CAF-2011-0022-ver9-Astorino_1P
Type: research-article

JOURNAL OF CAFFEINE RESEARCH
Volume 00, Number 00, 2011

DOI: 10.1089/caf.2011.0022

Original Article

Ergogenic Effects of Caffeine on Simulated Time-Trial Performance Are Independent of Fitness Level

Todd Anthony Astorino,[1] Trisha Cottrell,[1] Andrea Talhami Lozano,[1,2]
Kylan Aburto-Pratt,[1] and Jessica Duhon[1]

Background: The primary aim of this study was to compare the ergogenic effects of caffeine on cycling performance in endurance-trained and recreationally active participants.
Methods: Endurance-trained [$n = 8$, $VO_2max = 57.5 \pm 3.9$ mL/(kg·min)] and active [$n = 8$, $VO_2max = 46.5 \pm 6.3$ mL/(kg·min)] participants initially completed two familiarization trials separated by at least 48 hours. Over the next three trials, they completed a 10 km cycling time trial preceded by ingestion of drinks containing caffeine (5 mg/kg ingested on 2 separate days) or placebo. Treatments were ingested using a single-blind, crossover design, and participants were deceived as to the content of all drinks. During exercise, heart rate (HR), rating of perceived exertion (RPE), and time were recorded every 1.6 km. Repeated measures analysis of variance was used to assess differences in cycling time, HR, and RPE between treatments, with fitness level used as a between-subjects variable.
Results: Caffeine increased ($p < 0.05$) cycling performance by 0.3%–2.0% versus placebo, with no effect ($p > 0.05$) of fitness level. Magnitude of performance improvement in both caffeine trials (−0.21 and −0.23 minutes, respectively) was similar versus placebo. Compared with placebo, exercise HR was higher ($p < 0.05$) with caffeine, although RPE was similar ($p > 0.05$) across treatments.
Conclusions: In active men of varying fitness, data reveal a small caffeine-mediated improvement in cycling performance that was similar in magnitude.

Introduction

Approximately 30 years of data reveal that acute caffeine intake in doses from 3 to 13 mg/kg body weight enhances exercise performance, especially in endurance exercise such as cycling,[1] running,[2] as well as in team sports.[3] Mechanisms responsible for this performance-enhancing effect remain elusive, although adenosine antagonism[4] and reduced perceptions of exertion[5] seem to be the most widely acknowledged. However, data from a few studies[6–8] demonstrate no effect of caffeine on performance, similar to Hunter *et al.*[9] who revealed no effect of caffeine on 100 km time-trial performance. Collectively, these data oppose most findings supporting ergogenic effects of this drug, and it is unknown why these results oppose the majority of the literature.

However, it is evident that there is wide interindividual variation in the effects of caffeine[10,11]; in that, some individuals respond to caffeine, whereas others do not. The exact mechanism explaining these differences is unknown, although it may be due to discrepancies in caffeine metabolism, drug habituation, or fitness level across subjects in various studies. Cornelis *et al.*[12] demonstrated discrepancies in caffeine metabolism mediated by alterations in various genes. In a recent study, Irwin *et al.*[13] showed that 3 mg/kg of caffeine increased cycling performance regardless of withdrawal period, so this explanation is unlikely. Collomp *et al.*[14] showed that caffeine was ergogenic only for competitive swimmers and not recreational swimmers during repeated 100 m races, although it is unknown what trait of trained individuals elicits these effects. Some have postulated that this is because athletes perform more reliably on a given task than nonathletes, which improves ability to detect differences between treatments.[15] In contrast to Collomp *et al.*,[14] recent data[16] showed similar performance improvements (1.0% and 1.1%) in trained and recreational runners performing an outdoor 5 km time trial after caffeine intake. To our knowledge, these are the only studies that have directly compared performance-enhancing effects of caffeine in individuals of varying fitness, so further study is merited to elucidate these equivocal results. Identifying potential ergogenic effects of caffeine in untrained persons is important, as sedentarism is widespread in the general population, with only 49% of adults meeting the recommended guidelines for physical activity.[17] It would be desirable if caffeine ingestion improved

[1]Department of Kinesiology, California State University—San Marcos, San Marcos, California.
[2]Department of Nutrition, Tufts University, Boston, Massachusetts.

performance and reduced fatigue associated with exercise in nonathletes, to ultimately enhance exercise adherence, which in the long run should improve health status in this population.

The primary aim of this study was to compare the magnitude of caffeine's ergogenic effects on cycling performance in trained as well as recreationally active individuals. It was hypothesized that the effect of caffeine on cycling performance will not differ across individuals of various fitness levels. To better confirm the potential ergogenic properties of this drug and to identify whether improvements in performance are repeatable within subjects, two caffeine trials were administered as recommended by Davis and Green.[11]

Materials and Methods

Participants

Sixteen healthy, active men who completed a minimum of 5 hours/week of exercise for the preceding 2 year participated in the study. Their physical characteristics are revealed in Table 1. There were no differences ($p > 0.05$) in these traits across groups with the exception of VO_2max and maximal workload. The trained group was composed of athletes competing in sports including cycling, running, or triathlon, while persons in the active group regularly participated in team sports, resistance training, and/or cardiovascular exercise. All persons habitually ingested caffeine 2–7 days/week, although none was a heavy caffeine user (>350 mg/day). They filled out a health-history questionnaire to ensure they met all inclusion criteria and were free of known disease, and provided written informed consent prior to participating in the study, which was approved by the University Institutional Review Board.

Design

Participants were instructed to come to the lab (temperature = 21°C–23°C, humidity = 35%–40%) in a well-rested and hydrated state. They visited the laboratory on five occasions at the same time of day within subjects. Prior to each visit, they refrained from intense lower-body exercise for 48 hours and were 3 hours postabsorptive. Familiarization testing was completed on days 1 and 2, followed by completion of a 10 km cycling time trial on days 3–5. One hour prior to exercise, they ingested 5 mg/kg caffeine or placebo. A single-blind, crossover design was used, and treatment order was assigned using a Latin Squares design.

Table 1. Physical Characteristics (Mean ± Standard Deviation) of Subjects

Parameter	*Endurance-trained men*	*Active men*
Age (year)	28.0 ± 6.0	26.7 ± 5.9
Height (cm)	178.7 ± 5.6	176.4 ± 6.8
Mass (kg)	73.1 ± 7.2	76.2 ± 8.9
Body fat (%)	9.3 ± 2.4	9.4 ± 5.1
Physical activity (hour/week)	8.6 ± 4.4	8.3 ± 2.1
Caffeine intake (mg/day)	67.5 ± 53.9	125.6 ± 120.6
VO_2max [mL/(kg·min)]	56.9 ± 3.8	46.5 ± 6.3[a]
Wmax (W)	388.8 ± 47.2	320.5 ± 32.8[a]

[a] $p < 0.05$ versus endurance-trained subjects.

Familiarization testing

On day 1, height and body mass were measured, and a sum of three skinfold at various sites (chest, abdomen, and thigh for men) was obtained to assess percent body fat.[18] Initially, participants completed ramp exercise to volitional fatigue on an electrically braked cycle ergometer (Velotron DynaFit Pro; RacerMate, Seattle, WA) to assess VO_2max. They warmed up for 2 minutes at intensities between 50 and 80 W/min, and subsequently power output was increased by 25–40 W/min. VO_2max was confirmed using established criteria[19] and represented the mean of the last two 15-second values obtained at volitional fatigue. During exercise, gas exchange data were obtained every 15 seconds using a metabolic cart (ParvoMedics True One, Sandy, UT), and heart rate (HR) was continuously assessed via telemetry (Polar Electro, Lake Success, NY). The metabolic cart was calibrated pretrial following standardized procedures.[19] After this bout, participants cooled down for 5 minutes at 50 W, then rested for 10 minutes, during which water intake was allowed *ad libitum*. They warmed up for 5 minutes at 50 W, and then were familiarized with a 10 km self-paced time trial (Central Park course; Velotron RacerMate 3-D Software, Seattle, WA) characterized by periods of hill inclines, downhill cycling, and flat terrain during which they were instructed to complete the course as fast as possible, and told that selecting a higher gear allowed them to pedal faster. This bout was chosen as performance was independent of carbohydrate availability, as glycogen utilization or blood glucose levels do not limit performance. During exercise, they were continuously provided with strong verbal encouragement and were allowed to drink water *ad libitum*. The only feedback provided during the trial was their cadence, gearing, and progress on the course, which were revealed on the computer screen. HR, cycling time, and rating of perceived exertion (RPE)[20] were assessed every 1.6 km as well as at exercise cessation. They returned 48 hours later at the same time of day and repeated this time trial after a 5-minute warm-up at each of 50 and 100 W. The intraclass correlation coefficient and CV for the time trial across all subjects were equal to 0.93% and 1.5% for performance time and 0.97% and 3.0% for mean power, respectively, which are similar to a recent study[21] in which a similar cycle ergometer and software were used.

Experimental protocol

For the next three visits separated by at least 48 hours, participants completed the 10 km time trial after completion of the standard 10-minute warm-up. Pretrial, they were refamiliarized with the RPE scale, reminded to go "all-out" during the trial, and were asked whether they experienced any symptoms of drink ingestion, which were denoted. RPE, HR, and cycling time were recorded every 1.6 km. After the last trial, participants were asked whether they could identify any differences between trials.

Treatment ingestion

Solutions ingested over the 3 days of testing included two boluses of anhydrous caffeine (Gallipot, St. Paul, MN) (5 mg/kg body weight) (C1 and C2) or placebo. All doses were weighed to the nearest 0.001 g on a calibrated balance scale (Denver Instrument, Bohemia, NY). This caffeine dose was

Table 2. Time-Trial Performance, Mean Power, Heart Rate, and Rating of Perceived Exertion (Mean ± Standard Deviation) in Response to Caffeine and Placebo Intake

Variable	*C1:trained*	*C2:trained*	*Placebo:trained*	*C1:active*	*C2:active*	*Placebo:active*
Time (min)	17.07 ± 0.99[a]	17.01 ± 1.0[a]	17.35 ± 0.98	18.53 ± 0.61	18.65 ± 0.80	18.71 ± 0.68
Mean power output (W)	267.0 ± 28.2	274.1 ± 31.8	263.0 ± 34.3	214.1 ± 22.4	209.0 ± 19.0	212.2 ± 25.3
HRend (beats/min)	188.4 ± 9.2	188.0 ± 8.7	183.5 ± 12.1	194.1 ± 7.6	191.5 ± 7.5	191.3 ± 8.0
RPEend	18.0 ± 1.7	18.1 ± 1.9	17.8 ± 2.0	17.5 ± 1.7	17.5 ± 1.7	17.3 ± 1.6

[a]$p < 0.05$ from corresponding placebo value within trained subjects; cycling time and mean power were different ($p < 0.05$) in endurance-trained versus active subjects in all treatments.

C1, caffeine trial 1; C2, caffeine trial 2; HR, heart rate; RPE, rating of perceived exertion.

used in a study by Pasman *et al.*[22] showing improved endurance performance in trained men. Drinks were housed in identical opaque containers containing one package of a commercially available, noncaloric lemon-flavored beverage (Crystal Light, Northfield, IL), 5 mg/kg of glucose, and 125 mL of noncaloric 7-UP. The drinks appeared, smelled, and tasted similar. Participants were unaware of the order of treatments and were deceived of the true content of the drinks, as they were told that the study aim was to examine effects of a new carbohydrate beverage. This was done as placebo effects of caffeine have been revealed.[23] Participants were provided their solution for the first day of testing during their last familiarization trial, and this process ensued during remaining trials. They were provided specific instructions with each drink to mix it with 250 mL of cold water and drink it within a 5-minute period 1 hour prior to exercise. This timing of ingestion has been shown to maximize plasma caffeine levels.[24] They returned empty bottles on the day of each trial to verify drink ingestion, and underwent a brief interview with the primary investigator to ensure that drink timing and ingestion were proper.

Monitoring of exercise status and dietary intake

Initially, participants were instructed how to complete 24-hour dietary logs before each trial, and were asked to follow the same diet on the day before each trial. These were photocopied and returned to participants everyday, and they were required to confirm maintenance of their diet as on arrival to the lab; their food diary was qualitatively assessed by an investigator for compliance with these dietary guidelines prior to trial initiation. They were provided a list of items that contain caffeine (coffee, chocolate, soda, tea, energy drinks, etc., as well as common over-the-counter medications) so they refrained from caffeine intake for 48 hours before each visit. Before each trial, they did not complete intense exercise in the preceding 48 hours and fasted for 3 hours. This was confirmed through completion of formal questionnaires submitted on each visit. Participants were provided a training log in which they denoted all physical activity completed during the course of the study, and were instructed to maintain their current exercise volume and intensity during the study.

Statistical analyses

Data are reported as mean ± standard deviation and were analyzed using SPSS 17.0 (Chicago, IL). One-way analysis of variance (ANOVA) with repeated measures was used to assess differences in time-trial performance across treatments (C1, C2, and placebo), with fitness level used as a between-subjects variable. Potential order effects of treatment ingestion on time-trial performance were examined with a one-way ANOVA with repeated measures. Two-way repeated measures ANOVA was used to examine differences in HR and RPE across time and treatment, with fitness level used as a between-subjects variable. The Greenhouse-Geisser correction was used to account for the sphericity assumption of unequal variances across groups. If a significant F ratio was obtained, Tukey's *post hoc* test was used to detect significant differences between means. Independent t-test was used to examine differences in various parameters when applicable. Effect size for the F ratio was expressed as partial eta-squared (η^2). Statistical significance was set at $p < 0.05$.

Results

Cycling performance in endurance-trained and active subjects

Mean cycling performance and power output are revealed in Table 2. No effect ($p > 0.05$) of treatment order on performance was revealed. Time-trial performance was superior ($p < 0.01$) in trained athletes versus recreationally active men. Caffeine significantly increased time-trial performance compared with placebo [$F(2,28) = 5.08$, $p < 0.01$, $\eta^2 = 0.27$], with performance in C1 and C2 significantly different from placebo by 1.6% and 2.0%, respectively, in the endurance-trained athletes and 0.3% and 1.0% in active men. There was no effect of fitness level on caffeine's ergogenic properties, as the treatment × group interaction was not significant [$F(2,28) = 1.54$, $p = 0.23$], and a performance-enhancing effect was still observed when fitness level was not considered and data were combined across subjects. However, only in trained athletes did *post hoc* analyses reveal significant differences ($p < 0.05$) between means when comparing performance in the caffeine trials (C1 and C2) with placebo. Compared with placebo, mean performance improvement for all subjects was similar ($p > 0.05$) in C1 (−0.23 ± 0.29 minutes, 95% CI = −0.41–0.22 minutes) versus C2 (−0.21 ± 0.36 minutes, 95% CI = −0.62–0.09 minutes) and in trained versus active men in C1 (−0.28 ± 0.26 minutes vs. −0.18 ± 0.36 minutes, 95% CI = −0.42–0.24) and C2 (−0.34 ± 0.28 vs. −0.07 ± 0.41 minutes, 95% CI = −0.64–0.11). Alterations in performance time across treatments and subjects are revealed in Table 3. There was a significant main effect of treatment [$F(2,28) = 5.42$, $\eta^2 = 0.28$, $p < 0.05$] and distance [$F(5,70) = 7592.8$, $\eta^2 = 0.99$, $p < 0.01$] on cycling time as well as a significant ($p < 0.05$) distance by group interaction. All means were significantly different ($p < 0.05$) from each other across distance; however, *post hoc* analyses revealed

Table 3. Cycling Performance in Minutes (Mean ± Standard Deviation) During a 10 km Time Trial in Trained and Recreationally Active Subjects in Response to Caffeine and Placebo Intake

Distance (km)	*C1 Time (min)*	*C2 Time (min)*	*Placebo Time (min)*
Trained			
1.6	2.59 ± 0.16	2.43 ± 0.40	2.61 ± 0.21
3.3	5.27 ± 0.34	5.27 ± 0.35	5.38 ± 0.36
5.0	8.37 ± 0.55	8.41 ± 0.55	8.52 ± 0.55
6.6	10.77 ± 0.64	10.79 ± 0.65	10.95 ± 0.67
8.3	13.51 ± 0.78	13.52 ± 0.77	13.72 ± 0.80
9.9	16.67 ± 0.97	16.61 ± 1.02	16.93 ± 0.97
Active			
1.6	2.81 ± 0.13	2.82 ± 0.20	2.86 ± 0.15
3.3	5.65 ± 0.28	5.73 ± 0.40	5.81 ± 0.25
5.0	9.05 ± 0.31	9.14 ± 0.50	9.22 ± 0.36
6.6	11.65 ± 0.34	11.73 ± 0.55	11.81 ± 0.40
8.3	14.54 ± 0.39	14.68 ± 0.60	14.74 ± 0.47
9.9	18.04 ± 0.56	18.04 ± 0.58	18.26 ± 0.64

C1, caffeine trial 1; C2, caffeine trial 2.

no differences ($p > 0.05$) between means within treatment for both groups.

Individual data

F1 ▶ Figure 1 reveals individual data for all participants across all trials. In the endurance-trained subjects, 6/8 (75%) revealed superior performance in both caffeine trials compared with placebo, one demonstrated improved performance only in the C2 trial, and one revealed the fastest time in placebo (−0.07 minutes vs. C1 and C2). In active men, 6/8 (75%) demonstrated enhanced performance in both caffeine trials versus placebo, yet two recorded their best time in the placebo trial. Of these participants, one showed superior performance in the placebo trial versus both caffeine trials, and in the other, performance in C1 was similar to placebo.

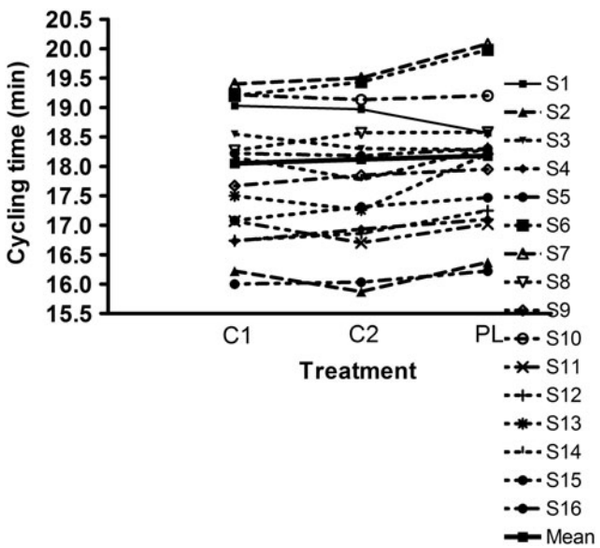

FIG. 1. Individual data showing changes in overall 10 km performance across all treatments in response to caffeine (C1 and C2) and placebo (PL).

Mean power output

Compared with placebo, mean power was consistently higher by 1.5%–3.8% in C1 and C2 across all subjects, although this difference was not significant ($p = 0.13$). There was no treatment × group interaction ($p = 0.37$). These data are revealed in Table 2.

HR and RPE data

End-exercise data are revealed in Table 2 across all treatments, and changes in these parameters during the time trial are demonstrated in Figure 2a and 2b. There was a significant main effect for HR across treatment [$F(2,28) = 9.74$, $\eta^2 = 0.41$, $p < 0.01$] and time [$F(6,84) = 103.5$, $\eta^2 = 0.88$, $p < 0.01$] during exercise, as HR was consistently higher in the caffeine trials compared with placebo, and gradually increased during exercise. The HR response was similar ($p > 0.05$) across groups. All HR values were different from each other with the exception of values at 3.3–8.3 km. ◀ F2

The RPE increased over time [$F(5,70) = 55.7$, $\eta^2 = 0.80$, $p < 0.01$] but was not different ($p > 0.05$) across treatment or group (Fig. 2b). For example, it was equal to 10–11 at 1.6 km and increased to 14–15, representing "hard," by 6.6–8.3 km of the trial in all subjects across all treatments.

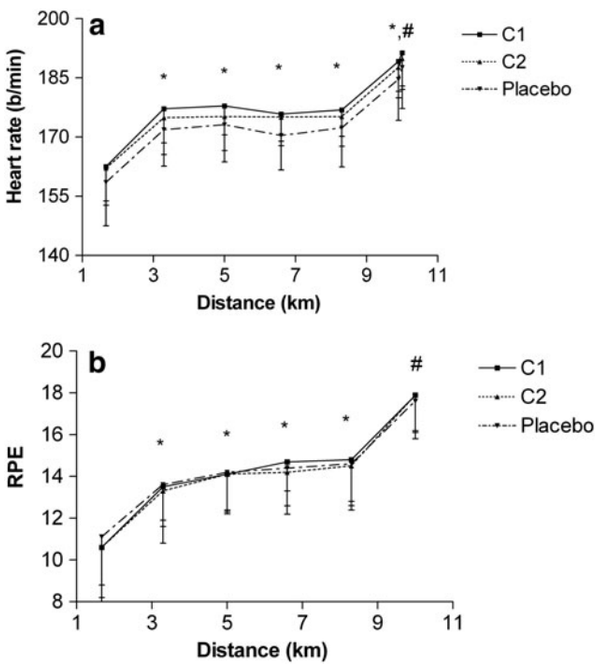

FIG. 2. Change in **(a)** heart rate (HR) and **(b)** rating of perceived exertion (RPE) during a 10 km cycling time trial in response to caffeine (C1 and C2) and placebo. Data were combined across groups as there was no difference in these variables across fitness level. HR $^{*}p < 0.05$ from value at 1.6 km; $^{\#}p < 0.05$ from all preceding values; RPE $^{*}p < 0.05$ from value at 1.6 km; $^{\#}p < 0.05$ from all preceding values.

Post hoc analyses revealed that in all treatments, RPE at all time points was different ($p < 0.05$) from that reported at 1.6 km, and the end-exercise value was different from all preceding RPE values.

Side effects of drink ingestion

Symptoms reported with caffeine ingestion included perceptions of increased energy, anxiety, mild tremor, and nausea. Out of 16 subjects, only 5 (31%) were able to differentiate between the treatments.

Discussion

The primary aim of the current study was to compare caffeine's effects on cycling performance in endurance-trained and active men. Previous work[11,24] postulated that superior fitness level allows trained athletes to benefit from caffeine more than recreationally active individuals, although only two studies have investigated this phenomenon.[14,16] However, no mechanism has been identified to explain this statement, although it has been suggested that athletes perform more reliably on a given performance task,[15] which would enhance possibility of any treatment effect versus moderately active individuals. Our data reveal that caffeine significantly increased time-trial performance in men differing in fitness level. Consequently, caffeine may elicit similar ergogenic effects in trained and active individuals completing self-paced cycling mimicking the demands of a 10 km cycling time trial.

The magnitude of performance improvement observed in the current study is similar to recent investigations employing short-term exercise independent of carbohydrate availability. In competitive oarsmen[25] completing a 2000 m time trial, performance was improved by 1.0% and 1.3% after ingestion of 9 and 6 mg/kg of caffeine, although individual differences existed. Replication of this protocol in competitive oarswomen[26] revealed similar enhancements in performance compared with placebo, although the magnitude of improvement was greater in the 9 mg/kg dose (1.3%) versus the 6 mg/kg dose (0.7%). In both studies, mean power output was improved by about 2.0%, similar to the current study, although our changes were not significant ($p = 0.13$). In male cyclists, 3 mg/kg caffeine improved cycling performance by 3.0%–3.6% during a 1-hour performance ride.[13] In sprint cyclists completing a 1 km laboratory time trial, 5 mg/kg of caffeine improved performance and mean power by 3.1% and 4.0%.[27] In another study,[2] caffeinated coffee improved 1500 m running performance by 4.2 seconds, or approximately 1.5%, versus placebo. Overall, this magnitude of improved performance, albeit small, is meaningful to athletes during competition. Nevertheless, despite six of eight active men (75%) revealing improved cycling performance in both caffeine trials compared with placebo, the size of the improvement (0.3%–1.0% = 3.7–11.0 seconds) appears too small to be real.

To our knowledge, only two studies have specifically compared ergogenic effects of caffeine in individuals of different fitness. Collomp *et al*.[14] required trained and novice swimmers to complete repeated bouts of 100 m swimming after ingestion of 250 mg of caffeine. Results showed that swim velocity was enhanced only in trained swimmers. However, the authors did not employ a performance-based test in which time was recorded, did not report whether familiarization trials were employed, used a 1-week caffeine withdrawal, and it could be argued that swimming would seem to require more skill than activities including cycling, which may minimize any potential benefit of caffeine. O'Rourke *et al*.[16] required trained runners and active subjects to complete an outdoor 5 km run on a track. Performance was significantly improved in both groups by 1.0%–1.1% with 5 mg/kg of caffeine ingested 1 hour pretrial, although the magnitude of improvement in the active men was less than the test-retest reliability of the measurement (1.4%). In older individuals,[28] data revealed improved cycling performance with caffeine; however, no benefit was revealed in sedentary women during brief all-out cycling[29] as well as sedentary men completing a bench press test and running to exhaustion at 85% VO_2max.[30] However, with the exception of one study,[31] any effect of caffeine on bench press performance is minimal, and time to exhaustion protocols were used in these studies[29,30] that are extremely unreliable and may mask any performance improvement. Consequently, it may be premature to state that caffeine is of little benefit to individuals who are not athletes, yet further study is merited to elucidate this issue, especially to discern whether caffeine can improve performance during chronic training in a wide range of individuals.

Results from Cureton *et al*.[32] and Ganio *et al*.[33] revealed reduced RPE during 2 hours of submaximal cycling preceding a 15-minute time trial with caffeine intake. However, in both studies, any effect of caffeine on RPE was eliminated during the time trial. Our findings demonstrating no difference in RPE with caffeine corroborate previous data showing no difference in end-exercise RPE in rowers completing an "all-out" time trial lasting approximately 8 minutes.[25] Several factors may explain these discrepant data across studies. First, it is plausible that the relatively brief duration of our bout is too short to elicit alterations in RPE. For the first 35 and 45 minutes of exercise in these studies,[32,33] RPE was similar across treatments. In the current study, subjects ate 3 hours pretrial, and as performance of 10 km cycling is independent of carbohydrate availability, it may be that caffeine modifies RPE during exercise only when reductions in muscle glycogen and blood glucose occur as during prolonged cycling. Findings from a recent study[34] revealing no caffeine-mediated alteration in RPE during repeated bouts of maximal knee extension/flexion exercise support this assertion.

Various mechanisms have been proposed to explain caffeine's performance enhancing effects, as described in previous reviews.[10,11] Historically, caffeine was thought to enhance fatty acid oxidation,[35] although more recent studies[7] refute this explanation. Caffeine has been recognized to act as an adenosine antagonist in the nervous system,[4] thereby counteracting inhibited neuroexcitability, arousal, and fatigue induced by adenosine, whose concentration increases with exercise. Alternatively, large doses of caffeine have been demonstrated to reduce muscle pain during submaximal cycling[36] as well as eccentric exercise,[37] yet these activities differ from the muscular demands of a simulated "all-out" cycling time trial as completed in the current study. Ganio *et al*.[31] demonstrated that caffeine blunted the decline in maximal voluntary contraction strength during 2 hours of constant load cycling followed by a brief performance ride, in which performance was augmented with caffeine. In this study, attenuated RPE as well as adenosine

◀ AU2

antagonism were highlighted as the primary determinants of caffeine's ergogenic effects. Overall, based on the results of the current study as well as O'Rourke *et al.*,[16] it could be speculated that in both athletes and active individuals, the mechanisms explaining caffeine's ergogenic effects are similar, although further study is needed to confirm this.

This study maintains a few limitations. First, blood or urine samples were not obtained to quantify caffeine concentration or to ensure that participants truly abstained from caffeine in the 48 hours prior to each visit. However, plasma caffeine concentration is unrelated to time-trial performance[8] and, moreover, was not associated with the magnitude of improved performance with caffeine intake.[38] Between-subject variations in caffeine concentration in response to caffeine ingestion are marked,[8,22] so this measure may lack adequate sensitivity to identify "responders" and "nonresponders" to caffeine ingestion. Second, participants began all trials in the fed state, which some speculate[8] may minimize potential ergogenic effects by slowing caffeine absorption. However, requiring participants to initiate intense cycling exercise after an overnight fast does not simulate what athletes do in competition, so they came into the lab 3 hours postabsorptive. Similarly, participants were not provided prepackaged food before all trials, but were required to ingest foods they regularly consume, which allowed them to follow their typical dietary intake. The caffeine dose provided was larger than typical daily intakes of caffeine, and lower doses have also been shown to be ergogenic in cyclists.[1,39]

Our study was strengthened by several factors. First, pretrial food and caffeine intake as well as exercise status were rigorously controlled to ensure that participants were in an identical state prior to all trials. Second, two familiarization bouts were completed prior to experimental trials to allow individuals to learn how to pace themselves during exercise, select the proper gear for an ever-changing course, and exert an "all-out" effort across all trials, which enhances reliability.[15] Our coefficient of variation for time-trial performance (1.5%) is similar to a previous study[19] employing cycling time trials, yet higher than that recorded for rowers (0.7%–0.9%) completing a 2000 m time trial[25] or elite cyclists (0.5%–1.0%) completing a 1-hour time trial.[40] It is evident that interindividual variability in performance effects occurs in response to acute caffeine ingestion,[8,24] so two caffeine trials were employed to confirm potential ergogenic effects of the drug. Our data revealed that in both trained and recreationally active men, caffeine's ergogenic properties are comparable, as there was no significant difference ($p > 0.05$) in the performance effect across groups. Lastly, participants were unaware of the specific ingredients of each drink as well as the aim of the study, which helped to minimize expectations of improved performance that have been previously documented.[41,42] Only 5 of 16 participants could differentiate between drinks, which suggests that the blinding was successful and that the results were not influenced by prior knowledge of the treatment.

Conclusions

In this study, we compared magnitude of effects of caffeine on cycling performance in persons varying in fitness level. The improvement in performance was similar across trained and active participants, as there was no group × treatment interaction, and approximately 75% of participants in both groups exhibited improved performance with caffeine. Two identical caffeine doses equal to 5 mg/kg helped to verify the ergogenic effects of this drug, as there was no difference in the magnitude of improved performance across days. Overall, acute caffeine intake improves 10 km time-trial performance in endurance-trained athletes and active men.

Acknowledgments

The experimenters thank the subjects for participating in the current study, which was partially funded by a College of Arts and Sciences Faculty Development Grant.

Author Disclosure Statement

No competing financial interests exist in execution of this study.

References

1. Cox GR, Desbrow B, Montgomery PG, *et al.* Effect of different protocols of caffeine intake on metabolism and endurance performance. J Appl Physiol. 2002;93:990–999.
2. Wiles JD, Bird SR, Hopkins J, Riley M. Effect of caffeinated coffee on running speed, respiratory factors, blood lactate, and perceived exertion during 1500 m treadmill running. Br J Sports Med. 1992;26:116–120.
3. Schneiker KT, Bishop D, Dawson B, Hackett LP. Effects of caffeine on prolonged intermittent-sprint ability in team-sport athletes. Med Sci Sports Exerc. 2006;38:578–585.
4. Davis JM, Zhao Z, Stock HS, Mehl KA, Buggy J, Hand GA. Central nervous system effects of caffeine and adenosine on fatigue. Am J Physiol. 2002;284:R399–R404.
5. Doherty M, Smith PM. Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis. Scand J Med Sci Sports. 2005;15:69–78.
6. Cohen BS, Nelson AG, Prevost MC, Thompson GD, Marx BD, Morris GS. Effects of caffeine ingestion on endurance racing in heat and humidity. Eur J Appl Physiol. 1996;3: 358–363.
7. Jacobson TL, Febbraio MA, Arkinstall MJ, Hawley JA. Effect of caffeine co-ingested with carbohydrate or fat on metabolism and performance in endurance-trained men. Exper Physiol. 2001;86:137–144.
8. Skinner TL, Jenkins DG, Coombes JS, Taaffe DR, Leveritt MD. Dose response of caffeine on 2000-m rowing performance. Med Sci Sports Exerc. 2010;42:571–576.
9. Hunter AM, St. Clair Gibson A, Collins M, Lambert M, Noakes TD. Caffeine ingestion does not alter performance during a 100-km cycling time-trial performance. Int J Sports Nutr Exerc Metab. 2002;12:238–252.
10. Astorino TA, Roberson DW. Efficacy of acute caffeine-ingestion for short-term high-intensity exercise: a systematic review. J Strength Cond Res. 2010;24:257–265.
11. Davis JK, Green JM. Caffeine and anaerobic performance: ergogenic value and mechanisms of action. Sports Med. 2009; 39:813–832.
12. Cornelis MC, El-Sohemy A, Campos H. Genetic polymorphism of the adenosine A2A receptor is associated with habitual caffeine consumption. Am J Clin Nutr. 2007;86: 240–244.
13. Irwin C, Desbrow B, Ellis A, O'Keeffe B, Grant G, Leveritt M. Caffeine withdrawal and high-intensity endurance cycling performance. J Sports Sci. 2011;29:509–515.

14. Collomp K, Ahmaidi S, Chatard JC, Audran M, Prefaut C. Benefits of caffeine ingestion on sprint performance in trained and untrained swimmers. Eur J Appl Physiol. 1992; 64:377–380.
15. Hopkins WG, Hawley JA, Burke LM. Design and analysis of research on sport performance enhancement. Med Sci Sports Exerc. 1999;31:472–485.
16. O'Rourke MP, O'Brien BJ, Knez WL, Paton CD. Caffeine has a small effect on 5-km running performance of well-trained and recreational runners. J Sci Med Sport. 2008;11:232–233.
17. Centers for Disease Control. Behavioral Risk Factor Surveillance System. Physical Activity Statistics, 2007.
18. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr. 1978;40:497–504.
19. Astorino TA. Alterations in VO_2max and the VO_2 plateau with manipulation of sampling interval. Clin Physiol Funct Imaging. 2009;29:60–67.
20. Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14:377–381.
21. Sporer BC, McKenzie DC. Reproducibility of a lab-based 20-km time trial evaluation in competitive cyclists using the Velotron Pro ergometer. Int J Sports Med. 2008;28:940–944.
22. Pasman WJ, Van Baak MA, Juekendrup AE, De Haan A. The effect of different dosages of caffeine on endurance performance time. Int J Sports Med. 1995;16:225–230.
23. Duncan MJ, Lyons M, Hankey J. Placebo effects of caffeine on short-term resistance exercise to failure. Int J Sports Physiol Perform. 2007;4:244–254.
24. Graham TE. Caffeine and exercise: metabolism, endurance, and performance. Sports Med. 2001;31:785–807.
25. Bruce CR, Anderson ME, Fraser SF, *et al.* Enhancement of 2000-m rowing performance after caffeine ingestion. Med Sci Sports Exerc. 2000;32:1958–1963.
26. Anderson ME, Bruce CR, Fraser SF, *et al.* Improved 2000-meter rowing performance in competitive oarswomen after caffeine ingestion. Int J Sports Nutr. 2000;10:464–475.
27. Wiles JD, Coleman D, Tegerdine M, Swaine IL. The effects of caffeine ingestion on performance time, speed and power during a laboratory-based 1 km cycling time-trial. J Sports Sci. 2006;24:1165–1171.
28. Norager CB, Jensen MB, Madsen MR, Laurberg S. Caffeine improves endurance in 75-year-old citizens: a randomized, double-blind, placebo-controlled crossover study. J Appl Physiol. 2005;99:2302–2306.
29. Wallman KE, Goh JW, Guelfi KJ. Effects of caffeine on exercise performance in sedentary females. J Sports Sci Med. 2009;9:183–189.
30. Beck TW, Housh TJ, Malek MH, Mielke M, Hendrix R. The acute effects of a caffeine-containing supplement on bench press strength and time to running exhaustion. J Strength Cond Res. 2006;22:1654–1658.
31. Woolf KW, Bidwell WK, Carlson AG. The effect of caffeine as an ergogenic aid in anaerobic exercise. Int J Sports Nutr Exerc Metab. 2008;18:412–429.
32. Cureton KJ, Warren GL, Millard-Stafford ML, Wingo JE, Trilk J, Buyckx M. Caffeinated sports drink: ergogenic effects and possible mechanisms. Int J Sports Nutr Exerc Metab. 2007;17:35–55.
33. Ganio MS, Klau JF, Lee EC, *et al.* Effect of various carbohydrate-electrolyte fluids on cycling performance and maximal voluntary contraction. Int J Sports Nutr Exerc Metab. 2010;20:104–114.
34. Astorino TA, Terzi MN, Roberson DW, Burnett TR. Effect of two doses of caffeine on muscular function during knee extension exercise. Med Sci Sports Exerc. 2010;42:2205–2210.
35. Costill DL, Dalsky GP, Fink WJ. Effects of caffeine on metabolism and exercise performance. Med Sci Sports. 1978;10: 155–158.
36. Motl RW, O'Connor PJ, Dishman RK. Effect of caffeine on perceptions of leg muscle pain during moderate intensity cycling exercise. J Pain. 2003;4:316–321.
37. Maridakis V, O'Connor PJ, Dudley GA, McCully KK. Caffeine attenuates delayed-onset muscle pain and force loss following eccentric exercise. J Pain. 2007;8:237–243.
38. Astorino TA, Martin BJ, Schachtsiek L, Wong K, Ng K. Minimal effect of acute caffeine ingestion on intense resistance training performance. J Strength Cond Res. 2011;25:1752–1758.
39. Jenkins NT, Trilk JL, Singhal A, O'Connor PL, Cureton KJ. Ergogenic effects of low doses of caffeine on cycling performance. Int J Sports Nutr Exerc Metab. 2008;18:328–342.
40. Paton CD, Hopkins WG. Variation in performance of elite cyclists from race to race. Eur J Sports Sci. 2005;6:1–7.
41. Beedie CJ, Stuart EM, Coleman DA, Foad AJ. Placebo effect of caffeine in cycling performance. Med Sci Sports Exerc. 2006;38:1–6.
42. Foad AJ, Beedie CJ, Coleman DA. Pharmacological and psychological effects of caffeine ingestion in 40-km cycling performance. Med Sci Sports Exerc. 2008;40:158–165.

Address correspondence to:
Todd Anthony Astorino, Ph.D.
Department of Kinesiology
California State University, San Marcos
333. S. Twin Oaks Valley Road, MH 352
San Marcos, CA 92096-0001

E-mail: astorino@csusm.edu

AUTHOR QUERY FOR CAF-2011-0022-VER9-ASTORINO_1P

AU1: Please define CI.
AU2: "Ganio et al.[31]" does not match with reference list. Please check.
AU3: In Ref. 17, please mention the other publication details or URL, if any.
AU4: In Table 2, "b/min" has been changed to "beats/min." Please confirm.