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ORIGINAL RESEARCH

Acute Ingestion of Caffeinated Chewing Gum Improves Repeated Sprint Performance of Team Sport Athletes With Low Habitual Caffeine Consumption

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The effects of acute ingestion of caffeine on short-duration high-intensity performance are equivocal, while studies of novel modes of delivery and the efficacy of low doses of caffeine are warranted. The aims of the present study were to investigate the effect of acute ingestion of caffeinated chewing gum on repeated sprint performance (RSP) in team sport athletes, and whether habitual caffeine consumption alters the ergogenic effect, if any, on RSP. A total of 18 male team sport athletes undertook four RSP trials using a 40-m maximum shuttle run test, which incorporates 10 × 40-m sprints with 30 s between the start of each sprint. Each participant completed two familiarization sessions, followed by caffeine (CAF; caffeinated chewing gum; 200 mg caffeine) and placebo (PLA; noncaffeinated chewing gum) trials in a randomized, double-blind manner. RSP, assessed by sprint performance decrement (%), did not differ ($p = .209$; effect size = 0.16; $N = 18$) between CAF (5.00 ± 2.84%) and PLA (5.43 ± 2.68%). Secondary analysis revealed that low habitual caffeine consumers (<40 mg/day, $n = 10$) experienced an attenuation of sprint performance decrement during CAF relative to PLA (5.53 ± 3.12% vs. 6.53 ± 2.91%, respectively; $p = .049$; effect size = 0.33); an effect not observed in moderate/high habitual caffeine consumers (>130 mg/day, $n = 6$; 3.98 ± 2.57% vs. 3.80 ± 1.79%, respectively; $p = .684$; effect size = 0.08). The data suggest that a low dose of caffeine in the form of caffeinated chewing gum attenuates the sprint performance decrement during RSP by team sport athletes with low, but not moderate-to-high, habitual consumption of caffeine.

Keywords: ergogenic aid, fatigue, habituation, performance decrement, supplement

An important determinant of success in team sports is repeated sprint performance (RSP; Girard et al., 2011). RSP involves maximal or near-maximal short-duration sprints repeated in succession with brief recovery periods. Fatigue manifests as a sprint performance decrement (S_{dec}; %) over time indicated by a decline in maximal sprint speed with subsequent sprints, that is, an increase in sprint duration over a set distance. Clearly, any ergogenic aid that can attenuate fatigue and maintain RSP in team sport athletes may prove beneficial and warrant use during competition.

A wide body of literature supports the use of caffeine to improve endurance exercise performance (Burke, 2008; Goldstein et al., 2010; Graham, 2001; Spriet, 2014), such as 10-km running and 1-hr cycling time-trial performance (Bell et al., 2002; McNaughton et al., 2008). Among elite athletes, 74% of urine samples taken before or after competing contain detectable quantities of caffeine (Del Coso et al., 2011). However, effects on short-duration high-intensity exercise performance are equivocal to date, with a large degree of variability based on the dose of caffeine administered (Spriet, 2014) and the specific test undertaken (Astorino & Roberson, 2010; Davis & Green, 2009). Only a handful of studies have examined the effects of caffeine on RSP (Andrade-Souza et al., 2015; Del Coso et al., 2012, 2013; Glaister et al., 2008a; Kopec et al., 2016; Lee et al., 2011; Paton et al., 2001, 2010; Schneiker et al., 2006; Stuart et al., 2005; Trexler et al., 2016), again with equivocal results. Moreover, most have used high doses of caffeine (>3 mg/kg body mass [BM]), and there remains a question as to whether low doses of caffeine are efficacious for team sport athletes (Spriet, 2014).

Anhydrous caffeine in capsule or tablet form is typically used in sports performance studies, but caffeinated chewing gum offers a novel route of administration with a different pharmacokinetic profile (Kamimori et al., 2002). Ingestion of caffeinated chewing gum results in earlier peak plasma caffeine concentrations, with 85% of caffeine released after 5 min of chewing and a relative bioavailability of 90% (Kamimori et al., 2002; Syed et al., 2005). Therefore, caffeinated chewing gum may be of value when rapid caffeine absorption and/or low dosing is desirable. Although the ergogenic effect of caffeinated chewing gum on cycling RSP has

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received attention (Paton et al., 2010), effects on running-based RSP protocols warrant investigation given that this is the modality of exercise in most high-intensity intermittent, team-based sports.

Habitual consumption reduces sensitivity to the physiological effects of caffeine (Fredholm, 1982; Fredholm et al., 1999), suggesting that habitual consumers of caffeine may not benefit from the ergogenic potential of acute ingestion. However, the habituation effect and/or restoration of sensitivity upon withdrawal is not always observed in exercise performance settings (Irwin et al., 2011; Van Soeren & Graham, 1998). Therefore, the effects, if any, of habituation is a salient question in sports performance research (Beaumont et al., 2017; Gonçalves et al., 2017), given the high rates of habitual consumption (Fredholm et al., 1999) and ergogenic use (Del Coso et al., 2011).

The aim of the present study was to investigate the effect of caffeinated chewing gum on RSP in team sport athletes. Work to date on caffeinated chewing gum has been completed in cyclists (Paton et al., 2010, 2015; Ryan et al., 2012, 2013) but has not been tested in team sport athletes during high-intensity running protocols. A secondary aim was to investigate whether habitual caffeine consumption alters the ergogenic effect, if any, of acute caffeine ingestion prior to RSP.

Methods

Participants

A total of 18 male team sport athletes participated in the study (age, 21.2 ± 1.1 years; height, 1.78 ± 0.06 m; BM, 80.4 ± 6.6 kg; body fat, 14.7 ± 3.9%; and fat-free mass, 68.7 ± 6.0 kg). Participants were required to be actively training and competing at least three times weekly in a team sport at university level or equivalent. Participants were recruited from university rugby union, soccer, and hockey teams, and testing was conducted during their competitive season. The University College Dublin Research Ethics Committee, in accordance with the Declaration of Helsinki, approved all experimental procedures. Each participant provided written informed consent prior to participation.

Experimental Design

Participants visited the High Performance Unit at University College Dublin on four separate testing occasions including two familiarization sessions (Glaister et al., 2009), and caffeine (CAF) and placebo (PLA) trials. The CAF and PLA trials were conducted in a double-blind, crossover manner in randomized order. All sessions took place on the same indoor tartan running track in the same clothing and footwear and were conducted at the same time of day ±1 hr to control for diurnal variations.

For all visits, participants presented to the laboratory having consumed the same self-selected breakfast 3 hr before each trial. Hydration status was assessed using a handheld osmometer (Osmocheck; Vitech Scientific, Horsham, UK), and a resting blood lactate concentration was measured from a finger prick sample (Lactate Pro2; Arkray, Kyoto, Japan). A standardized warm-up was performed consisting of 5 min on a stationary cycle ergometer, followed by 5 min of supervised dynamic exercises (walking lunges, marching, heel flicks, high knees, and leg swings). Participants then performed two practice runs of the 40-m shuttle (Figure 1) at 60% and 80% effort with 1 min between efforts, before commencing the main exercise protocol, the 40-m maximal shuttle run test (MST; Glaister et al., 2009). The MST protocol

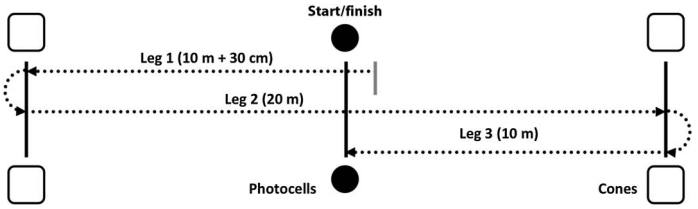

Figure 1 — Schematic of the 40-m maximal shuttle run test. Participants run at maximum effort between two lines placed 20-m apart, with the start/finish line placed at the midpoint of the course. Starting 0.3 m behind the start/finish line, participants sprint 10 m from this line to the end of the course, turn 180°, sprint 20 m to the other end of the course, turn 180°, and sprint 10 m back through the start/finish line. This completes one sprint, with the test protocol comprising of 10 sprints with a 30-s interval between the start of each sprint.

required the participants to complete 10 repetitions of the 40-m shuttle with a 30-s interval between the start of each sprint, that is, recovery time between sprints was 30 s minus the time taken to complete the previous sprint. Sprint times were recorded to the nearest 0.001 s using photoelectric timing gates (Fusion Sport, Brisbane, Australia) positioned at the start/finish line. Heart rate was monitored by telemetry in 5-s intervals throughout the MST (Polar, Oulu, Finland). A second blood lactate sample was measured immediately after completion of the MST. No feedback on sprint times was given to the participants during trials. Verbal encouragement to give maximum effort for each sprint was standardized and provided throughout each visit.

Pretrial Preparation

Participants were instructed to refrain from strenuous physical activity and alcohol for 24 hr before each visit and abstained from caffeine on the morning of each visit. Prior to the first visit, participants were asked to keep a portion estimate food diary for the day before that visit and for their breakfast on the morning of the first visit. This breakfast was eaten 3 hr before commencing the MST. A copy of this food diary was provided back to participants in advance of subsequent visits for which they were asked to follow this exact pattern of intake. Analysis of these food diaries (Nutritics Dietary Analysis Software; Nutritics, Dublin, Ireland) revealed that participants consumed 32.0 ± 9.0 kcal/kg BM, 2.1 ± 1.1 g/kg BM protein, 3.1 ± 1.2 g/kg BM carbohydrate, and 1.3 ± 0.6 g/kg BM fat on the day prior to each trial, and a breakfast providing 6.6 ± 2.0 kcal/kg BM, 0.3 ± 0.2 g/kg BM protein, 0.9 ± 0.4 g/kg BM carbohydrate, and 0.2 ± 0.1 g/kg BM fat for breakfast before each trial. The participants' habitual caffeine consumption was assessed by questionnaire and calculated based on nutrient data from the Food and Drug Administration (2010). All participants had previous experience of acute ingestion of caffeine to support exercise performance either in the form of coffee, energy drinks, or preworkout supplements, but none had previously used caffeinated chewing gum.

Administration of Caffeinated Chewing Gum and Placebo

Either caffeinated or noncaffeinated chewing gum was provided to participants 5 min before commencing the standardized warm-up. A researcher not involved in the MST testing administered the gum directly into the participant's mouth from a nontransparent container in order to avoid possible visual cues from the appearance of

each gum. The caffeinated or noncaffeinated chewing gums were chopped into small cubes approximately 0.5 cm in length to further disguise their physical attributes. Two sticks of CAF chewing gum (Military Energy Gum; MarketRight Inc., Plano, IL, USA) were administered to each participant, with each stick providing 100 mg of caffeine. Based on each participant's BM, the dose of caffeine averaged 2.5 ± 0.2 mg/kg BM and ranged from 2.1 to 2.8 mg/kg BM. The noncaffeinated chewing gum was chosen to be similar in taste and texture, and contained no caffeine. The respective chewing gums were chewed for 10 min prior to each trial, that is, 5 min prior to the warm-up, and for 5 min during the warm-up, and then expelled.

Data Treatment and Statistical Analysis

RSP was assessed by the S_{dec}, which quantifies fatigue by comparing actual sprint performance over the MST to ideal sprint performance, conceptualized as the fastest sprint time (FT) being repeated for each sprint (Fitzsimons et al., 1993; Glaister et al., 2008b). The S_{dec} method is established as the most valid and reliable method of quantifying fatigue in tests of multiple sprint performance (Glaister et al., 2008b). The following variables were recorded for analysis: FT, the fastest sprint of each MST trial; total sprint time (TT), the sum of the 10 sprint times in one MST trial. Average sprint time and slowest sprint time for each MST trial were also recorded. S_{dec} (%) was calculated as $S_{dec} = \{[TT/(FT \times 10)] - 1\} \times 100$.

Statistical analyses were performed using GraphPad Prism version 7.0b (GraphPad Software Inc., La Jolla, CA, USA). Data are reported as mean ± *SD*. Differences between CAF and PLA for each variable were assessed by a paired samples *t* test, with the exception of heart rate and individual sprint times, which were assessed using a two-way (Condition × Time) repeated-measures analysis of variance. In addition, standardized differences in the mean of S_{dec} were used to assess the magnitudes of effects and were calculated using Cohen's *d* effect size (ES) and interpreted using thresholds of 0.2, 0.6, 1.2, and 2.0 for small, moderate, large, and very large, respectively. Because the habitual caffeine consumption data were not normally distributed, the relationship between consumption (in milligrams/day) and difference in S_{dec} for CAF versus PLA was determined by Spearman's rho correlation coefficient. Participants were initially analyzed a priori as a whole group (N = 18). A secondary analysis by low (n = 10; <40 mg/day; 22 ± 12 mg/day) and moderate/high (n = 6; >130 mg/day; 231 ± 88 mg/day) habitual caffeine consumption was performed. Two participants whose habitual caffeine intake fell between the <40 and >130 mg/day cutoffs were removed prior to the secondary analysis. Statistical significance was accepted at the level of $p < .05$ for all statistical tests.

Results

Hydration status, measured as urine specific gravity, prior to each trial did not differ (CAF, 1.0159 ± 0.0086; PLA, 1.0172 ± 0.0082; p = .521; ES = 0.16). There were main effects of time for individual sprint times and heart rate (both ps < .001), but no main effect of condition or interaction effects was observed for either parameter (Figure 2). There was no difference between CAF and PLA trials for TT (CAF, 87.5 ± 3.1 s; PLA, 87.8 ± 3.0 s; p = .214; ES = 0.10), FT (CAF, 8.33 ± 0.23 s; PLA, 8.33 ± 0.20 s; p = .879; ES = 0.02), or slowest sprint time (CAF, 9.06 ± 0.39 s; PLA, 9.10 ± 0.43 s; p = .452; ES = 0.10) (Figure 3). Blood lactate concentrations were higher immediately after MST during CAF (11.2 ± 2.3 mM) compared with PLA (10.3 ± 2.6 mM) (p = .035; ES = 0.36; Figure 4).

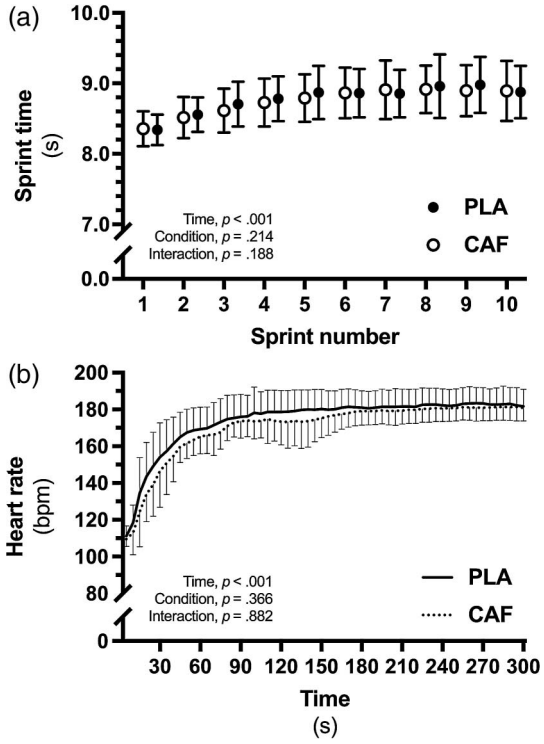

Figure 2 — Sprint times for individual sprints 1–10 (a) and heart rate responses over time (b), during the 40-m MST for PLA and CAF trials. Data are presented as mean ± *SD*. MST = maximal shuttle run test; PLA = placebo; CAF = caffeine; bpm = beats per minute.

RSP measured by S_{dec} did not differ (p = .209; ES = 0.16) between CAF (5.00 ± 2.84%) and PLA (5.43 ± 2.68%) (Figure 5). There was a tendency (p = .076) for a moderate positive correlation (Spearman's ρ = .352) between habitual caffeine consumption (in milligrams/day) and difference in S_{dec} for CAF versus PLA. Secondary analysis by low (<40 mg/day) or moderate/high (>130 mg/day) habitual caffeine consumption revealed an attenuation of S_{dec} during CAF relative to PLA (5.53 ± 3.12% vs. 6.53 ± 2.91%, respectively; p = .049; ES = 0.33) in those with low habitual caffeine consumption (Figure 6a). However, no difference in S_{dec} existed between CAF and PLA in those with moderate-to-high habitual caffeine consumption (3.98 ± 2.57% vs. 3.80 ± 1.79%, respectively; p = .684; ES = 0.08; Figure 6b).

Discussion

The primary aim of the present study was to investigate the effect of acute ingestion of caffeinated chewing gum on RSP in team sport athletes. A secondary aim was to investigate if low (<40 mg/day) or moderate/high (>130 mg/day) habitual caffeine consumption alters the ergogenic potential of caffeine ingestion in this model. Acute ingestion of a 200-mg (2.1–2.8 mg/kg BM) dose of caffeine in the form of caffeinated chewing gum had no effect on S_{dec} during RSP when analyzing the present athlete cohort as a whole. However, when comparing athletes with divergent habitual consumption of caffeine, a small effect (ES = 0.33) of improved performance was observed as an attenuation of S_{dec} by 18% in those with low, but not moderate-to-high, habitual caffeine consumption. This suggests

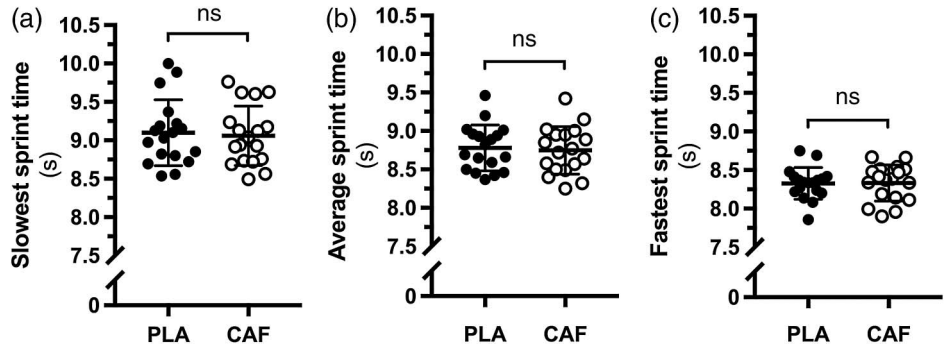

Figure 3 — Slowest (a), average (b), and fastest (c) sprint times during the 40-m MST for PLA and CAF trials. Individual data are shown along with mean ± *SD*. MST = maximal shuttle run test; ns = nonsignificant difference; PLA = placebo; CAF = caffeine.

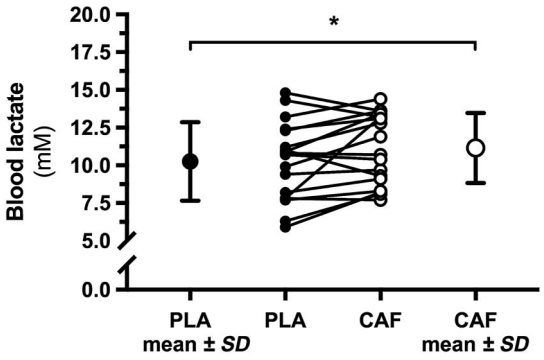

Figure 4 — Blood lactate response to the 40-m MST for PLA and CAF trials sampled immediately after completion of the MST. Individual data are shown along with mean ± *SD*. MST = maximal shuttle run test; PLA = placebo; CAF = caffeine. *Significant difference at $p < .05$.

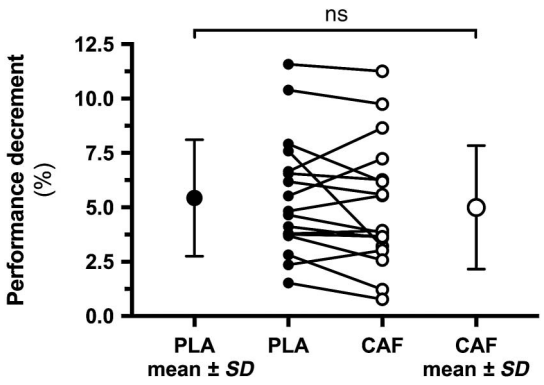

Figure 5 — Sprint performance decrement (%) during the 40-m MST for PLA and CAF trials. Individual data are shown along with mean ± *SD*. MST = maximal shuttle run test; ns = nonsignificant difference; PLA = placebo; CAF = caffeine.

that habitual caffeine consumption modulates the ergogenic potential of caffeinated chewing gum for high-intensity exercise performance.

Few studies have previously examined the effect of acute caffeine ingestion on RSP, and results have been equivocal with reports of both no effect (Andrade-Souza et al., 2015; Kopec et al., 2016; Paton et al., 2001) and benefits to performance (Del Coso et al., 2013; Glaister et al., 2008a; Lee et al., 2011; Paton et al., 2010; Schneiker et al., 2006; Stuart et al., 2005; Trexler et al., 2016). A variety of test protocols has been implemented making direct comparisons to the present study difficult. Of the previous studies employing short-duration RSP running tests similar to our work, acute caffeine ingestion had negligible effects in a 10 × 20-m sprint protocol (Paton et al., 2001), but improved FT by 1.4% in a 12 × 30-m sprint protocol (Glaister et al., 2008a). Conversely, this improvement in FT coincided with an overall increase in performance decrement over time. The data from the group as a whole in the present study are in agreement with the lack of effect of acute caffeine ingestion on short-duration RSP tests. In general, benefits to performance have been observed during RSP protocols where recovery between sprints is longer, or tests are performed on a background of variable intensities and simulated match activities (Del Coso et al., 2013; Glaister et al., 2008a; Lee et al., 2011; Schneiker et al., 2006; Stuart et al., 2005; Trexler et al., 2016). However, the dose and mode of delivery, and role of habitual caffeine consumption are worthy of further consideration in the present work.

The majority of previous studies on caffeine and RSP have typically administered caffeine in doses of 5.0–6.0 mg/kg BM in anhydrous form approximately 1 hr before performance (Glaister et al., 2008a; Paton et al., 2001; Schneiker et al., 2006; Stuart et al., 2005). However, a need for further investigations using low doses of caffeine and by other modes of delivery has been identified (Spriet, 2014). To our knowledge, this is the first study investigating RSP in team sport athletes using a caffeinated chewing gum delivering a low dose of caffeine (200 mg total; ~2.5 mg/kg BM). Similar doses delivered in caffeinated chewing gum demonstrated marked increases in plasma caffeine concentrations (Kamimori et al., 2002; Ryan et al., 2013; Syed et al., 2005), including a faster peak in concentration (vs. anhydrous caffeine) occurring after ~20 min (Kamimori et al., 2002). The major site of caffeine absorption differs between the modes of delivery, with caffeine absorption from chewing gum predominantly through the buccal cavity considered faster due to extensive vascularization and bypassing of intestinal and hepatic first-pass metabolism (Aarons et al., 1981). However, relatively few studies have previously investigated the effect of caffeinated chewing gum on exercise performance, but effects have been generally positive (Paton et al., 2010, 2015; Ryan et al., 2012, 2013). Ingestion (~3 mg/kg BM) 10 min prior to a multiset cycling RSP protocol attenuated fatigue in the latter sets of RSP compared with placebo chewing gum (Paton et al., 2010). Similarly, average and sprint power was improved in the final 10 km of a 30-km cycling time trial when ~3–4 mg/kg BM was ingested after 10 km of the trial (Paton et al., 2015). Notably,

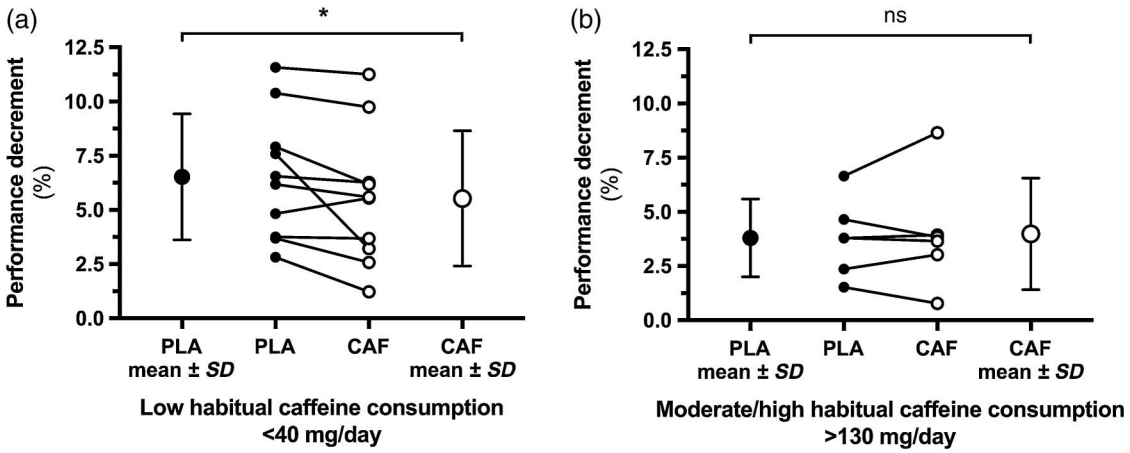

Figure 6 — Sprint performance decrement (%) during the 40-m MST for PLA and CAF trials for participants stratified based on low (a) or moderate/high (b) habitual caffeine consumption. Individual data are shown along with mean ± *SD*. MST = maximal shuttle run test; ns = nonsignificant difference; PLA = placebo; CAF = caffeine. *Significant difference at $p < .05$.

when caffeinated chewing gum (~3 mg/kg BM) was ingested 5 min prior to a ~40-min cycling time trial, performance was improved by ~2 min versus placebo, but performance was unaffected when ingested at 60 or 120 min prior to cycling (Ryan et al., 2013). Finally, cycling time to exhaustion at 85% maximal oxygen uptake (VO_{2max}) was not improved by ingestion of gum providing ~2 mg/kg BM of caffeine (Ryan et al., 2012). Overall, these data suggest that the ergogenic effect of caffeinated chewing gum is sensitive to the dose and timing of ingestion, and given the different pharmacokinetics, may require different recommendations to other forms of caffeine. However, the dose and timing employed in the present study is similar to that which improved performance in a cycling RSP protocol (Paton et al., 2010) and consistent with low caffeine dosing as an isolated ingredient that can improve performance in multiple models (Spriet, 2014).

Whether caffeine habituation can impact the potential ergogenic effects of caffeine is a salient issue in the field, with athletes often advised to refrain from caffeine consumption in the days leading up to competition in order to enhance the ergogenic effect (Sökmen et al., 2008). Data on such habituation effects are conflicting, and a lack of consensus exists (Beaumont et al., 2017; Gonçalves et al., 2017). Tolerance to the behavioral and physiological effects of caffeine occurs in several species, including humans (Fredholm et al., 1999). One week of caffeine administration increased the number of A1 and A2A adenosine receptors in rat cerebral cortical membranes by 25% (Fredholm, 1982). Thus, a larger dose of caffeine would be needed to antagonize the same percentage of adenosine receptors and exhibit the same physiological effects. For ergogenic effects, early work examining the effects of habituation used time to exhaustion protocols (Bell & McLellan, 2002; Dodd et al., 1991), which are known to have low reproducibility (Currell & Jeukendrup, 2008), and therefore, this issue has been recently revisited (Beaumont et al., 2017; Gonçalves et al., 2017). When participants with low habitual caffeine consumption (<75 mg/day) ingested 1.5–3.0 mg/kg BM per day for 28 days, the performance benefit of acute caffeine ingestion (3 mg/kg BM) compared with placebo during a 30-min bout of maximal work cycling was lost, that is, a tolerance to ergogenic effects of caffeine ingestion had developed (Beaumont et al., 2017). In contrast, in a separate study, when participants were stratified into tertiles based on habitual caffeine consumption (low = 58 ± 29 mg/day; moderate = 143 ± 25 mg/day; and high = 351 ± 139 mg/day), there was no effect of habitual caffeine intake on ergogenic effects of 6.0 mg/kg BM caffeine in a cycling time trial lasting ~30 min (Gonçalves et al., 2017). The contrasting outcomes in these two studies may be explained in part by the magnitude of the acute caffeine dose, that is, a habituation effect with moderate-to-high habitual caffeine intake may be overcome if the acute dose is appropriately high, for example, ≥6.0 mg/kg BM. Our secondary analysis based on low (<40 mg/day; 22 ± 12 mg/day) and moderate-to-high (>130 mg/day; 231 ± 88 mg/day) caffeine consumption suggests that habitual caffeine consumption influences the ergogenic potential of acute caffeine ingestion on RSP in team sport athletes. In short, the S_{dec} was attenuated by ~18% in athletes with low habitual caffeine consumption during CAF compared with PLA, but was unaffected by CAF in those athletes with moderate-to-high habitual caffeine consumption. This finding supports the notion of a habituation effect, but it cannot be discounted that habituation can be overcome by providing a larger acute dose of caffeine than the ~2.5 mg/kg BM provided in the present study.

For future work, clearly there is a need to classify the intake of caffeine that can be considered "habituated" and that would be considered low and high quantities for habitual consumption. The cutoffs for low and moderate/high used in the present study were opportunistic based on the secondary analysis of the recruited participants. However, the low cutoff is consistent with the lowest tertile of consumption in a recent study (Gonçalves et al., 2017), whereas the moderate/high cutoff is consistent with average consumption in U.K. and U.S. male adults (Fitt et al., 2015). The recruitment of larger sample sizes for similar studies will also be important to allow further stratification of habitual consumers as previously highlighted (Gonçalves et al., 2017), in addition to a deeper analysis of the role of genotype in the physiological response to caffeine (Salinero et al., 2017), which was beyond the scope of the present study. Indeed, the convenience sampling and secondary analysis approach to study the influence of habitual intake in the present study resulted in a small sample size ($n = 6$) of moderate/high habitual consumers of caffeine. Therefore, a Type I error for the lack of effect of caffeinated chewing gum on RSP in this cohort remains a possibility.

In conclusion, the present study demonstrates that a low dose of caffeine in the form of caffeinated chewing gum has a small effect in attenuating the S_{dec} during RSP by team sport athletes

in low, but not moderate-to-high, habitual consumers of caffeine. In practical terms, ingestion of caffeinated chewing gum may be of value to team sport athletes, when rapid caffeine absorption and/or a low dose of caffeine is desirable, such as for prematch or half-time ingestion. While the ergogenic potential of caffeine is long-established, further work is still warranted in the context of team sport performance, particularly around timing and dose with this novel mode of delivery, in addition to the potential influence of genotype and habituation.

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