Habitual Caffeine Consumption Does Not Affect the Ergogenicity of Coffee Ingestion During a 5 km Cycling Time Trial

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Habitual Caffeine Consumption Does Not Affect the Ergogenicity of Coffee Ingestion During a 5 km Cycling Time Trial

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There is growing evidence that caffeine and coffee ingestion prior to exercise provide similar ergogenic benefits. However, there has been a long-standing paradigm that habitual caffeine intake may influence the ergogenicity of caffeine supplementation. The aim of the present study was to investigate the effect of habitual caffeine intake on 5-km cycling time-trial performance following the ingestion of caffeinated coffee. Following institutional ethical approval, in a double-blind, randomized, crossover, placebo-controlled design, 46 recreationally active participants (27 men and 19 women) completed a 5-km cycling time trial on a cycle ergometer 60 m in following the ingestion of 0.09 g/kg coffee providing 3 mg/kg of caffeine, or a placebo. Habitual caffeine consumption was assessed using a caffeine consumption questionnaire with low habitual caffeine consumption defined as <3 and ≥6 $mg \cdot kg^{-1} \cdot day^{-1}$ defined as high. An analysis of covariance using habitual caffeine intake as a covariant was performed to establish if habitual caffeine consumption had an impact on the ergogenic effect of coffee ingestion. Sixteen participants were classified as high-caffeine users and 30 as low. Ingesting caffeinated coffee improved 5-km cycling time-trial performance by 8 ± 12 s; 95% confidence interval (CI) [5, 13]; $p < .001$; $d = 0.30$, with low, 9±14 s; 95% CI [3, 14]; $p = .002$; $d = 0.18$, and high, 8 ± 10 s; 95% CI [−1, 17]; $p = .008$; $d = 0.06$, users improving by a similar magnitude, 95% CI [−12, 12]; $p = .946$; $d = 0.08$. In conclusion, habitual caffeine consumption did not affect the ergogenicity of coffee ingestion prior to a 5-km cycling time trial.

Keywords: exercise performance, ergogenic, individual responses, supplements

Caffeine (1,3,7-trimethylxanthine) is consumed daily by approximately 80% of the world's population (Ogawa & Ueki, 2007). Furthermore, due to the ergogenic potential, urine caffeine data suggests that caffeine is widely ingested prior to competition (Aguilar-Navarro et al., 2019), and athletes regularly consume caffeine in the form of coffee (Desbrow & Leveritt, 2006). However, the majority of the research to date typically focuses on the ingestion of caffeine, rather than coffee (Higgins, Straight, & Lewis, 2016). Finally, the responses to caffeine are often variable (Spriet, 2014) and possibly affected by a number of factors such as training status, genotype, and habitual caffeine use (Pickering & Grgic, 2019a).

Caffeine's primary ergogenic mechanisms are considered to arise from the antagonism of adenosine receptors leading to an increase in neurotransmitter release, motor unit firing rates, pain suppression, reduced fatigue, and improved neuromuscular performance (Davis & Green, 2009; Graham, 2001). However, there has been a long-standing paradigm that habitual caffeine intake may influence the ergogenicity of caffeine supplementation (Sökmen et al., 2008), and thus coffee ingestion. Habitual caffeine ingestion is associated with an upregulation in the number of adenosine receptors (Fredholm, 1982), potentially reducing the efficacy of the blocking action of caffeine. Furthermore, Svenningsson et al. (1999) reported caffeine-tolerant rats had downregulated levels of adenosine A_{2A} receptors and the corresponding mRNA in rostral parts of striatum, potentially affecting caffeine metabolism, and thus altering the ergogenic effect of coffee. Therefore, caffeine habituation is commonly identified as a factor influencing the ergogenic effect of caffeine (Sökmen et al., 2008), although research provides conflicting findings (Pickering & Kiely, 2019), and with few studies reporting blood or salivary caffeine concentrations, or assessing men and women.

To date, few studies report no effect of habitual caffeine intake on exercise performance following caffeine ingestion (≤25 vs. >300 mg/day [Dodd, Brooks, Powers, & Tulley, 1991]; 58–351 mg/day [Gonçalves et al., 2017]; 27 ± 36 vs. 358 ± 210 mg/day [Sabol, Grgic, & Mikulic, 2019]; 14 ± 17 vs. 777 ± 295 mg/day [Tarnopolsky & Cupido, 2000]). Similarly, Irwin et al. (2011) concluded that acute caffeine supplementation provides an ergogenic benefit in regular caffeine users regardless of any withdrawal period. In contrast, Bell and McLellan (2002) reported that nonusers (<50 mg/day) exhibited a greater, and longer lasting, ergogenic effect following the ingestion of 5 mg/kg of caffeine than regular caffeine users (≥300 mg/day). Furthermore, Lara et al. (2019) reported that the ergogenic effects of caffeine ($3\ mg \cdot kg^{-1} \cdot day^{-1}$) after 20 days of consecutive ingestion to be lower than the first day of ingestion. In addition, Beaumont et al. (2017) demonstrated that the ergogenic effect of caffeine to be reduced after 28 days of caffeine ingestion (Days 1–7: 1.5 mg/kg; Days 8–28: 3 mg/kg), suggesting the development of caffeine tolerance. These findings provide equivocal evidence for the existence of a reduction in caffeine's ergogenicity with continuous ingestion. However, the variation in these findings could be due to different thresholds to categorize individuals and the different performance protocols. Consequently, the relationship between habitual caffeine use and performance is poorly understood (Filip, Wilk, Krzysztofik, & Del Cosco, 2020), and no previous study has investigated the effect of caffeine habituation on the ergogenic effect of coffee ingestion. Therefore, the aim of the present study was to investigate the effect of habitual caffeine

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intake on 5-km cycling time-trial performance following the ingestion of caffeinated coffee.

Methods

In a double-blind, Latin-square randomized, crossover, placebo-controlled design, in which participants and treatments were the blocking factors, 46 recreationally active participants (27 men: [mean ± SD] age = 29 ± 6 years, height = 180 ± 6 cm, body mass = 78 ± 12 kg; $\dot{V}O_2max = 55 \pm 11$ ml · kg^{-1} · min^{-1} and 19 women: age = 28 ± 6 years, height = 166 ± 7 cm, body mass = 72 ± 11 kg; $\dot{V}O_2max = 41 \pm 9$ ml · kg^{-1} · min^{-1}) completed a 5-km cycling time trial on a cycle ergometer 60 min following the ingestion of 0.09 g/kg coffee providing 3 mg/kg of caffeine, or a placebo (PLA). A caffeine dose of 3 mg/kg was ingested as this dose has been demonstrated to offer ergogenic effects (Pickering & Grgic, 2019b). Participants were recreational cyclists and had consistently trained on average 2 ± 1 times per week for at least 1 year. Originally, 54 participants were recruited, but seven were excluded due to not fulfilling the caffeine consumption inclusion criteria. All trials were conducted at the same time of day (09:00–12:00) and were consistent for each participant in order to minimize circadian variation (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005). Women were regularly taking a monophasic oral contraceptive pill for at least 3 months prior to the first trial. To control for possible differences during the oral contraceptive cycle, testing was performed during Days 5–8 and 19–22 of the cycle, as no changes in energy metabolism have been reported between these time points (Lynch, De Vito, & Nimmo, 2001). All procedures were undertaken in accordance with the Declaration of Helsinki and approved by Coventry University 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.

Habitual caffeine consumption was assessed using a caffeine consumption questionnaire and assessed caffeine content (Bühler et al., 2014), and based on the proposals by Filip et al. (2020), low users included naïve to mild habitual caffeine consumption defined as <3 mg · kg^{-1} · day^{-1} and ≥6 mg · kg^{-1} · day^{-1} defined as high users. The doses were chosen in order to make sure that there was a clear distension between the two groups. In addition, each participant completed a 24-hr dietary record prior to the first trial; this was then photocopied and handed back to the participants so that the same diet could be repeated for subsequent trials. Participants were also instructed to abstain from caffeine, alcohol, and strenuous activity for at least 12 hr, which along with diet, was confirmed verbally prior to each trial. Nescafe original coffee (from the same batch; Nescafé Original, Nestlé, United Kingdom) was used and dissolved in 300 ml of water (58 ± 3 °C) and served in lidded cups. Participants were given a maximum of 10 min to consume the beverage, and the 60-min rest period started once the cup was emptied (Figure 1). The PLA trial was water of the same volume and temperature with coffee flavor (Espresso Coffee Flavoring Compound; MSK Ingredients, Chesterfield, United Kingdom) and color (Brown Food Coloring, Lakeland, United Kingdom). The coffee and PLA samples were analyzed externally for their caffeine content (Laserchrom HPLC Laboratories Ltd, Rochester, United Kingdom) using a high-performance liquid chromatography method. The coffee sample provided 35.1 mg of caffeine per 1 g of coffee, and the PLA contained no traces of caffeine. Based on this analysis, it was calculated that each participant consumed 0.09 g/kg of coffee to achieve the 3 mg/kg of caffeine required.

Before the experimental trials, participants completed a graded exercise test to exhaustion on a cycle ergometer (Wattbike Pro; Wattbike Ltd, Nottingham, United Kingdom) and a familiarization of the 5-km time trial, performed on the same day. Prior to all trials, participants performed a 2-min pretest warm-up. The protocol consisted of 2 min of cycling at a self-selected power output, 2 min of cycling including three 6-s maximal sprints, and finished with 3 min of cycling at a self-selected power output (Bellinger & Minahan, 2014). Following completion of the warm-up, there was a 60-s period where the participants sat passively before a standardized countdown to initiate the time trial. The participants then performed a 5-km cycling time trial where they were instructed to complete the distance as fast as possible. During each time trial, participants had access to the distance remaining, and with the exception of verbal encouragement, no other information was provided. The gearing was self-selected by the participants on the Wattbike during the familiarization trial and then replicated during each time trial. Trials were separated by a minimum period of 48 hr to ensure recovery and caffeine washout. In order to establish any learning effect, following completion of the experimental trials, 5-km time to completion was compared between the familiarization trial and PLA trial of the main experimental using a paired samples *t* test. No significant difference between

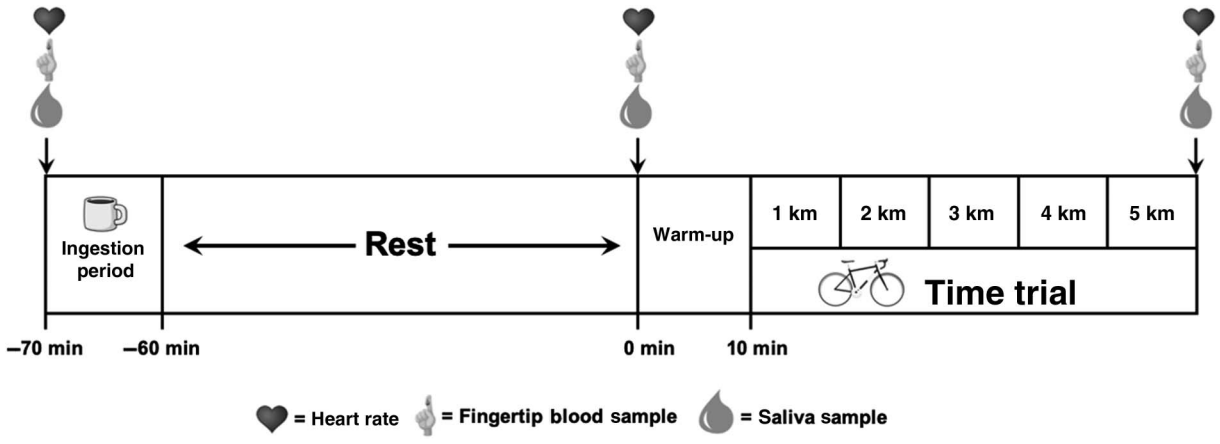

Figure 1 — Schematic of the experimental protocol.

trials was observed, familiarization: 487 ± 50 s, PLA: 490 ± 49 s; $t(45) = 0.265$; $p = .792$; 95% confidence interval (CI) [−19, 25]; Hedge's $g = -0.06$, 95% CI [−0.47, 0.35].

Saliva samples (minimum 0.5 ml by the passive drool technique) were obtained immediately before fluid ingestion, 1-hr postingestion prior to commencing the time trial, and 120 s following the time trial. Participants expectorated into a 20-ml plastic cup, and the sample was then transferred to a capped glass vial that was immediately placed in a −80 °C freezer for subsequent analysis of caffeine concentration using a standard enzyme-linked immunosorbent assay kit (Caffeine ELISA Kit; Creative Diagnostics, Shirley, NY). Saliva samples have been shown to be valid surrogates of plasma measures of caffeine in multiple studies (Scott, Chakraborty, & Marks, 1984; Suzuki, Uematsu, Mizuno, Fujii, & Nakashima, 1989). For example, data from Scott et al. (1984) revealed a strong correlation ($r = .94$) between determinations of serum and saliva caffeine concentrations. Heart rate was measured throughout each time trial (Polar RS400; Polar Electro Oy, Kempele, Finland), and at the same time points, a capillary blood sample was drawn from the index finger for determination of blood lactate concentration (Biosen C-line; EKF-diagnostic GmbH, Barleben, Germany).

A statistical power analysis was performed for sample size estimation based on the race time from a previous coffee-ingestion study (Clarke, Richardson, Thie, & Taylor, 2018). As this study did not present correlation values between conditions, a conservative effect size value of 0.5 was used for the calculation. Consequently, an a priori power calculation suggested a sample size of 11 participants was deemed necessary to detect a difference between conditions given an estimated effect size of 0.44, a $1 - \beta$ error probability of .95 and an alpha value of <.05. A mixed-design 2 (between-subject factor; high-/low-caffeine users) × 2 (within-subject factor; condition: caffeinated coffee, PLA) an analysis of variance was applied. Where any differences were identified, post hoc pairwise comparisons with Bonferroni correction were conducted. In addition, an analysis of covariance was performed using habitual caffeine intake and baseline performance as covariates in order to further establish the ergogenic effect of coffee ingestion and the effect of habitual caffeine intake and initial performance. Linear regressions were performed between habitual caffeine intake, postdrink salivary caffeine concentration, and the absolute change in performance. All data were analyzed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY). Finally, 95% CIs and effect sizes, (partial eta squared [η_p^2]) defined as trivial (<.10), small (.10–.24), moderate (.25–.39), or large (≥.40), and Hedge's g defined as trivial (≤0.19), small (0.20–0.49), moderate (0.50–0.79), and large (≥0.80) according to the cutoffs suggested by Cohen (1992), were also calculated.

Results

A total of 16 participants (11 men and five women) were classified as high-caffeine users, 6 ± 2 mg · kg^{-1} · day^{-1}; 95% CI [5, 7]; 415 ± 133 mg/day; 95% CI [344, 486], and 30 as low, 16 men and 14 women; 2 ± 1 mg · kg^{-1} · day^{-1}; 95% CI [1, 2]; 153 ± 99 mg/day; 95% CI [116, 190]. Coffee ingestion increased salivary caffeine levels, $F(3, 132) = 278.553$; $p < .001$; 95% CI [6.1, 7.9]; $\eta_p^2 = .86$ (Figure 2a), but with no difference between low, 7.3 ± 2.3 µg/ml; 95% CI [6.5, 8.0]; Hedge's $g = 4.13$, 95% CI [3.25, 5.01], and high, 6.7 ± 1.5 µg/ml; 95% CI [5.7, 7.8]; Hedge's $g = 4.88$, 95% CI [3.35, 6.14], users, $F(1, 44) = 1.017$; $p = .319$; 95% CI [−0.4, 1.2]; $\eta_p^2 = .02$ (Figure 2b).

Overall, performance in the coffee trial (482 ± 46 s) was faster than the PLA, 490 ± 49 s; $t(45) = -4.523$; $p < .001$; 95% CI [−12, −5]; Hedge's $g = 0.17$, 95% CI [−0.24, 0.56], trial. Low-caffeine users (Coffee: 477 ± 49 s; PLA 486 ± 52 s) and high users performed similarly, Coffee: 490 ± 40 s; PLA 497 ± 0. s; $F(1, 44) = 0.679$; $p = .415$; 95% CI [−41, −17]; $\eta_p^2 = .02$). Ingesting coffee improved 5-km cycling time-trial performance by 8 ± 12 s, 95% CI [5, 13]; $F(1, 44) = 18.032$; $p < .001$; $\eta_p^2 = .30$ (Figure 3a), with low, 9 ± 14 s; 95% CI [3, 14]; $p = .002$; Hedge's $g = 0.18$, 95% CI [−0.33, 0.68], and high users, 8 ± 10 s; 95% CI [−1, 17]; $p = .008$; Hedge's $g = 0.17$, 95% CI [−0.53, 0.86], improving by a similar magnitude, 95% CI [−12, 12]; $p = .946$; Hedge's $g = 0.07$, 95% CI [−0.54, 0.68] (Figure 3b). Analysis of covariance revealed no influence of habitual caffeine intake on exercise performance, $F(1, 43) = 0.013$; $p = .910$; $\eta_p^2 = .00$. Men (COF: 451 ± 31 s; PLA 465 ± 38 s) completed the time trial moderately quicker than women, COF: 516 ± 42 s; PLA 526 ± 40 s; $F(1, 41) = 0.984$; $p = .761$; 95% CI [−85, −38]; $\eta_p^2 = .40$.

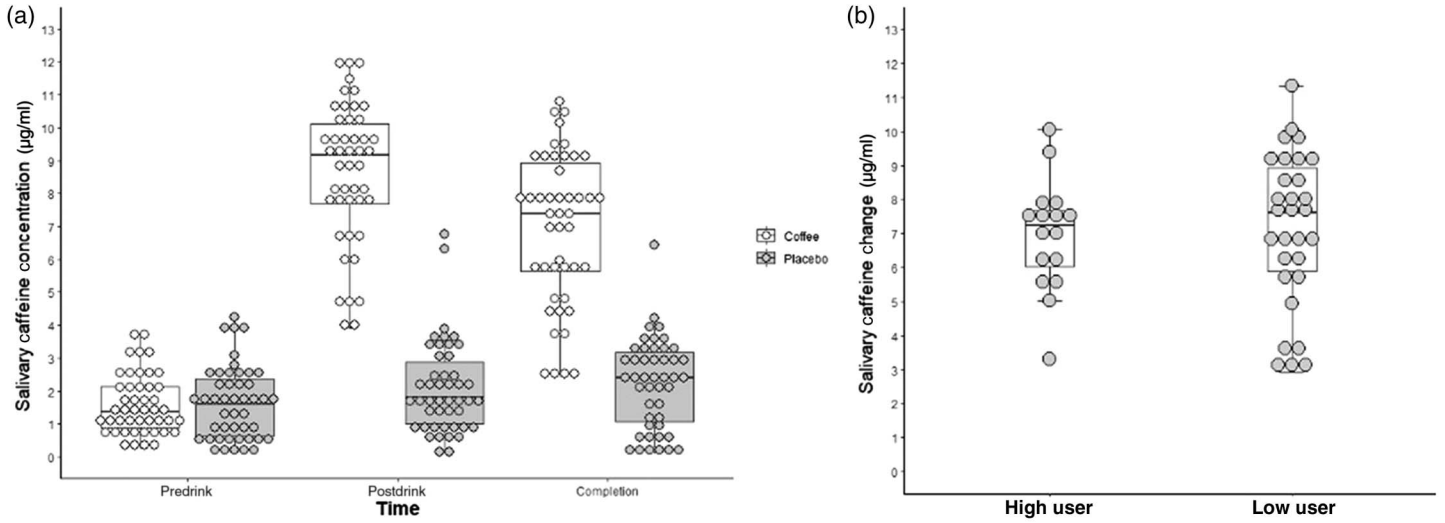

Figure 2 — (a) Distribution and individual salivary caffeine responses during the 5-km cycling time trial. (b) Individual changes in salivary caffeine concentration following coffee ingestion in habitually low- and high-caffeine users.

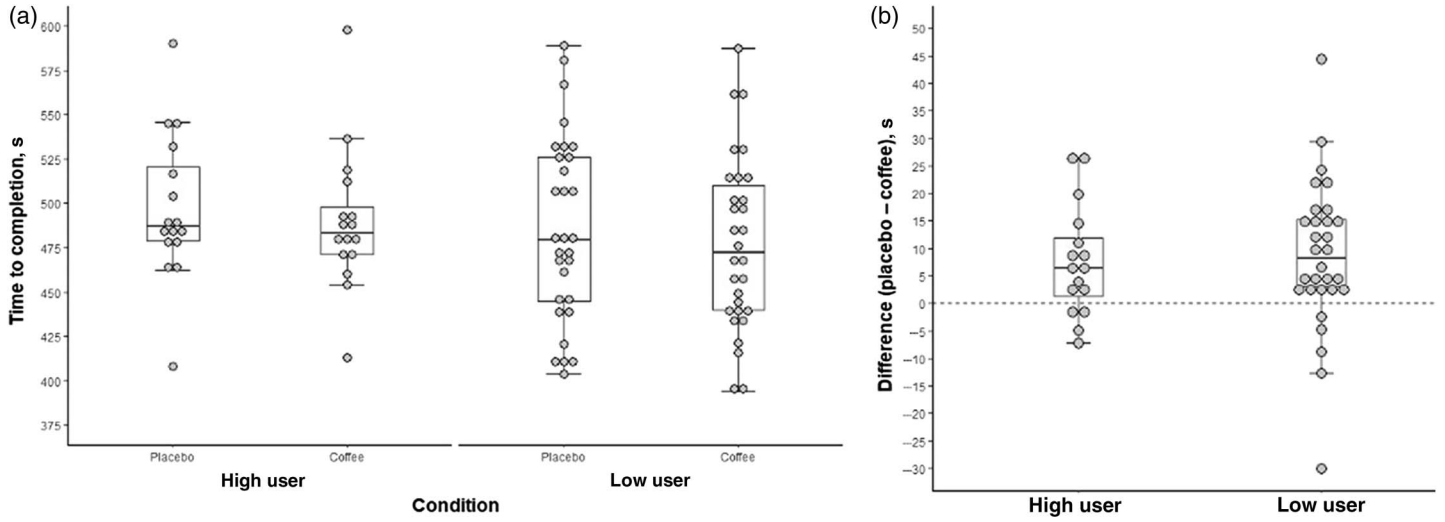

Figure 3 — (a) Distribution and individual 5-km cycling time-trial time for completion in habitually low- and high-caffeine users. (b) Individual changes in time-trial duration (placebo time minus coffee time, where positive values represent a faster time following the ingestion of coffee) in habitually low- and high-caffeine users.

However, no significant sex and trial interaction was observed, $F(1, 41) = 0.504$; $p = .482$; $\eta_p^2 = .01$, with men and women both improving by approximately 8 and 9 s, respectively, following coffee ingestion, and with only a Trivial trial × Sex × Habitual caffeine intake interaction, $F(1, 41) = 0.984$; $p = .327$; $\eta_p^2 = .02$. Furthermore, in order to account for baseline performance (PLA) between low and high users, an analysis of covariance was performed using the PLA condition as a covariant, which demonstrated no significant difference in the performance following the ingestion of coffee, $F(1, 43) = 0.708$; $p = .405$; $\eta_p^2 = .02$, and as such, both groups improved by a similar magnitude (low users: 1.7 ± 2.8%; high users: 1.8 ± 2.0%). In addition, no order effect was observed, $t(45) = 0.253$; $p = .802$; Hedge's $g = 0.04$, 95% CI [−0.37, 0.44]. Finally, no association was observed between habitual caffeine intake ($r^2 = .002$; $p = .828$; Figure 4a) or postdrink salivary caffeine concentration ($r^2 = .002$; $p = .188$; Figure 4b) and time-trial performance following coffee ingestion.

A small condition and time interaction for blood lactate was observed, $F(2, 88) = 6.818$; $p = .002$; $\eta_p^2 = .13$ (Table 1), with values higher at the completion of COF compared with PLA, $p = .001$; 95% CI [0.5, 1.8]; Hedge's $g = 0.42$, 95% CI [0.01, 0.84]. However, there were no differences observed between low- and high-caffeine users, $F(1, 44) = 0.163$; $p = .688$; $\eta_p^2 = .00$. Similarly, a small increase heart rate was observed during COF compared with PLA, $F(1, 41) = 6.296$; $p = .016$; 95% CI [1, 5]; $\eta_p^2 = .13$ (Table 1), although only trivial differences, $F(1,41) = 0.829$; $p = .368$; 95% CI [−9, 3]; $\eta_p^2 = .02$ (Table 1), in heart rate were observed between low- and high-caffeine users.

Discussion

The aim of the present study was to investigate the effect of habitual caffeine intake on 5-km cycling time-trial performance following the ingestion of coffee. Ingesting coffee, providing 3 mg/kg of caffeine improved 5-km cycling time-trial performance with similar performance observed between habitually low- and high-caffeine users. Consequently, habitual caffeine consumption did not affect the ergogenic effect of coffee ingestion prior to a 5-km cycling time trial.

Ingesting coffee reduced 5-km cycling time-trial completion time by 1.7 ± 2.6% (8 ± 12 s), with low users improving by 1.7 ± 2.8% (9 ± 14 s) and high users by 1.8 ± 2.0% (8 ± 10 s). These findings support Clarke et al. (2019), who observed that coffee providing 3 mg/kg of caffeine improved 5-km cycling time-trial performance by 1.9% (men: 2.1% and women: 1.8%) compared with a PLA and Clarke et al. (2018) where the ingestion of caffeinated coffee providing 3 mg/kg of caffeine improved 1-mile race time by 1.9% compared with a PLA. In addition, Wiles et al. (1992) 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. (2013) demonstrated that coffee and caffeine (5 mg/kg) ingestion improved time-trial performance by approximately 5%. Despite these overall observations, individual performance responses to coffee ingestion do exist as highlighted in Figure 3b; that is, the magnitude of performance change varies between individuals (−7.3% to 8.1%). Consequently, habitual caffeine intake is a potential factor for the underlying heterogeneous responses (Bell & McLellan, 2002). However, empirically this suggestion is not conclusive; three studies have reported a blunting of caffeine's acute ergogenic effects with habitual use (Beaumont et al., 2017; Bell & McLellan, 2002; Lara et al., 2019), and two reported no differences in response to acute caffeine ingestion between individuals with different habitual caffeine intakes (Dodd et al., 1991; Gonçalves et al., 2017). The present study suggests there is no association between habitual caffeine intake and the absolute change in the 5-km time-trial performance (Figure 4a), refuting the suggestion that habitual caffeine intake might reduce the ergogenic effect of coffee ingestion. One possible explanation for this occurrence is the limited association between preexercise salivary caffeine concentration and exercise performance (Figure 4b). Therefore, the findings of the present study add to the body of evidence suggesting that habitual caffeine consumption does not negatively affect the ergogenic effect of caffeine or coffee.

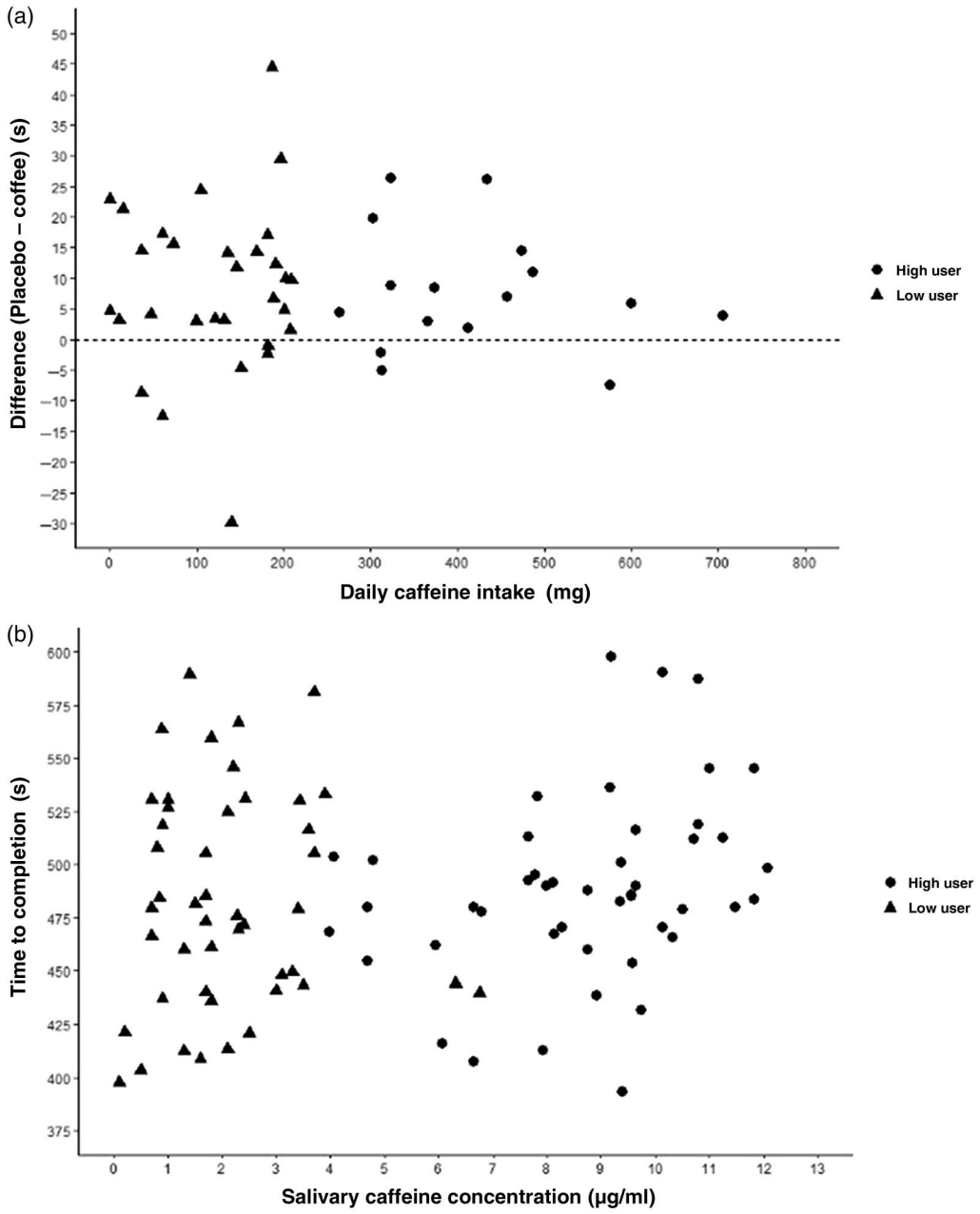

Figure 4 — (a) Relationship between individual changes in time-trial duration (placebo – coffee, where positive values represents a faster time following the ingestion of coffee) and habitual daily caffeine intake. (b) Relationship between postdrink salivary caffeine concentration and time-trial duration.

However, it should be noted that the concept that habitual caffeine intake moderates the acute ergogenic effects of caffeine supplementation was derived from animal studies with very high doses (i.e., 20 mg/kg) (Fredholm, 1982), and as such may not be relevant to humans.

The metabolism of caffeine in the liver is largely dependent on the CYP1A2 isoform of cytochrome 450 and Djordjevic et al. (2010) reported that the daily consumption of at least 3 cups of coffee, defined as "heavy drinkers," increased CYP1A2 activity potentially increasing caffeine metabolism. Furthermore, Svenningsson et al. (1999) reported alterations in gene expression within the striatum albeit in rats, which may be crucial in the development of tolerance to caffeine, potentially affecting caffeine metabolism, and thus altering the ergogenic effect of caffeine and coffee. 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 (Graham, 2001). Furthermore, Meeusen et al. (2013) suggested that both motor effects and motivational aspects increase when caffeine blocks adenosine receptors, creating a greater dopaminergic drive, and thus enhancing 5-km performance. However, data suggest that habitual intake of caffeine is associated with an increased number of adenosine receptors (Fredholm, 1982) attenuating caffeine's

Table 1 Mean ± SD Heart Rate and Blood Lactate Concentrations During the 5-Km Cycling Time Trial in Habitually Low- and High-Caffeine Users

	Placebo			Coffee		
Variable	Predrink	Postdrink	Completion	Predrink	Postdrink	Completion
Heart rate (beats per minute)						
Overall	69 ± 12	68 ± 13	171 ± 12	71 ± 14	70 ± 13	180 ± 11
Low user	71 ± 14	68 ± 14	173 ± 12	71 ± 15	71 ± 15	179 ± 11
High user	71 ± 10	73 ± 10	178 ± 12	74 ± 10	74 ± 10	182 ± 11
Blood lactate (mmol/L)						
Overall	1.9 ± 0.8	2.3 ± 1	12.0 ± 2.8	2.1 ± 0.9	2.6 ± 1.2	13.2 ± 2.8
Low user	2.0 ± 0.9	2.3 ± 1.1	12.3 ± 2.8	2.2 ± 1.0	2.5 ± 1.1	13.1 ± 2.6
High user	1.7 ± 0.4	2.3 ± 0.8	11.4 ± 3.0	2.0 ± 0.9	2.9 ± 1.4	13.4 ± 3.3

stimulatory effects (Svenningsson et al., 1999). In addition, a caffeine-induced increase in the secretion of β-endorphins (Laurent et al., 2000) may be a potential mechanism via which, caffeine attenuates pain sensation and rating of perceived exertion during exercise, thereby decreasing perceptions of effort and/or improving performance, as observed in the present study. However, Haskell et al. (2005) reported that the ingestion of caffeine tended to improve mood and cognitive performance more in low-caffeine users compared high. Consequently, while habitual caffeine consumption may cause alterations in caffeine metabolism, the efficacy of adenosine antagonism and mood, the evidence from the present study suggests that they do not translate into impaired exercise performance in high-caffeine users.

On a practical level, Lara et al. (2019) reported that there is a progressive tolerance to caffeine ingestion, and there are suggestions that the preexercise caffeine dose needs to exceed the level of habitual intake (Pickering & Kiely, 2018). However, the present study showed that the level of habitual caffeine ingestion was not associated with the magnitude of improvement in 5-km performance following the ingestion of coffee providing 3 mg/kg of caffeine, a value below the habitual intake of the high users (6 ± 2 mg $\cdot$ kg^{-1} $\cdot$ day^{-1}). Furthermore, Pickering and Kiely (2019) concluded that short-term precompetition caffeine withdrawal appears to offer little benefit, and given the potential negative side effects, withdrawal strategies are not recommended. In addition, Irwin et al. (2011) concluded that acute caffeine supplementation positively effects exercise performance and provides an ergogenic benefit in regular caffeine users regardless of any withdrawal period. Therefore, consuming coffee providing 3 mg/kg 60 min prior to exercise is a practical source of caffeine prior to exercise in habitual low- and high-caffeine users. However, given the individual response to caffeine, athletes should experiment with various doses and timing strategies when using caffeine to enhance performance (Pickering & Kiely, 2019).

The present study is not without limitations. There are difficulties with relying on self-report caffeine consumption questionnaires in order to determine habitual use of caffeine as participants may not be fully aware of what products contain caffeine, and the caffeine content in drinks can vary between caffeine sources and time points (Desbrow et al., 2007). Furthermore, the use of a 24-hr dietary record to ensure pretrial standardization, while being an acceptable method, under reporting can occur (Poslusna, Ruprich, de Vries, Jakubikova, & van't Veer, 2009). In addition, the baseline salivary caffeine concentrations suggest that possibly not all participants abstained from caffeine for 12 hr prior to each trial. However, both factors are likely to provide a more ecologically valid condition and represent typical precompetition preparation. Furthermore, there are also important strengths to this study, namely the caffeine content of the coffee and salivary caffeine concentration has been assessed.

Conclusions

Habitual caffeine consumption did not affect the ergogenic effect of coffee ingestion during 5-km cycling time trial. Furthermore, ingesting coffee providing 3 mg/kg of caffeine increased salivary caffeine levels and improved 5-km cycling time-trial performance, and thus, coffee is a practical source of caffeine. However, the underlying mechanisms are not fully elucidated, and given the limitations listed, further investigations are required to understand the impact of habitual caffeine ingestion on the ergogenic effect of coffee and caffeine ingestion.

Acknowledgments

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