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ORIGINAL RESEARCH

Caffeinated Chewing Gum Improves Bicycle Motocross Time-Trial Performance

Amin Daneshfar and Carl J. Petersen — University of Canterbury
Majid S. Koozehchian — Jacksonville State University
Daniel E. Gahreman — Charles Darwin University

This study aimed to identify the acute effects of caffeinated chewing gum (CAF) on bicycle motocross (BMX) time-trial (TT) performance. In a randomized, placebo-controlled, double-blind cross-over design, 14 male BMX riders (age = 20.0 ± 3.3 years; height = 1.78 ± 0.04 m; body mass = 72 ± 4 kg), consumed either (300 mg; 4.2 ± 0.2 mg/kg) caffeinated (300 mg caffeine, 6 g sugars) or a placebo (0 mg caffeine, 0 g sugars) gum, and undertook three BMX TTs. Repeated-measure analysis revealed that CAF has a large ergogenic effect on TT time, $F(1, 14) = 33.570$, $p = .001$, $\eta_p^2 = .71$; −1.5% ± 0.4 compared with the placebo. Peak power and maximal power to weight ratio also increased significantly compared with the placebo condition, $F(1, 14) = 54.666$, $p = .001$, $\eta_p^2 = .79$; +3.5% ± 0.6, and $F(1, 14) = 57.399$, $p = .001$, $\eta_p^2 = .80$; +3% ± 0.3, respectively. Rating of perceived exertion was significantly lower $F(1, 14) = 25.020$, $p = .001$, $\eta_p^2 = .64$ in CAF (6.6 ± 1.3) compared with the placebo (7.2 ± 1.7). Administering a moderate dose (300 mg) of CAF could improve TT time by enhancing power and reducing the perception of exertion. BMX coaches and riders may consider consuming CAF before a BMX race to improve performance and reduce rating of perceived exertion.

Keywords: caffeine, power output, sprint cycling

Research demonstrates anaerobic performance can improve following caffeine supplementation (Stojanović et al., 2019). Proposed mechanisms include increasing neurotransmitter release and motor unit firing rates (Kalmar, 2005), enhancing muscle contractility as a result of altered calcium kinetics and/or sensitivity (Allen & Westerblad, 1995), and decreasing perception of effort related to adenosine receptor antagonism (Davis et al., 2003). A recent meta-analysis demonstrated caffeine might induce meaningful improvements in power and upper body muscular strength (Grgic et al., 2018). Acute improvement in vertical jump height following a single caffeine ingestion has reported roughly equivalent to 4 weeks of plyometric training (Grgic et al., 2018; Markovic, 2007); however, other studies have reported no improvements in anaerobic performance following caffeine consumption (Anderson et al., 2018; Polito et al., 2016). Given various methodological consideration including dose; consumption method (capsules/pills, drink, and chewing gum); and testing procedures (Goods et al., 2017), the effects of caffeine on short-duration high-intensity performances are equivocal.

Chewing gum was first used by the military to rapidly restore alertness and performance and is an alternate form of caffeine administration (Wickham & Spriet, 2018). Effective absorption of caffeine via gum occurs primarily through buccal mucosa within 5–10 min of administration, compared with 20–30 min with capsule ingestion, although total caffeine absorption over time is not different (Syed et al., 2005; Wickham & Spriet, 2018). Previous studies have used caffeine doses ranging from 100 to 300 mg, administered 5–10 min preexercise. Venier et al. (2019) reported up to 4.5% improvement in vertical jump and power in resistance-trained men after consuming 300 mg caffeinated chewing gum (CAF). Paton et al. (2010) administered 240 mg of CAF to competitive cyclists who completed four sets of five 30 s maximal sprints with 30 s of active recovery between each set. Their results showed that the rate of dropped power output in sets 3 and 4 was significantly reduced after CAF versus placebo. Similarly, Ryan et al. (2013) observed enhanced cycling time trial (TT) after delivering 300 mg of caffeine via chewing gum 5 min before exercise. Interestingly, the same dosage 60 and 120 min preexercise failed to show any ergogenic effects. Therefore, CAF may prove beneficial where athletes are required to provide a quick increase in repeated anaerobic performance, such as in bicycle motocross (BMX) racing.

The BMX racing is a mass-start bicycle event where riders race entirely in a standing position. A race typically lasts 35–45 s and takes place on a 300 to 400 m track. Riders generally complete up to six races on a competition day with 15–30 min recovery between races (Cowell et al., 2012). Multiple physiological factors contribute to the success of a rider include explosive start, time to peak power, and anaerobic muscular power (Daneshfar et al., 2020b; Debraux & William, 2011). BMX is considered an intermittent sprint cycling sport, and researchers continue to investigate ways to improve performance (Daneshfar et al., 2020a; Rylands & Roberts, 2019).

If caffeine enhances short-duration, high-intensity performance by increasing anaerobic power and sprint speed, then

Daneshfar and Petersen are with the School of Health Sciences, University of Canterbury, Christchurch, New Zealand. Koozehchian is with the Department of Kinesiology, Jacksonville State University, Jacksonville, AL, USA. Gahreman is with the College of Health & Human Sciences, Charles Darwin University, Darwin, NT, Australia. Daneshfar (amindaneshfar11@gmail.com) is corresponding author.

BMX riders may benefit from the consumption of CAF. No previous study has investigated the benefits of caffeine administration on BMX performance. This study aimed to determine the acute effects of CAF on BMX TT performance. It was hypothesized that CAF would improve TT time and power production.

Methods

Experimental Design

In a randomized, placebo-controlled, double-blind, cross-over design, the effects of consuming CAF were assessed on TT time as the primary outcome. Power output, blood lactate (BL), heart rate (HR), and rating of perceived exertion (RPE) were also measured as possible mechanistic factors responsible for changes in TT time. After familiarization, data were collected on two additional occasions (CAF trial and placebo trial), interspersed with 1-week washout period. This study was conducted during the competitive phase of the BMX season, and all trials took place between 5 and 7 p.m. to control for diurnal variation (Figure 1). The study was carried out according to the Declaration of Helsinki and approved by the University of Canterbury's Ethics Committee.

Participants

Riders for the study were recruited via advertisement within BMX clubs, and 16 riders expressed interest. Only 14 male riders, who compete regionally and train four sessions per week, (age = 20 ± 3.3 years; height = 1.78 ± 0.04 m; body mass = 72 ±4 kg; BMX experience = 6.5 ± 2 years) met all the inclusion criteria and were included in the study. Riders needed to be 16–35 years, not a regular caffeine consumer, have any allergies to caffeine, and have no current injuries or movement restrictions. All riders were informed of the purpose and risks associated with participation before giving their written consent. Parental consent was obtained for riders under 18 years of age. To calculate study power, a conservative estimate in the statistical program G*Power (version 3.1; Heinrich Heine Universität Düsseldorf, Düsseldorf, Germany; Faul et al., 2007) for a within-factor repeated-measures analysis of variance was performed. This analysis suggested a minimum of 12 riders to obtain a moderate effect size (Cohen's $d = 0.50$) based on research examining effects of CAF on sprint cycling (Paton et al., 2010), an alpha error probability of .05, and statistical power of 0.90.

Dietary and Food Control

To identify any caffeinated products that riders regularly consumed, they were provided with a list of common caffeinated products including beverages, food, medicines, and supplements prior to participating in the study. A 3-day food diary analysis showed average daily caffeine consumption was ~52.8 ± 40.0 mg, which is classified as low caffeine users (Paton et al., 2010). Riders were instructed to follow an identical diet, abstain from caffeine, and any vigorous physical activity 24 hr prior to the familiarization trial, and replicate for subsequent trials.

Experimental Trial

Riders first performed a familiarization trial, followed by two additional trials separated by a 1-week washout period. In the familiarization trial, height and mass were measured; then, after 10 min standard warm-up, riders performed three BMX TTs interspersed with 15 min passive recovery. TTs were conducted on a 342 m outdoor BMX track with a 28° descent, 5 m high start ramp, four straights with several technical jumps on each straight section, and three corners. On completion of the familiarization trial, an independent academic, who was not an investigator in this study, randomized the order in which riders would complete two other trials, using a random sequence generator (GraphPad Software, San Diego, CA). On the two additional trials, riders' weight was measured, and they completed similar BMX TTs with either CAF or a placebo administered. The TTs were conducted in summer at temperatures of 19–25 °C, humidity of 40–45%, and wind speed of ~5–8 km/hr (Metservice, 2020).

CAF Administration

Caffeine was administered as an absolute dose of three pieces (300 mg; 4.2 ± 0.2 mg/kg body mass) of a commercially available gum (Military Energy Gum, Chicago, IL), with each stick providing 100 mg of caffeine and 2 g of sugars. The placebo was a similar looking and tasting (0 mg caffeine, 0 g sugars), commercially available gum (Spearmint Extra, NSW, Australia). In order to aid blind delivery, gums were divided into small pieces and placed in a container. The effectiveness of blinding was explored following the method by Saunders et al. (2017). In this study, we asked the riders before and after each TT which type of gum they had consumed. The three-scale response included: (a) caffeinated gum, (b) placebo gum, and (c) I do not know. In both experimental conditions

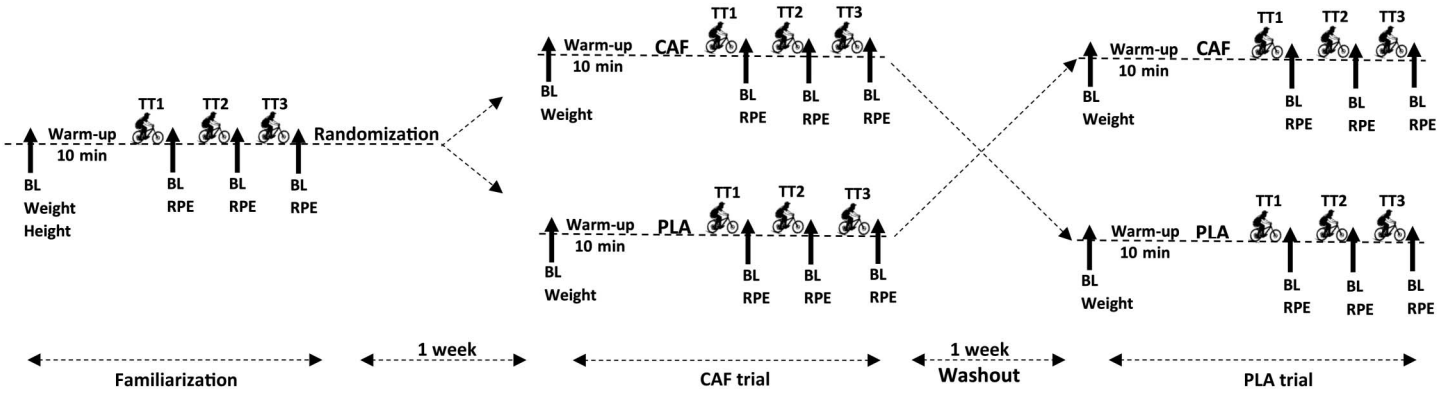

Figure 1 — Overview of the experimental design. TT_n = Time Trial 1, 2, and 3; BL = blood lactate; RPE = rating of perceived exertion; CAF = caffeinated chewing gum; PLA = placebo chewing gum.

(caffeine and placebo), the gums were chewed for 10 min before TTs (Venier et al., 2019), then expectorated into a container.

Performance Measures

The performance measures (dependent variables) included TT time, absolute peak power, maximal power to weight ratio (MPW), time to peak power, cadence at peak power, BL, HR, and post TT RPE. To record TT time, two pairs of photocells (NEOtm Swift Performance, QLD, Australia) were positioned at the start gate and on the finish line. BL concentration (mmol/L) was measured using a Lactate Pro2 analyzer (ARKRAY, Inc., Koyoto, Japan). A finger prick was taken before warm-up and 3 min post each TT (Tanner et al., 2010). To record RPE, riders rated "how hard was that TT" on a CR-10 Borg scale immediately following each TT. The RPE represented a recall of their feeling during the TT that they had just completed (Borg, 1982; Foster et al., 2001). This method was introduced to riders in the familiarization trial and was replicated for the additional trials. A Garmin HR chest strap (HRM-Dual™, Olathe, KS) was used to monitor HR during TTs.

The power output was measured using a Schoberer Rad Messtechnik (SRM) power meter, which incorporates an eight strain gauge and 175-mm crank arm. This was attached to the BMX testing bike (gear ratio of 43/16) used by all riders. SRM has shown to be a valid tool for measuring power output during field conditions (Gardner et al., 2004). All the relative power output data were downloaded using Power Control8 software (PC8DeviceAgent, Jülich, Germany; http://www.srm.de/products/software/). Relative maximal power to riders' weight was also calculated and presented as MPW (in watts per kilogram).

Statistical Analysis

Statistical analyses were performed using SPSS (version 25.0; IBM Corp., Armonk, NY). Data are presented as mean ± *SD* and an alpha level of $p \leq .05$ was considered statistically significant. A series of 2 × 3 repeated-measures analysis of variance for conditions (CAF and placebo) and time (TT1, TT2, and TT3) were used to analyze data. With repeated measures, when analysis of variance interactions were significant, adjusted Bonferroni post hoc tests were also performed. Effect sizes were reported as partial eta-squared (η_p^2), with values of <.10, .10–.24, .25–.39, and ≥.40 considered trivial, small, moderate, and large effect sizes, respectively (Cohen, 1992). A coefficient of variation (CV) was calculated using data collected during familiarization TTs and placebo TTs to study the day-to-day variation of the performance variables. To explore the effectiveness of blinding, the Bang's Blinding Index was utilized. The blinding index was scaled to an interval of −1 to 1, with 1 indicating complete lack of blinding, 0 being consistent with perfect blinding, and −1 indicating opposite guessing. Blinding data were reported as a percentage of individuals who identified the correct condition beyond chance.

Results

Body Mass

There was no significant difference in riders' body mass $F(2, 28) = 3.452$, $p = .451$, $\eta_p^2 = .19$ in CAF trial (72.4 ± 3.0 kg) compared with placebo trial (72.2 ± 6.2 kg).

Time-Trial Time

There was a significant condition effect on TT time $F(1, 14) = 33.570$, $p = .001$, $\eta_p^2 = .71$; −1.5% ± 0.4 following CAF consumption compared with placebo. There was no significant interaction of Condition × Time, $F(1.65, 23.16) = 0.105$, $p = .866$, $\eta_p^2 = .01$, on TT time (Figure 2).

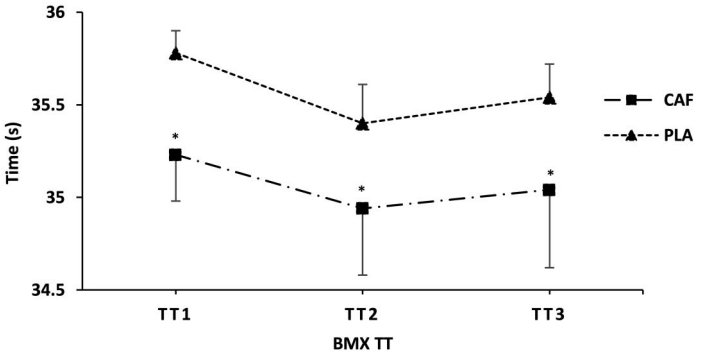

Figure 2 — Mean ± *SD* of the BMX performance time over three TTs. CAF = caffeinated chewing gum; PLA = placebo chewing gum; TT = time trial. *Significant main effect of condition $p < .001$, indicating that riders completed each TT faster following CAF compared with PLA.

Power Output

Peak power. A significant condition effect was observed for peak power, $F(1, 14) = 54.666$, $p = .001$, $\eta_p^2 = .79$, and riders in the CAF condition generated more power compared with placebo +3.5% ± 0.6. There was no significant interaction of Condition × Time, $F(2, 28) = 3.420$, $p = .082$, $\eta_p^2 = .14$, on riders' peak power.

Maximal power to weight ratio. Consuming CAF influenced riders' MPW, $F(1, 14) = 57.399$, $p = .001$, $\eta_p^2 = .80$, with values in the CAF condition being 3% ± 0.3 greater than placebo (Figure 3). There was no significant interaction of Condition × Time, $F(2, 28) = 3.512$, $p = .088$, $\eta_p^2 = .13$, on riders' MPW.

Time to peak power. There was no significant interaction of Condition × Time, $F(2, 28) = 0.621$, $p = .411$, $\eta_p^2 = .10$, nor condition effect, $F(1, 14) = 1.890$, $p = .124$, $\eta_p^2 = .14$, on riders' time to peak power (Figure 4).

Cadence. The authors' data demonstrated no significant main effect of condition, $F(1, 14) = 2.542$, $p = .133$, $\eta_p^2 = .15$, on cadence at peak power. There was no significant interaction of Condition × Time, $F(2, 28) = 3.310$, $p = .098$, $\eta_p^2 = .19$, on riders' cadence.

Heart Rate

There was no significant effect of CAF on riders' HR during the TT, $F(1, 14) = 1.472$, $p = .245$, $\eta_p^2 = .09$, as well as no significant interaction of Condition × Time, $F(2, 28) = 2.415$, $p = .108$, $\eta_p^2 = .12$ (Table 1).

Rating of Perceived Exertion

The RPE values significantly reduced, $F(1, 14) = 25.020$, $p = .001$, $\eta_p^2 = .64$, in CAF condition (6.6 ± 1.3) compared with the placebo (7.2 ± 1.7). There was no significant interaction of Condition × Time, $F(2, 28) = 1.437$, $p = .322$, $\eta_p^2 = .10$, over TTs (Table 1).

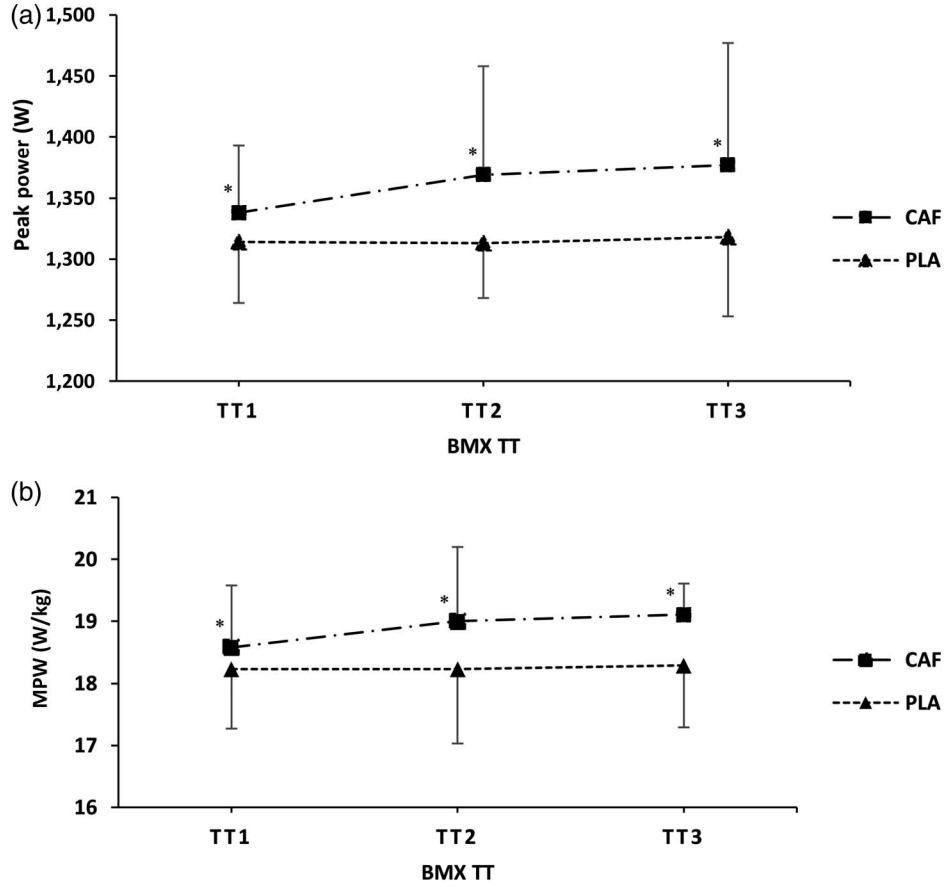

Figure 3 — Mean ± *SD* of (a) peak power and (b) MPW over three TTs. CAF = caffeinated chewing gum; PLA = placebo; TT = time trial; MPW = maximal power to weight ratio. *Significant main effect of condition $p < .001$, CAF more than PLA.

Blood Lactate

There was a significant effect of time on riders' BL values, $F(2, 28) = 457.191$, $p = .001$, $\eta_p^2 = .97$; however, no significant interaction of condition was observed, $F(1, 14) = 2.404$, $p = .143$, $\eta_p^2 = .15$ (Table 1).

Coefficient of Variation

The day-to-day variation of TT variables was shown in Table 2.

Blinding Evaluation

Before starting the TTs, 44% of riders in the placebo and 56% in the CAF condition correctly guessed the content of the chewing gum. While after TTs, 27% and 59% of riders in the placebo and caffeine conditions correctly identified the gum type, respectively, whereas 14% of riders declared they did not know what they had consumed.

Discussion

Caffeine's effects on short-term high-intensity activities are inconclusive (Cordingley et al., 2016). This study set out with the aim of identifying the effects of CAF administration on BMX riders' TT performance. The authors' findings indicated that 300 mg; 4.2 ± 0.2 mg/kg caffeine delivered via chewing gum improved TT time, absolute power, and MPW with riders demonstrating lower RPE. To date, a few studies have identified the effects of CAF on sporting performances (Dittrich et al., 2019; Paton et al., 2015; Ranchordas et al., 2019; Russell et al., 2020); however, to the best of the authors' knowledge, this is the first to investigate caffeine intake on BMX TT performance.

Compared with placebo, CAF significantly improved TT time by 1.5%. A BMX race is generally very close, and the variation of time is marginal. Based on analysis of the 2012 World Cup Supercross Series by Rylands and Roberts (2014), mean deviation in final positioning between first and second place was 0.13–0.85 s, and from first to third place was 0.38–1.52 s. In the current study, administering CAF resulted in a 0.50 s improvement in time, which could influence the final positioning in a BMX race. However, as riders' day-to-day variation for TT time were 1.2%, despite demonstrating a large effect size, the improved TT time following caffeine condition was close to the day-to-day variation. The authors calculated the day-to-day variation using data collected under different conditions (familiarization and placebo), which might affect the reliability of CV. Future research might need to consider having separate baseline measurements to analyze the precise CV and provide further details on the role of CAF on BMX TT time.

In the current study, a moderate dose of CAF improved riders' absolute power by +3.5% with a large effect size. This magnitude was in line with Paton et al. (2015), who reported ~4% enhancement in sprint power output during a laboratory simulated, 10-km cycling trial, following approximately 3–4 mg/kg caffeine administration.

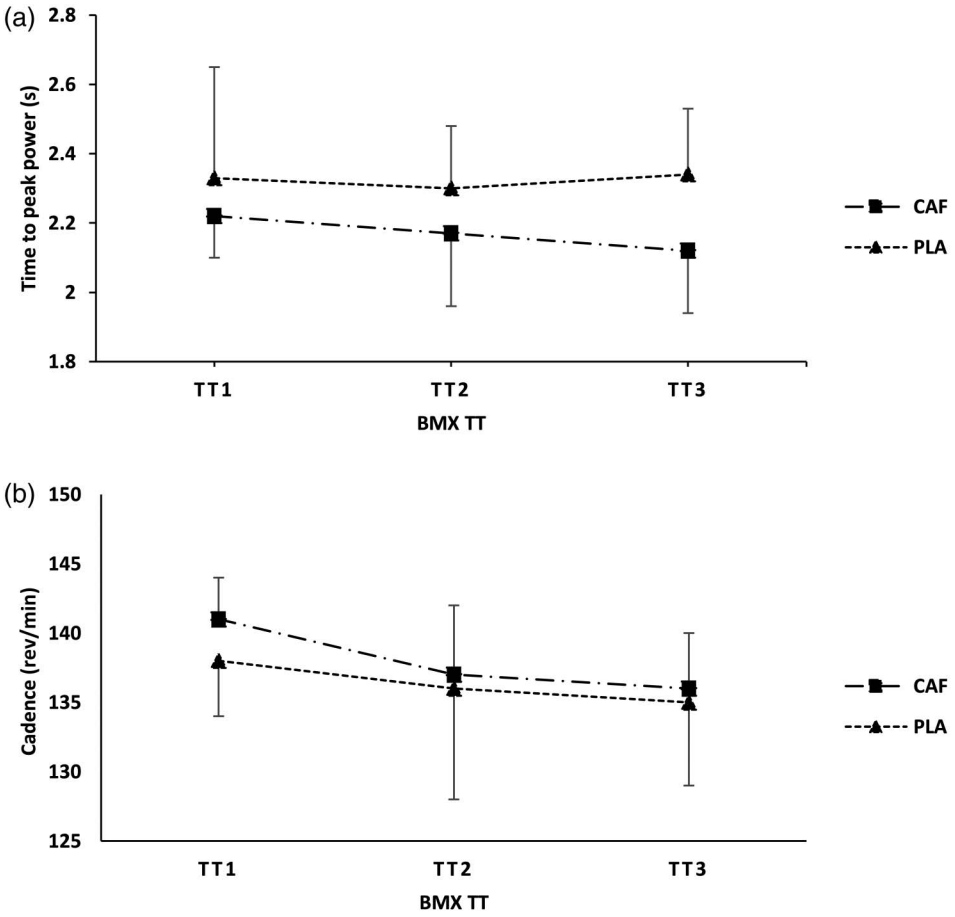

Figure 4 — Mean ± *SD* of (a) time to peak power production and (b) cadence at maximum power over three TTs. CAF = caffeinated chewing gum; PLA = placebo; TT = time trial.

Table 1 Heart Rate, RPE, and Blood Lactate Over Three BMX TTs

		BMX TTs		
TT variables	**Condition**	**TT1**	**TT2**	**TT3**
Heart rate (beats/min)	CAF	176 ± 5	182 ± 4	186 ± 2
	PLA	175 ± 3	183 ± 3	183 ± 3
RPE (1–10)	CAF	6.5 ± 1.3*	6.5 ± 1.0*	6.7 ± 1.8*
	PLA	6.9 ± 2.0	7.1 ± 1.2	7.3 ± 1.2
Blood lactate (mmol/L)	CAF	10.4 ± 2.3**	14.1 ± 2.6	16.3 ± 2.1
	PLA	10.3 ± 1.4**	13.9 ± 1.2	16.2 ± 1.8

Note. Values are presented as mean (*SD*). RPE = rating of perceived exertion; TT = time trial; CAF = caffeinated chewing gum; PLA = placebo chewing gum. *Significant main effect of condition $p < .001$, CAF lower than PLA. **Significant effect of time $p < .001$, TT1 compared with TT2 and TT3.

Table 2 Test–Retest Reliability of the BMX TT Measurement

TT variables	**Average CV (%)**
Time (s)	1.2
Power (W)	1.5
MPW (W/kg)	1.5
Cadence (rev/min)	1.6
Blood lactate (mmol/L)	1.8
Heart rate (beats/min)	2.1
RPE (1–10)	1.7

Note. RPE = rating of perceived exertion; TT = time trial; CAF = caffeinated chewing gum; PLA = placebo chewing gum; MPW = maximal power to weight ratio.

Paton et al. (2010) also showed ~6% improvement in repeated 30 s sprint performance in male competitive cyclists who consumed 240 mg caffeine by chewing gum. In another experiment, Ryan et al. (2013) showed that a dose of 3 mg/kg caffeine delivered 5 min precycling by gum in trained cyclists, improved 7-kJ/kg TT cycling performance. Consuming CAF in the current study helped BMX riders to produce ~40 W greater peak power in TT3 compared with TT1. Increasing power production can significantly influence BMX riders' race performance (Daneshfar et al., 2020a). Specifically, at the start of the race, where gaining the front position would significantly affect the overall results (Rylands & Roberts, 2014). As chewing gum appears to be an effective and quicker method of caffeine ingestion for athletes compared with pills/capsules, administration by this method may be particularly

advantageous for BMX riders prior to racing or during recovery time.

Anaerobic power output relative to body weight (power to weight ratio) is a popular measure of ability among competitive cyclists (Lunn et al., 2009). Similar to peak power, the authors found CAF improved riders' MPW up to 3% compared with placebo. These findings are contrary to a recent study by Anderson et al. (2018), who reported no positive effects of consuming (250 mg, 3–6 mg/kg) caffeine on anaerobic power, even though five out of nine cyclists exhibited an increase in Wingate peak power during the caffeine trial. The results of the current study are in line with Woolf et al. (2008), who demonstrated ~5% improvement in MPW of Wingate test following 5 mg/kg caffeine consumption in 18 highly trained men. Therefore, the authors' study, in addition to Woolf et al.'s (2008) study, supports the ergogenic effects of CAF on cycling anaerobic power.

The BL concentration showed a significant increase from 10 mmol/L in TT1 to 16 mmol/L in the TT3, which supports the highly anaerobic nature of BMX racing (Louis et al., 2013). While CAF has no ergogenic effects on BL, these findings seem to be consistent with other researchers who reported no significant effect of caffeine on BL (Anderson et al., 2018; Glaister et al., 2012; Greer et al., 1998; Hahn et al., 2018). In contrast, a number of studies have found a significant increase in BL following caffeine ingestion in both trained and untrained subjects (Anselme et al., 1992; Carr et al., 2008; Cordingley et al., 2016; Woolf et al., 2008). Further research is required to establish the effects of caffeine on BL during BMX TTs. While the authors' data showed a main effect of time on HR over TTs, there was no significant effect of CAF on riders' HR. It was expected an increased HR response in CAF condition as caffeine directly reduces the parasympathetic nervous system activity (Sondermeijer et al., 2002), but in higher exercise intensities, this difference tends to disappear as the sympathetic nervous system dominantly controls HR (Karapetian et al., 2012). The findings of the current study support those who reported no ergogenic effects of CAF on HR (Ryan et al., 2013; Woolf et al., 2008).

Another mechanism by which caffeine improves performance is a reduction in perception of effort (Davis et al., 2003). It is believed caffeine works as an adenosine antagonist and hence delays fatigue and improves alertness and mood (Astorino & Roberson, 2010; Hahn et al., 2018). Stuart et al. (2005) reported the ergogenic effect became more apparent in the latter half of repeated tests. Caffeine also lowers peripheral fatigue and RPE (Sökmen et al., 2008) and provides a greater capacity to tolerate the discomfort associated with tiredness during exercise (Doherty & Smith, 2005). This is supported by data in the present study, whereby CAF decreased riders' RPE levels with a large effect size. The authors' findings are in agreement with researchers who reported the ergogenic benefits of caffeine on RPE (Doherty & Smith, 2005; Doherty et al., 2004; Glaister & Gissane, 2018; Greenland et al., 2019). The authors' data provided an insight for those competitive BMX riders who have low habitual caffeine consumption and who are interested in consuming caffeine prior to training and racing to improve their performance. Future research should be undertaken to validate these findings, using elite or riders who are habitual caffeine consumers.

In the current study, all subjects received the same dosage of 300 mg of caffeine, and this corresponded to a range of 3.8–4.4 mg/kg. The authors did not measure blood caffeine concentrations; therefore, the amount of caffeine absorption in the blood with different doses of caffeine remains unclear. Also, absorbed sugar from CAF in oral cavity could potentially affect performance by activating brain regions related to the sense of reward and pleasure, similar to the mechanism involved in improved performance following carbohydrate mouth rinse (de Ataide e Silva et al., 2013; Ferreira et al., 2018). Furthermore, CAF and placebo gums contained a variety of other different ingredients (e.g., artificial colors and flavors) that may have affected the study outcomes. Future research should use chewing gum with identical contents to avoid the influence of additional substances. In addition, despite the effective blinding method, given the greater importance of the pre-TT responses compared with the post-TT responses, the percentage of riders who correctly identified the placebo beyond chance pre-TT (44%) was greater compared with post-TT (14%). Also, the authors did not measure exercise-induced pain after TTs, and the effects of CAF on riders' perception of pain remained unclear. Despite providing instruction for riders' diet, the authors did not control their diet and hydration during the trials which may have affected the study outcomes and is therefore a limitation of the present study. It is worth noticing that based on Foster et al. (2001) study to collect retrospective recall RPE; subjects would rate the Borg CR-10 scale 30 min after experiment. The authors asked riders to rate their feeling immediately following TTs, which could affect the validity of the RPE results. Finally, to measure performance, riders performed TTs using the same BMX bike with a fixed gear ratio. As riders typically use their personal bike and compete with others in a race, this might affect the power production and their overall performance.

This is the first study to explore the effects of CAF on BMX performance. The authors' novel findings demonstrated that CAF containing 300 mg caffeine and 6 g of sugar versus noncaffeinated sugar-free placebo gum improved TT time, boosted riders' power up to 3%, and decreased their post-TT RPE. It may be appropriate to consume the current caffeine amount 10 min prior to a BMX race to improve performance by enhancing power production and reducing perception of exertion, particularly where successive races are required.

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