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Influence of a Caffeine Mouth-Rinse on 3-Kilometer Cycling Performance

A Project Presented to
the Faculty of the Undergraduate
College of Health and Behavioral Studies
James Madison University

In Partial Fulfillment of the Requirements
For the Degree of Bachelor of Science

By Jenna Louise Goffe

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Accepted by the faculty of the Department of Kinesiology, James Madison University, in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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Table of Contents

| | |
|----------------------|----|
| List of Tables..... | 3 |
| List of Figures..... | 4 |
| Acknowledgments..... | 5 |
| Abstract..... | 6 |
| I. Introduction..... | 7 |
| II. Methodology..... | 10 |
| III. Results..... | 15 |
| IV. Discussion..... | 20 |
| V. References..... | 24 |

List of Tables

| | |
|--|----|
| Table 2.1. Subject Characteristics..... | 14 |
| Table 3.1. 3-km Time Trial Performance – Qualitative Inferences | 16 |
| Table 3.2. Split Times for 1-km, 2-km, and 3-km During 3-km-Time Trial, and Final Time..... | 17 |

List of Figures

Figure 3.1. 3-km Finishing Times – Individual Responses – Caffeine Mouth Rinse (PLA-CAF) Compared to Placebo Conditions (PLA-PLA).....18

Figure 3.2. 3-km Finishing Times – Individual Responses – Caffeine Capsule (CAF-PLA) Compared to Placebo Conditions (PLA-PLA).....19

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Abstract

Purpose: Caffeine ingestion is widely accepted for its ergogenic properties. Recent evidence suggests that mouth rinsing with caffeine prior to exercise can improve short duration sprint performance. The purpose of this study was to examine whether the benefits of caffeine mouth rinsing can be extended to include sustained high intensity performance and whether a caffeine rinse can provide additive value to the performance benefits of caffeine intake (i.e. caffeine ingestion plus caffeine rinse > caffeine ingestion). **Methods:** 25 recreational cyclists performed six separate 3-km time trials (2 familiarization and 4 treatment trials), each trial separated by 3-7 days. Subjects were given a combination of caffeine and placebo capsules (6mg/kg body weight taken one hour prior to trial) and mouth-rinses (1.2% weight/volume administered immediately prior). Thus, the treatments were: PLA-PLA, PLA-CAF, CAF-CAF, CAF-PLA (capsule-mouth-rinse). Treatments were provided in a randomized, counterbalanced, double blind, placebo controlled fashion. Magnitude-based qualitative inferences were applied to evaluate treatment differences. **Results:** Caffeine ingestion led to better cycling performance, as CAF-CAF and CAF-PLA treatments both 'likely' improved performance time by 1.4% and 1.7% compared to PLA-PLA, while also improving average power output. The effects of the caffeine mouth-rinse on 3-km time trial performance were unclear compared to placebo conditions. **Conclusion:** Caffeine ingestion enhanced short, high intensity cycling time trial performance, while the caffeine mouth-rinse had unclear effects. Collectively, these data confirm that caffeine ingestion is useful as an ergogenic aid for high intensity cycling, while a caffeine mouth-rinse does not appear to have similar ergogenic effects.

Chapter 1

Introduction

Caffeine is widely recognized as a performance-enhancing agent. Initial evidence for the performance benefit of caffeine intake was demonstrated by Costill (1977) who reported that 330 mg of caffeine extended cycling time to exhaustion (80% VO_{2max}) by approximately 20%. Subsequent research has confirmed this finding (Pasman, 1995, Cole, 1996; Greer, 2000; Jenkins, 2008; and McNaughton, 2008). More recent work has indicated that caffeine can also improve power output during anaerobic exercise (Bell et al., 2001), as well as repeated sprint performance (Beaven et al., 2012). Many of these studies also indicated that caffeine intake elevated blood lactate and heart rate, either as a direct effect of the caffeine or as a function of being able to perform at higher intensities (Anselme et al., 1992). However, it is unlikely that caffeine raises blood lactate because of increased anaerobic glycolysis, as a number of studies have shown increased blood lactate without increased muscle lactate (Erickson, 1987 and Bell, 2002). It is worth noting that the performance benefits of caffeine have not been consistently reported (Bell, 1998, Doherty, 2002, and Beck, 2008). Though it is clear that not all individuals favorably respond to caffeine under all conditions, on balance caffeine appears to deliver considerable performance benefits.

Though the physiological mechanisms responsible for the ergogenic effect of caffeine are not completely understood, one plausible explanation involves CNS stimulation. Following liver metabolism, caffeine can readily cross the blood-brain barrier due to its lipophilic nature (Davis, 2003 and McCall, 1982), whereby it antagonizes adenosine, an inhibitory neurotransmitter. Thus, caffeine has been shown

to counteract many of the inhibitory effects of adenosine, consequently enhancing neuroexcitability, neurotransmitter release, and arousal (Davis, 2003). Likely through this mechanism, pre-exercise caffeine intake can decrease perception of effort and by extension can lead to greater workloads when riding at a fixed perceived exertion (RPE) (Cole, 1996). A separate and less likely mechanism for caffeine-induced performance gains is the idea that caffeine can create a more favorable intracellular environment in working skeletal muscles (Graham, 2001). This is theoretically accomplished by maintaining electrolyte homeostasis, which perhaps would increase force production per motor unit and/or increase motor unit recruitment during exercise. However, this theory has been called into question (Davis, 2003 and Jenkins, 2008).

Like many drugs that target the central nervous system (i.e. ephedrine, amphetamine, and nicotine), caffeine ingestion can elicit a number of negative side effects. Large doses of caffeine can increase the risk of hypovolemia given the purported diuretic effects of caffeine (Bytomski and Parker, 2011). Large doses of caffeine can also lead to symptoms such as nervousness, irritability, muscle twitching, heart palpitations, and respiratory alkalosis (Bytomski and Parker, 2011). It should also be noted that regularly using caffeine intake prior to exercise can induce a tolerance adaptation; meaning higher doses are required to elicit the same ergogenic effect (Bytomski and Parker, 2011), perhaps amplifying certain side effects.

Interestingly, there is recent evidence that caffeine can benefit performance without using traditional means of ingestion. For example, chewing caffeinated gum immediately prior to exercise improved repeated sprint performance (Paton et al., 2010). A similar study reported that a caffeine solution rinsed in the mouth immediately

prior to exercise (without ingestion) elicited a rapid increase in maximal voluntary power production (Beaven et al., 2012). Although the mechanism through which sprint performance was improved is unclear, it may be similar to what has been demonstrated with the mouth rinsing of carbohydrate. For example, Carter (2004) found that a carbohydrate mouth-rinse had a positive effect on 1-hour time trial cycling performance, while Rollo (2008) observed an increase in total distance covered during a 30-minute run when rinsing with a carbohydrate rinse vs. a placebo rinse. Together these data support the presence of oropharyngeal caffeine receptors that may be providing feedback to the brain, thereby eliciting an excitatory effect. One of the possible benefits of a caffeine mouth-rinse treatment as opposed to caffeine ingestion is that the rinse should minimize many of the negative systemic side effects of caffeine, since the rinse would be affecting the body neurally, not systemically. Similarly, because some authors have reported that caffeine has no effect on high intensity cycling performance (Bell, 1998, Jacobson et al., 2001, and Doherty, 2002), a caffeine mouth-rinse may be able to elicit ergogenic benefits to individuals who fail to respond to caffeine ingestion.

While the findings of Paton and Beaven highlighted above provide initial support for the possible benefits of a caffeine mouth-rinse (Paton, 2010 and Beaven, 2012), it is unknown whether a caffeine mouth-rinse influences sustained high intensity performance. Similarly, the possibility that caffeine ingestion and mouth rinse could enhance performance more than either one alone has not yet been examined. As a result, the purpose of this investigation was to determine whether or not rinsing with caffeine enhances 3-km cycling performance, while also investigating the potentially added benefit of both ingesting and rinsing with caffeine prior to high intensity cycling.

Chapter 2

Methodology

Subjects:

Twenty-five recreationally active college-aged males and females were recruited from James Madison University and the surrounding Harrisonburg area. Subject characteristics are described in Table 1. Subjects were free of medications and at minimum performed intermittent cycling over the past two months. Subjects were provided with written and verbal information about the experimental procedures and potential risks prior to completing the informed consent. The James Madison University Institutional Review Board approved all procedures.

Experimental Overview:

Familiarization and Treatment Trials

Subjects performed six separate 3-km cycling time trials on a computerized Racermate Veletron bicycle ergometer (Seattle, WA). Each trial was separated by 3-7 days and all were completed at the same time of day (± 2 hours). The two initial trials were familiarization trials to minimize any training or learning effect that would occur during the subsequent experimental trials. The remaining four visits included four experimental trials where separate treatments were provided in a randomized, counterbalanced, double blind, placebo controlled fashion. Subjects were encouraged to treat each trial as a competition. Subjects did not receive any verbal feedback or encouragement during the trials, and only elapsed distance was displayed on the computer monitor. The primary dependant measures were time to complete the 3-km

time trial and average power output. Further, time and average power output were calculated for each 1-km increment to assess any influence that caffeine may have had on pacing strategy.

Treatments

No treatments were provided during the familiarization trials, with the exception of a pre-exercise practice mouth rinse (water). The experimental trials included the following treatments: 1. Caffeine mouth rinse (PLA-CAF); mouth rinse solution administered immediately prior to- and during exercise where subjects were instructed to only rinse the caffeine solution in their mouths and then spit it out (without swallowing). A placebo pill was also administered 1 hour prior to exercise. 2. Caffeine pill (CAF-PLA); subjects ingested a caffeine pill (6mg/kg body weight) whole (to avoid any contact with oral receptors) 1 hour prior to exercise. A placebo mouth rinse solution was also administered. 3. Caffeine pill + caffeine mouth rinse (CAF-CAF); a caffeine pill and caffeine mouth rinse were administered. 4. Placebo (PLA-PLA); a placebo pill and placebo mouth rinse were administered. When reporting different treatment types, 'PLA' and 'CAF' are used for simplicities sake. The first letters represent the capsule treatment, while the second represent the mouth-rinse treatment. Thus, PLA-CAF would represent the PLA capsule and CAF mouth-rinse, and so on.

All mouth rinses (25 ml) were administered in Dixie cups and were comprised of saccharine (Sweet N' Low) and water with or without caffeine (1.2% weight/volume). Rinses were provided 5 minutes prior to the time trial and again 30 seconds prior to the

time trial. The solution was swished around in the mouth for 5 seconds, upon which it was expectorated.

Dietary, Exercise, and Time of Day Controls:

Subjects recorded food intake 24 hours prior to their first experimental trial. The subjects were then provided with a copy of their initial dietary log, which they were instructed to replicate for the 24 hrs preceding each subsequent experimental trial. Additionally, subjects abstained from any alcohol and caffeine for 24 hours and 12 hours prior to the experimental trials, respectively. Finally, subjects avoided food intake for 2 hours preceding each experimental trial.

Subjects also refrained from heavy/unaccustomed exercise for 48 hrs prior to each experimental trial, recorded all physical activity performed during this time frame, and maintain consistent exercise habits between trials. All experimental trials were separated by 3-7 days and performed at the same time of day (within a 2-hour range).

Statistics:

Univariate Analysis of Variance (ANOVA) was applied to determine treatment differences for all variables. Simple contrasts between treatment conditions were used to generate *P* values for subsequent analysis as described below. Statistical analyses were performed using IBM Statistical Package for Social Sciences (SPSS) 21 for Macintosh (SPSS Inc., Chicago, IL, USA).

Magnitude-based inferences about the data were derived using methods described by Hopkins and colleagues (Hopkins et al., 2009). A previously established 'smallest worthwhile change' in performance was used as the threshold value for a

substantial treatment effect (separate treatment conditions vs. placebo) (Hopkins, 2004). The smallest worthwhile change in performance has been defined as 0.3 x the within subject variability across repeated time trials (Hopkins, 2004). The coefficients of variability for the performance parameters were derived from the familiarization trials of the current investigation.

A published spreadsheet (Hopkins, 2007) was then used to determine the likelihoods of the true treatment effect (of the population) reaching the substantial change threshold (0.3 x CV); these were classified as <1% almost certainly no chance, 1-5% = very unlikely, 5-25% = unlikely, 25-75% = possible, 75-95% = likely, 95-99% = very likely, and >99% = almost certain. If the percent chance of the effect reaching the substantial change threshold was <25% and the effect was clear, it was classified as a 'trivial' effect. If 90% confidence intervals included values that exceeded the substantial change threshold for both a positive and negative effect, effects were classified as unclear (>5% chance of reaching the substantial threshold for both a positive and negative effect). For ease of interpretation data are displayed as raw means \pm SD.

Table 2.1 Subject Characteristics

| | Age (yrs) | Height (cm) | Weight (kg) | Recent Physical Activity (Days/Week) | Weekly Caffeine Usage (Servings of Coffee + Soda) |
|-----------------------|------------------|--------------------|--------------------|---|--|
| Male (n = 17) | 21.1 ± 1.7 | 169 ± 30 | 81.2 ± 21.3 | 4.9 ± 1.5 | 3.8 ± 5.3 |
| Female (n = 8) | 21.1 ± 1.8 | 163 ± 9 | 57.9 ± 7.2 | 5.3 ± 1.1 | 6.8 ± 9.3 |
| Total (n = 25) | 21.1 ± 1.7 | 167 ± 25 | 73.8 ± 21.0 | 5.0 ± 1.4 | 4.8 ± 6.8 |

Data are displayed as means ± SD

Chapter 3

Results

Average performance times and power output for all treatment conditions and qualitative inferences about treatment comparisons are displayed in Tables 3.1 and 3.2. CAF-CAF and CAF-PLA treatments both 'likely' improved performance time by 1.4% and 1.7% compared to PLA-PLA. It was unclear whether the PLA-CAF treatment had any effect on 3-km time trial performance compared to PLA-PLA. When compared to the PLA-CAF treatment, CAF-PLA had a 'very likely' beneficial effect on performance time (96.9% likelihood), improving finishing time by 1.9%. When looking at the statistical outcomes for each split time, PLA-CAF 'likely' improved performance time in both the second and third split when compared to PLA-PLA. Similarly, CAF-CAF treatment also 'likely' improved performance time for the 3-km split compared to PLA-PLA.

Mean 3-km power outputs are shown in Table 3.2. Mean power output for CAF-CAF and CAF-PLA were improved by 4.6% and 4.5%, respectively, when compared to the PLA-PLA treatment. There was no significant difference in average power outputs in PLA-CAF treatment when compared to PLA-PLA.

Individual data for the 3-km times are also displayed in Figures 3.1 and 3.2. Note that data points below the line of identity reflect an improvement in 3-km time in the CAF-PLA or PLA-CAF trials. 18 out of 25 individuals performed better after caffeine ingestion (CAF-PLA vs. PLA-PLA), whereas only 12 out of 25 performed faster with the caffeine mouth-rinse (PLA-CAF vs. PLA-PLA).

Table 3.1. 3-km Time Trial Performance – Qualitative Inferences

| Comparison | Time Difference (sec) ± 90% CL | Clinical Inference |
|----------------------------|---|--|
| PLA-PLA vs. PLA-CAF | -0.82 ± 3.4 | Unclear |
| PLA-PLA vs. CAF-CAF | 4.3 ± 3.3 | CAF-CAF Likely Beneficial (84.8% likelihood) |
| PLA-PLA vs. CAF-PLA | 5.1 ± 3.3 | CAF-PLA Likely Beneficial (92.4% likelihood) |
| PLA-CAF vs. CAF-CAF | 5.2 ± 4.6 | CAF-CAF Likely Beneficial (84.8% likelihood) |
| PLA-CAF vs. CAF-PLA | 6.0 ± 3.2 | CAF-PLA Very Likely Beneficial (96.9% likelihood) |
| CAF-CAF vs. CAF-PLA | -0.80 ± 3.4 | Unclear |

Data are displayed as means ± SD

Table 3.2 3-km Time Trial Finishing Time and Split Times for 1-km, 2-km, and 3-km During 3-km-Time Trial

| | Total 3 Kilometer | Kilometer 1 | Kilometer 2 | Kilometer 3 |
|----------------|---|---|--|---|
| PLA-PLA | 309.5 ± 29.5 (239 ± 55 W) | 101.2 ± 11.5 (261 ± 67 W) | 105.3 ± 9.7 (223 ± 50 W) | 103.1 ± 9.7 (238 ± 59 W) |
| PLA-CAF | 310.3 ± 28.2 (237 ± 53 W) | 102.8 ± 11.9 (248 ± 68 W) | 104.9 ± 9.2 (225 ± 50 W) | 102.6 ± 9.4 (241 ± 59 W) |
| CAF-CAF | 305.2 ± 24.7 ^a (250 ± 45 W) | 98.5 ± 8.2 ^c (273 ± 59 W) | 103.0 ± 7.4 ^e (233 ± 43 W) | 101.2 ± 8.2 ^g (249 ± 53 W) |
| CAF-PLA | 304.4 ± 28.3 ^b (250 ± 58 W) | 99.7 ± 9.8 ^d (267 ± 63 W) | 103.2 ± 9.6 ^f (236 ± 55 W) | 101.5 ± 10.0 ^h (248 ± 63 W) |

^aCAF-CAF vs. PLA-PLA Likely (84.8%); ^bCAF-PLA vs. PLA-PLA Likely (92.4%); ^cCAF-CAF vs. PLA-PLA Possible (47.6%); ^dCAF-PLA vs. PLA-PLA Possible (43.2%); ^eCAF-CAF vs. PLA-PLA Possible (73.3%); ^fCAF-PLA vs. PLA-PLA Likely (93.3%); ^gCAF-CAF vs. PLA-PLA Likely (81.3%); ^hCAF-PLA vs. PLA-PLA Very Likely (96.4%). All other treatment comparisons were unclear.

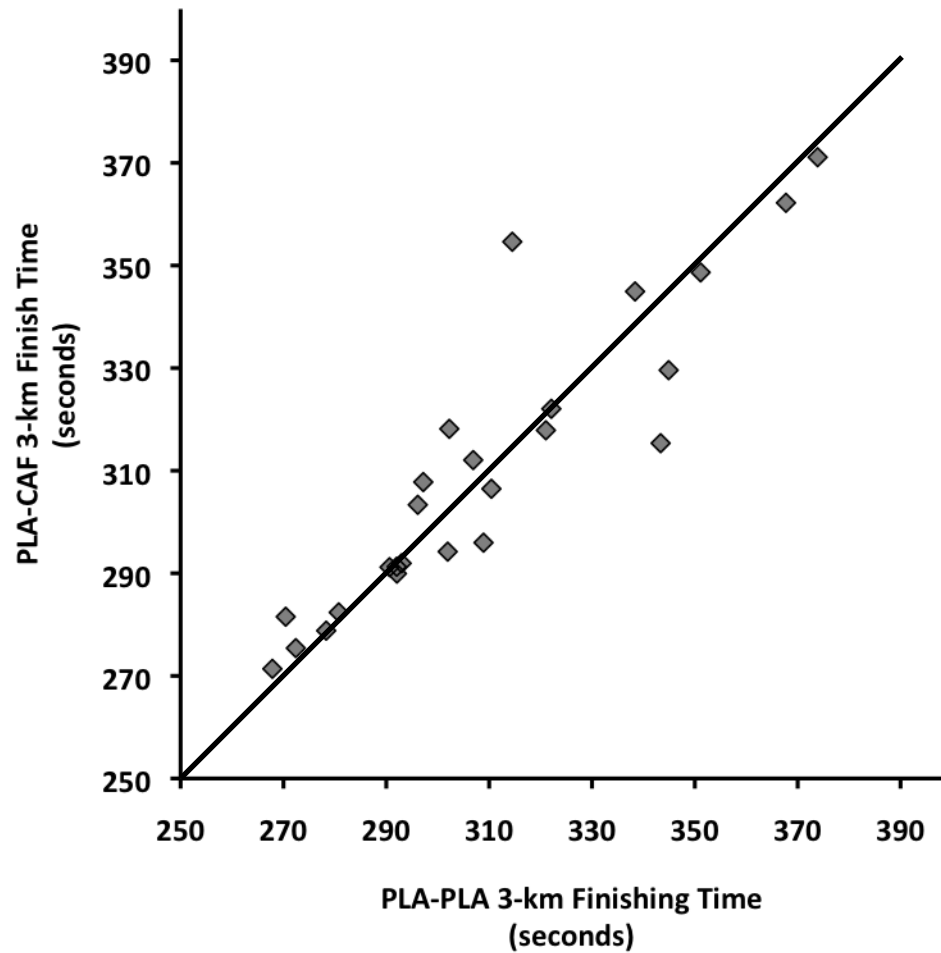


Figure 3.1. 3-km Finishing Times – Individual Responses – Caffeine Mouth Rinse (PLA-CAF) Compared to Placebo Conditions (PLA-PLA). The line of identity reflects no difference between the two trials. Data points below the line of identity reflect an improved 3-km time in the PLA-CAF condition.

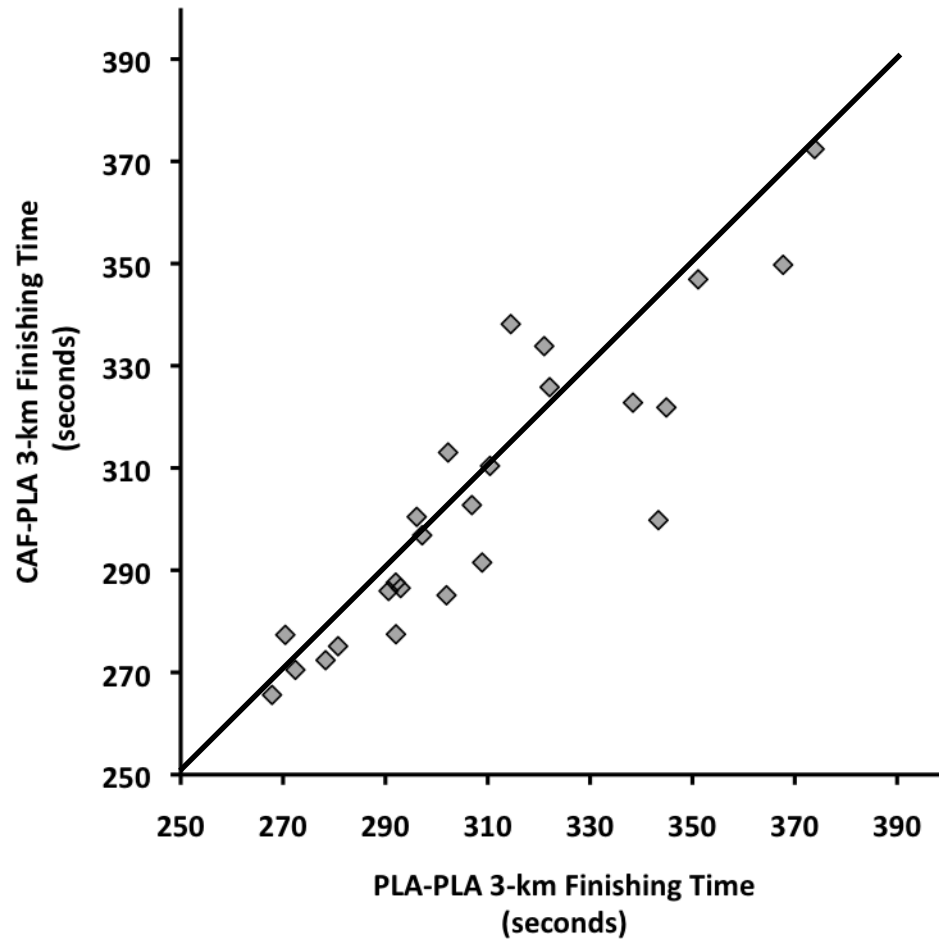


Figure 3.2. 3-km Finishing Times – Individual Responses – Caffeine Capsule (CAF-PLA) Compared to Placebo Conditions (PLA-PLA). The line of identity is plotted and reflects no difference between the two trials. Data points below the line of identity reflect an improved 3-km time in the CAF-PLA condition.

Chapter 4

Discussion

We assessed 3-km time trial performance in response to a combination of caffeine ingestion and caffeine mouth-rinse treatments. As hypothesized, caffeine capsule intake 'very likely' improved 3-km TT performance, evidenced by 1.4% and 1.7% improvements in both caffeine capsule trials. This finding is consistent with a large body of literature. The most novel aspect of this investigation was the inclusion of the mouth-rinse conditions. Our results indicate that the performance effect of caffeine mouth rinsing is unclear. Likewise, the addition of the caffeine mouth in the trials where subjects had already consumed a caffeine capsule failed to elicit a clear effect.

Very few studies have evaluated the impact of a caffeine mouth-rinse prior to exercise, with only one study observing potential benefits from this strategy (Beaven et al., 2012). Beaven (2012) reported that a caffeine mouth-rinse solution administered immediately prior to exercise rapidly enhanced maximal voluntary power production. Differences in experimental conditions and subject characteristics may be responsible for the contrasting results. It may be that caffeine mouth rinse increases excitatory drive for a brief period of time that does not translate to longer sustained performances. This is reinforced by a recent report that caffeine mouth rinsing does not impart performance benefits in a performance protocol lasting around 1 hour (Doering, 2013). Similar to our findings, Doering observed no significant improvement in cycling time trial performance from a caffeine mouth-rinse (3918 ± 243 s) compared to placebo (3940 ± 227 s) (Doering, 2013). When combined with the previous related literature, caffeine mouth rinse may

facilitate a brief improvement in power output that does not translate to events lasting longer than ~3 minutes.

An additional possibility for the lack of a performance effect with caffeine mouth rinsing is the confounding effect of previous caffeine habits. A number of studies have investigated the benefits of caffeine ingestion prior to exercise in habitual caffeine users versus non-users. Early work indicated that habitually high caffeine users acquire a tolerance to caffeine, reducing its effects during prolonged exercise (Fisher, 1986). Bell et al. (2002) observed similar effects, as both duration and magnitude of the ergogenic effect following caffeine ingestion was greater in caffeine nonusers compared to users. Other studies have confirmed these findings (Tarnolpolsky et al., 1989 and Van Soeren et al., 1993). In concert with this phenomenon, Beaven noted that subjects self-reported as light caffeine users (Beaven, 2012) in the aforementioned study that observed and increase in peak power following a caffeine mouth rinse. Moreover, a subset of non-users responded favorably to the caffeine mouth rinse administered by Doering, whereas users were not influenced by the caffeine rinse. While not systematically addressed, it is possible that we happened to recruit a large number of heavy users of caffeine, thereby blunting any potential response to the mouth-rinse. However, this is somewhat unlikely because we did find an overall improvement in the caffeine capsule times versus the placebo (18/25 subjects performed better with caffeine ingestion alone, indicating our study had an adequate number of 'responders' to caffeine).

Another explanation for the absence of a benefit with the caffeine rinse may be related to the bitter taste of caffeine. While providing a bitter tasting placebo mouth-rinse is one of the strengths of this investigation because of its indistinguishable taste

from the caffeine mouth-rinse, recent data suggests that bitterness may also improve performance. Gam (2014) found that when individuals rinsed a bitter tasting quinine solution prior to a 30 second cycling sprint, mean power output was improved by 2.4-3.9% when compared to water, a sweet aspartame solution, or no solution at all. Therefore, it is possible that the bitter taste of the placebo rinse actually enhanced performance, thereby minimizing or masking any potential effect that the caffeine may have elicited on its own.

While the effectiveness of a caffeine mouth-rinse remains unclear, it is evident that a caffeine capsule 'likely' improved 3-km time trial performance. While few studies found no improvements in performance with caffeine ingestion prior to exercise (Bell, 1998, Doherty, 2002, and Beck, 2008), the findings in this study were consistent with the larger body of the literature (Costill, 1977; Pasman, 1995, Cole, 1996; Greer, 2000; Jenkins, 2008; and McNaughton, 2008). However, only 18 of the 25 subjects participating in this study performed better after caffeine capsule ingestion, meaning that about 30 percent of individuals saw no benefit from taking a caffeine capsule prior to their 3-km time trial. This is consistent with the number of non-responders reported in prior work by Doherty (1998). Recent work suggests that a (C/A) single-nucleotide polymorphism (variant allele at a single position) on the CYP1A2 gene (which encodes for cytochrome p450, a key hepatic enzyme involved in caffeine metabolism) may partially mediate the individual ergogenic response to caffeine consumption (Womack et al., 2012). Specifically, caffeine significantly improved 40-km cycling time trial performance in AA homozygotes (3.8 minutes) to a greater extent than C allele carriers (1.3 minutes) (Womack, et al., 2012). This polymorphism and genetic variation is a

possible reason as to why close to one-third of subjects in this study saw no benefit from caffeine ingestion. Interestingly, of the 7 individuals that were non-responders to the caffeine capsule, 5 also saw no effect from the caffeine mouth-rinse.

While this study presents several small limitations to the generalizability of our findings, the double-blind, counterbalanced, and randomized design of our study provides a strong basis for our conclusion that a caffeine mouth-rinse is of limited ergogenic value. The present study demonstrates that a 1.2% weight/volume caffeine mouth-rinse does not improve, nor impair TT cycling performance. However, caffeine ingestion improved performance time in most individuals, and is a 'likely' beneficial treatment prior to a 3-km time trial. Collectively, this data suggests that a majority of individuals will benefit from caffeine ingestion prior to high intensity cycling, while very few will benefit with a caffeine mouth-rinse alone. Further work should be done to better profile the influence habitual caffeine usage has on the effects of a caffeine mouth-rinse, as well as examine the genetic influence (if any) on the response to a caffeine mouth-rinse.

References

- Anselme F., Collomp K., Mercier B., Ahmaidi S., Prefaut C. 1992. Caffeine increases maximal anaerobic power and blood lactate concentration. *European Journal of Applied Physiology and Occupational Physiology*. 65(2): 188-191.
- Beaven, C. M., Maulder, P., Pooley, A., Kilduff, L., & Cook, C. 2013. Effects of caffeine and carbohydrate mouth rinses on repeated sprint performance. *Applied Physiology, Nutrition, and Metabolism*. 38(999): 633-637.
- Bell D.G., Jacobs I., Ellerington K. 2001. Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. *Medicine and Science in Sports and Exercise*. 33(8): 1399-1403.
- Bell, D. G., Jacobs, I., & Zamecnik, J. 1998. Effects of caffeine, ephedrine and their combination on time to exhaustion during high-intensity exercise. *European Journal of Applied Physiology and Occupational Physiology*. 77(5): 427-433.
- Bell, D. G., & McLellan, T. M. 2002. Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers. *Journal of Applied Physiology*. 93(4): 1227-1234.
- Beck, T. W., Housh, T. J., Malek, M. H., Mielke, M., & Hendrix, R. 2008. The acute effects of a caffeine-containing supplement on bench press strength and time to running exhaustion. *The Journal of Strength & Conditioning Research*. 22(5): 1654-1658.
- Bytomski, J., & Parker, B. 2011. Caffeine and exercise. In L. Micheli (Ed.), *Encyclopedia of Sports Medicine*. 214-216.
- Carter, J. M., Jeukendrup, A. E., & Jones, D. A. 2004. The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. *Medicine and Science in Sports and Exercise*. 36(12): 2107-2111.
- Cole, K. J., Costill, D. L., Starling, R. D., Goodpaster, B. H., Trappe, S. W., & Fink, W. J. 1996. Effect of caffeine ingestion on perception of effort and subsequent work production. *International Journal of Sport Nutrition*. 6: 14-23.
- Davis, J. M., Zhao, Z., Stock, H. S., Mehl, K. A., Buggy, J., & Hand, G. A. 2003. Central nervous system effects of caffeine and adenosine on fatigue. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*. 284(2): R399-R404.
- Doering, T. M., Fell, J. W., Leveritt, M. D., Desbrow, B., & Shing, C. M. 2013. The Effect of a Caffeinated Mouth-Rinse on Endurance Cycling Time-Trial Performance. *International Journal of Sport Nutrition and Exercise Metabolism*.

Doherty, M. 1998. The effects of caffeine on the maximal accumulated oxygen deficit and short-term running performance. *International Journal of Sport Nutrition*. 8: 95-104.

Doherty, M. I. K. E., Smith, P. M., Davison, R. R., & Hughes, M. G. 2002. Caffeine is ergogenic after supplementation of oral creatine monohydrate. *Medicine and Science in Sports and Exercise*. 34(11): 1785-1792.

Erickson, M. A., Schwarzkopf, R. J., & McKenzie, R. D. 1987. Effects of caffeine, fructose, and glucose ingestion on muscle glycogen utilization during exercise. *Medicine and Science in Sports and Exercise*. 19(6): 579.

Fisher, S. M., McMurray, R. G., Berry, M., Mar, M. H., & Forsythe, W. A. 1986. Influence of caffeine on exercise performance in habitual caffeine users. *International Journal of Sports Medicine*. 7(5): 276-280.

Gam, S., Guelfi, K. J., & Fournier, P. A. 2014. Mouth Rinsing and Ingesting a Bitter Solution Improves Sprint Cycling Performance. *Medicine and Science in Sports and Exercise*.

Graham T.E. 2001. Caffeine and Exercise: Metabolism, Endurance and Performance. *Sports Medicine*. 31(11): 785-807.

Graham T.E. 2001. Caffeine and Exercise: Metabolism, Endurance and Performance. *Sports Medicine*. 31(11): 785-807.

Graham, T.E., and Spriet, L.L. 1991. Performance and metabolic responses to a high caffeine dose during prolonged exercise. *Journal of Applied Physiology*. 71(6): 2292–2298.

Greer, F., Friars, D., & Graham, T. E. 2000. Comparison of caffeine and theophylline ingestion: exercise metabolism and endurance. *Journal of Applied Physiology*. 89(5): 1837-1844.

McCall, A. L., Millington, W. R., & Wurtman, R. J. 1982. Blood-brain barrier transport of caffeine: dose-related restriction of adenine transport. *Life Sciences*. 31(24): 2709-2715.

Jacobson, T. L., Febbraio, M. A., Arkinstall, M. J., & Hawley, J. A. 2001. Effect of caffeine co-ingested with carbohydrate or fat on metabolism and performance in endurance-trained men. *Experimental physiology*. 86(1): 137-144.

Pasman, W.J., van Baak, M.A., Jeukendrup, A.E., de Haan, A. 1995. The effect of different dosages of caffeine on endurance performance time. *International Journal of Sports Medicine*. 16(4): 225-230.

Paton, C. D., Lowe, T., & Irvine, A. 2010. Caffeinated chewing gum increases repeated sprint performance and augments increases in testosterone in competitive cyclists. *European Journal of Applied Physiology*. 110(6): 1243-1250.

Rollo, I., Williams, C., Gant, N., & Nutea, M. 2008. The influence of carbohydrate mouth rinse on self-selected speeds during a 30-min treadmill run. *International Journal of Sport Nutrition & Exercise Metabolism*. 18(6).

Van Soeren, M. H., Sathasivam, P., Spriet, L. L., & Graham, T. E. 1993. Caffeine metabolism and epinephrine responses during exercise in users and nonusers. *Journal of Applied Physiology*. 75(2): 805-812.

Womack, C. J., Saunders, M. J., Bechtel, M. K., Bolton, D. J., Martin, M., Luden, N. D., ... & Hancock, M. 2012. The influence of a CYP1A2 polymorphism on the ergogenic effects of caffeine. *Journal of the International Society of Sports Nutrition*. 9(1): 7.