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Abstract

Purpose: Caffeine, often in the form of coffee, is frequently supplemented by athletes in an attempt to facilitate improved performance during exercise. The aim of the present study was to investigate the effectiveness of coffee ingestion as an ergogenic aid prior to a one-mile (1609 m) race. **Methods:** In a double-blind, randomised, crossover, placebo-controlled design 13 trained male runners completed a one-mile race 60 minutes following the ingestion of 0.09 $g \cdot kg^{-1}$ coffee (COF), 0.09 $g \cdot kg^{-1}$ decaffeinated coffee (DEC), or a placebo (PLA). All trials were dissolved in 300 ml of hot water. **Results:** The race completion time was 1.3% faster following the ingestion of COF (04:35:37 ± 00:10:51 mm:ss) compared with DEC (04:39:14 ± 00:11:21 mm:ss; *P*=0.018; 95%CI: -0.11, -0.01; *d*=0.32) and 1.9% faster compared with PLA (04:41:00 ± 00:09:57 mm:ss; *P*=0.006; 95%CI: -0.15, -0.03; *d*=0.51). A large trial and time interaction for salivary caffeine concentration was observed (*P*<0.001; η_p^2 =0.69) with a very large increase (6.40 ± 1.57 $\mu g \cdot ml^{-1}$, 95%CI: 5.5, 7.3; *d*=3.86) following the ingestion of COF. However, only a trivial difference between DEC and PLA was observed (*P*=0.602; 95%CI: -0.09, 0.03; *d*=0.17). Furthermore, only trivial differences for blood glucose (*P*=0.839; η_p^2 =0.02) and lactate (*P*=0.096; η_p^2 =0.18), and maximal heart rate (*P*=0.286; η_p^2 =0.13) were observed between trials. **Conclusions:** The results of the present study show that 60 minutes after ingesting 0.09 $g \cdot kg^{-1}$ of caffeinated coffee one-mile race performance was enhanced by 1.9% and 1.3% compared with placebo and decaffeinated coffee respectively, in trained male runners.

Keywords: Caffeine; Ergogenic aid; Competition; Middle distance running.

Introduction

Caffeine, often in the form of coffee[1], is frequently supplemented by athletes in an attempt to facilitate improved performance during exercise. However, the available research typically focuses on the ingestion of 3-8 $mg \cdot kg^{-1}$ of anhydrous caffeine rather than coffee[1]. Caffeine non-selectively blocks both adenosine receptors and competitively inhibits the action of adenosine, which during exercise, can lower pain perception, increase neuro-excitability and sustain motor unit firing[2]. Therefore, adenosine receptor antagonism is the leading hypothesis as to how caffeine could have an ergogenic effect on exercise performance[2]. Despite this, Astorino and Roberson[3] concluded that the mechanism by which caffeine provides an ergogenic effect in high intensity exercise is likely to be multifactorial, with central factors such as adenosine antagonism being the most probable mechanism, but with reductions in perceived exertion, and increased reaction time, cognition, and mood also having an influence on performance.

Recently, there has been debate as to whether the same ergogenic benefits observed from caffeine ingestion can be obtained from consuming caffeine in the form of coffee, especially as Liguori et al.[4] reported that peak salivary caffeine concentration was faster and higher following coffee ingestion, compared with a caffeine capsule. However, Graham et al.[5] concluded that only 4.5 $mg \cdot kg^{-1}$ of anhydrous caffeine increased exercise distance by 2-3 km when running at 85% $\dot{V}O_{2max}$ until voluntary exhaustion and proposed that chlorogenic acids, and possibly other ingredients within coffee, nullified the ergogenic benefits of caffeine. In contrast, Hodgson et al.[6] compared 5 $mg \cdot kg^{-1}$ of anhydrous caffeine to coffee during a cycling time trial lasting approximately 75 min and observed that both coffee and caffeine ingestion were beneficial to exercise performance by

similar magnitudes (~5%). Furthermore, Trexler et al.[7] concluded that providing 3-5 mg·kg^{-1} of caffeine in the form of coffee or anhydrous caffeine improved repeated sprint performance and Wiles et al.[8] observed that 1500 m running performance improved by 4.2 s following the ingestion of 3 g of coffee (150-200 mg caffeine). In addition, Richardson and Clarke[9] reported that during resistance exercise, the total weight lifted during back squats was 22% higher following the ingestion of coffee, providing 5 mg·kg^{-1} of caffeine, when compared with a placebo. The inconsistency in performance outcomes associated with coffee ingestion may be due to the blend of coffee ingested and consequently substantial variation in chlorogenic acid content and caffeine concentration of the coffee[10], exercise modality[11], and training status[12]. However, Higgins et al.[1] concluded that coffee providing 3 mg·kg^{-1} of caffeine may be used as an alternative to anhydrous caffeine to improve endurance performance.

While sporting performance is more than just a physiological construct, many of the interventions that are researched tend to be physiological in nature, such as nutritional or training. Furthermore, to be a valid simulation of competitive performance, the protocol should provide similar physiological (and psychological) responses to actual performance[13] but actual competitive events are seldom investigated. Consequently, with studies suggesting that coffee may improve exercise performance[8,14], it would be beneficial to investigate the effect of coffee ingestion on actual race performance, as no previous study has investigated the effect of coffee ingestion on performance in ecologically valid situations such as a competitive race. Therefore, the aim of the present study was to provide an insight into the effectiveness of coffee ingestion as an ergogenic aid prior to a one-mile (1609 m) race in trained males.

Methods

Participants

Fifteen trained middle distance male runners began the study, although only 13 (Mean ± SD age: 24 ± 6 years, height: 1.81 ± 0.07 m, body mass, 69.3 ± 4.7 kg, 800 m personal best performance time: 01:54:43 ± 00:33:19 mm:ss, 1500 m personal best performance time: 04:07:56 ± 00:15:18 ms:ss; one mile personal best performance time: 04:37:33 ± 00:23:25 mm:ss) completed all the races and are therefore included in the data analysis. In a double-blind, Latin-square randomisation, crossover, placebo-controlled design, participants completed a one-mile (1609 m) race following the ingestion of 0.09 $g \cdot kg^{-1}$ coffee (COF), 0.09 $g \cdot kg^{-1}$ decaffeinated coffee (DEC), or a placebo (PLA). All procedures were undertaken in accordance with the Declaration of Helsinki and approved by the institutional ethics committee. Participants were made fully aware of the exact procedures, including any risks and benefits of participation in the study before providing written informed consent.

On separate days, trials were performed on an indoor 200 m running track with banked curves (temperature: 19.2 ± 0.9°C and relative humidity: 45 ± 3%) at the same time (17:30) to minimise performance variation due to circadian variation[15]. Participants were instructed to abstain from caffeine, alcohol, and strenuous activity for 12 h prior to each race. Caffeine was not withheld for the 24-h period prior because it has been demonstrated that a 3 $mg \cdot kg^{-1}$ body mass dose of caffeine improves performance irrespective of whether a withdrawal period is imposed on habitual caffeine users[16]. In addition, the participants had not been taking any additional supplements, such as beta

alanine, that may influence running performance for at least three months prior to data collection. Trials were separated by a period of seven days to ensure complete recovery. Habitual caffeine consumption was assessed using an adapted version of the Landrum et al.[17] caffeine consumption questionnaire. Many participants were regular consumers of caffeine (mean ± SD: 171 ± 250 $mg \cdot day^{-1}$ and range: 0-705 $mg \cdot day^{-1}$) with low habitual caffeine consumption defined as <300 $mg \cdot day^{-1}$ and >300 $mg \cdot day^{-1}$ was defined as high[18]. In addition, a 24-hour dietary record was completed by each participant prior to the first race; it was then photocopied and handed back to the participants so that the same diet could be repeated for subsequent trials (Daily energy: 2738 ± 650 Kcal; Carbohydrate: 394 ± 95 g; Protein: 95 ± 32 g; Fat: 98 ± 29 g; Water: 2409 ± 2132 ml).

Coffee Treatments

Each participant competed in three races following the ingestion of the following: 0.09 $g \cdot kg^{-1}$ coffee (Nescafé Original, Nestlé, UK; COF), 0.09 $g \cdot kg^{-1}$ decaffeinated coffee (Nescafé Original Decaffeinated, Nestlé, UK; DEC), and a placebo (PLA). Nescafé original coffee (from the same batch) was used in the coffee trials as it has been reported by Hodgson et al.[6] to contain 3.4 g of caffeine per 100 g of coffee meaning that each participant consumed 0.09 $g \cdot kg^{-1}$ of coffee to achieve the 3 $mg \cdot kg^{-1}$ of caffeine required. Nescafé decaffeinated coffee was used and provides ~0.17 $mg \cdot kg^{-1}$ of caffeine[6] and was prepared in identical fashion and concentration to the coffee trial. All trials were dissolved in 300 ml of hot water (65.8 ± 3.1ºC) and served in lidded cups. The placebo trial was hot water of the same volume and temperature as the other trials with coffee flavour (Espresso Coffee Flavouring Compound**,** MSK Ingredients, UK) and colour (Brown Food

Colouring, Lakeland, UK) added to maintain treatment blinding and to ensure all treatments tasted similar. Participants had a maximum of five minutes to fully consume the treatment beverage.

Procedures

On arrival at the athletics track the body mass of each participant was recorded and saliva and capillary blood samples were collected before ingesting the test drink (baseline). The participants then performed their usual pre-race standardised warm-up lasting 45 min, which consisted of a 2000 m self-paced jog followed by an individual static and dynamic stretching programme and ending with 3 × 80 m strides. Then, 60 minutes after the ingestion of the fluid, further saliva and capillary blood samples were collected (post-warm-up) and the one-mile race was run. Collection of saliva and blood samples were repeated post-race. No encouragement was given and watches were removed. The one mile was timed using electronic timing lights (ALGE Timing GmbH, Lustenau, Austria). Time to completion was not given to the participants until after the end of the study. To ensure maximum effort, the races were handicapped based on the participants' personal best time and adjusted based on their performance for the following race to ensure each trial was a competitive race e.g. a participant with a one-mile personal best of 04:22 mm:ss started 3 s after a participant with a personal best of 04:25 mm:ss. Furthermore, the participants received £2 for each place in every race i.e. £2 for 13^{th} and £26 for 1^{st} and an additional £50 gift voucher for the overall winner based on accumulated prize money.

Measurements

Heart rate (HR) was measured throughout each race using a short-range telemetry HR transmitter strap recording at 1 s intervals (Polar Team 2 System, Polar Electro Oy, Kempele, Finland). Saliva samples (minimum 0.5 ml by the passive drool technique) were obtained immediately before fluid ingestion to establish compliance with the washout period, one-hour post-ingestion and following the race. Participants were instructed to *expectorate* into a 20-ml plastic cup, and the sample was then transferred to a capped glass vial that was immediately placed in a portable −20°C freezer before being transferred to a −80°C freezer for subsequent analysis of caffeine concentration using a standard enzyme-linked immunoassay kit (Caffeine ELISA Kit; Creative Diagnostics, Shirley, USA). At the same time points, a capillary blood sample was drawn from the index finger for determination of blood glucose and lactate concentrations (*Biosen* C-line, EKF-diagnostic GmbH, Germany).

Data Analysis

An *a priori* power calculation based for race time revealed that a sample size of ten participants were necessary to detect a statistical difference given an estimated effect size of 0.5, a 1-β error probability of 0.8 and a *P* value of less than 0.05. Data are reported as the mean ± the standard deviation (SD). The Shapiro-Wilk test was applied to the data to assess for a normal distribution. All variables, except for salivary caffeine and blood glucose and lactate were assessed using a one-way analysis of variance (ANOVA) with repeated measures. Salivary caffeine concentration and blood glucose and lactate were analysed with a two-way ANOVA with repeated measures.

Sphericity was analysed by Mauchly's test of sphericity followed by the Greenhouse-Geisser adjustment where required. Where any differences were identified, pairwise comparisons with Bonferroni correction were used to show where they lay. The data was analysed using IBM SPSS Statistics for Windows, Version 24.0 (Armonk, NY: IBM Corp.). Furthermore, 95% confidence intervals (95%CI) and effect sizes using partial eta squared (η_p^2), defined as trivial (<0.10), small (0.10-0.24), moderate (0.25-0.39) or large (≥0.40), and Cohen's *d*, defined as trivial (<0.20), small (0.20-0.49), moderate (0.50-0.79) or large (≥0.80) according to the cut-offs suggested by Cohen[19], were also calculated. In addition, the changes in race performance were standardized and expressed as a factor of the smallest worthwhile change, based on Cohen's effect size principle.

Results

The results show a large main effect for trial ($F_{2,24}$=9.524; *P*=0.001; η_p^2 =0.44; Figure 1) with race completion time being faster following the ingestion of COF (04:35:37 ± 00:10:51 mm:ss) compared with DEC (04:39:14 ± 00:11:21 mm:ss; *P*=0.018; 95%CI: -0.11, -0.01; *d*=0.32) and PLA (04:41:00 ± 00:09:57 mm:ss; *P*=0.006; 95%CI: -0.15, -0.03; *d*=0.51). However, only a trivial difference between DEC and PLA was observed (*P*=0.602; 95%CI: -0.09, 0.03; *d*=0.17). Overall, race performance was improved by 1.9 ± 1.7% (95%CI: 1, 2.8) and 1.3± 1.4% (95%CI: 0.5, 2.0) following the ingestion of COF, compared with PLA and DEC respectively with a 0.6± 1.6% (95%CI: -0.2, 1.5) improvement following DEC compared with PLA. Furthermore, no order effect was observed ($F_{2,24}$=0.041; *P*=0.959; η_p^2 =0.00).

A large trial and time interaction for salivary caffeine concentration was observed ($F_{2,21}$=24.260; P<0.001; η_p^2 =0.69; Figure 2) with a very large increase (6.40 ± 1.57 μg·ml^{-1}, 95%CI: 5.5, 7.3, d=3.86) in salivary caffeine concentration between pre-race and post-warm-up observed following the ingestion of COF. In contrast, only small changes were observed during DEC (0.87 ± 1.68 μg·ml^{-1}, 95%CI: -0.1, 1.8, d=0.43) and PLA (0.83 ± 2.06 μg·ml^{-1}, 95%CI: -0.3, 2.0, d=41). Only trivial differences between trials for blood glucose ($F_{2,24}$=0.177; P=0.839; η_p^2 =0.02; Table 1) and lactate ($F_{2,24}$=2.584; P=0.096; η_p^2 =0.18; Table 1), and maximum heart rate ($F_{1,10}$=1.345; P=0.286; η_p^2 =0.13; Table 1) were observed.

Discussion

The aim of the present study was to determine the effect of ingesting caffeinated coffee on one-mile (1609 m) race performance. The main findings are that the ingestion of COF markedly increased salivary caffeine concentration and improved one-mile race performance compared with DEC and PLA. In addition, blood glucose and lactate concentration, and maximal heart rate were unaffected by the ingestion of COF or DEC.

Following the ingestion of caffeinated coffee race performance was improved by 1.9% and 1.3% compared with PLA and DEC respectively. The ergogenic benefits of caffeine ingestion are well documented (e.g.[3,21]). However, fewer studies have documented the effects of coffee ingestion. In support of the findings of the present study, Wiles et al.[8] reported that the ingestion of 3 g of caffeinated coffee, containing approximately 150-200 mg of caffeine, improved 1500 m treadmill running performance by 4.2 s (1.4%) when compared with decaffeinated coffee. Similarly,

Hodgson et al.[6] demonstrated that coffee and caffeine ingestion improved time trial performance by approximately 5%. Richardson and Clarke[9] also reported that resistance exercise performance was improved by 22% following coffee ingestion, when compared with a placebo. Furthermore, Trexler et al.[7] reported that caffeine and coffee ingestion improved total work performed during repeated sprints (95%CI: 40, 219 J). In contrast, Clarke et al.[20] observed that the ingestion of coffee had little effect on repeated sprint cycling performance in relatively untrained males. Graham et al.[5] previously suggested that the bioactive compounds in coffee, such as chlorogenic acids, may attenuate the ergogenic effect of caffeine. However, more recent studies[6,7,14] have reported both coffee and caffeine ingestion yield similar benefits for exercise performance, most likely through the antagonistic effect on adenosine receptors reducing symptoms of central fatigue[1]. One potential reason for the inconsistent findings is training status. It is apparent that caffeine and coffee is less effective for non-trained individuals participating in high-intensity exercise[12], possibly due to trained athletes, like the participants in the present study, having more muscle mass than recreational athletes and the concentration of adenosine receptors (the hypothesised primary target of caffeine[2]) appearing to be higher in trained compared to untrained individuals[21]. In addition, the high variability in performance that is typical for untrained subjects may also contribute.

Although the purpose of this study was not to determine the mechanism of coffee action, adenosine antagonism, enhanced motor unit recruitment and reduced perception of pain and exertion have been proposed to explain the effects of caffeine supplementation on sport performance[2]. However, since caffeine interacts with many tissues, it is difficult to independently investigate its effects on the central and peripheral nervous systems, and metabolism[22]. When specifically examining exercise of the nature in the present study, the primary mechanisms by which caffeine exerts its

ergogenic effects are considered to arise from the antagonism of adenosine receptors leading to an increase in neurotransmitter release and motor unit firing rates, pain suppression, reduced fatigue and improved neuromuscular performance[2]. Another possible mechanism through which caffeine may improve performance is by increasing the secretion of β-endorphins[23], which may, at least partially, explain the mechanism by which caffeine attenuates pain sensation[24] and rating of perceived exertion[25] during exercise, thereby decreasing perceptions of effort and improving performance, as observed in the present study.

In addition to its impact on the central nervous system, caffeine can affect substrate utilization during exercise with a decrease in glycogen utilization and an increase in free fatty acid mobilization[26]. However, alterations in substrate utilization is unlikely to mediate performance changes in the present study due to fat metabolism representing a minor substrate and muscle glycogen not being limiting[2]. In addition, de Paulis, et al.[27] demonstrated that coffee ingestion caused a blunted response of adrenaline which was attributed to chlorogenic acids antagonising the binding of caffeine to adenosine receptors. Furthermore, Hodgson, et al.[6] reported that the increase in glucose, fatty acids and glycerol observed when ingesting caffeine had an attenuated response following coffee ingestion, which was attributed to other compounds in coffee inducing subtle effects on the antagonism of A_1 and A_{2A} adenosine receptors. Despite these findings, the performance improvements observed by Hodgson, et al.[6] were similar for both caffeine and coffee leading the authors to conclude coffee ingestion may alter the metabolic effects, but not the ergogenic effects on performance. In support of this observation, McLellan and Bell[14] and Trexler et al.[7] reported similar performance benefits from ingesting coffee and caffeine. However, in the present study no differences in blood glucose and lactate concentrations, and heart rate were

observed, although these values were comparable with previous studies[5,8,14]. Overall, it is probable that coffee and caffeine supplementation enhances physical performance via a combined effect on both the central and peripheral systems.

The present study is not without limitations. The use of a 24-hour dietary record to ensure pre-trial standardisation, whilst being an acceptable method and a good reflection of standard nutritional practice, there may be some concern about the accuracy. In addition, the baseline salivary caffeine concentrations suggest that caffeine was not abstained from prior to each trial. However, both factors are likely to provide a more ecologically valid condition and represent typical pre-race preparation. A further potential limitation is the wide range of the participants' habitual caffeine intake, although Gonçalves et al.[28] recently demonstrated that during ~30 min cycling time trials, performance was not influenced by habitual caffeine consumption.

Practical Implications

The coefficient of variation (CV) for running performance at distances between 1500 m and 10,000 m for elite males has been reported to be 1.4% (90%CI: 1.2-1.6)[29] and the smallest worthwhile enhancement in performance of similar distances to be 0.3-0.5 of the CV[29]. In the present study, based on the placebo condition, this corresponds to a 1.01-2.25 s improvement in the time taken to complete the mile. Therefore, the performance improvements observed [*vs*. PLA: 5.38 ± 4.75 s (95%CI: 2.80, 7.97); *vs*. DEC: 3.62 ± 3.84 s (95%CI: 1.53, 5.70)] following the ingestion of 300 ml of caffeinated coffee providing 3 $mg \cdot kg^{-1}$ of caffeine 60 minutes before a race could be considered practically meaningful during actual competitions. However, athletes need to be aware

that the type of coffee and brewing method alters the caffeine and chlorogenic acids content[10] and inter-individual variation in pharmacodynamic and pharmacokinetic polymorphisms[30] may cause variation in the responses to caffeine and its ergogenic effects.

Conclusion

In conclusion, the ingestion of caffeinated coffee 60 minutes before a one-mile race markedly increased salivary caffeine concentration and improved race performance compared with decaffeinated coffee and a placebo solution. These findings suggest that the ingestion of caffeinated coffee is a suitable source of caffeine prior to a one-mile running race.

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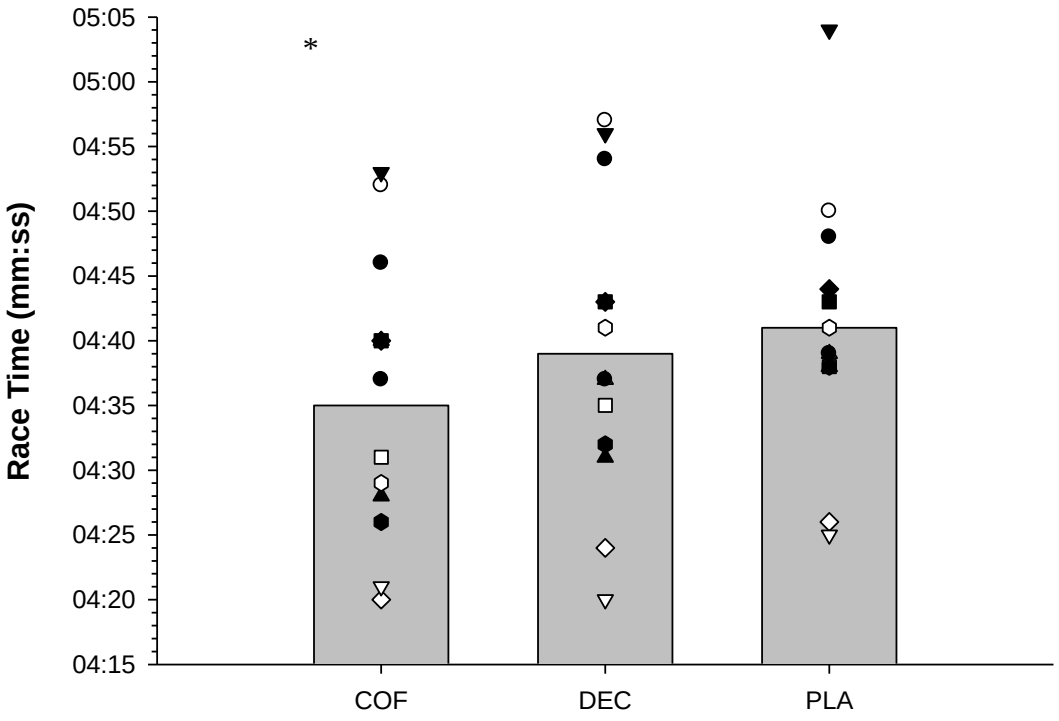

Figure 1: Mean and individual race completion times for each condition.

* COF time faster than PLA (*d*=0.32) and DEC (*d*=0.51).

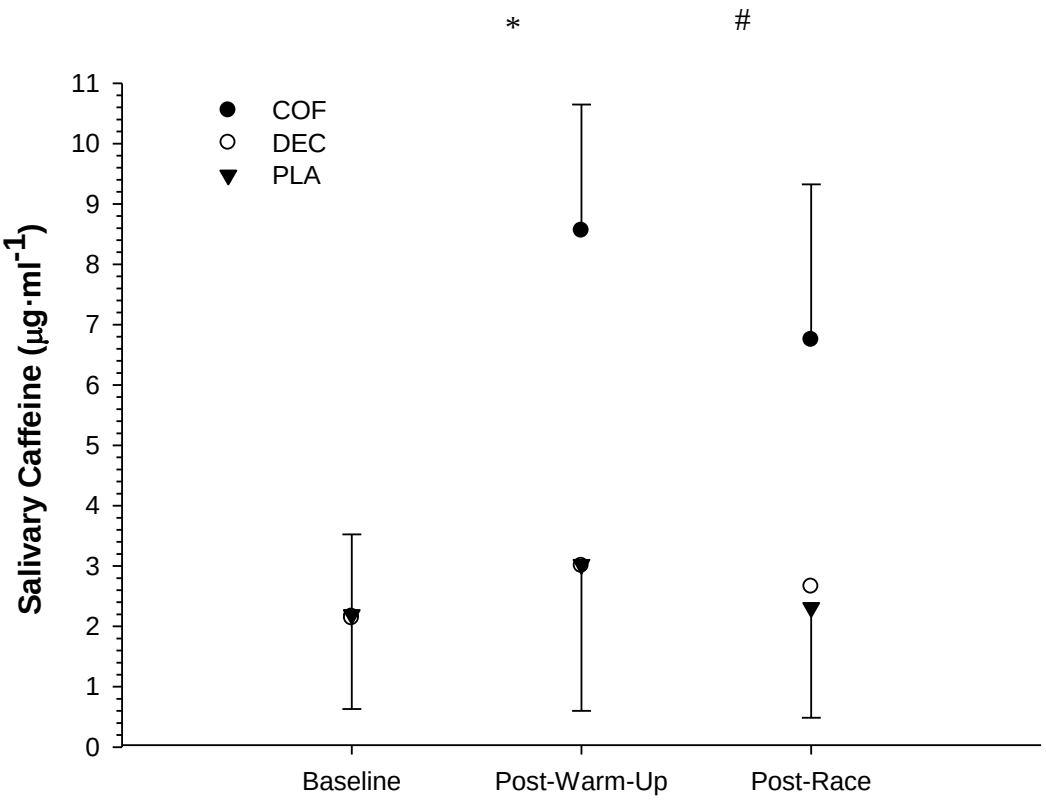

Figure 2: Mean (±SD) salivary caffeine concentration during each condition.

* COF higher than PLA (*d*=2.34) and DEC (*d*=2.47).

COF higher than PLA (*d*=1.99) and DEC (*d*=1.83).

Table 1: Blood glucose and lactate at baseline, post-warm-up and post-race, and heart rate post-warm-up and maximum value achieved during each race.

	COF	**DEC**	**PLA**
Blood Glucose (mmol·l^{-1})			
Baseline	4.64 ± 0.71	4.33 ± 0.83	4.72 ± 0.54
Post-Warm-Up	4.86 ± 0.52	4.78 ± 0.48	4.85 ± 0.79
Post-Race	7.47 ± 1.17	7.54 ± 1.15	7.14 ± 0.92
Blood Lactate (mmol·l^{-1})			
Baseline	1.94 ± 0.52	1.91 ± 0.64	1.66 ± 0.45
Post-Warm-Up	4.07 ± 0.99	3.99 ± 1.11	3.99 ± 1.08
Post-Race	14.35 ± 3.52	13.42 ± 3.26	12.40 ± 3.02
Heart Rate (beats·min^{-1})			
Post-Warm-Up	104 ± 11	104 ± 13	106 ± 5
Maximal	187 ± 10	182 ± 17	190 ± 7