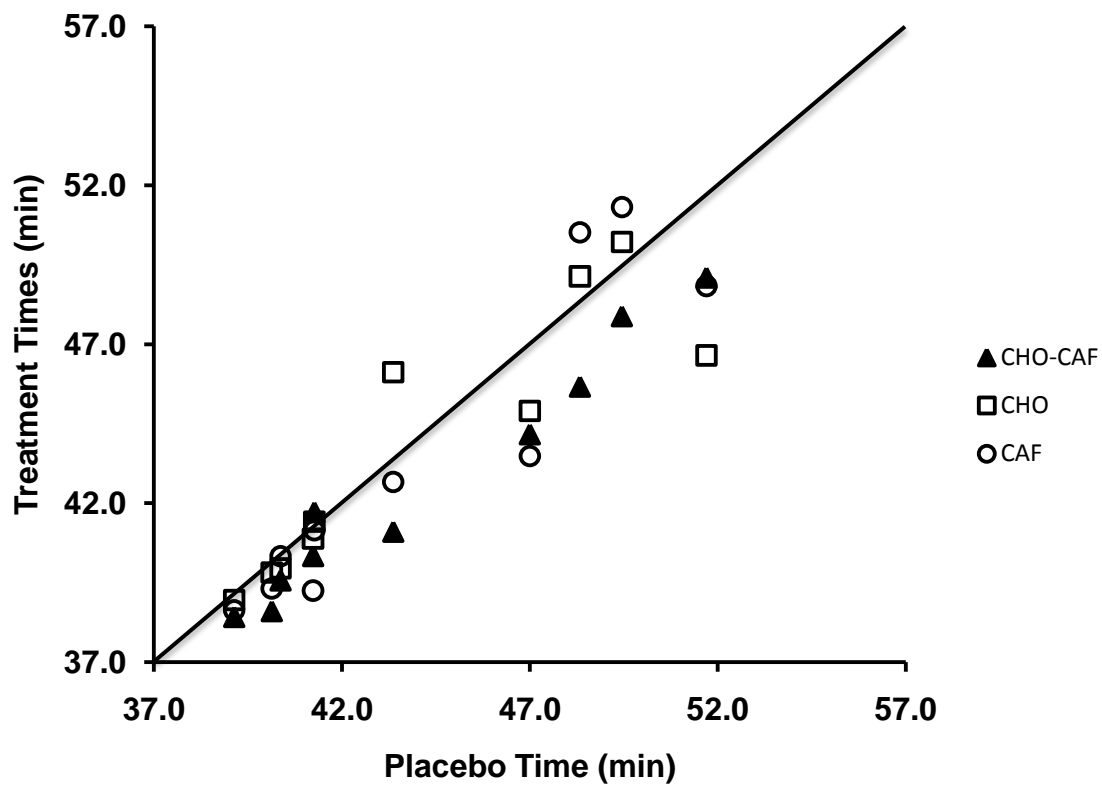
Mean 20-km performance times are displayed in Figure 4.2, individual performance times are displayed in Figure 4.3, and mean power output is displayed in Figure 4.4. There was a trend for an overall within-subject treatment effect for performance time ( $p = 0.068$ ), and there was a significant overall within-subject treatment effect for mean power output ( $p = 0.03$ ). Performance times and mean power output for the 20-km TT were CHO-CAF ( $42.7 \pm 1.2$  min,  $256 \pm 12$  W), CHO ( $43.8 \pm 1.3$  min,  $245 \pm 14$  W), CAF ( $43.6 \pm 1.5$  min,  $252 \pm 16$  W), and PLA ( $44.2 \pm 1.4$  min,  $245 \pm 13$  W). Subjects rode 3.4% faster ( $p < 0.05$ ) under the CHO-CAF condition compared to PLA. There were no differences in 20-km finishing time between CHO, CAF, and PLA. Power output was significantly higher during CHO-CAF compared to PLA ( $p < 0.05$ , 5.0%). No other differences in mean power output were detected between treatments.

Reliability of the time trial was measured across the first three trials with the expectation that the coefficient of variation (CV) would decrease with the presence of a familiarization trial. The CV between trials one and two was 1.91, and between trials two and three, the CV was 1.48.

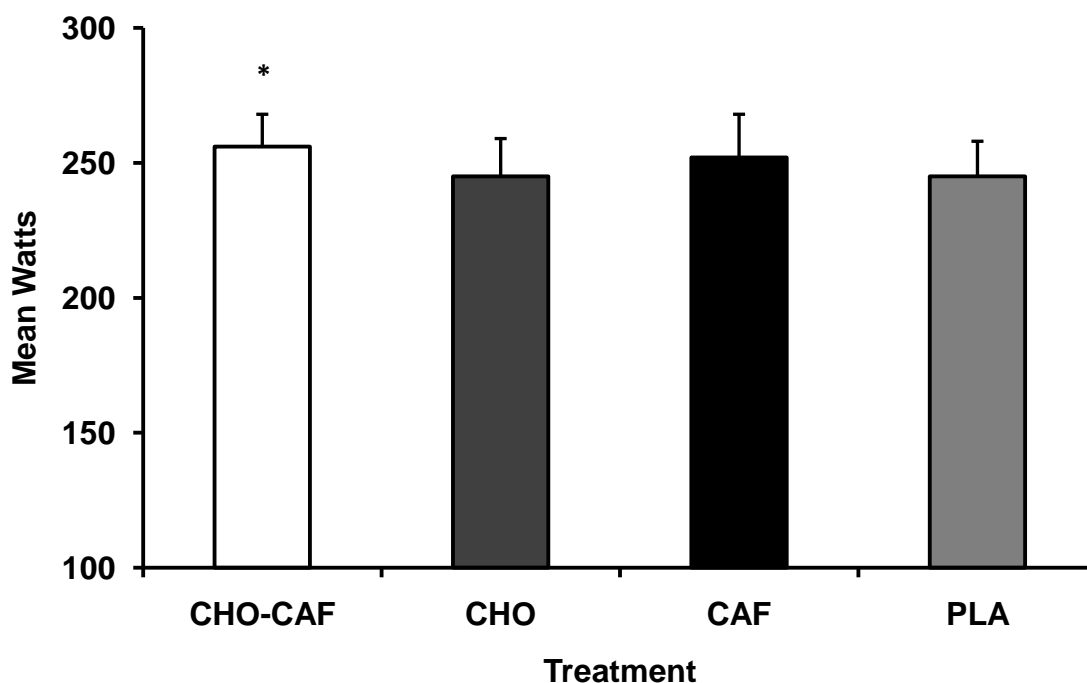
Figure 4.2: 20-km Time Trial Performance



\*Trend for main effect ( $p = 0.068$ ) - CHOCAF significantly faster than PLA ( $p < 0.05$ )

**Figure 4.3: 20-km Time Trial Performance Compare to Placebo**

Data points that fall below the line of identity indicate that 20-km time trial performance faster in that particular treatment condition compared to PLA.

**Figure 4.4: Mean Power Output during the 20-km Time Trial**

\*p < 0.05 compared to placebo

### **Final 5-km Performance**

There were no treatment differences for performance time or mean power output. Performance times and mean power output for the final 5-km portion of the TT were: CHO-CAF ( $15.9 \pm 0.6$  min,  $265 \pm 12$  W), CHO ( $16.6 \pm 0.7$  min,  $254 \pm 13$  W), CAF ( $16.5 \pm 0.9$  min,  $257 \pm 15$  W), and PLA ( $16.4 \pm 0.7$  min,  $253 \pm 13$  W).

### **MVC**

When compared to PLA, CHO-CAF and CAF demonstrated a statistical trend ( $p = 0.038$  and  $p = 0.029$ ). No other differences in pre-MVC were detected. It should be

noted that only two conditions were tested, CAF and PLA, as pre-MVC was tested before the CHO/PLA beverage was administered.

Post-exercise MVC included all four treatments rather than CAF and PLA as above. There was an overall trend for post-MVC within-subject effects ( $p = 0.071$ ); however, there were no individual differences between treatments.

### **VO<sub>2</sub>, VE, and RER**

VO<sub>2</sub>, VE, and RER are displayed in Table 3. There were no differences in VO<sub>2</sub> or ventilation ( $p > 0.05$ ). There was a significant treatment effect for RER ( $p < 0.05$ ), as all treatment conditions elicited a higher RER than PLA.

**Table 4.2 Physiological Response to Cycling at ~66% VO<sub>2max</sub>**

	<b>VO<sub>2</sub> (ml/kg/min)</b>	<b>VE (L/min)</b>	<b>RER</b>
<b>CHO-CAF</b>	44.6 ± 1.8	73.4 ± 5.5	.953 ± 0.005*
<b>CHO</b>	42.7 ± 1.7	68.2 ± 6.3	.923 ± 0.012*
<b>CAF</b>	44.2 ± 1.7	72.5 ± 5.9	.962 ± 0.022*
<b>PLA</b>	46.7 ± 1.6	69.6 ± 3.4	.887 ± 0.010

\* $p < 0.05$  compared to placebo

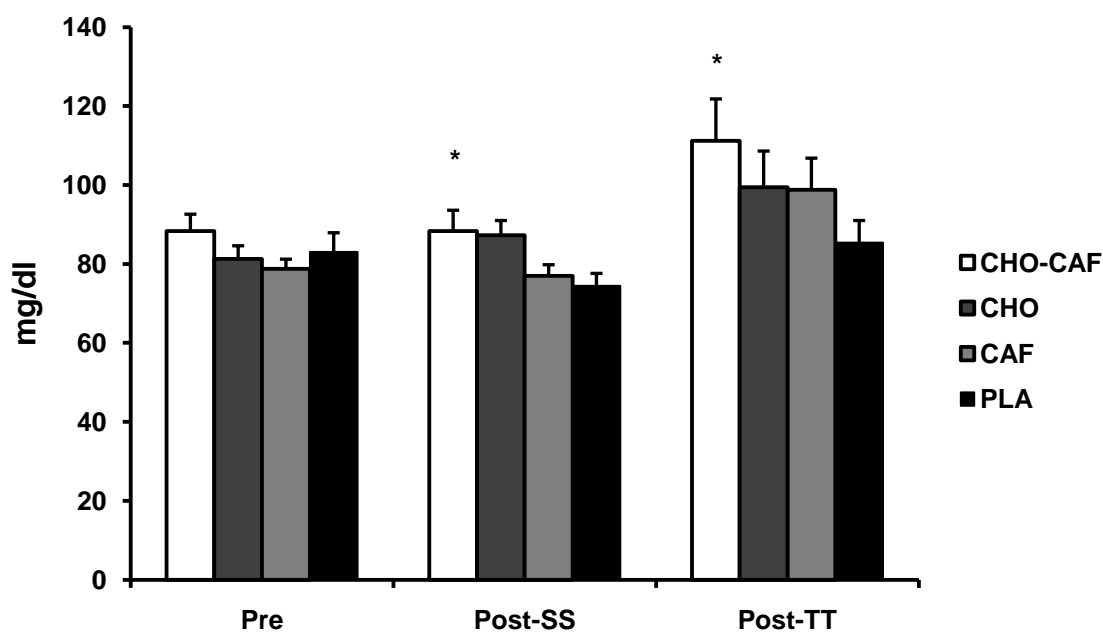
### **Blood Glucose**

Pre-exercise blood glucose was not different between treatments: CHO-CAF (88.3 ± 4.3 mg/dl), CHO (81.3 ± 3.3 mg/dl), CAF (78.8 ± 2.4 mg/dl), and PLA (83.1 ± 4.8 mg/dl).

There was an overall treatment effect for blood glucose levels post steady-state ( $p = 0.001$ ). Blood glucose was significantly higher in the CHO-CAF compared to PLA (88.3 ± 5.3 vs. 74.5 ± 3.1 mg/dl) ( $p < 0.05$ ).

There was also a significant treatment difference for post TT glucose. Post TT glucose was significantly greater in CHO-CAF ( $111.2 \pm 10.6$  mg/dl) compared to PLA ( $85.4 \pm 5.6$  mg/dl) ( $p < 0.05$ ). There was no difference between all remaining trials, as post TT glucose levels for CHO was  $99.4 \pm 9.2$  mg/dl and CAF was  $98.8 \pm 8.0$  mg/dl.

**Figure 4.5: Blood Glucose Concentrations**



\* $p < 0.05$  compared to PLA

### Blood Lactate

There was a significant main effect for pre-exercise blood lactate ( $p = 0.019$ ); however, there were no significant differences between individual treatments: CHO-CAF ( $1.37 \pm 0.10$  mmol/L), CAF ( $1.21 \pm 0.12$  mmol/L), CHO ( $1.31 \pm 0.12$  mmol/L), and PLA ( $1.65 \pm 0.13$  mmol/L).

A significant main effect was observed for post steady-state blood lactate levels ( $p = 0.019$ ). However, there were no significant differences between individual treatments:

CHO-CAF ( $2.36 \pm 0.21$  mmol/L), CHO ( $2.05 \pm 0.17$  mmol/L), CAF ( $2.17 \pm 0.13$  mmol/L), and PLA ( $1.75 \pm 0.16$  mmol/L).

A significant main effect was observed for post TT lactate levels ( $p = 0.048$ ) with no differences between individual treatments: CHO-CAF ( $7.17 \pm 0.56$ ), CHO ( $5.29 \pm 0.30$ ), CAF ( $6.26 \pm 0.63$  mmol/L), and PLA ( $5.81 \pm 0.60$  mmol/L).

### Heart Rate

All HR data is displayed in Table 4.2. Relative to placebo, there was a significant difference in pre-exercise HR between CAF ( $72 \pm 2$ ) compared to PLA ( $81 \pm 3$ ) ( $p = 0.002$ ); however, there was no difference between CHO-CAF compared to PLA. No differences were detected for heart rate at any of the other three time points.

**Table 4.3: HR (bpm) and RPE**

	Pre	Mid SS		Post SS		Post TT	
	HR	HR	RPE	HR	RPE	HR	RPE
<b>CHO-CAF</b>	$78 \pm 2$	$147 \pm 4$	$12.1 \pm .3$	$150 \pm 3$	$12.5 \pm .2$	$185 \pm 4$	$17.7 \pm .4$
<b>CHO</b>	$76 \pm 4$	$144 \pm 3$	$12.3 \pm .4$	$149 \pm 3$	$12.7 \pm .3$	$181 \pm 3$	$17.7 \pm .4$
<b>CAF</b>	$72 \pm 2^*$	$140 \pm 2$	$11.4 \pm .6$	$143 \pm 2$	$12.1 \pm .6$	$179 \pm 3$	$17.5 \pm .5$
<b>PLA</b>	$81 \pm 3$	$146 \pm 2$	$11.9 \pm .3$	$148 \pm 3$	$12.5 \pm .3$	$178 \pm 5$	$17.6 \pm .6$

\* $p < 0.05$  compared to PLA

### RPE

All RPE data is displayed in Table 4.2. No differences were detected for RPE at mid-steady-state, post steady-state, or post TT.



## Discussion

The primary aim of this study was to determine the independent and combined effects of carbohydrate and caffeine ingestion on 20-km time trial cycling performance. Concomitant measures of muscle function, blood glucose, blood lactate, HR, RPE,  $VO_2$ , VE, and RER were also obtained under each treatment condition. Contrary to our hypothesis, neither CHO nor CAF provision improved time trial performance compared to PLA. Interestingly, when CHO and CAF were combined, subjects performed an average of 3.4% (93 seconds) faster than PLA. Although RER was elevated in all conditions compared to placebo, the only instance where blood glucose was increased post steady-state and post TT was during the CHO-CAF. This suggests that caffeine and carbohydrate ingestion may have promoted increased exogenous carbohydrates utilization, though it is not possible from our design to either confirm this finding or to determine whether this directly impacted performance. Also noteworthy is that although there was not a significant difference with pre-MVC, there was a trend for CAF to improve muscle function.

The 3.4% improvement in performance with CHO-CAF in the current study is in accordance with recent findings on the effects of carbohydrate and caffeine on high-intensity or prolonged cycling. Specifically, it was reported that when moderate doses of CAF were added to a CHO-solution performance was improved compared to PLA during a time trial lasting about one hour (Kovacs, 1998). Similar to the current study, they found that CHO did not improve performance compared to water. These findings suggest that CHO supplementation only improves performance when CAF ingestion is added during high-intensity cycling exercise. However, Cureton (2007), Hogervorst (2008),

and Hulston and Jeukendrup (2008) all reported that CHO-CAF significantly improved prolonged cycling performance over both PLA and CHO alone, which contrasts with the current findings. Two of these studies also found that CHO alone improved performance compared to PLA, which was not evident in the current study (Hogervorst, 2008; Hulston and Jeukendrup, 2008). Ingestion of CHO may have improved performance compared to PLA during these studies due to maintenance of blood glucose levels because blood glucose levels were elevated for CHO and CHO-CAF in both studies. In the present study, blood glucose was elevated only during CHO-CAF compared to placebo, which is suggestive of possible improvements due to blood glucose maintenance.

Although it is difficult to provide a direct physiological explanation for the performance outcomes, the current data suggest that the performance gains associated with CHO-CAF may be related to high blood glucose levels and a greater reliance on carbohydrate oxidation, as evidenced by increased RER. Yeo (2005) contended that 5 mg/kg of CAF ingested along with CHO increased exogenous carbohydrate utilization compared to CHO alone, in part because caffeine is known to increase glucose absorption rates in the intestines when combined with carbohydrate ingestion (Van Nieuwenhoven, 2000). The most compelling evidence for the improvement in performance during our study may be due to a decreased reliance on hepatic glucose and a greater reliance on exogenous carbohydrate oxidation (Hulston and Jeukendrup, 2009). RER was elevated in all conditions compared to PLA but only during the CHO-CAF trial was blood glucose higher than PLA, which was similar to findings during the Hulston and Jeukendrup (2008) study. Blood glucose does not typically limit high-intensity performance, but maintenance of blood glucose has been hypothesized as an important consideration when

assessing performance benefits from carbohydrate ingestion (Mitchell, 1988). Mitchell (1988) found that although blood glucose was not low during the PLA trial, the elevated blood glucose and RER in the CHO trial was large enough to improve performance. Our data is suggestive of an increase in exogenous carbohydrate utilization, but further research is needed to determine if increases in exogenous carbohydrate oxidation can explain improvements during 20-km cycling when carbohydrate and caffeine are combined.

Another possible mechanism for the improvement in performance with CHO-CAF may be the ability of the muscle to produce a greater amount of force when caffeine is ingested. Although we only found a trend toward significance, the potential improvement in pre-MVC should not be underestimated. Kalmar and Cafarelli (1999) compared the effect of caffeine on neuromuscular function by testing subjects before and one hour after ingestion of caffeine, a placebo, or a control. They found that MVC was increased from pre-test to post-test by 3.5% when caffeine was ingested compared to the placebo and control, which negatively affected performance. The same study also reported that time to fatigue at 50% MVC was improved by 26%. They concluded that because subjects could voluntarily activate more motor units when caffeine was ingested without altering H reflexes, caffeine may 1) alter neural functioning at the supraspinal level, 2) alter calcium levels in skeletal muscle, and/or 3) alter central mechanisms. The improvement in performance during the CHO-CAF trial may be due to the fact that more motor unit recruitment allowed subjects to maintain a higher power output for the entire 20-km TT. However, because there was no improvement in performance during the CAF

only trial, this suggests that only when CHO and CAF are combined, which raises blood glucose and RER, does it provide a benefit for performance.

It is worth noting that CHO alone did not improve time trial performance. This is not necessarily a surprising finding as the literature is equivocal, with numerous studies supporting the benefits of CHO during high-intensity performance (Anataraman, 1995; Below, 1995; Jeukendrup, 1997; Clark, 2000; Carter, 2003; Carter, 2004a) and other studies refuting the use of CHO (Carter, 2004b; Desbrow, 2004; Jeukendrup, 2008; Beelen, 2009). The common thread among the refuting evidence is that the subjects entered the trial in the fed state. The most striking example is that carbohydrate mouth rinse improved TT performance by 3% in unfed subjects (Carter, 2004a). In 2009, two studies were published using the same protocol as Carter et al. (Beelen, 2009; Chambers, 2009). One study found that glucose and maltodextrin improved TT performance compared to a PLA by 2.0% and 3.1% respectively. Using functional magnetic resonance imaging, it was determined that the area of the brain responsible for reward-related behaviors were activated when these two substances were rinsed in the mouth compared to a PLA, which did not activate this area of the brain (Chambers, 2009). The other reported that performance during the TT was not improved. However, subjects ate breakfast two hours prior to exercise (Beelen, 2009). Thus, it appears that the benefits of carbohydrate ingestion during high-intensity cycling may be eliminated when subjects exercise in the fed state.

The lack of caffeine-derived benefits observed in the current study is in contrast to the vast body of literature documenting the performance benefits of caffeine (Costill, 1978; Ivy, 1979; Graham and Spriet, 1991; Spriet, 1992; Fulco, 1994; Pasman, 1995;

Cole, 1996; Bell, 1998; Denadai and Denadai, 1998; Van Soerren and Graham, 1998; Graham, 2000; Greer and Graham, 2000; Sungpil, 2001; Bell and McLellan, 2002; Bell and McLellan, 2003; Jenkins, 2008; McNaughton, 2008; Walker, 2008; Ivy, 2009). Interestingly, a recent study conducted by our laboratory found that the ergogenic effects of caffeine during 40-km cycling were mediated by genetic variations in the A variant genotype (unpublished observations). In the present study, at least two subjects were known to possess the C variant of the CYP1A2 gene, which was reported to negatively impact caffeine response (Womack, 2009). It is unknown whether the remaining eight subjects also possessed the C variant or the A variant, which is known to positively impact caffeine response (Womack, 2009).

A number of our physiological findings were unexpected. For instance, blood lactate levels were similar following the 20-minute steady-state ride. This is unusual as caffeine has consistently been shown to elevate lactate levels compared to placebos (Graham, 1991; Spriet, 1992; Pasma, 1995; Graham and Spriet, 1995; Chesley, 1998; Graham, 2000; Greer, 2000; Sungpil, 2001; Bell, 2002; Bell, 2003; Ivy, 2009). Yeo (2005) reported that caffeine had no effect on blood lactate until after 60 minutes of cycling at 55%  $W_{max}$ , which was similar to the wattage used in the current study. This suggests that the steady-state was either too short or not at a high enough intensity to produce elevated blood lactate levels.

In a meta-analysis, Doherty and Smith (2005) found that when caffeine is ingested Ratings of Perceived Exertion (RPE) are reduced by 5.6% when compared to a placebo for constant load exercise (e.g. steady-state). Slivka (2008) reported that there was no difference in RPE when caffeine was ingested alone or in combination with

carbohydrate. Cole (1996) reported that CAF increased the total amount of work (watts) when cycling at a given RPE compared to PLA and this finding was observed at varying exercise intensities. In the present study, there was no difference in RPE when taken at any time point during the protocol. It has been reported that trained swimmers increased swimming velocity compared to untrained swimmers when caffeine is ingested (Collomp, 1992), and the subjects used in our study were recreationally trained cyclists who had an average  $VO_{2max}$  of 65.5 ml/kg/min, which means they should have had a lower perception of effort. Doherty and Smith (2005) also reported that mode of exercise did not affect their findings of a reduced RPE. The only logical explanations for no reduction in RPE when caffeine is ingested during the steady-state would be that had the steady-state been longer we may have seen a reduction in RPE or that caffeine does not influence RPE under these conditions.

Although more studies are beginning to use time trial elements as the performance criterion, the time trial protocols 1) typically follow a long steady-state (> 90 min), 2) are for a given amount of time, or 3) are for a given amount of work usually measured in kJ, which are not as realistic as who can complete the given distance in the fastest time possible. Our study used a simulated time trial course that has a low coefficient of variance (~2%) (demonstrated in the current study). A strength of the current study is that the results of this study can be applied to a real-world time trial where the objective is to complete a given distance in the fastest time possible.

In conclusion, CHO and CAF appear to improve 20-km time trial cycling performance (3.4%, 93 seconds), but only when combined. An important factor is that the cyclists competed in a fed state, a scenario that appears to negate the ergogenic effects

of carbohydrate during high-intensity exercise. While acknowledging the limitations of the current design, our results suggest that the gain in performance may be due to enhanced exogenous carbohydrate oxidation, supported by an increase in RER as well as an increase in blood glucose levels. The improvement may have also been facilitated by the ability to generate higher muscular force (MVC), assuming that this translated to a higher sustainable power output, but only when CHO and CAF are combined. Future research should be conducted to better understand the possible mechanism for improved performance in conditions similar to that of the current investigation. Regardless of the mechanism, these data suggest that cyclists should ingest CHO and CAF together to improve high-intensity time trial performance, while in the fed state.

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## CHAPTER FIVE- SUMMARY

The primary aim of the present study was to determine the independent and combined effects of carbohydrate and caffeine ingestion on performance and physiological variables during high-intensity aerobic cycling (~60 minutes).

We hypothesized that: 1) supplementing with carbohydrate alone would improve performance, 2) supplementing with caffeine alone would improve performance, and 3) the combination of carbohydrate and caffeine would improve performance more than carbohydrate alone and caffeine alone, and that there would be an additive effect.

However, carbohydrate alone and caffeine alone did not improve performance compared to a placebo. The combination of carbohydrate and caffeine improved performance compared to placebo by 3.4% (93 seconds). This improvement in performance may be due to an increase in exogenous carbohydrate oxidation, which was evident with the elevated RER and the increase in blood glucose levels. Although RER was elevated under all conditions compared to placebo, it was only during the combination of the two supplements where blood glucose levels were elevated compared to placebo suggesting an increase use of exogenous carbohydrates during high-intensity aerobic cycling (~60 minutes). Maintenance of blood glucose is a potential underlying mechanism for the improved performance during the CHO-CAF trial, but future research is needed to make the determination. Another possible mechanism may be recruitment of more motor units as determined by a trend of MVC when caffeine is ingested.

Data of the present study suggest that cyclists should ingest CHO and CAF together to improve high-intensity time trial performance, while in the fed state.



*Appendix I*

**James Madison University**  
 School of Kinesiology and Recreation Studies  
**Consent for Investigative Procedure**

I, \_\_\_\_\_, hereby agree on \_\_\_\_\_ (date) to participate in the research project conducted by Dr. Michael Saunders, Dr. Nick Luden, and Tiffany Acker, from James Madison University titled “The Independent and Combined Effects of Carbohydrate and Caffeine Ingestion on High Intensity Aerobic Cycling Performance.”

**Purpose**

The primary aim of the current project is to determine the independent and combined effects of caffeine and carbohydrate ingestion on performance and physiology during high intensity aerobic cycling (~60 minutes). A parallel purpose is to conduct a validation experiment within the working confines of the proposed study design.

**Experimental Procedures**

I understand that I am being asked to undergo the following testing in the study:

Pre-testing Phase: (n = 1 session)

Before any physical evaluation is given, pre-screening forms will be completed to ensure that I meet the study criteria, and that I do not have any risk factors for heavy exercise. In the process of filling out these forms, I will be asked to share information regarding my general health and lifestyle with the researchers. If I meet the criteria for the study, an assessment of my cardiorespiratory fitness and body mass will be performed. During this assessment, an exercise test will be conducted to determine my maximal oxygen uptake ( $VO_{2max}$ ). To do this, I will ride a stationary cycle at an initial workload that is ‘fairly easy’. Workload will be increased every few minutes during the test. I will be encouraged to continue to cycle until I request to stop due to fatigue or am unable to continue at a cadence  $>60$  rpm. In order to be included as a participant in the study, I must achieve a  $VO_{2max}$  of  $>50$  ml/kg/min. If I meet these criteria, I will be asked to complete two familiarization trials, which involve the procedures described below.

Exercise Trials: (n = 6 sessions)

Following pre-testing, six exercise trials will be performed. The first two trials will serve as familiarization trials in which no blood will be sampled (see below). With the exception of the blood draws and treatment intervention, each of these six trials will be identical. Different treatments or combinations of treatments will be administered during each phase. Approximately 5-14 days will separate each exercise trial.

I will be asked to complete the following procedures during each protocol:

*Exercise Performance*

An exercise performance test consisting of 20-min of moderate-intensity cycling followed by a 20 km time-trial, which will take approximately 50-55 min to complete. I will be encouraged to treat each trial as a competitive event, and give my best effort throughout the trials.

*Skeletal Muscle Function*

Immediately prior to and 5 minutes following each exercise session, a skeletal muscle function test will be performed. To test my thigh muscle strength, I will be asked to maximally push against a shin pad for five seconds, three times in a row.

### *Blood Draws*

Blood will be collected immediately prior to the 20-min steady-state, immediately prior to the 20-km time trial, and at the cessation of exercise (this will only occur in the final four exercise trials). Each of these blood draws will be conducted by inserting a needle into a vein in the upper forearm. During each sample, small amounts of blood (~5ml) will be obtained, and utilized to measure blood glucose and lactate. The total amount of blood obtained during each trial period is approximately 15 ml, (60 ml over the course of the entire trial). This total amount is analogous to 20% of a can of soda or 12% of the amount given when donating blood in a single session (approximately 1 pint, or 473 ml). The indicated frequency of blood draws represents the bare minimum number required to be able to assess the dependent measurements indicated within this protocol (glucose, lactate, and stored serum for future analysis of free fatty acids). Study participants should refrain from donating blood during the study period.

### *Measurements During Exercise*

At one time-point during the 20-minute steady-state the following measurements will be obtained:

**Metabolic Measurements:** Metabolic measurements such as oxygen uptake, ventilation, etc. will be measured using a SensorMedics metabolic cart. To do this, I will be asked to breathe through a mouthpiece/breathing apparatus that collects my expired breath for approximately 5 minutes. The mouthpiece/breathing apparatus will NOT be worn during exercise other than at the indicated time-point.

**Ratings of Perceived Exertion:** I will be asked to provide subjective ratings of my exertion level. I will do this by pointing to my corresponding level of exertion (rated numerically from 6-20) on a Borg RPE scale.

**Heart Rate:** My heart rate measured using a Polar heart rate monitor that is worn around my chest throughout each exercise session.

### **Treatments**

The study protocol will be performed on six occasions (separated by 5-14 days each), using a different treatment or combination of treatments during each session. Treatments consist of both a caffeine pill/placebo pill and a carbohydrate beverage/artificially sweetened placebo. One hour prior to each trial, I will receive a pill containing caffeine or placebo. I will also receive a 250 ml of beverage (3 x during each trial for a total of 750 ml). The beverage will contain either carbohydrates or an artificially flavored sweetener. The specific treatments will not be revealed to me at the time of the trial. However, I may request this information upon completion of the study.

Two hours prior to each trial, I will receive and consume a small standardized meal. I may select the specific food type from one of three choices, but the specific foods consumed during this period will be replicated across each of the six exercise trials. In addition, I will be encouraged to maintain consistent dietary and exercise habits across the duration of the study. I will complete a dietary log of all foods consumed during the 24 hours prior to each exercise trial. In addition, I will record the type, amount and intensity of all exercise performed during for 48 hours prior to each exercise trial. I will also refrain from heavy exercise for 48-hours prior to each exercise trial.

### **Risks**

Participants are expected to be honest about disclosing all known risk factors to the researcher. There are no known risk factors associated with sports beverage consumption.

According to the American College of Sports Medicine, the risks associated with maximal exercise/testing for healthy individuals are very minimal. Any subjects who do not meet the criteria for “low risk” will not be allowed to participate in the study. In the unlikely event of cardiac or other complications during exercise, an emergency plan is in place. This includes immediate access to a phone to call emergency personnel. In addition, each of the investigators is CPR certified.

The exercise protocol may result in minor-moderate levels of muscle soreness and fatigue for 1-2 days following each exercise session. However, the level of muscle soreness is expected to be lower than levels normally experienced when people perform other ‘normal’ activities that are not part of their regular exercise routine (i.e. if a cyclist played a game of basketball with friends for 2 hours).

The risks of blood draws include possible mild bruising, and the risk of transfer of blood-borne pathogens. This risk is considered to be very minimal, and all safety precautions for handling blood samples will be followed according to OSHA protocols. The investigators have been trained in phlebotomy and completed JMU blood-borne pathogen training.

#### **Benefits**

Benefits include free maximal oxygen uptake testing and a \$150 stipend for study completion. In the event that I am unable to complete all testing, payments will be distributed in the following manner: \$25 for completing each exercise trial.

#### **Inquiries**

If you have any questions of concerns, please contact Dr. Nicholas Luden at [ludennd@jmu.edu](mailto:ludennd@jmu.edu) or (540) 568-4069. In the case of any immediate concerns or adverse reactions during the study, contact Dr. Luden at his cell phone (540) 746-6134.

#### **Confidentiality**

All data and results will be kept confidential. Subjects will be assigned an identification code. At no time will a subject's name be identified with individual data. The researcher retains the right to use and publish non-identifiable data. All data will be kept secured in a locked cabinet. Upon completion of the study, all information that matches up individual respondents with their answers will be destroyed. Final aggregate results will be made available to participants upon request.

#### **Freedom of Consent**

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form. I certify that I am at least 18 years of age.

\_\_\_\_\_  
Name of Subject (Printed)

\_\_\_\_\_  
Name of Researcher (Printed)

\_\_\_\_\_  
Name of Subject (Signed)

\_\_\_\_\_  
Name of Researcher (Signed)

\_\_\_\_\_  
Date

\_\_\_\_\_  
Date

*For questions about your rights as a research subject, you may contact the chair of JMU's Institutional Review Board (IRB). Dr. David Cockley, (540) 568-2834, [cocklede@jmu.edu](mailto:cocklede@jmu.edu).*

**Appendix II****AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire**Assess your health status by marking all *true* statements**History**

You have had:

- a heart attack  
 heart surgery  
 cardiac catheterization  
 coronary angioplasty (PTCA)  
 pacemaker/implantable cardiac  
 defibrillator/rhythm disturbance  
 heart valve disease  
 heart failure  
 heart transplantation  
 congenital heart disease

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a **medically qualified staff**.

**Symptoms**

- You experience chest discomfort with exertion  
 You experience unreasonable breathlessness  
 You experience dizziness, fainting, or blackouts  
 You take heart medications

**Other Health Issues**

- You have diabetes  
 You have asthma or other lung disease  
 You have burning or cramping sensation in your lower legs when walking short distances  
 You have musculoskeletal problems that limit your physical activity  
 You have concerns about the safety of exercise  
 You take prescription medication(s)

**Cardiovascular risk factors**

- You are a man older than 45 years  
 You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal  
 You smoke, or quit smoking within the previous 6 months  
 Your blood pressure is > 140/90 mmHg  
 You do not know your blood pressure  
 You take blood pressure medication  
 Your blood cholesterol level is > 200 mg/dl  
 You do not know your cholesterol level  
 You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)  
 You are physically inactive (i.e. you get < 30 minutes of physical activity on at least 3 days of the week)  
 You are > 20 pounds overweight

If you marked two or more of the statements in this section, you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a **professionally qualified exercise staff** to guide your exercise program.

- None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

*Appendix II (Continued)***Subject Prescreening Information****Please Complete the Following:****Gender:** Male Female (circle one)**Age:** \_\_\_\_\_ years**Height** \_\_\_\_\_ **Weight** \_\_\_\_\_**Average Exercise Habits over the Past 2 Months:**

Avg. # days of exercise per week \_\_\_\_\_

Avg. # of days of aerobic exercise per week \_\_\_\_\_

Avg. # of days of cycling per week \_\_\_\_\_

**Do you have any of the following:**

Muscle or joint injury/condition that precludes the completion of exercise protocol? Yes/No (circle)

Currently use medications for relief of pain and/or soreness? Yes/No (circle)

**Appendix III**

Subject #:

**Caffeine Habits Questionnaire**

Please list your approximate WEEKLY intake of the following:

Cups of coffee:

Cups of tea:

Cans (12 oz) of caffeinated soda:

Servings of chocolate:

Doses of caffeinated pills (No-Doz, Vivarin, etc.):

Other caffeinated beverages not listed (please list specific drink and weekly intake):

Appendix IV  
**24-HOUR DIET RECORD**  
Subject number \_\_\_\_\_

Date \_\_\_\_\_

Day of Week \_\_\_\_\_

Time	Food and/or Drink	Method of Preparation	Quantity Consumed	Brand Name

Adapted From: Lee RD, Nieman DC. *Nutritional Assessment*. 2nd ed. United States of America: Mosby; 1996

### INSTRUCTIONS FOR KEEPING YOUR 24-HOUR FOOD RECORD

Keep your record for three days per trial. You will include the day before, the day of, and the day after each trial. Include all meals, snacks, nibbling, and beverages including water and cocktails

1. Fill out the date and day of the week at the top of food record sheet
2. Record the time you consumed your food and/or drink. To be most accurate, fill out the food record as soon as you finish eating.
3. List the first food and/or drink you consumed when you began your day and continue to record until you consume your last food and/or drink of your day (usually before bedtime)
4. List each food and/or drink on a separate line  
*Example: cereal with milk, cereal and milk should each be on separate lines  
 spaghetti, noodles and sauce should each be on separate lines*

#### Combination foods:

List parts of food on separate lines

Include preparation method, quantity, and brand name of each food

*Example: Sandwich (4 oz healthy choice turkey, 2 slices Sara Lee wheat bread, 1 tbsp Hellman's light mayo, 2 oz Kraft American cheese, 1 slice of red fresh tomato)*

5. Record the method of preparation  
*Example: fried, baked, grilled  
 salt, oil (olive, canola, corn, other) butter or margarine, spices, etc.*
6. Record quantity consumed  
 Do not record any food not eaten  
*Example: made two cups of vegetables but ate half so you would record one cup*  
  
 Quantity of food and/or drink  
*Example: cups, ounces, liters, grams, each, or other unit of measure  
 Example: 1 cup of vegetables, 4 ounces of meat, one medium apple*
7. Record brand name  
*Example: fast food chain name and/or package name  
 Example: Wendy's, Betty Crocker, Lean Cuisine, Gatorade, Thomas Bagel*
8. Place any helpful food labels in manila envelope that is attached to folder



**USE THE FOLLOWING TO HELP DETERMINE PORTION SIZES AND TYPES OF FOODS**

PLEASE SPECIFY	
Beverages	Sugar or creamer? Regular or sugar-free? Alcohol content? Name of drink and ingredients (if mixed drink)
Breads	Butter or margarine added?
Cereal/Milk	Milk, sugar, or fruit added? The type of milk? (skim, 1%, 2%, whole) Cereal: dry or cooked measure?
Dairy	Is yogurt fruited or plain? % fat of milk or yogurt? Indicate brand name of cheese substitute and/or nondairy creamer.
Desserts	Whipped topping added? Frosting? Fat modified (i.e., reduced)? Sugar-free?
Eggs	Preparation method (scrambled, hard-boiled, etc)? Fat used in cooking?
Fast Food	What restaurant? If not a national fast food chain, describe food in detail Size order of fries? Super-size? ExtRa toppings on sandwich?
Fats/Oils	Regular or salt-free? Stick, tub, or liquid margarine? Reduced calorie or diet product?
Fish	Water or oil packed (fresh or canned)? Baked or fried (With batter or without)? Type of fat added? Raw or cooked weight?
Fruit	Sweetened or unsweetened? Fresh, canned, or frozen? With or without skin?
Meats	Visible fat removed? Light or dark meat? Raw or cooked?
Sugars and Sweets	Regular or reduced-calorie? Don't forget hard candy as well as chocolate.
Vegetables	Raw or cooked? Fresh, frozen, or canned? Low-sodium or regular? Added fat or sauce?

### Helpful Hints with Portion Sizes

- 1 teaspoon (5 ml)
  - about the size of the top half / tip of your thumb
- 1oz (28g)
  - approximately inch cube of cheese
  - volume of four stacked dice
  - slice of cheese is about the size of a 3 1/2 inch computer disk
  - chunk of cheese is about as thick as 2 dominoes
  - 1 handful (palm) of nuts
- 2 ounces (57 g)
  - 1 small chicken leg or thigh
  - 1/2 cup of cottage cheese or tuna
- 3 ounces (85 g)
  - serving of meat is about the size of a deck of playing cards (3 exchanges)
  - the size of the palm of your hand
  - 1/2 of whole chicken breast
  - 1 medium pork chop
  - 1 small hamburger
  - unbreaded fish fillet
- 1/2 cup (118 ml)
  - fruit or vegetables can fit in the palm of your hand
  - about the volume of a tennis ball
- 1 cup (236 ml)
  - about the size of a woman's fist
  - breakfast cereal goes halfway up the side of a standard cereal bowl
  - broccoli is about the size of a light bulb
- 1 medium apple = A tennis ball



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