Effect of Caffeine on Reactive Agility Time When Fresh and Fatigued

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ABSTRACT

DUVNJAK-ZAKNICH, D. M., B. T. DAWSON, K. E. WALLMAN, and G. HENRY. Effect of Caffeine on Reactive Agility Time When Fresh and Fatigued. *Med. Sci. Sports Exerc.*, Vol. 43, No. 8, pp. 1523–1530, 2011. **Purpose**: This study examined the effects of acute caffeine ingestion on agility performance and decision-making accuracy after simulated team-sport exercise. **Methods**: Using a randomized, double-blinded, counterbalanced design, 10 moderately trained male team-sport athletes ingested either caffeine (6 mg·kg^{-1}) or placebo (dextrose) 60 min before completing an 80-min (4 × 20 min) simulated team-game, intermittent running protocol. Interspersed between each exercise quarter was a reactive agility test (RAT) consisting of five trials where measures of total time (TT), reactive agility (RA) time, decision time (DT), movement time (MT), and decision-making accuracy were obtained. **Results**: Although there were no significant differences between trials for TT ($P = 0.54$), RA time ($P = 0.84$), MT ($P = 0.89$), or DT ($P = 0.91$), caffeine ingestion resulted in consistently faster TT (2.3%), RA time (3.9%), MT (2.7%), and DT (9.3%) scores compared with placebo (significant main effect for condition for RA time, TT, DT, and MT; $P < 0.05$). These faster times were supported by qualitative analyses of "almost certain benefit" and large effect size (ES) for RA (quarter 3) and "likely" to "very likely benefits" and moderate to large ES for TT (precircuit and quarters 1, 2, and 4) and RA time (precircuit and quarters 1, 2 and 4). A "likely benefit" and moderate ES was found for MT (quarters 1 and 3), but the effect of caffeine on DT was largely "unclear," with small ES and only a "likely" chance of benefit (quarters 2 and 3). Improved decision-making accuracy (3.8%) after caffeine ingestion was supported by a "likely benefit" (quarter 1) and large ES (quarters 1 and 4). **Conclusion**: Caffeine ingestion may be beneficial to RA performance when athletes are fresh and fatigued. **Key Words:** ERGOGENIC AID, REACTION TIME, MOVEMENT TIME, TEAM SPORTS

The potential ergogenic benefits of caffeine have been promoted in recent years, with scientific research increasing after the removal of caffeine from the World Anti-Doping Authority's list of banned substances in January 2004. The common use of caffeine as an everyday stimulant to improve alertness and attentional focus, coupled with its relatively low cost and ease of administration, has made it a popular supplement for improving athletic performance (13,14,25,31).

According to two review articles, most research to date has investigated the effects of caffeine ingestion on endurance exercise performance (12,20). Significant ergogenic benefits have consistently been shown in measures of time to exhaustion (3,10,21,22), decreased times to complete a set distance (6), and in the lowering of an athlete's perceived exertion (13). Improvements in short-term high-intensity exercise performance have also been reported after caffeine ingestion (1,7,9,15). Recently, research attention has examined repeated sprint ability in protocols aiming to simulate team-sport game demands, with results suggesting improved mean power outputs and faster sprint times after caffeine ingestion (8,33). Although studies have investigated the effects of a wide range of caffeine doses (1.5–13 mg·kg^{-1}) on performance, 6 mg·kg^{-1} has consistently been reported to result in similar ergogenic effects commonly associated with higher doses (9–13 mg·kg^{-1}) (7,21,32). Consequently, this dose is often used by researchers in performance studies, as reported in a meta-analysis by Doherty and Smith (13). Furthermore, no benefit has been reported in taking multiple doses of caffeine during exercise performance, as opposed to a single dose before performance (11).

The ergogenic effects of caffeine may be associated with the blocking of adenosine receptor sites, which in turn produces a stimulatory effect on the CNS (18,19,31). Improved neural firing rates, reductions in feelings of fatigue and effort, and enhanced alertness and concentration have been reported after caffeine ingestion (18,19), with these effects improving psychomotor performance (26,29,36,37). Despite the importance of maintaining alertness and attentional focus, particularly when fatigued in team-sport settings, there exists a lack of research investigating sport-specific reaction time. Some studies have supported the use of caffeine to enhance simple and choice reaction times but used only

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simple hand or finger responses in their test protocols (23,27). The lack of a sport-specific response task significantly affects the ecological validity of these studies, particularly in the application of these results to competitive sport settings. Of relevance to team-sport performance, caffeine ingestion has been found to improve skilled performance accuracy (17,35).

Typical movement patterns in field-/court-based sports involve many changes of direction, commonly called *agility*. However, the use of the term *agility* to describe both preplanned, directional sprinting, as well as movements in response to an external stimulus (player or ball) has created some confusion in the literature. The importance of both change of direction speed and perceptual and decision-making ability to agility performance, as outlined by Young et al. (39), has lead to the recent defining of agility as "a rapid whole-body movement with change of velocity or direction in response to a stimulus" (34). Two studies to date have investigated the effects of caffeine ingestion on preplanned, directional sprints, with results being equivocal (28,35). Lorino et al. (28) found no improvement in total time (TT) to complete a proagility run after ingesting 6 $mg \cdot kg^{-1}$ body mass (BM) of caffeine 1 h before exercise. In contrast, Stuart et al. (35) reported that caffeine ingestion (6 $mg \cdot kg^{-1}$ BM) resulted in a 2.2% improvement in mean performance across three separate agility sprints performed in a zigzagging manner. A limitation with these studies was that both used preplanned movement tests, which required no decision to be made by participants to initiate the movement response (34). Further studies are needed to assess the effect of caffeine on agility where the performance requires both a perceptual and a physical response. An improvement in central stimulation, as well as reduced feelings of fatigue and effort, could improve an athlete's ability to maintain vigilance and skill level, both during the early and final stages of team-game performance. Therefore, the primary aim of this study was to investigate the effect of ingesting a single 6-$mg \cdot kg^{-1}$ dose of caffeine on reactive agility (RA) time before, during, and after an 80-min team-game exercise simulation. A secondary aim was to evaluate the decision-making accuracy of athletes with caffeine ingestion when fresh and fatigued.

METHODS

Participants. Ten moderately trained (7.6 ± 2.7 $h \cdot wk^{-1}$) male athletes from amateur and semiprofessional team-sports were recruited (mean ± SD: age = 21.6 ± 2 yr, height = 183.2 ± 5.6 cm, body mass = 80.1 ± 5.3 kg). The study was approved by the human research ethics committee of the University of Western Australia, and all participants provided written informed consent before participation.

Experimental design. Participants performed an 80-min (4 × 20 min) simulated, team-game exercise protocol interspersed with five sets of an RA test (RAT), on two separate occasions. After a familiarization session for both the team-game exercise circuit and RAT, two experimental trials were performed in a randomized, double-blinded, counterbalanced manner, with a minimum of 1 wk between sessions. Participants maintained a similar diet and presession routine and refrained from intense exercise for 24 h before each experimental trial. They were provided with an adapted list of caffeine-containing foods, beverages, and nonprescription pharmaceuticals, which they were advised to abstain from consuming in the 24-h period preceding each trial. Participants also did not consume any food or fluids in the 30 min before reporting to the laboratory on testing days.

At 90 min before each trial, athletes were given a muesli bar (Nestle® Uncle Tobys®, Wahgunyah, Victoria, Australia; 540 kJ total energy; 3.9 g of fat, 1.8 g of protein, and 20.7 g of CHO) and 500 mL of water to consume within the next 30 min. One hour before testing, participants ingested opaque gelatin capsules (Melbourne Food Ingredient Depot, East Brunswick, Victoria, Australia) containing either a 6-$mg \cdot kg^{-1}$ dose of anhydrous caffeine (Nō-Dōz®; Key Pharmaceuticals Pty. Ltd., Rhodes, NSW, Australia) combined with 0.55 g of a lactose/sucralose artificial sweetener (Splenda®; Johnson & Johnson Pacific Pty. Ltd., Ultimo, NSW, Australia) or a placebo dose containing just 0.55 g of the artificial sweetener. Opaque capsules were used as a method of blinding participants to the substance ingested, and artificial sweetener was combined in the caffeine dose to mask any possible after taste. After resting for 50 min, participants commenced the pretrial warm-up.

Reactive agility test. Before commencing the first exercise quarter and then at four stages after each 20-min period, RA time was measured. Four pairs of electronic, single-beamed, infrared timing gates (Fitness Technologies, Adelaide, Australia) were positioned as shown in Figure 1. The timing gates were used to assess the ability of participants to react to a stimulus in the shortest time possible, moving to either the left or right after chasing a "life-sized opponent" in a defensive "pursuit" scenario that typically

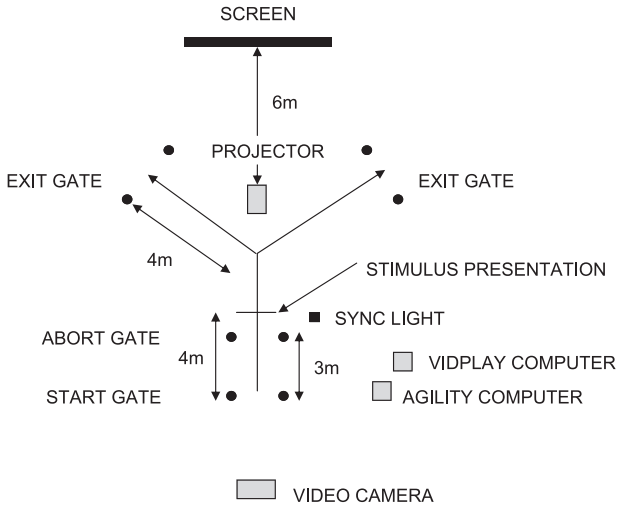

FIGURE 1—Schematic diagram of the RAT.

occurs in team sports. The agility protocol used in this study is similar in design to that used by Farrow et al. (16); however, the actual movements and cues used during the testing protocol were different.

Participants began each trial 20 cm behind the starting gates before running at maximum speed in a straight line toward a mounted projection screen displaying the visual image. After passing through the abort gates, positioned 3 m from the start line, the player (opponent) in the video began to change direction. Participants had to reach the abort gates in an individual, predetermined (abort) time, which was based on their fastest 4-m sprint time. This time was used to ensure that each participant was completing the RAT at very near his individual maximum speed, similar to that performed during a match-play situation. The test concluded when participants passed through the left or right exit gates, after responding to the video opponent. The inclusion of a delay time (designed to allow for a degree of system latency) and an abort time meant that the presentation of the first lateral foot movement of the video opponent (stimulus point) was always within a 1-m distance after the abort gates, despite varying participant sprinting speeds.

Participants were instructed to run at maximum speed from the start to the exit gates and to not attempt to anticipate the movement direction of the video opponent, but to react to the stimuli as they would in a game situation. Each RAT consisted of five trials, with participants performing a trial every minute. Participants were informed that there would be five potential directional changes, including fakes. The test involved the randomized presentation of two left and two right changes of direction with the remaining trial being a fake movement (no turn), which was automatically excluded from the final performance measure analysis. Inclusion of the fake movement assisted in preventing participants from anticipating movement direction. The order of the five directional changes was also randomly determined, and to decrease the likelihood of test familiarity and anticipation, participants did not view each other's trials.

Two interfaced, desktop computers (Intel® Pentium® 4 CPU 2.79 GHz; University of Western Australia, Perth, Australia), one containing specific agility software (agility) and the other containing video playback software (vidplay), were connected to a roof mounted projector (Epson®, model EMP – 1715) and interfaced with the electronic timing gates to present the prerecorded video stimuli. A videocamera (Sony® miniDV, model DCR-VX2100E) was positioned 3 m behind the start gate to capture the change of direction movement of participants in relation to the movement of the video opponent. Two red lights were synchronized with the timing gates to illuminate when the start gate had been triggered and then to turn off when one of the two exit gates was breached. These lights were essential in the *post hoc* review of video footage, allowing for a clear distinction of the beginning and end of each trial.

A video footage (50 Hz) of each experimental trial was reviewed in audio–video interleave format using video analysis software (Silicon Coach, Dunedin, New Zealand). Performance measures were generated through frame by frame analysis (within ±20 ms) of the video recordings. The time taken from the stimulus point in the video image to the first lateral foot movement in the leg initiating the change of direction was defined as decision time (DT), whereas movement time (MT) was observed as the time from this initial foot movement to the breaching of the left or right exit gate. Both DT and MT were combined to produce RA time, a measure of true agility performance (from the point of stimulus presentation to the completion of the change of direction). The TT to complete the test from start to exit gate was automatically recorded via the timing gates through customized agility software (to the nearest 0.001 s). The time point (i.e., pre, quarters 1 and 2 (Q1 and Q2), etc.) average for these performance variables consisted of the average for the four applicable trials in each RAT. Decision-making accuracy was defined as, firstly, whether a participant made the correct decision when presented with the stimulus and, secondly, whether the athlete moved through the correct finish gate. Trials containing an incorrect decision or an apparent indecision about the movement direction were excluded before final analysis (n = 96, of a total of 600).

Simulated team-game protocol. The simulated team-game circuit was performed outdoors on grass (Fig. 2) and consisted of 80 min (4 × 20-min quarters) of intermittent running, with 10 min of recovery between each quarter, in which the five sets of the RAT were performed. The exercise circuit used was described by Bishop et al. (4), and this is designed to replicate typical intermittent exercise demands and movement patterns observed in team sports. The 20-min quarter consisted of 20 × 1-lap repetitions, with a lap beginning each minute. The individual repetitions involved three maximal sprints, a 12-m change of direction section, one striding effort, two periods of jogging, and three

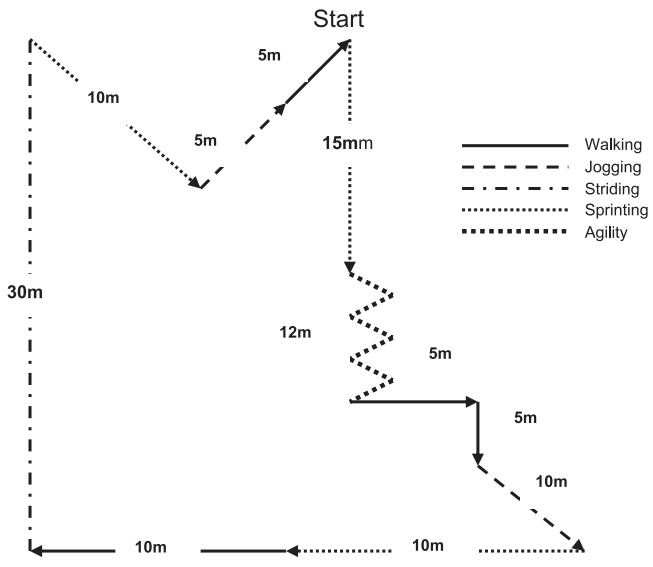

FIGURE 2—Simulated team-game exercise circuit.

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periods of walking. The total distance per repetition was 117 m, equating to a total distance of 9360 m during the 80-min period (80 laps). Individual circuits were completed in 38–48 s, allowing between 12- and 22-s rest before commencing another repetition. Participants were considered "fresh" before Q1, "fatigued" at the end of Q4, and in an "increasing state of fatigue" from Q1 to Q3. Time to complete every fifth circuit was measured and averaged for each exercise quarter to determine consistency between experimental treatments. Athletes exercised in groups of two to five to provide each other with verbal and physical motivation, which accompanied the verbal encouragement given by researchers. Ambient temperature and relative humidity were determined outdoors using a digital temperature and humidity monitor (model QuestTemp °32; Quest Technologies, Oconomowoc, WI), whereas wind speed was measured using a digital anemometer (model AM-4203HA; Lutron, Taipei, Taiwan). Mean ± SD dry and wet bulb temperatures, relative humidity, and wind speed across all trials were 17.4°C ± 1.4°C, 14.6°C ± 1.6°C, 45% ± 12%, and 5.3 ± 4.0 $km \cdot h^{-1}$, respectively. Participants were given 125 mL of water to consume before and after each 20-min exercise quarter.

HR and RPE measures. HR (Polar Electro Oy, Kempele, Finland) and RPE based on the Borg (5) scale (from 6 to 20) were obtained before the pretrial warm-up, before the start, and then immediately after completion of each 20-min exercise quarter.

Posttest questionnaire. After completing each exercise trial, participants were required to identify which experimental treatment (caffeine or placebo) they believed they had received during the session. The reasons for their choice, as well as any adverse effects from the treatments, were documented.

Statistical analyses. Before the performance of the two-way ANOVA, the data were screened for normality, and the equality of variance in the differences between levels of the repeated measures was confirmed by the Mauchly sphericity test. Dependent variables (TT, DT, MT, RA time, HR, and RPE) were analyzed using a five (time) by two (condition), two-way repeated-measures ANOVA. Where appropriate, Bonferroni *post hoc* comparisons were used. Average times to complete every fifth circuit in each exercise quarter, for each treatment condition, were analyzed using a four (time) by two (condition), two-way repeated-measures ANOVA. Statistical significance was set at $P \leq 0.05$ for all analyses, and data were analyzed using SPSS (Version 13.0 for Windows; SPSS, Inc., Chicago, IL). Cohen *d* effect sizes (ES) and thresholds (<0.5, small; 0.5–0.79, moderate; ≥0.8, large) were also used to identify trends in the performance data. Only moderate to large effects are reported.

Further analysis was conducted to identify the smallest worthwhile change in performance scores between the caffeine and placebo trials, using the method outlined by Batterham and Hopkins (2). This approach represents a contemporary method of data analysis that uses confidence intervals to calculate the probability that an effect is clinically beneficial, trivial, or harmful (2). The smallest worthwhile value of change was set at 0.2 (outcome in Cohen units), representing the hypothetical, smallest change in RA time that would benefit the athlete. Where the chance of benefit and harm were both calculated to be ≥5%, the true effect was deemed unclear (2). When clear interpretation was definitively possible, a qualitative descriptor was assigned to the following quantitative chances of benefit: 25%–75%, benefit possible; 75%–85%, benefit likely; 95%–99%, benefit very likely; >99%, benefit almost certain (2).

RESULTS

Simulated team-game protocol. All results are presented as mean ± SD. Results for the exercise circuit times showed that exercise intensities for each quarter were similar between conditions (interaction effect: $F_{3,27} = 0.226$, $P = 0.878$) and over time ($F_{3,27} = 0.720$, $P = 0.549$). Nonetheless, whereas there were no significant interaction effects for RPE ($F_{3,27} = 1.638$, $P = 0.204$) or HR ($F_{3,27} = 0.556$, $P = 0.649$), there was a significant main effect for time for RPE ($F_{3,27} = 17.437$, $P = 0.000$), reflecting an increased perception of effort as exercise time progressed (Table 1). In addition, there was a trend (ES = 0.63) for higher RPE levels to be recorded after Q2 and Q3 with caffeine ingestion.

TT. Results for TT obtained in the RAT are summarized in Table 2. Although caffeine ingestion resulted in faster TT values across all time points (main effect of condition: $F_{1,9} = 21.438$, $P = 0.001$), there was no significant interaction ($F_{4,36} = 0.795$, $P = 0.536$). Similarly, TT values increased over most time points for both conditions (main effect of time: $F_{4,36} = 6.105$, $P = 0.001$), demonstrating the fatiguing nature of the exercise circuit protocol, but there was no significant interaction. Qualitative analyses resulted in a large ES and a "very likely" chance of benefit in the caffeine trial for TT when participants were fresh (PRE), whereas moderate to large ES and "likely" or "very likely" chances of benefit were observed when fatigued (Q1, Q2, and Q4).

TABLE 1. Mean ± SD, Cohen ES, and smallest worthwhile changes for HR and RPE measured during the simulated team-game protocol for the caffeine and placebo trials ($n = 10$).

	Mean ± SD		Cohen *d*/Mean Change (%) ± 90% Confidence Intervals
	Placebo	Caffeine	Caffeine/Placebo
HR (bpm)			
Q1	172 ± 8	174 ± 14	0.18/0.6 ± 5.0
Q2	175 ± 11	171 ± 14	−0.32/−2.0 ± 6.0
Q3	172 ± 8	173 ± 17	0.08/0.6 ± 5.6
Q4	175 ± 6	177 ± 12	0.21/1.0 ± 4.3
RPE*			
Q1	12 ± 2	12 ± 1	0.00/−0.1 ± 8.9
Q2	13 ± 1	14 ± 2	0.63/0.5 ± 4.3
Q3	14 ± 1	15 ± 2	0.63/6.6 ± 5.1
Q4	15 ± 1	15 ± 2	0.00/−0.4 ± 7.3

* Significant main effect for time ($P = 0.000$).

TABLE 2. Mean (±SD), Cohen ES, and smallest worthwhile changes for TT, RA time, DT, and MT measured during the RAT for the caffeine and placebo trials (n = 10).

	Mean ± SD		Cohen *d*/Mean Change (%) ± 90% Confidence Intervals/%; Qualitative Chance Effect Is Beneficial (Trivial/Harmful)
	Placebo	Caffeine	Caffeine/Placebo
TT (ms)			
PRE	2269 ± 94	2198 ± 67	−0.87/−3.1 ± 1.5/99 (1/0); benefit very likely
Q1	2290 ± 107	2235 ± 52	−0.65/−2.3 ± 2.0/89 (10/1); benefit likely
Q2	2310 ± 74	2244 ± 62	−0.97/−2.9 ± 1.4/99 (1/0); benefit very likely
Q3	2293 ± 101	2257 ± 53	−0.45/−1.5 ± 1.9/75 (23/2); benefit possible
Q4	2312 ± 69	2276 ± 74	−0.50/−1.6 ± 1.2/92 (8/0); benefit likely
RA time (ms)			
PRE	1392 ± 97	1336 ± 72	−0.66/−4.0 ± 3.0/94 (6/0); benefit likely
Q1	1414 ± 107	1360 ± 42	−0.66/−3.6 ± 3.5/88 (11/1); benefit likely
Q2	1442 ± 79	1378 ± 74	−0.84/−4.5 ± 2.4/99 (1/0); benefit very likely
Q3	1448 ± 67	1383 ± 58	−1.04/−4.5 ± 1.7/100 (0/0); benefit almost certain
Q4	1441 ± 72	1401 ± 80	−0.53/−2.9 ± 1.7/97 (3/0); benefit very likely
DT (ms)			
PRE	290 ± 68	266 ± 79	−0.33/−11.0 ± 19.0/69 (26/5); benefit unclear
Q1	290 ± 60	280 ± 67	−0.16/−5.3 ± 15.7/47 (41/12); benefit unclear
Q2	299 ± 40	267 ± 55	−0.67/−11.8 ± 11.5/92 (7/2); benefit likely
Q3	305 ± 57	275 ± 75	−0.45/−11.9 ± 13.6/82 (15/3); benefit likely
Q4	317 ± 81	295 ± 69	−0.29/−6.6 ± 10.7/63 (34/3); benefit possible
MT (ms)			
PRE	1102 ± 89	1070 ± 74	−0.39/−2.8 ± 3.9/72 (25/3); benefit possible
Q1	1124 ± 94	1080 ± 77	−0.51/−3.8 ± 2.7/91 (9/0); benefit likely
Q2	1143 ± 77	1111 ± 68	−0.44/−2.8 ± 3.4/79 (19/2); benefit likely
Q3	1143 ± 80	1108 ± 46	−0.54/−2.9 ± 3.4/81 (17/2); benefit likely
Q4	1124 ± 105	1106 ± 61	−0.21/−1.4 ± 3.4/45 (51/4); benefit possible

Chances of benefit or harm were assessed as follows: ≤1%, almost certainly not; 1%–5%, very unlikely; 5%–25%, unlikely; 25%–75%, possible; 75%–95%, likely; 95%–99%, very likely; >99%, almost certain.

RA time. Although there was no significant interaction effect (time × condition) for RA time ($F_{4,36}$ = 0.350, P = 0.842), caffeine ingestion resulted in consistently faster times when both fresh and fatigued across all time points (Table 2; main effect for condition: $F_{1,9}$ = 23.385, P = 0.001). Qualitative analyses resulted in a "likely benefit" (PRE, Q1, and Q4), "very likely" (Q2), and "almost certain benefit" (Q3), as well as large and moderate ES after caffeine ingestion. A significant main effect for time for RAT ($F_{4,36}$ = 7.054, P = 0.000) further demonstrated the fatiguing nature of the exercise circuit.

DT. Although there was no significant interaction effect (time × condition) for DT ($F_{4,36}$ = 0.249, P = 0.908), caffeine scores were faster across all time points than placebo (main effect for condition: $F_{1,9}$ = 5.432, P = 0.45). Qualitative analyses resulted in a "likely" benefit for Q2 and Q3 only, with a moderate ES recorded for Q2 (Table 2).

MT. Although MT scores were consistently faster after caffeine ingestion (main effect for condition: $F_{1,9}$ = 5.576, P = 0.043), there was no significant interaction effect ($F_{4,36}$ = 0.274, P = 0.893). Qualitatively, the majority of ES were small, with moderate ES and a "likely" chance of benefit for caffeine ingestion only being observed for Q1 and Q3 (Table 2). A significant main effect for time ($F_{4,36}$ = 2.824, P = 0.039) was again recorded.

Decision-making accuracy. For the number of correct decisions made, no significant interaction effect was observed ($F_{4,36}$ = 1.017, P = 0.412). Qualitative analysis resulted in a large ES for Q1 (1.41; 4/4 vs 3/4 correct decisions for caffeine and placebo trials, respectively) and Q4 (1.00; 4/4 vs 3/4 correct decisions for caffeine and placebo trials, respectively) with a "likely" beneficial effect observed for Q1. The remaining ES were small and associated with "unclear" outcomes.

Further, the interaction effect (condition × time) for the number of wrong decisions in the RAT was also not significant ($F_{4,36}$ = 0.524, P = 0.719), but again, large ES were found for Q1 (ES = −1.41; 0 vs 1 wrong decision for caffeine and placebo trials, respectively) and Q4 (ES = −1.00; 0 vs 1 wrong decision for caffeine and placebo trials, respectively) with a "likely" beneficial effect observed for Q1. The remaining time points showed "unclear" effects, accompanied by small ES.

Posttest questionnaire. Four of the 10 participants correctly identified their exposure to both the caffeine and placebo conditions in the posttest questionnaire. In the experimental trials where participants correctly identified that they had ingested caffeine (6/10), they reported that they felt more alert and energetic, as well as restless at times. These participants also reported that they found the exercise protocol easier to complete. Four of these participants reported slight nausea associated with caffeine ingestion, whereas one of these four participants also reported slightly shaky hands. These adverse effects were all described by participants as minor and, more importantly, were not considered deleterious to their exercise performance.

DISCUSSION

The purposes of this study were to examine the effects of a 6-mg·kg^{-1} dose of caffeine on RA time before, during, and after a simulated team-sport fatiguing protocol and also to investigate whether caffeine ingestion could improve decision-making accuracy during an extended exercise

protocol. Although there were no statistically significant interaction effects (time × condition) recorded, RAT performance measures were consistently faster after caffeine ingestion for all time points (significant main effect for condition; $P = 0.005$), with mean percentage improvements of 2.3% in TT, 3.9% in RA time, 9.3% in DT, and 2.7% in MT. Qualitative analysis showed many potential benefits ("possible," "likely," "very likely," and "almost certain") and moderate to large ES favoring caffeine ingestion in these variables. In addition, potential beneficial improvements were observed in decision-making accuracy after caffeine ingestion, especially early in the team-sport exercise simulation.

This is the first study to investigate the effects of caffeine ingestion on RA time, a unique measure of agility requiring participants to react appropriately to a sport-specific video stimulus through engaging in a whole-body, physical change of direction (34). Previous studies examining the effect of caffeine ingestion on total agility time have returned equivocal results (28,35). The only study to report an improvement in agility time was Stuart et al. (35), who investigated the effects of a 6-mg·kg^{-1} dose of caffeine on three separate, rugby-specific sprints that followed a zigzag pattern. An improvement of 2.2% after caffeine ingestion was observed; however, a "likely benefit" in mean agility time was documented in only two of the sprints. This is similar to the "likely benefit" of 2.3% improvement observed in the current study for TT to complete the RAT. Although the magnitude of improvement is similar between studies, comparison of results is limited, as Stuart et al. (35) used sprints of a preplanned nature, requiring no decision to be made in response to an external stimulus, from which a whole-body movement is initiated. Also incorporated into their agility sprints were rugby-specific tasks, including tackling and passing, which were absent in the pursuit scenario incorporated in the present study.

However, although TT and RA time are important variables in the overall context of athletic performance, our data also permitted an analysis of the DT and MT components. Generally, lesser qualitative changes and smaller ES were recorded for these variables than for TT and RA time, which may highlight the relevance of using agility tests that incorporate both perceptual (decision making) and physical components, to be sport specific.

Caffeine ingestion has been reported to positively affect response preparation at the central motor level, through reducing the influence of irrelevant visual information, producing faster reaction times (30). However, reaction time in previous research represents a predominantly cognitive measure, with simplistic motor actions required in response to generic stimuli (i.e., light or picture based). In contrast, DT is comparatively more complex, here representing the ability of participants to orientate with the "moving" video opponent, noting body position and directional movement, before initiating a whole-body change of direction. Differences between initiating simplistic finger or hand movements and a sport-specific whole-body response could explain the relatively lesser qualitative effects of caffeine on DT observed in the current study, when compared with TT and RA time. However, obtaining greater differences between conditions for DT may have been limited by the strength of the movement analysis used here. As frame-by-frame analysis allowed DT to be recorded to within ±20 ms and given that four of five time points in the caffeine condition were faster than placebo by <20 ms, it is possible that a greater effect of caffeine ingestion was not easily identifiable.

Overall, qualitative analysis suggested some benefit of caffeine ingestion on decision-making accuracy (3.8%), which supports the findings of Stuart et al. (35), who reported that athletes were 10% more accurate at passing rugby balls after caffeine ingestion, both when fresh and fatigued. Any beneficial effect is likely due to the improved interpretation and response to the visual stimuli of participants when ingesting caffeine (17). The ability of caffeine to reduce the influence of irrelevant visual information, as stated previously (30), could have aided decision-making accuracy, especially as athletes become fatigued. Interestingly, it should also be emphasized that there were no differences in the number of correct decisions between the caffeine and placebo conditions in three of the five time points measured (precircuit, Q2, and Q3). Therefore, while observing no increase in the number of wrong decisions or apparent indecisions, these results suggest that a 6-mg·kg^{-1} dose of caffeine does not lead to overarousal and a subsequent decrease in decision-making accuracy during RAT.

The qualitative results and ES reported here also suggest that any effect of caffeine ingestion on performance was similar when the participants were fresh or fatigued. Only in DT was there a trend for caffeine ingestion to enhance performance slightly more when fatigued (Q2 and Q3 especially). Although HR was not increased from Q1 levels at these time points, RPE in both caffeine and placebo trials was greater (13–15, up from 12 after Q1). Previous research suggests that the effects of caffeine on psychomotor function are most pronounced in fatigued rather than fresh conditions (29,37,38). For example, Kruk et al. (27) reported no effect of caffeine ingestion on choice reaction time immediately before the start of exercise but faster times during and after exercise. This may be due to emotional arousal resulting from the anticipation of the impending exercise, which could dampen any stimulating action of caffeine.

Also, the lessening of the perception of fatigue during exercise is one of the more common reported effects of caffeine ingestion, which may be associated with a stimulatory effect on the CNS (18,19,31). This may explain the improvements reported previously in skilled performance accuracy (17,35); however, previous studies on caffeine ingestion and agility performance have only used preplanned movement patterns (28,35) not requiring any perceptual response.

The most likely mechanism behind the slight improvements in agility performance observed with caffeine in this study may be the blocking of adenosine receptors in various tissues in the body, producing a stimulatory effect on the CNS (19,24). An increase in neural firing rate, alertness, and arousal as a result of caffeine-induced adenosine inhibition has been shown to decrease feelings of perceived exertion, leading to an increase in performance when fatigued (18,19,24). When athletes are fresh, a direct stimulation of the CNS, improving neural firing rates and the release of stimulatory neurotransmitters, could also explain the improvements seen in agility performance. However, this remains speculatory until further research is conducted regarding the potential mechanisms behind improved RA performance after caffeine ingestion.

In conclusion, the results showed that a 6-mg·kg^{-1} dose of caffeine resulted in small beneficial improvements in RAT, as demonstrated by qualitative analyses. Furthermore, qualitative results from this study also demonstrated a likely ergogenic effect of caffeine ingestion on decision-making accuracy. In addition, a likely benefit of caffeine ingestion on RAT performance when participants were either fresh or fatigued was suggested. Future research should use a higher video capturing rate in the change of direction analysis, as well as closer analysis of the initial foot movement (DT), to within ±5–10 ms. Potentially, this could magnify any effect that caffeine ingestion may have on DT and, therefore, RA time. In addition, use of three-dimensional "real-person" analysis rather than two-dimensional projected image assessment would provide a more realistic sporting scenario, as well as more postural cues. Finally, a larger cohort may have resulted in statistically significant results between experimental conditions.

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