The effects of caffeine ingestion on performance time, and power during a laboratory based 5-km cycling time trial

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Abstract
Current literature is inconclusive as to the effects of a moderate dose of caffeine on short duration high intensity cycling time trial performance. Moderate doses of caffeine have improved cycling performance during 60 sec intervals and two-hour time trials, but there is lack of research using short time-trial distances. In this study, we hypothesized that 5 mg/kg of caffeine consumed 60 min prior to starting a 5 km cycling time trial, would decrease time to completion and increase average and peak power output. **Methods:** Eleven female and two male recreational cyclists (32 ± 10 yrs, 165 ± 8 cm, 70 ± 22 kg) participated in this double-blind, placebo controlled, randomized cross-over study. Three 5 km time trials were performed on a magnetically braked cycle ergometer which included a practice test (P), 5 mg/kg caffeine (C), and placebo (P). Each time trial began with a 15 min warm-up at a resistance equal to 30% VO2max and ended with one minute rest without pedaling. Each time trial was controlled by a 5 km preset (Velotron software) that adjusted workload according to age, height, and weight of subject. Subjects were told when they completed each km. They had no access to time, heart rate or power measurements, and encouragement was not allowed. **Results:** Overall time to completion was fastest in the C trial but not statistically significant (caffeine vs. placebo: 619 ± 41 vs. 628 ± 50 sec; \( P = 0.10 \)). Average power (caffeine vs. placebo: 149 ± 24 vs. 144 ± 33 watts) and peak power were highest during the C trial (caffeine vs. placebo: 206 ± 43 vs. 200 ± 46 watts) but did not reach significance (\( P = 0.13 \) and \( P = 0.17 \)). **Conclusions:** A 5 mg/kg dose of caffeine 60 min prior to a 5 km cycling time trial did improve time to completion, average and peak power output, but not significantly. These results show that further research is necessary to determine if the trend toward significance could lead to true significance if confounding variables were controlled, or a different dose of caffeine is used.

Introduction
According to recent literature, the effect of caffeine on exercise performance has been criticized due to inconclusive results. Several studies (Flinn, 1990; McNaughton, 1986 & Jenkins, 2008) have concluded that caffeine can be used as an ergogenic aid because performance was improved during running and cycling maximal exertion tests. Even though most studies showed an increase in performance after ingestion of caffeine, the study designs varied depending upon the dose of caffeine, intensity, duration, and mode of exercise. Studies that focused on performance during endurance exercise of at least 45 min., or exercising to exhaustion (Denadai, 1998; Doherty, 1998; Hogervorst, 2008; Jackman, 1996; McNaughton, 1986; McNaughton, 2008; Pasman, 1995; Sasaki, 1987 & Spriet, 1992), showed significant improvement when 5-10 mg/kg doses of caffeine were used at least 60 min prior to exercise. Studies that used anaerobic intervals (30 -120 sec) with short recovery (60 – 120 sec) periods, after consuming 5-6 mg/kg of caffeine resulted in a significant increase in time to exhaustion (Doherty 2004; Wiles, 2006; & Jackman, 1996). Studies that used low doses of caffeine <3 mg/kgbw (Jenkins, 2008; Candow, 2009 & Dodd, 1991) showed high variability on performance depending upon individual subjects. Burke (2008) stated that protocols that study the effect of caffeine on exercise performance should focus on completion of a specific distance in the fastest time possible. This requires pacing rather than simply exercising to fatigue. The majority of cycling specific research to-date is focused on
exercising to fatigue (Denadai et al., 1998; Flinn et al., 1990; Hogervorst et al., 2008; Jackman et al., 1996; Pasman et al., 1995; & Spriet et al., 1992) and not completing the session as fast as possible. Burke (2008) also stated that studies should simulate real-life events and reflect the population to which the results of the study are intended to apply. The few studies that have shown that caffeine improves performance during short-duration high intensity exercise were not cycling-specific. Wiles et al., (1992) showed improved performance during a 1500m run (~ 5 min) on a treadmill after ingestion of 5 mg/kg of caffeine, and Bruce et al., showed improved rowing performance during 2000m (~ 7 min) after ingestion of 5 mg/kg of caffeine.

There is a lack of cycling specific research on the ergogenic effect of a moderate dose of caffeine during exercise at 85-90% VO2max, that covers a specific distance, and lasts approximately 9 – 11 minutes. To test the possible ergogenic effect that caffeine has on short duration high intensity cycling, students from the physiology class BIOL-5790, hypothesize that ingestion of a 5 mg/kg dose of caffeine 60 min prior to completion of a 5 km cycling time trial, will decrease time to completion while increasing average power output compared to a placebo.

**Methods**

**Subjects**

Thirteen non-smoking recreational cyclists, eleven female and two male (32 ± 10 yo, 165 ± 8 cm, 70 ± 22 kg), participated in this intervention (Table 1). All subjects lived at altitude (6500’) for at least one year prior to the study. Consent was obtained from each participant and the protocol was approved by the institutional review board.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Range (mean ± SD)</th>
</tr>
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<tbody>
<tr>
<td>Age (years)</td>
<td>32 ± 10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165 ± 8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70 ± 22</td>
</tr>
<tr>
<td>Male</td>
<td>2</td>
</tr>
<tr>
<td>Female</td>
<td>11</td>
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</table>

Diet for subjects was not controlled, but they were instructed to maintain their normal carbohydrate intake for 24 h prior to each test to maintain glycogen levels. Maintaining a consistent carbohydrate intake has been shown to result in similar pretest glycogen concentrations (Pasman, 1995). Subjects used personal 24 h diet recalls during those three days but these logs were not analyzed by a dietitian. During the 24 h prior to testing sessions, subjects were instructed to avoid strenuous physical activity (defined subjectively by each subject), and no exercise was allowed the day of the test. Most subjects used caffeine to various degrees, however on the day of each test, caffeine was limited to 200mg at least four hours before the start of each test.

A series of three trials (practice, trial 1, and trial 2) were performed at least 48 h a part over two weeks. The specific days of each trial for each subject varied. Subjects participated in a practice ride at least 48 h before their first test trial that mimicked the test trials except that they were not given a treatment (placebo or caffeine). The purpose of the practice test was to give subjects the opportunity to experience the methods that will be used during the test trials. Practice tests have been used successfully in many high intensity cycling and running studies to prepare subjects for the actual test trials (Hogervorst, 2008).

Sixty minutes before time trial 1 and time trial 2, subjects consumed a pill that was either a placebo (Pl), or 5mg/kgbw of caffeine (CAF). This dose of caffeine is similar to that which has been used in previous research (McNaughton, 2008; Doherty, 1998; Jackman, 1996; Denadai, 1998; Dodd, 1981 & Pasman, 1995). As a double-blind, cross-over study, subjects did not know which pill they were taking before each trial. The director of the research lab prepared the placebo and caffeine pills.

Tests were performed on a magnetically braked cycle ergometer (Velotron Electronic Bicycle Ergometer, Elite Model, Racer Mate, Seattle WA, USA) in the physiology lab at The University of Colorado at Colorado Springs. The Velotron is a computer-controlled, electric ergometer that provides high levels of accuracy.
and repeatability in the lab. Its Windows PC software can be activated in manual ergometer or simulation mode. Manual ergometer mode was used during warm-up to set the individual workload for each subject. Race simulation was used during Trial 1 and Trial 2. Testing and training protocols can be established in terms of either watts and time, or distance and grade. The results are displayed instantaneously as well as in averages and maximum values for each performance variable (Velotron, 2011). Each subject adjusted the saddle height and fore-aft position, stem length, and handlebar height for a customized fit on the ergometer. Subjects used the same bike, setup measurements, and pedal/cleat system for all three trials. Heart rate was measured using a Polar Heart Rate Monitor (Lake Success, NY). Neither the temperature nor relative humidity was controlled during any of the cycling sessions.

Warm-up Program

The same warm-up protocols were used for the practice test and both time trial tests. Each subject warmed-up for 15 minutes on the Velotron ergometer with the resistance set to 30% of his or her maximum watts. Maximum wattage was determined during a previous study in which subjects completed a VO2max test. Before the start of each test trial warm-up period subjects were asked if they had consumed either the placebo or the caffeine pill, or were unsure which pill they had ingested. Cadence was undefined during the warm-up period. Subjects rested without pedaling for one minute at the conclusion of their warm-up before the start of the test.

5km time trials

The 5km time trial was simulated using a pre-set 5 km time trial course included in the Velotron software. Data for each subject (age, height, weight, gender, age) was entered into the Velotron software and used to determine workload during the 5 km test. Subjects were told when they completed a kilometer but were not given any other information. During the test, subjects did not have access to time, duration, watts, or heart rate information so they could not pace themselves. No music, cheering or other motivational aids were allowed.

At the conclusion of each kilometer, researchers recorded current time, watts, heart rate (bpm), cadence (rpm), and RPE (Borg Scale). Average and peak values were also recorded for watts, heart rate, and cadence. Performance was measured by time to completion of 5 km. No blood work or gas exchange was measured. At the end of the 5 km time trial subjects were asked for the second time, if they thought they ingested the placebo or caffeine pill, or if they were unsure which one they used.

Statistical Analysis

Performance markers that were obtained during each test included time, watts, HR, RPM, and RPE for each kilometer during the rides as well as average and peak watts, HR, and RPM overall. The data was reviewed for accuracy and the mean and standard deviation were calculated. One-way paired t-tests were used to analyze the data. Post hoc paired t-tests were conducted on relevant data to investigate significant trends. Statistical significance was set at p<0.05. All statistical procedures were performed using Microsoft® Excel® 2008 for the Mac, Version 12.2.9 (Microsoft Corporation, Redmond, WA).

Results

Overall, six subjects guessed correctly that they had ingested a caffeine pill and seven subjects guessed correctly that they ingested a placebo.

Caffeine ingestion resulted in a 1.4% improvement in time to completion of the 5 km time trial for nine of the 13 subjects (caffeine vs. placebo: 619 ± 41 vs. 628 ± 50 sec), however the improvement was not statistically significant (P=0.10) (Figure 1). Although nine of the 13 subjects increased their average power by 3.4% (caffeine vs. placebo: 149 ± 24 vs. 144 ± 33 watts), and seven subjects increased their peak power (caffeine vs. placebo: 206 ± 43 vs. 200 ± 46 watts) by 3% after caffeine ingestion, these differences did not reach significance (P=0.13 and P=0.17) (Figure 2).
Table 2. Overall time, average power, max power, average heart rate, and peak heart rate for three 5 km cycling time trials (caffeine, placebo, and habituation). (mean ± SD, N=13)

<table>
<thead>
<tr>
<th></th>
<th>Caffeine</th>
<th>Placebo</th>
<th>Habituation</th>
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<tbody>
<tr>
<td>Overall Time (s)</td>
<td>619 ± 41</td>
<td>628 ± 50</td>
<td>626 ± 61</td>
</tr>
<tr>
<td>Average Work (W)</td>
<td>149 ± 24</td>
<td>144 ± 33</td>
<td>145 ± 35</td>
</tr>
<tr>
<td>Peak Work (W)</td>
<td>206 ± 43</td>
<td>200 ± 46</td>
<td>206 ± 47</td>
</tr>
<tr>
<td>Average HR (bpm)</td>
<td>166 ± 16</td>
<td>166 ± 15</td>
<td>166 ± 13</td>
</tr>
<tr>
<td>Peak HR (bpm)</td>
<td>184 ± 14</td>
<td>184 ± 12</td>
<td>183 ± 10</td>
</tr>
</tbody>
</table>

Table 3. Rate of perceived exertion for three 5 km cycling time trials (caffeine, placebo, and habituation). (6-20 Borg Scale) *Statistically different than placebo P<0.05

<table>
<thead>
<tr>
<th>Kilometer</th>
<th>Caffeine</th>
<th>Placebo</th>
<th>Habituation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.6*</td>
<td>13.2</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>14*</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>16</td>
<td>15</td>
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<tr>
<td>4</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 4. Average time per kilometer of three 5 km cycling time trials (caffeine, placebo, and habituation). (mean ± SD, N=13)

<table>
<thead>
<tr>
<th>Kilometer</th>
<th>Caffeine</th>
<th>Placebo</th>
<th>Habituation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>129 ± 8</td>
<td>134 ± 16</td>
<td>133 ± 19</td>
</tr>
<tr>
<td>2</td>
<td>123 ± 7</td>
<td>126 ± 11</td>
<td>126 ± 15</td>
</tr>
<tr>
<td>3</td>
<td>122 ± 8</td>
<td>124 ± 9</td>
<td>125 ± 12</td>
</tr>
<tr>
<td>4</td>
<td>124 ± 10</td>
<td>125 ± 10</td>
<td>123 ± 10</td>
</tr>
<tr>
<td>5</td>
<td>120 ± 9</td>
<td>120 ± 10</td>
<td>118 ± 9</td>
</tr>
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</table>

Figure 1. Time to completion of three 5 km cycling time trials (caffeine, placebo, and habituation), for individual participants.
Individual participants showed a wide variety in time to completion between all three trials (Figure 1). Six subjects (1, 2, 3, 4, 6, 10) completed the trial with caffeine fastest; two subjects (8, 13) completed the placebo trial fastest; three subjects (5, 9, 12) completed the habituation trial fastest; two subjects (1, 11) had the same time for habituation and placebo, while one subject (7) had the same time for the caffeine and habituation trial.

Neither the mean average heart rate, nor mean peak heart rate, showed an overall increase or decrease during performance after caffeine (166 ± 16 bpm; \( P = 0.48 \)) or placebo ingestion (166 ± 15 bpm; \( P = 0.34 \)).

Per kilometer, power and time varied throughout each time trial, but never changed significantly between caffeine and placebo trials. The average power output of subjects was highest during the first three kilometers when subjects ingested caffeine, but decreased through the fourth kilometer and was lowest during the last kilometer compared to their work output with a placebo and their habituation trial. Time to complete each individual kilometer was fastest during the first three kilometers of the caffeine trial, but then slowed to second fastest during the
fourth km and tied for duration with the placebo group during the last kilometer (Table 4).

During the caffeine trial, two out of the 13 subjects (subjects 6, 9) performed their fastest time during the first km (116 & 118 s) but progressively slowed each km until completion of the trial (134 & 130 s respectively). Subject 11 shared the fastest first km time (118 s) with Subject 9, and maintained within six seconds of their first km to finish their last km faster than the first by one second (117 s). Ten subjects completed the first km of the caffeine trial slower than the rest, while six subjects completed the last km faster than the rest (Figure 3).

RPE during the first (P=0.04) and second kilometer (P=0.03) of the caffeine trial was significantly lower than that of the placebo trial (Table 3). The high power output during the first kilometer of the caffeine trial illustrates results found by Doherty et al. (2002) that showed a tendency for decreased RPE during the first 2 min of constant load running exercise above 100% VO2max.

**Discussion and Limitations**

The aim of this study was to determine the effects of caffeine ingestion on cycling performance during a 5 km time trial. Results indicate a non-significant decrease (P=0.10) in time to completion (9.0 s), an increase in average (5 w) and peak power (6 w), and increase in average and peak cadence (rpm) after ingestion of 5 mg/kg of caffeine 60 min prior to completion of a 5 km time trial. Average and peak heart rate values were the same for the caffeine and placebo trials.

There could be several reasons why this trend towards improved performance time was not significant: training status, habituated vs. non-habituated caffeine drinkers, dosage of caffeine, stress, and gender.

Training status of subjects has been discussed as a reason for equivocal results from previous studies on the effects of caffeine ingestion before high intensity cycling (Wiles, 2006). Experienced competitive cyclists will have a different RPE and pacing strategy than a recreational cyclist, which can skew overall time to completion and average power output. Swart et al. (2009) found that knowing the distance and duration of exercise affected RPE and pacing strategies of competitive cyclists during five 40 km time trials. RPE decreased during the fifth 40 km time trial compared to the first four trials. Time trials of shorter distances (5k, 10k) were completed by recreational cyclists who showed average RPE responses similar to those of experienced cyclists during the last 20% of each trial. Hunter et al. (2002) noted a lack of an ergogenic effect during a 100 km time trial after consuming 6 mg/kg due to pacing strategies by subjects.

Future research should account for the training status and racing experience of each subject. Experienced cyclists, who race frequently in circuit or criterium events, will have a different pacing strategy than recreational cyclists. Their average and peak power output, and time per kilometer during 5 km will look much different from an inexperienced cyclist due to increased racing specific fitness. For example, Subject 5 had the fifth slowest first kilometer time (134 s), but their last kilometer was the fastest overall split per kilometer (99 s) in the entire caffeine trial. If we knew the training status of this subject was, it could clarify why this person was able to ride so fast after already covering 4 km at what was supposed to be a maximum effort. If this subject competes in criterium events they would be used to riding several miles at 75-80% VO2max before sprinting to the finish at 85-90% VO2max. Pacing strategies were completely different between Subjects 5 and 6. Subject 6 averaged 16 s slower during the second, third, fourth and fifth km compared to the first. Whereas Subject 5 started off slow and increased speed to the finish, and Subject 6 started off fast and then faded to the finish, Subject 11 held a steady pace from start to finish with an average of 121 s/km (Figure 5).

Pacing strategies and level of experience could play a role in why power output during the caffeine trial was lower than the placebo and habituation trial during the last two kilometers (Figure 4). Normally when subjects know they have one mile or kilometer left to go before the end of a race or trial, they push themselves knowing that the discomfort they feel will be short-lived. However, RPE was the same during the fourth and fifth kilometer for all three trials, even though power output decreased. The average time to complete the first three kilometers was faster in the caffeine trial than the placebo and habituation, however, the fourth (caffeine vs.
placebo vs. habituation: 124, 125, 123 sec) and fifth km (caffeine vs. placebo vs. habituation: 120, 120, 118 sec) were fastest in the habituation trial.

Subjects in the studied varied greatly in their daily caffeine consumption with some stating they drink 2 – 3 cups of coffee a day and others never ingesting any form of caffeine. Fisher (1986) found habitual caffeine users (>600 mg/day) develop a tolerance to caffeine that requires a 4-day withdrawal from its consumption, before they can notice an increase in alertness and dampening effects on RPE from a 5 mg/kg dose. Flinn et al. (1990) found that a caffeine dose of 10 mg/kg three hours prior to an incremental cycling test to exhaustion, allowed recreational cyclists who do not regularly consume caffeine, to work for a longer period of time and produce more work. Dodd et al. (1991) used 3mg/kg and 5 mg/kg doses of caffeine on subjects who consumed either 25 mg/day or >300 mg/day of caffeine, and did not see a significant increase in time to exhaustion. Future research should include more control over daily caffeine intake for at least four days prior to a habituation trial. This could be implemented by decreasing a subject’s total caffeine intake by 10% per day until 24 h before the practice test, so that they are at 50% of their usual intake the day of their practice test. Common sources that should be taken into consideration are coffee, cola, energy drinks, chocolate, pain relief medications (Excedrin™), and sports gels.

Various doses of caffeine have been used in combination with short duration high intensity (anaerobic) and long duration endurance (aerobic) cycling efforts. Most research has studied the effects of either a low dose (<3 mg/kg) or high dose (>6 mg/kg) of caffeine on endurance performance for events that last 30 – 120 min in duration. Doherty et al. (2003) and Wiles et al. (2006) studied the effects of a moderate dose of caffeine (5 mg/kg) on anaerobic cycling efforts that last <2 minutes. Doherty et al. (2003) found an increase in power output while performing a 1 min effort to exhaustion, and subjects in the study by Wiles et al. (2006) showed a decrease in time to completion of a 1 km time trial. Pasman et al. (1995) used several different caffeine doses (5, 9, 13 mg/kg) one hour before cyclists exercised to exhaustion (34-71 min) but was unable to determine a direct dose response per increase in endurance performance. McNaughton (1986) utilized higher dosages of 10 and 15 mg/kg on incremental running performance at 70-75% VO2max, and found that caffeine can be an effective ergogenic aid for short term high intensity running. However, there has not been any research that tested the effect of a 5 mg/kg dose of caffeine on high intensity efforts that last 9 – 11 minutes.

Future research should be done using the same 5 km time trial protocol but include a higher dose of 10 mg/kg for subjects that are known to consume at least 200 mg/day (two 8 oz servings of black coffee) of caffeine and possible caffeine withdrawal during the days prior to the test. Since Doherty et al. (2004) and Wiles et al. (2006) were successful using a 5 mg/kg dose of caffeine during short, high intensity cycling sessions, this dose could be maintained for subjects who consume less than 20 mg caffeine per day (equal to one sports gel).

All of the subjects in this study were students who manage varying levels of stress and sleep-deprivation during the course of a week. Subjects were instructed to replicate the same diet, sleep, energy expenditure, and stress levels during the 24 h before each trial, but since the trials did not fall on the same day of the week, it is very unlikely that subjects were able to create the exact same 24 h environment before each test. VanHelder and Radomski (1989) found time to exhaustion is decreased and RPE is increased after periods of sleep deprivation. McArdle et al. (2007) suggest that caffeine acts by reducing the threshold for motor unit recruitment (not direct action on the central nervous system), and possibly alters muscle contraction force, leading to a decrease in RPE during exercise. If a subject slept for only four hours the night before the caffeine trial, they might not have been able to benefit from the increase in mental acuity or pushed themselves to maximum effort due to an increase in RPE. Of note, regarding RPE during this study is that the highest score referenced by subjects during all three trials was 18. This could mean that none of the subjects exercised to their maximum abilities and/or exhaustion. We can only speculate that if they did reach an RPE score of 20, that the trend toward improvement in performance, would have become a statistically significant one.
One last consideration as to why a 5 mg/kg dose of caffeine did not have a statistically significant effect on a 5 km cycling time trial performance is gender. Eleven out of thirteen subjects in this study were women, whereas, most previous research that has resulted in improved performance (decreased time to completion or increased time to exhaustion) from having ingested <6 mg/kg caffeine prior to 1 – 120 min. cycling, have used males (Cox et al., 2002; Dodd et al., 1991; Doherty et al., 2004; Flinn et al., 1990; Hunter et al., 2002; Jenkins et al., 2008; McNaughton et al., 2008 & Wiles et al., 2006). Future research should include women covering several different distances (5, 10, 25 km) using various doses of caffeine (3, 5, 9 mg/kg) to see if women excel during longer distances compared to short high intensity ones.

Conclusion

In conclusion, the results of this experiment suggest that a 5 mg/kg dose of caffeine, 60 min prior to a 5 km cycling time trial shows a trend towards improved performance, but not a statistically significant one. The lack of control over confounding variables during the 24 h prior to each test and lifestyle variables such as training status, and daily caffeine consumption, make it difficult to identify the primary reason why a statistically significant improvement in performance was not obtained. These results show that further research is necessary to determine if the trend toward significance could lead to true significance if confounding variables were controlled, or a different dose of caffeine is used.

References


