Manuscript Title: Caffeine gum improves reaction time but reduces composure versus placebo during the extra-time period of simulated soccer match-play in male semi-professional players

Abstract

This study aimed to determine whether caffeine gum influenced perceptual-cognitive and physical performance during the extra-time period of simulated soccer match-play. Semi-professional male soccer players (n=12, age: 22 ± 3 years, stature: 1.78 ± 0.06 m, mass: 75 ± 9 kg) performed 120-min soccer specific exercise on two occasions. In a triple blind, randomised, crossover design, players chewed caffeinated (200-mg; caffeine) or control (0-mg; placebo) gum for 5-min following 90-min of soccer specific exercise. Perceptual-cognitive skills (i.e., passing accuracy, reaction time, composure, adaptability) were assessed using a soccer specific virtual reality simulator, collected pre- and post-trial. Neuromuscular performance (reactive-strength index, vertical jump height, absolute and relative peak power output, and negative vertical displacement) and sprint performance (15- and 30-m) were measured at pre-trial, half-time, 90-min and post-trial. Caffeine gum attenuated declines in reaction time (pre: 90.8 ± 0.8 AU to post: 90.7 ± 0.8 AU) by a further 4.2% than placebo (pre: 92.1 ± 0.8 AU to post: 88.2 ± 0.8 AU; p <0.01). Caffeine gum reduced composure by 4.7% (pre: 69.1 ± 0.8 AU to post: 65.9 ± 0.8 AU) versus placebo (pre: 68.8 ± 0.8 AU to post: 68.3 ± 0.8 AU; p <0.01). Caffeine gum did not influence any other variables (p >0.05). Where caffeine gum is consumed by players prior to extra-time, reaction time increases but composure may be compromised, and neuromuscular and sprint performance remain unchanged. Future work should assess caffeine gum mixes with substances like L-theanine that promote a relaxed state under stressful conditions.

Key words perceptual-cognitive processing • nutritional intervention • football • fatigue • physical performance • exercise physiology

Introduction

Caffeine is a naturally occurring compound with ergogenic effects mediated through the central nervous system (CNS) (Pickering & Kiely, 2018). The effects exerted occur *via* the antagonisation of adenosine receptors (mainly A1 and A2A receptors), and counteracting most of the inhibitory effects of adenosine on neuroexcitability, neurotransmitter release and arousal (Kennedy & Wightman, 2022; Meeusen & Decroix, 2018). Caffeine may also increase fat oxidation and spare muscle glycogen (Graham, 2001), promote adrenaline secretion (Davis & Green, 2009), enhance calcium ion release (Jacobson et al., 1992), upregulate muscle ion regulation (Mohr et al., 2011) and reduce perceptions of pain (Kizzi et al., 2016). Evidence suggests that even low (<3 $mg{\cdot}kg^{-1}$ body mass (BM)) and moderate caffeine doses (5–6 $mg{\cdot}kg^{-1}$ BM) are sufficient to increase vigilance, alertness, mood and cognitive processing (Spriet, 2014).

Caffeine is commonly administered in a capsule or beverage form (e.g., coffee or energy drinks). Following ingestion of caffeine *via* this route of administration, peak plasma concentrations are commonly observed 25–45 min post intake; however, the onset of action following the chewing of gum is 5–10 min (Aslani & Jalilian, 2013). The faster rate of appearance observed with caffeine gum relates to the increased speed of delivery to the blood by absorption through the buccal mucosa avoiding the first pass metabolism in the intestines or liver when absorbed *via* the gut (Wickham & Spriet, 2018). In sport, there is emerging survey data that suggests 97% of English professional soccer clubs administer caffeine, with the second most popular mode of consumption supplied *via* chewing gum (Tallis et al., 2021). Therefore, given the popularity and rapid absorption rates, caffeine gum presents a feasible solution during sporting scenarios where time is limited and the ability to maintain or improve performance and cognition is crucial.

One sport that may see a benefit from caffeine gum supplementation is soccer, specifically matches that enter the extra-time (ET) period. Soccer matches are traditionally competed over 90 min, with investigations demonstrating an increased fatigue response during a match (Carling & Dupont, 2011). However, when matches are tied, and an outright winner is required, for example during the knockout phase of major tournaments and domestic cup competitions, an additional 30 min period is played, termed ET. Recently, 33% of knockout matches progressed to ET at the 2022 FIFA

World Cup, with more than 85% of the finalists at the European and World Cup competing in a 120 min match over the last two decades (Mohr et al., 2023). A recent systematic review of ET reports that the additional 30 min period has a detrimental impact on physical (reductions in running distance, fewer sprints, diminished sprint performance and jump height) and technical performance (i.e., shot speed, number of passes and dribbles), but assessments on cognition have yet to be undertaken (Field et al., 2020).

Technical performance is a critical determinant of success in soccer and is largely dependent upon cognitive, perceptual, and motor skills (Ali, 2011). The cognitive effort during soccer matches is high with players required to maintain high attention levels and make rapid and accurate decisions within a rapidly changing environment (Smith et al., 2018). The mental and physical fatiguing effects of soccer are likely to impair cognitive function and technical performance acutely throughout matches (Russell & Kingsley, 2014). The inability to sustain cognitive function due to increasing mental fatigue may also lead to reductions in attention, concentration, reaction times, decision making capacity, and response accuracy (Smith et al., 2018). However, despite reports that caffeine can modulate cognitive function during non-sport specific activities (Souissi et al., 2021; van Duinen et al., 2005), few studies have conducted assessments which demonstrate specificity to soccer players. Therefore, it remains to be determined whether caffeine might be optimal for preservation of technical performances that require cognitive input in soccer players during ET.

The aim of the study was to assess the effects of caffeine gum on the perceptual-cognitive and physical performance responses during and following ET for semi-professional male soccer players. It was hypothesised that caffeine gum would attenuate reductions in perceptual-cognitive and physical performance responses during and following ET.

Methods

Ethical Approval

All participants gave written informed consent prior to participation after all experimental procedures and potential risks had been fully explained. The study was approved by the Ethics

Committee of Manchester Metropolitan University (ID: 48242) and conformed to the standards set by the latest revision of the *Declaration of Helsinki.*

Participants

Twelve male semi-professional soccer players (age: 22 ± 3 years, stature: 1.78 ± 0.06 m, mass: 75 ± 9 kg) with 14 ± 4 years of soccer experience voluntarily completed all study procedures between February and May 2023. Contraindications to exercise or adverse effects from caffeine ingestion would have made participants ineligible for participation. Participants' habitual caffeine intake of 587 ± 424 $mg \cdot week^{-1}$ was estimated using dietary recall methods asking participants to recount the caffeine containing nutrition consumed 7 days pre-trial (Meigs et al., 2022), with a caffeine chart to support this process (https://www.cspinet.org/caffeine-chart). An *a priori ANOVA: Repeated measures, within-between interaction power* calculation was undertaken with a sample size of 12 sufficient to detect a large effect size (Cohen's f = 0.4), based on 80% power (1–β) and an alpha (α) of 0.05 (GPower v3.1; Germany). These estimates were based on prior data assessing changes in reactive-strength index (RSI) pre to post 120-min of soccer specific exercise (Field et al., 2023). Six players dropped out of the study for reasons either relating to an inability to complete the desired speeds of the soccer match simulation (n=3) or lower-limb injury (n=3).

Experimental design

A repeated measures triple blind (i.e., participants, investigators, and outcome assessors were blinded to condition), crossover design was adopted with a random and counterbalanced allocation by an independent person to both caffeine gum and placebo conditions *via* a random number generator (random.org). The study involved three visits to the laboratory. The preliminary visit involved a health screening questionnaire and familiarisation with study procedures, including the soccer specific warm up, a 30 min segment of the soccer match simulation, and unlimited trials of the jump and sprint assessments to ensure habituation with the correct technique. The subsequent visits involved completion of 120 min of the soccer match simulation on two separate occasions, where they received either 200 mg of caffeine gum or a 0 mg placebo after 90 min.

Dietary standardisation

Dietary intake was recorded *via* weighed food diaries 24 h pre-trial, which was then replicated for the subsequent trial with the remote food photography method used to confirm compliance (Stables et al., 2021). Participants were advised to meet current guidelines (6–8 g·kg^{-1} BM, CHO, 1.6—2.2 g·kg^{-1} BM protein) 24 h pre-trial (Collins et al., 2021), and were asked to refrain from strenuous activity, alcohol, and caffeine for 48 h prior to testing. Participants consumed 3542 ± 657 kcal, 385 ± 137 g CHO (5.13 g·kg^{-1} BM), 181 ± 38 g protein (2.41 g·kg^{-1} BM), 142 ± 30 fat (1.89 g·kg^{-1} BM), and 5 ± 4 mg caffeine (0.07 mg·kg^{-1}) in the 24 h pre-trial period, with no differences between conditions (p >0.05). A standardised CHO rich meal (2 g·kg^{-1} BM) was provided to all participants 3 h before the experimental trial commenced. Participants consumed 250ml (~15g) CHO electrolyte solution (Lucozade Sport, GlaxoSmithKline, UK) prior to the warm-up, as well as at HT, FT, and 105 min. In total, 60g CHO (30 g·h^{-1} CHO) was consumed within current UEFA consensus recommendations (Collins et al., 2021).

Soccer match simulation

On the morning of the main experimental trials, participants reported to Manchester Metropolitan University's laboratory at ~10:00 h having consumed the pre-packaged, standardised breakfast provided (see above). Upon arrival, participants provided a mid-flow urine sample to assess osmolality (Osmocheck, Vitech Scientific, UK) and a resting fingertip capillary blood sample was taken. Following the collection of resting measures, participants completed virtual reality (VR) assessments followed by a standardised warm up routine, consisting of dynamic stretching, aerobic activity, technical tasks, multi directional drills and maximal sprinting (Zois et al., 2011). Prior to commencing the soccer match simulation, participants completed assessments of drop jump (DJ), countermovement jump (CMJ), and 30 m sprints.

Upon completion of all baseline measures, participants undertook 120 min soccer match simulation (Harper et al., 2016). The movements of the simulation were controlled by audio signals, involving the completion of varying running speeds, backwards and sideways activity over a 20 m distance, 15 m sprints, and 18 m ball dribbles between eight cones 20 m apart. The simulation was divided into standardised bouts of activity that were repeated across the 120 min exercise duration. The activity profile was identical throughout the simulation for all participants with the same speeds and distances completed.

Heart rate was continuously recorded throughout the trial (Polar H10, Polar Electro Oy, Finland) with mean (HR_{mean}) and peak (HR_{peak}) values derived from each 15 min period. Differential ratings of perceived exertion (d-RPE) were also recorded at each 15 min interval as a reflection of the preceding 15 min. Participants provided d-RPE in a counterbalanced order for legs (RPE-L), breathlessness (RPE-B) and overall (RPE-O), through use of the Borg CR-100 scale (CVs: ≤2.1%; (Field et al., 2020). Assessments of DJ, CMJ and sprint performance were taken at half time (HT), full time (FT), and post-trial. All testing was performed indoors, and environmental conditions were similar between conditions (temperature: 16.5 ± 2.2°C, pressure: 1018 ± 13 mmHg, humidity: 50 ± 10%; all p >0.05).

Post-trial, VR drills were completed, urine osmolality was assessed, and mass was determined before the participants departed from the laboratory. Sweat loss was determined using pre-and-post mass assessments with corrections made for within-trial urine output and fluid intake. Participants completed the subsequent trial 10 ± 3 days thereafter.

Primary and secondary outcomes relate to the perceptual-cognitive processing and physical performance variables, respectively.

Perceptual-cognitive processing

To overcome the challenge with assessing perceptual-cognitive skills from dynamic sports like soccer, we used a soccer specific immersive VR platform that has previously demonstrated good construct validity (Wood et al., 2021). Five VR soccer drills were performed once each at pre- and post-trial using the Rezzil Index VR platform (Version 1.0, Rezzil Ltd, Manchester, UK). Tasks included the Rondo scan, Color combo, Head smart, Shoulder sums and Pressure pass, with four separate 'performance' scores provided for each drill. Descriptions of each VR drill are provided in Table 1. Discrete 'process' scores were also provided reflecting passing accuracy (i.e., number of correct passes and the accuracy of these passes), reaction time (i.e., how long players dwelled on the ball before making a decision), composure (i.e., maintaining performance level despite increases in task difficulty), and adaptability (i.e., the number of touches with both feet). The system's algorithm then calculated an overall diagnostic score from the interaction of the performance and process scores termed the 'Rezzil Index' score. Test-retest comparisons in our lab show good to excellent reliability (intra-class correlation=0.79–0.96). The VR platform was operated through a commercially available gaming desktop PC (Processor: i7-8700K 6-Core 3.7, GPU: 1080 Ti, Memory: 16GB, OS: Windows 10 Pro), and participants wore a VR head mounted display (HTC Vive Pro, HTC Inc, Taoyuan City, Taiwan) and trackers (HTC Vive Pro, HTC Inc, Taoyuan City, Taiwan) that were securely fixed to the participants trainers.

TABLE 1

Neuromuscular performance

Neuromuscular performance was assessed using a portable force platform (Hawkin Dynamics Inc., Maine, USA; 1000 Hz). Participants performed three DJs, involving a controlled drop from a 0.4 m platform and upon landing, jumped maximally, whilst minimising ground contact time and maximising vertical jump height. RSI was calculated *via* the sum of jump height (cm) divided by contact time (ms). After a 60 s rest period, participants performed three CMJs and were instructed to jump as high and fast as possible while maintaining hands on hips throughout the effort. Jump height, absolute peak power output (PPO), PPO relative to mass (PPOrel), and negative vertical displacement were used for analyses. Jump height was calculated as take-off velocity squared divided by 19.62. PPO relates to the peak instantaneous power applied to the centre of mass during the propulsive phase, with PPOrel presented relative to mass. Negative displacement represents negative vertical displacement of the centre of mass during the braking phase. Following one practice effort, three efforts were performed for all jump assessments. All jumps were interspersed with 60 s and the mean of three jumps were presented for analyses. The CVs for between-trial measurements at timepoints prior to the intervention (i.e., at pre-trial, HT and FT) in our lab are below 7%.

Sprint performance

To measure sprint times participants performed a linear 30 m sprint, recorded *via* timing gates (Witty, Microgate®, Bolzano, Italy) placed 0.8 m from the ground with 15 and 30 m sprint times recorded. Participants commenced 0.6 m behind the first gate whilst adopting a 2-point staggered stance. Two 30 m sprints were performed with 120 s active recovery between efforts. The mean of two sprints was presented for analyses. The assessment of sprint times using similar methods demonstrated excellent reliability (CVs 1.2–4.6%; (Harper et al., 2016).

Blood sampling and analysis

Fingertip capillary blood samples were taken while participants adopted a seated position for 1 min prior to measurements at 15 min intervals and analysed for blood lactate and glucose (Biosen C-Line; EKF-diagnostic GmBH, Cardiff, Wales; CV both 1.5%), with pre-trial, HT, FT and post-trial samples also analysed for haemoglobin (Hgb; Hemocue, Hb 201, Hemocue Ltd, Ängelholm, Sweden) and haematocrit (Hct) concentrations. Capillary samples were centrifuged and analysed for Hct using a micro capillary reader (Hawksley and Sons Ltd, UK). Total blood volume was estimated using a previously developed formula (Sharma & Sharma, 2018), and presented as a percentage change (%BV). Changes in plasma (%ΔPV) were also calculated using an established equation (Dill & Costill, 1974). The %TBV and %ΔPV are presented as changes from pre-trial, with pre-trial values taken as 100%.

Caffeine gum administration

Caffeine gum contained 100 mg of caffeine per serving (energy gum, peppermint flavour, Blockhead HQ Ltd, UK). Players masticated two servings of gum (200 mg caffeine; ~2.7 ± 0.4 $mg \cdot kg^{-1}$) for 5 min following 90 min of soccer specific exercise. Plasma caffeine data demonstrates an 85% bioavailability of the oral caffeine within 5 min of chewing (Kamimori et al., 2002). The manufacturer produced placebo gum was identical in appearance, texture, scent, and taste but did not contain caffeine. Post-study enquiries revealed that 7 out of 12 participants (~58%) correctly distinguished between caffeine and placebo. An absolute caffeine dosage was chosen to reflect applied practices.

Statistical analyses

A linear mixed model (LMM) was conducted using IBM SPSS Statistics 28 for windows (SPSS Inc., Chicago, IL, USA). Following exploratory analyses, residuals >3.0 SD from the mean values were omitted (i.e., 96 out of 6,912 data points were omitted, across 15 variables and 23 conditions) and a basic variance components assessment revealed the model of best fit for each dependant variable. Models were first deemed as null and thereafter progressed to more complex models. The intraclass correlation (ICC) of the random factors (i.e., participant) were calculated to establish if a significant variance contributed to the dependant variables. Wald Z statistics were used to assess the null hypothesis that zero-variance existed between participants; if rejected, the random factor of participant was incorporated in the successive hierarchical models. The covariance structure of the random factors was set to variance components in all models. The fixed effects and their interactions included were intervention/placebo and time for each model. All models estimated parameters using the maximum likelihood method. Least significant corrections were applied post-hoc with 95% CI reported. A paired samples *t*-test assessed differences in dietary intake between conditions 24 h prior to the trials. Data are expressed as mean ± SE unless otherwise declared. Significance was set to <0.05.

Results

Physiological and perceptual responses to soccer match simulation

No differences were detected between conditions for blood lactate, blood glucose, HRmean, HRpeak, RPE-B, RPE-L or RPE-O (p >0.05), but time effects were identified for all variables (p <0.05; Table 2). No differences were detected for Hgb, Hct, %BV, %PV or urine osmolality between conditions (p >0.05), but time effects were evident for Hct (p <0.05; Table 3). No differences in sweat loss were identified between conditions (p >0.05); although, significant sweat loss (2.6 ± 0.2% BM) was observed pre-to-post trial (p <0.05).

TABLE 2

TABLE 3

Perceptual-cognitive skill performance

Interaction effects for condition and time were identified for reaction time (p <0.01) with caffeine (pre: 90.8 ± 0.8 AU, 95% CI = 89.2 to 92.4, post: 90.7 ± 0.8 AU, 95% CI = 89.0 to 92.2) attenuating reductions in reaction time post-trial versus placebo (pre: 92.1 ± 0.8 AU, 95% CI = 90.6 to 93.7, post: 88.2 ± 0.8 AU, 95% CI = 86.6 to 89.8; 95% CI for diff = 1.0 to 3.1). Interaction effects were also observed for composure (p <0.01) with caffeine (pre: 69.1 ± 0.8 AU, 95% CI = 67.3 to 70.8, post: 65.9 ± 0.8 AU, 95% CI = 64.2 to 67.6) reducing composure versus placebo (pre: 68.8 ± 0.8 AU, 95% CI = 67.1 to 70.6, post: 68.8 ± 0.8 AU, 95% CI = 67.1 to 70.6; 95% CI for diff = 0.6 to 2.7). Time effects were found for reaction time in the placebo condition, and for composure in the caffeine group (p <0.01). No interaction, condition or time effects were identified for any other perceptual-cognitive variables (p >0.05). Perceptual-cognitive responses are illustrated in Figure 1 and Figure 2.

INSERT FIGURE 1*

INSERT FIGURE 2*

Neuromuscular performance

No interaction (condition and time) or condition effects were identified for RSI (Figure 3), or CMJ height, PPO, PPOrel and negative vertical displacement (p >0.05; Figure 4).

***INSERT FIGURE 3 ***

INSERT FIGURE 4

Sprint performance

No interaction (condition and time) or condition effects were identified for 15 m and 30 m sprints (p >0.05; Figure 5). Reductions in 15 m sprint performance were observed from pre-trial (2.61 ± 0.32 s) to HT (2.67 ± 0.32 s; p =0.04), FT (2.71 ± 0.32 s; p =0.03) and post-trial (2.69 ± 0.32 s; p <0.04). Decreases in 30 m sprint performance were identified from pre-trial (4.49 ± 0.61 s) to FT (4.58 ± 0.61 s; p <0.01) and post-trial (4.61 ± 0.64 s; p <0.01), and from HT (4.51 ± 0.64 s) to FT (p =0.02) and post-trial (p =0.01).

INSERT FIGURE 5

Discussion

The aim of this study was to examine the influence of caffeine gum on the perceptual-cognitive and physical performance responses to the ET period of soccer. To realise our aim, we utilised a soccer match simulation protocol that is representative of the physiological responses to soccer match play combined with the novel application of VR systems to assess perceptual-cognitive skill performance. To this end, we provide the first report of perceptual-cognitive processing in response to 120 min of soccer specific exercise and demonstrate that reductions in reaction time were attenuated with concomitant reductions in composure following the ingestion of 200 mg caffeine gum immediately prior to the ET period.

Declines in reaction time (i.e., how long players dwelled on the ball before making a passing decision) were lessened when supplementing caffeine gum in this study. The drills completed on the VR system required participants to undertake varying soccer specific drills with reaction time measured through the total time to react to visual stimuli, process information, make decisions and respond appropriately to open tasks. A previous investigation found that 3 mg·kg^{-1} BM caffeine consumption significantly improved reaction times to pressing a button following fatiguing motor tasks, but no improvements in accuracy were identified (van Duinen et al., 2005). A separate investigation showed that 5 mg·kg^{-1} BM of caffeine ingestion decreased simple reaction time in response to a closed task involving responding to a visual stimulus while pushing on a key of a microcomputer (Souissi et al., 2021). However, although these studies appear to show increased reaction times during closed tasks, the present data are the first to demonstrate that caffeine enhances the speed of decision making during open soccer specific tasks. The ability to react quickly and make rapid and precise decisions concerning ball location, movements of team mates and opposing players is likely to deteriorate with increasing cognitive and physical fatigue. Diminished capacity to react to visual cues and process information rapidly might influence both the speed and accuracy of decision making and a player's capacity to react quickly to changing events on the pitch (Gantois et al., 2020). However, the current findings show that consuming caffeine gum potentially preserves cognitive function and a players' capability to make quick decisions in the latter stages of a prolonged simulated soccer match.

Caffeine gum significantly reduced composure (i.e., maintaining performance level despite increases in task difficulty) in the present investigation. Previous data shows that 6 mg·kg^{-1} BM of caffeine ingestion in a capsule form improved passing accuracy by 4.3% across a 90 min simulated soccer match (Foskett et al., 2009). However, passing performance remained unchanged following co-consumption of a 6.0% CHO electrolyte and 3.7 mg·kg^{-1} BM caffeine beverage 60 min prior to a simulated soccer match lasting 90 min (Gant et al., 2010). There is clear heterogeneity in the effects of caffeine on performance levels in the literature, and the current study shows that this may be related to the inability to maintain control despite increases in task difficultly. These reductions are possibly related to the reported side effects of 'jitteriness' and 'nervousness' that generally accompany acute caffeine administration (Sökmen et al., 2008). Another theory could relate to an increased arousal since caffeine appears to enhance arousal and vigilance by activating pathways that are associated with motivational and motor activity in the brain (Pickering & Kiely, 2018). Caffeine has been shown to influence arousal in a nature consistent with an inverted U-shape to suggest that arousal enhances performance until an optimal level is achieved beyond which increases are detrimental to performance (Doyle et al., 2016). Therefore, it might be that players reached a suboptimal level of arousal which in-turn diminished their ability to maintain performance despite increases in task difficulty. Given the translational accuracy of VR to 'real world' soccer environments (Wood et al., 2021), the current drills are likely to reflect a loss of composure under actual match conditions. Since there is a high probability of a penalty shootout after the ET period in major tournaments, whereby maintaining self-control in such a highly pressured situation remains a key challenge and priority, making decisions of whether caffeine gum is administered before ET requires careful consideration. Co-ingestion of caffeine (40 mg) with L-theanine (97 mg) helps to focus attention during cognitively demanding tasks (Giesbrecht et al., 2010); thus, the effects of these mixes should be investigated for their ability to modulate the anxiety inducing effects of caffeine.

The present study is the first to assess the influence of caffeine on physical performance during the ET period. No differences were identified for 15 and 30 m sprint performances following caffeine consumption, despite reductions over time. Similarly, caffeine ingestion has shown negligible ergogenic benefits on 20 m sprint performance following 200 mg of caffeine gum in university level soccer players (Ranchordas et al., 2018). Another study also demonstrated that a 6 mg·kg^{-1} BM dose of caffeine does not improve 15 m sprint times during a 90 min simulated protocol (Foskett et al., 2009). Despite evidence to suggest caffeine increases neurotransmitter release, motor unit firing rates, and dopaminergic transmission (Kalmar, 2005), this does not appear to translate to improved maximal sprint performance in soccer players. The potential that caffeine habituation influenced the results appears unlikely, since there is evidence to suggest that sprint performance does not appear to be impacted by caffeine habituation (Glaister et al., 2008). Additionally, because 11 out of 12 participants had lower weekly consumption versus normative data for UK based adult males (910 mg·week^{-1}; (Fitt et al., 2013) and all participants abstained from caffeine in the 48 h period prior to the trial, it is possible that the participants were overly sensitive to the physiological effects of caffeine. Thus, any effects that were present were probably not sufficient to elicit ergogenic changes to sprint performance. Finally, sprint tests at fixed time points may not be sensitive enough to detect potential performance enhancing effects of caffeine administration in critical periods of a game for the individual player. Thus, if caffeine is speculated to preserve performance via muscle glycogen sparring (Graham, 2001), enhanced intramuscluar Ca2+ (Jacobson et al., 1992), and Na+ and K+ regulation (Mohr et al., 2011), a certain (possibly severe) degree of fatigue and metabolic distbance may be required.

Caffeine failed to attenuate decrements in neuromuscular performance. A dose of 6 mg·kg^{-1} BM of caffeine consumed 60 min prior to performing a soccer specific exercise protocol improved jump performance by 2.7% (Foskett et al., 2009). A separate study found that co-ingestion of caffeine and CHO increased CMJ height versus solely CHO by 2.3% during simulated soccer (Gant et al., 2010). Previous work using 10 university level players adopting an identical absolute (200 mg) and relative dosage (~2.7 mg·kg^{-1} BM) of caffeine to the present study detected 2.2% improvements in CMJ performance (Ranchordas et al., 2018). The conflicting results between our research and other studies might be attributed to differences in dosage, timing and modes of consumption, and exercise modalities. The distinct participant characteristics (e.g., caffeine habituation status, responders vs non responders etc.) might also explain differences in that there are those that respond positively to caffeine, while others demonstrate minimal to no improvements (Davis & Green, 2009). Additionally, between-trial CV measures were as high as 7% for neuromuscular performance measurements in the current research, indicating the variation may have been too high to detect a small change.

Although plasma caffeine responses to gum ingestion were not measured in the present study, available pharmacokinetic data demonstrate significant elevations in plasma caffeine concentrations within ~15 minutes of ingestion of a 200 mg dose as used in the present study (Kamimori et al., 2002). Caffeine gum consumed at HT might have provided additional ergogenic advantages, although a decision was taken to isolate the effects of caffeine gum to the ET period to establish whether acute administration in the short 5 min time window could attenuate reductions in performance during ET. Female players were not included in the current study since comparisons between sexes are difficult given the physiological differences, and accurate menstrual cycle phase verification would present a logistical challenge beyond the potential of this study (McNulty et al., 2020). The soccer match simulation was also solely validated in male players (Harper et al., 2016). It is also prudent to acknowledge that participants (5.15 $g \cdot kg^{-1}$ BM) failed to achieve the 6-8 $g \cdot kg^{-1}$ BM CHO target, and performance may not have been maximised due to lower muscle glycogen availability. However, no differences were observed in CHO intake between conditions.

Practical applications

The enhanced speed of delivery associated with caffeine gum might provide a practical ergogenic solution; especially given the limited time for nutritional interventions in the short 5 min break at 90 min, with pragmatic and palatable delivery formats likely to facilitate player engagement. Improvements in reaction speed are likely to provide advantages concerning anticipation and responding quickly to rapidly evolving scenarios on the pitch. However, maintaining composure and self-control is crucial for highly pressured situations and techniques requiring fine motor skills or refined judgment. Supplementation might be considered individually in that those benefitting from caffeine ingestion might consider consumption during competition, while those displaying ergolytic effects should discontinue supplementation. Given the high prevalence of caffeine use in soccer (Tallis et al., 2021), it is plausible to assume that players might consume caffeine prior to matches that have the potential to progress to ET. However, emerging evidence suggests that caffeine's erogenicity is not reduced following pre exercise ingestion nor habituation, suggesting both low and high habitual caffeine users can benefit from pre competition caffeine supplementation and without the need for caffeine withdrawal prior to exercise (Carvalho et al., 2022).

Figure Captions

Figure 1 Change from pre to post trial for each player and the mean (± SD) for each VR drill (Rondo scan, Color combo, Head smart, Shoulder sums and Pressure pass) and process score (passing accuracy). Dashed lines with open circles represent the mean.

Figure 2 Change from pre to post trial for each player and the mean (± SD) for process score (composure, reaction time and adaptability), and the overall Rezzil Index. *Denotes significant condition and time interaction (p <0.05). [a]Represents significant difference from pre-trial (p <0.05). Dashed lines with open circles represent the mean.

Figure 3 Drop-jump derived neuromuscular performance (RSI) across timepoints (pre-trial, HT, FT and ET). Data are presented as change (Δ%) relative to pre-trial.

Figure 4 CMJ-derived neuromuscular performance (vertical jump height, absolute and relative PPO, and negative vertical displacement) across timepoints (pre-trial, HT, FT and ET). Data are presented as change (Δ%) relative to pre-trial.

Figure 5 Sprint performance (15 and 30 m) across timepoints (pre-trial, HT, FT and ET). [a-b]Represents significant difference from pre-trial and HT, respectively. Data are presented as change (Δ%) relative to pre-trial.

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Declaration

The authors report no competing interests directly applicable to the content of this manuscript. No financial support was provided for this study. The findings of this study do not represent an endorsement of the supplement by the authors, nor was any research input sought from or provided by the product manufacturer.

Protocol

The trial was pre-registered on the Open Science Framework (https://osf.io/byjqh)

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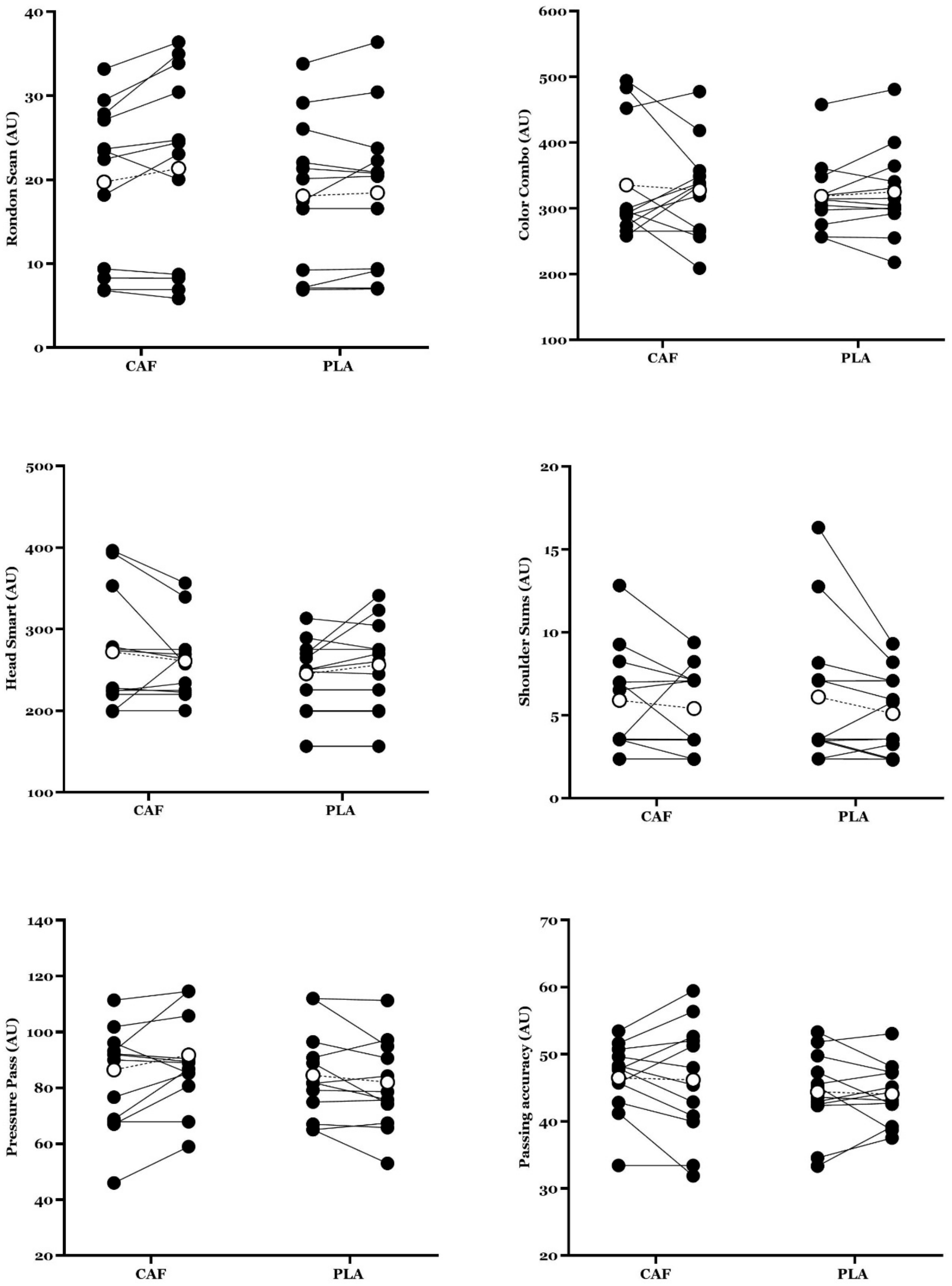
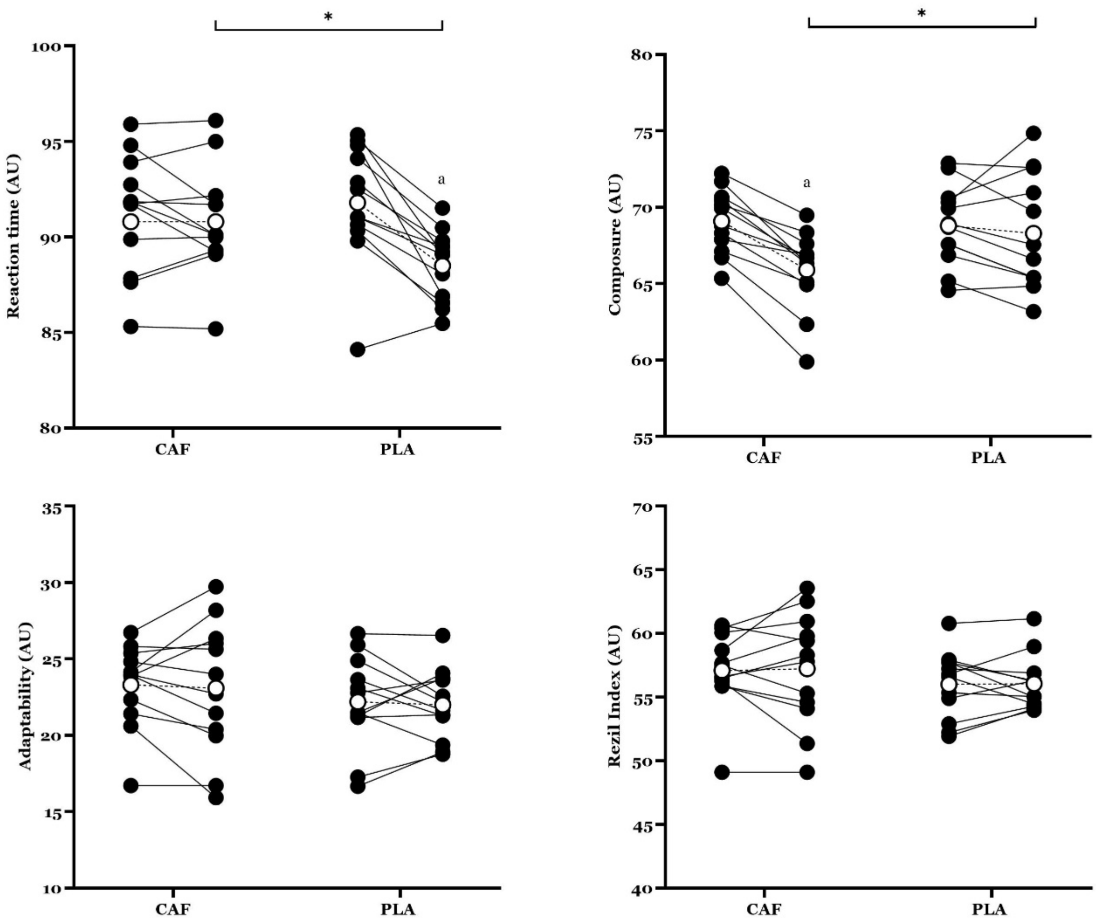
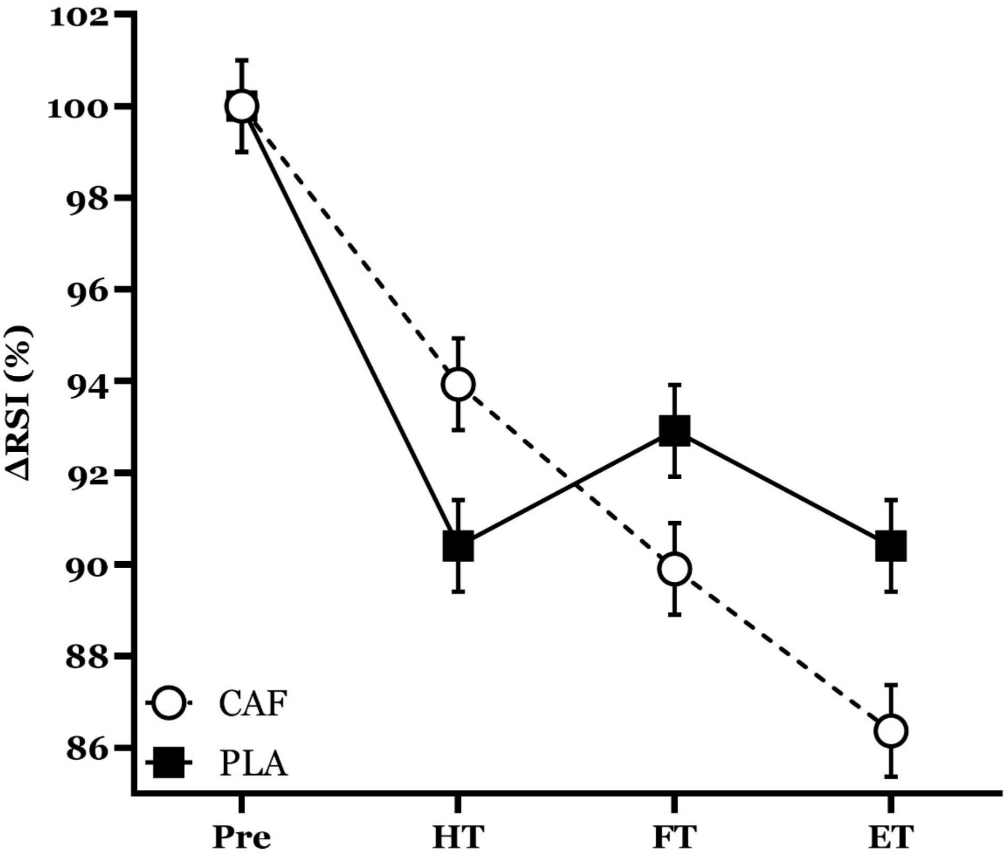
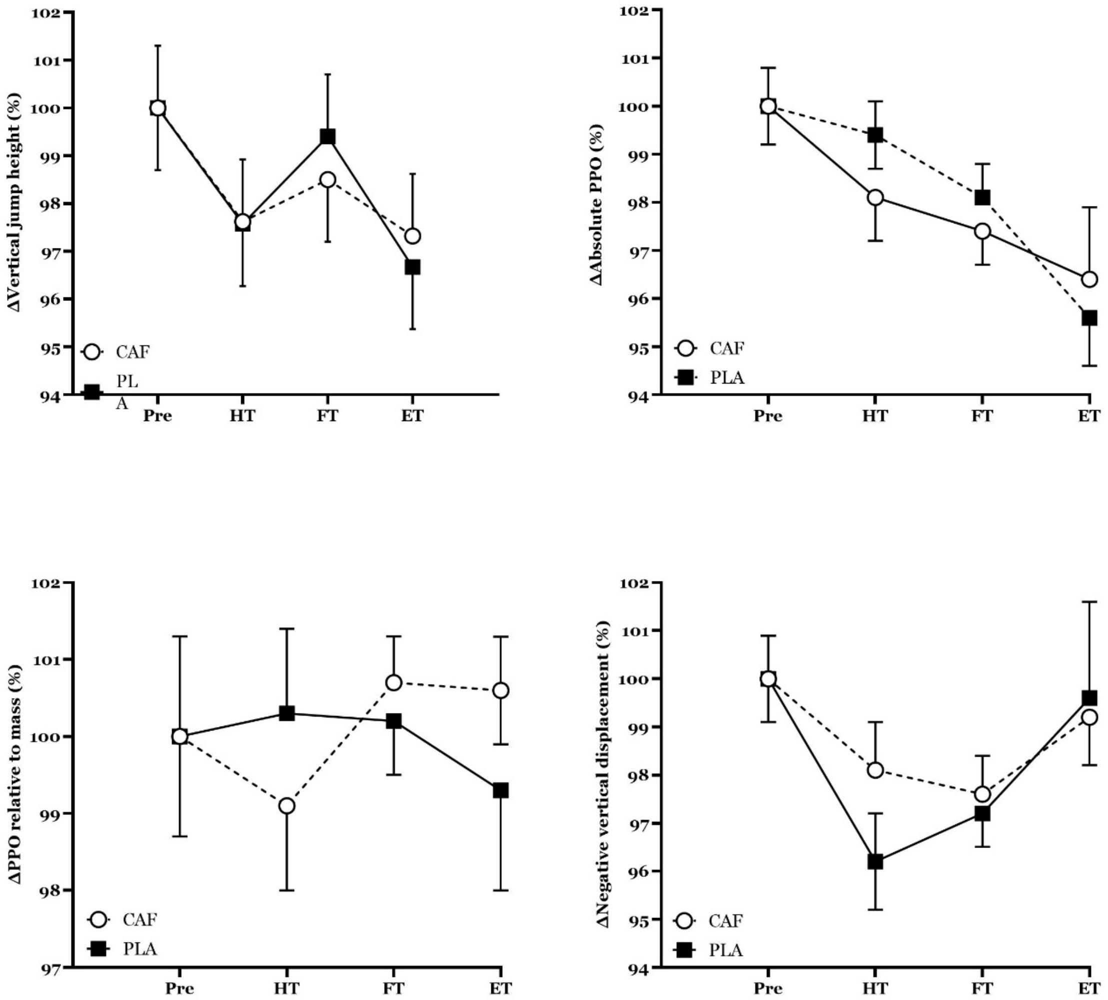


Rondon Scan (AU)
0
10
20
30
40
Color Combo (AU)
100
200
300
400
500
600
Head Smart (AU)
100
200
300
400
500
Shoulder Sums (AU)
0
5
10
15
20
Pressure Pass (AU)
20
40
60
80
100
120
140
Passing accuracy (AU)
20
30
40
50
60
70
CAF
PLA


*
Reaction time (AU)
100
95
90
85
80
a
CAF
PLA
*
Composure (AU)
80
75
70
65
60
55
a
CAF
PLA
Adaptability (AU)
35
30
25
20
15
10
CAF
PLA
Rezil Index (AU)
70
65
60
55
50
45
40
CAF
PLA


ΔRSI (%)
102
100
98
96
94
92
90
88
86
CAF
PLA
Pre
HT
FT
ET



ΔVertical jump height (%)
102
101
100
99
98
97
96
95
94
Pre
HT
FT
ET
CAF
PL
A
ΔAbsolute PPO (%)
102
101
100
99
98
97
96
95
94
Pre
HT
FT
ET
CAF
PLA
ΔPPO relative to mass (%)
102
101
100
99
98
97
Pre
HT
FT
ET
CAF
PLA
ΔNegative vertical displacement (%)
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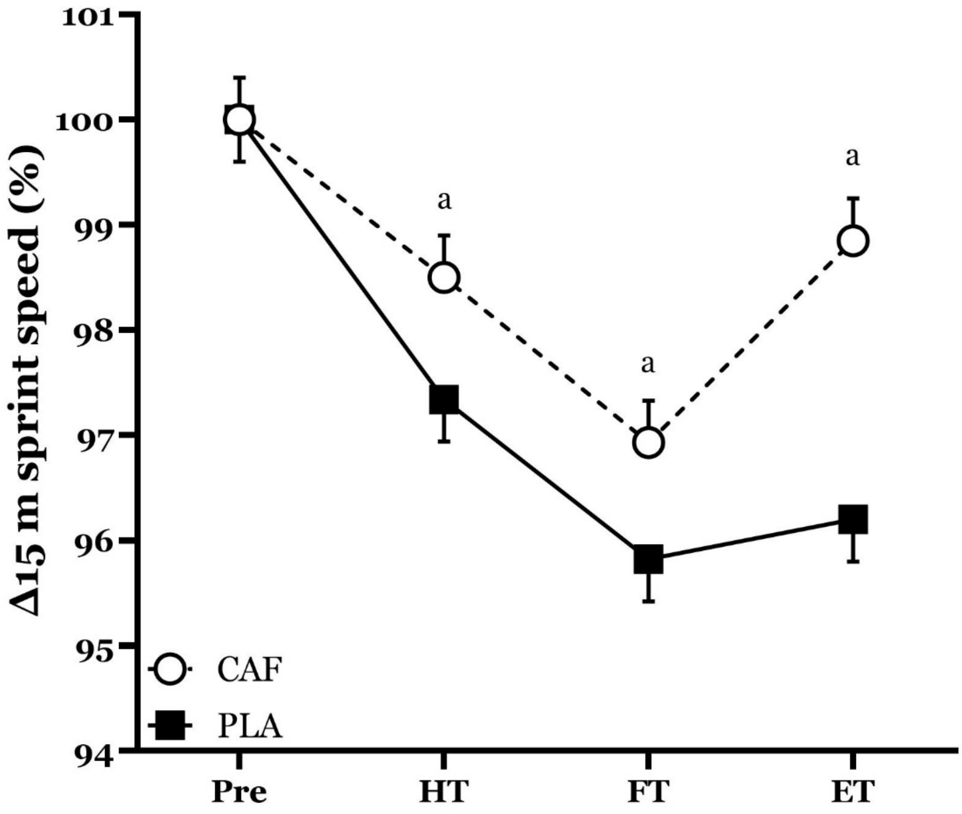
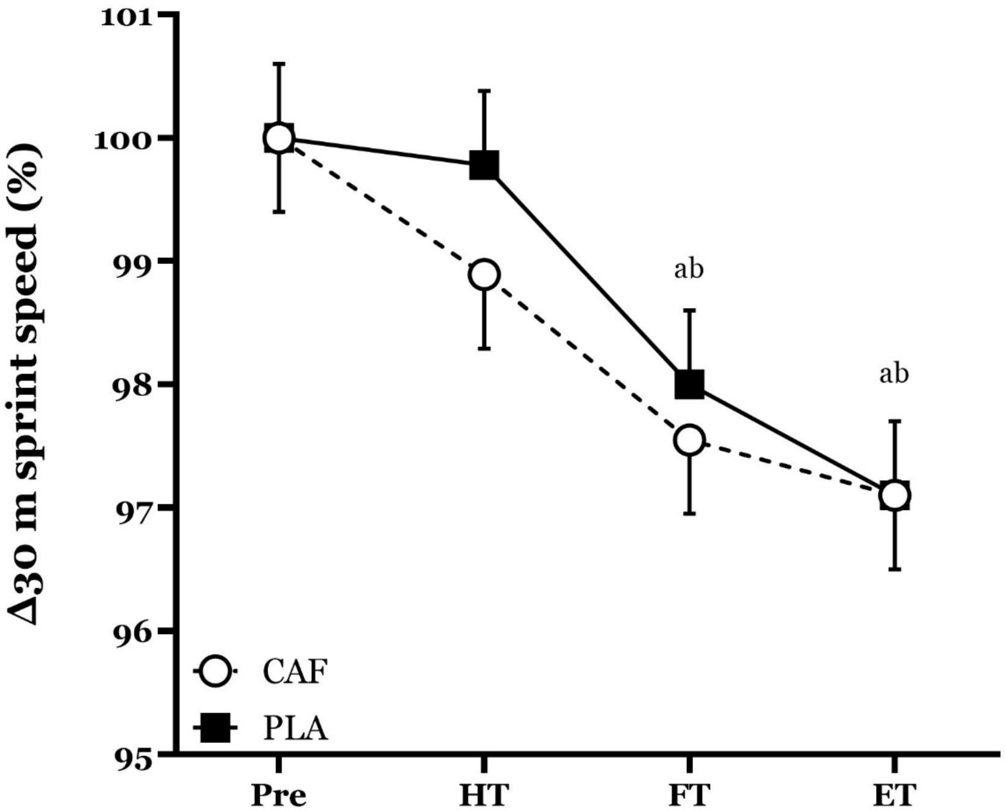
HT
FT
ET
CAF
PLA


Δ15 m sprint speed (%)
101
100
99
98
97
96
95
94
a
a
a
CAF
PLA
Pre
HT
FT
ET


Δ30 m sprint speed (%)
101
100
99
98
97
96
95
ab
ab
CAF
PLA
Pre
HT
FT
ET

628

Table 1. Descriptions of the virtual reality drills

Drill	Description
Rondo scan	Participants were presented with 11 virtual mini goals (width: 2-m x height: 1-m) aligned with ball feeder machines arranged in a 180° arc. A ball was fired randomly at the participant from one of these ball feeders, and they then had to pass the ball into a randomly highlighted goal from approximately 9 m. The participants had a set time from ball release to pass the ball into the goals, before the opportunity to complete the task elapsed, with less time provided throughout levels (level 1 = 5 s, Level 2 = 4s, Level 3 = 3s). The performance score for the rondo scan was derived from the number of balls passed into the correct goal and proximity from the centre of the goal in a three-minute time limit.
Color combo	Each half of the players' virtual boots were coloured a different colour. Coloured balls were then fired out of four virtual ball feeder machines from 10-m, and players had to intercept each ball with the matched coloured part of their virtual boot (e.g., red balls needed to be intercepted with the outside of the right foot). In addition, balls that were silver in colour could be intercepted by any side of any foot and gave the player three points. Balls that were grey were to be avoided or a 'life' would be lost. The drill progressed through five levels that gradually increase in speed (from 25 to 51 km/h) and number of balls presented. The performance score for the colour combo was derived from the number of correct balls intercepted with the correct side of the foot, the number of silver balls intercepted, and the number of grey balls avoided. This drill carried on indefinitely until participants lost three 'lives' by touching the grey balls.
Head smart	Players were presented with several virtual players (coloured red and yellow). Opposing red players were located at the forefront and were presented as an obstacle and the yellow teammates were positioned behind and presented as the target. The ball was served high out of one of several virtual ball feeders placed at varying locations surrounding the participant. As a ball was served into the participant, the objective was to header the ball accurately over the opposing players and into a large target area. As the drill progressed to Level 2, players were required to more accurately header the ball to highlighted teammates in varying locations. The performance score for the Head smart was derived from the accuracy of the header (i.e., how close it was to the target area/highlighted players).
Shoulder sums	Players were faced with four full sized (width: 7.32 x height: 2.44m) virtual goals with virtual ball feeders between each goal. As a ball was passed to the participant, several players (coloured red and yellow) appeared behind them. On-screen instructions asked the participant to count the total number of players by checking over both shoulders and then pass the ball from 9-m to the segment of the goal that matches the number of players. As the drill progresses to Level 2, players were required to only count the number of red or yellow players that matched the colour of the ball coming toward them (e.g., only yellow players were counted if the ball was yellow). The performance score for the shoulder sums was derived from the number of correct sums and the accuracy of the pass (i.e., how close it was to the centre of the goal) into the related goal.
Pressure pass	This was a dynamic passing drill where each player was surrounded by three teammates (in yellow) who were marked by three opposing red players. The opposing players moved toward and away from the participant creating dynamic passing angles and passing opportunities. Players were required to pass to all three teammates in yellow, in any order, without hitting the opposing players. If an opposing player was hit, then the number of teammates already hit was reduced by one. The performance score for the pressure passing drill was derived from the longest passing streak achieved and the accuracy of these passes (i.e., how close the ball hit to the centre of the player).

Table 2. Physiological responses throughout 120 min of soccer-specific exercise across conditions

	Pre-trial	0–15 min	15–30 min	30–45 min	45–60 min	60–75 min	75–90 min	90–105 min	105–120 min
BLa (mmol·L^{-1})									
Caffeine	1.4 ± 0.4	7.1 ± 2.5[a]	6.2± 2.0[a,b]	6.3 ± 2.3[a]	5.6 ± 2.1[a,b,c,d]	5.3 ± 2.4[a,b,c,d]	5.0 ± 1.8[a,b,c,d]	4.7 ± 1.9 [a,b,c,d]	4.5 ± 1.9 [a,b,c,d,e,f]
Placebo	1.3 ± 0.5	6.7 ± 3.3[a]	6.4 ± 3.2[a,b]	6.5 ± 3.5[a]	5.0 ± 2.0[a,b,c,d]	4.5 ± 1.7[a,b,c,d]	4.3 ± 1.5[a,b,c,d]	4.4 ± 1.7 [a,b,c,d]	3.8 ± 1.6 [a,b,c,d,e,f]
BG (mmol·L^{-1})									
Caffeine	5.3 ± 0.8	5.1 ± 1.1 [a]	4.9 ± 0.6 [a]	5.0 ± 0.7	5.0 ± 0.6 [a]	4.5 ± 0.5 [a,c,d,e]	4.5 ± 0.5 [a,c,d]	4.5 ± 0.5 [a,b,c,d,e]	4.8 ± 1.0 [a]
Placebo	5.0 ± 1.1	5.0 ± 0.8 [a]	5.0 ± 0.9 [a]	5.1 ± 0.7	4.7 ± 0.7 [a]	4.5 ± 0.5 [a,c,d,e]	4.6 ± 0.7 [a,c,d]	4.3 ± 0.5 [a,b,c,d,e]	4.5 ± 1.0 [a]

	0–15 min	15–30 min	30–45 min	45–60 min	60–75 min	75–90 min	90–105 min	105–120 min
HRmean (b·min^{-1})								
Caffeine	166 ± 10	167 ± 10	167 ± 9	164 ± 9	166 ± 8[b,c,d]	163 ± 9[b,c,f]	161 ± 10[b,c,d,f]	162 ± 10[b,c,d,f]
Placebo	169 ± 10	168 ± 10	168 ± 9	165 ± 9	166 ± 8[b,c,d]	165 ± 9[b,c,f]	164 ± 10[b,c,d,f]	164 ± 11[b,c,d,f]
HRpeak (%)								
Caffeine	95 ± 5	94 ± 5[b]	93 ± 5 [b]	93 ± 5[b]	92 ± 4[b]	93 ± 5[b]	93 ± 4[b]	92 ± 4[b,d,h]
Placebo	95 ± 4	94 ± 4[b]	93 ± 4[b]	95 ± 4[b]	93 ± 4[b]	92 ± 4[b]	93 ± 4[b]	92 ± 4[b,d,h]
RPE-O (au)								
Caffeine	35 ± 17	42 ± 19[b]	47 ± 18[b,c]	48 ± 16[b,c]	55 ± 20[b,c,d,e]	61 ± 21[b,c,d,e,f]	70 ± 26[b,c,d,e,f,g]	80 ± 27[b,c,d,e,f,g,h]
Placebo	31 ± 20	38 ± 23[b]	44 ± 24[b,c]	45 ± 19[b,c]	51 ± 23[b,c,d,e]	57 ± 26[b,c,d,e,f]	65 ± 25[b,c,d,e,f,g]	74 ± 29[b,c,d,e,f,g,h]
RPE-B (au)								
Caffeine	34 ± 16	40 ± 17[b]	45 ± 20[b,c]	47 ± 18[b,c]	52 ± 20[b,c,d]	57 ± 2121[b,c,d,e]	64 ± 26[b,c,d,e,f,g]	73 ± 26[b,c,d,e,f,g,h]
Placebo	27 ± 17	37 ± 25[b]	43 ± 22[b,c]	42 ± 22[b,c]	51 ± 23[b,c,d]	56 ± 2421[b,c,d,e]	66 ± 25[b,c,d,e,f,g]	71 ± 29[b,c,d,e,f,g,h]
RPE-L (au)								
Caffeine	35 ± 21	42 ± 18[b]	48 ± 19[b,c]	47 ± 19[b,c]	56 ± 20[b,c,d]	64 ± 23[b,c,d,e]	73 ± 25[b,c,d,e,f,g]	82 ± 27[b,c,d,e,f,g,h]
Placebo	23 ± 16	34 ± 24[b]	42 ± 27[b,c]	48 ± 21[b,c]	56 ± 25[b,c,d]	63 ± 23[b,c,d,e]	72 ± 25[b,c,d,e,f,g]	84 ± 28[b,c,d,e,f,g,h]

Data are reported as mean ± SD. [a–h] Indicates significant differences from Baseline to E7 ($p \leq 0.05$), respectively. Abbreviations: E – Epoch, BLa – Blood Lactate, BG – Blood Glucose, HR – Heart Rate, RPE-O – Rate of Perceived Exertion-Overall, RPE-B – Rate of Perceived Exertion-Breathing, RPE-L – Rate of Perceived Exertion-Legs.

Table 3. Haematological and hydration responses across 120-min of soccer-specific exercise across conditions

	Pre-trial	**HT**	**FT**	**Post-trial**
Haemoglobin (g·L⁻¹)				
Caffeine	153.0 ± 14.3	153.9 ± 8.4	151.5 ± 6.6	149.9 ± 6.6
Placebo	153.7 ± 10.3	152.3 ± 5.8	150.0 ± 8.4	149.8 ± 5.3
Haematocrit (%)				
Caffeine	45.9 ± 3.7	44.9 ± 3.2*	44.4 ± 2.2*	44.6 ± 3.7*
Placebo	45.0 ± 3.1	44.7 ± 1.8*	43.8 ± 2.5*	43.1 ± 3.2*
Blood volume changes (%)				
Caffeine	–	0.5 ± 2.9	1.1 ± 4.1	2.4 ± 4.4
Placebo	–	0.3 ± 1.2	1.8 ± 2.5	2.1 ± 2.0
Plasma volume changes (%)				
Caffeine	–	1.9 ± 4.5	3.8 ± 4.4	5.7 ± 4.4
Placebo	–	1.8 ± 1.7	3.6 ± 2.8	5.4 ± 2.2
	Pre-trial	**Post-trial**		
Urine osmolality (mOsm·kg⁻¹)				
Caffeine	632 ± 225	708 ± 235		
Placebo	588 ± 317	663 ± 287		

Data are reported as mean ± SD. * Indicates significant difference from pre-trial ($p \leq 0.05$). Abbreviations: HT – Half Time, FT– Full-time. Blood and plasma volume changes are presented as change (Δ%) relative to pre-trial.