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Effect of caffeine on target detection and rifle marksmanship

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Thirteen healthy and rifle-trained male military reservists performed shooting sessions on two separate occasions 1 h following the ingestion of placebo or 300 mg of caffeine. Shooting included both friend–foe (FF) and vigilance (VIG) tasks, and were performed in the following order: two FF sequences (4 min each), four VIG sequences (30 min each), and two additional FF sequences. The shooting sessions lasted approximately 2.5 h under outdoor conditions (air temperature range from -3 to 14°C) and were held 48 h apart in a counterbalanced order. Performance measures during the shooting session included engagement time, friend–foe discrimination, and marksmanship accuracy and precision. Assessments of thermal comfort, tiredness, and debilitating symptoms preceded and followed the shooting session, while a self-assessment on performance was administered post-shooting only. Blood was sampled immediately prior to the beginning of the shooting session and was used to determine plasma caffeine, cortisol, and testosterone levels. Engagement times were faster and certain measures of accuracy and precision were impaired during the later FF and VIG sequences. However, caffeine ingestion had no affect upon any of the marksmanship measures, although it did alleviate cold stress and tiredness. That caffeine ingestion did not affect target detection and rifle marksmanship is a finding that differs from other studies, and is explained by a beneficial arousal caused by the mild level of cold stress experienced by the participants.

1. Introduction

Previous investigations have demonstrated that caffeine ingestion produces rapid and significant improvements in both anaerobic and aerobic exercise capacity (Nehlig and Debry 1994, Graham 2001). Cognitive processes, as measured through various performance tasks, particularly the speed at which they are performed, are also enhanced with caffeine (Jacobson and Edgley 1987, Fine *et al*. 1994). Although the underlying ergogenic mechanism is not entirely known, it is believed that caffeine's behavioural and cognitive enhancements can be attributed to its stimulatory effects upon central adenosine receptors (Graham 2001, Lieberman 2001). Consequently, in conjunction with the low health risks of caffeine ingestion, its use is under consideration in military operations, specifically in situations where an advantage can be gained for both physical and cognitive performance.

The effects of caffeine ingestion on certain military activities have already been investigated (Tharion *et al*. 1997, Johnson and Merullo 1999). During sentry duty

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simulations, the ingestion of 200 mg of caffeine has been shown to reduce friend–foe discrimination errors and diminish the decrement in target detection time associated with time on the task, while not affecting marksmanship capability (Johnson and Merullo 1999, 2000). Similarly, it was found that the administration of 200 and 300 mg of caffeine did not negatively affect marksmanship in sleep-deprived Navy SEAL trainees (Tharion *et al*. 1997, 2003), despite its amplifying effects on physiological tremor (Hoffman and Lefkowitz 1990). Further, both dosages improved performance of a visual vigilance task (Tharion *et al*. 1997) and sighting time (Tharion *et al*. 2003).

The present study investigated the effects of caffeine ingestion (300 mg) on friend–foe discrimination, target detection, and rifle marksmanship in a group of Canadian Forces (CF) reservists on a live-fire Automated Training System (ATS). Although previous studies reported beneficial results with caffeine ingestion, these effects were examined with the use of marksmanship simulators. Despite the reported validity of such simulators in assessing marksmanship capability and predicting live fire performance (Schendel and Heller 1985, English and Marsden 1995), it would be prudent to conduct studies of caffeine ingestion in a live fire environment before it can be recommended as an ergogenic aid for soldiers deployed in a live theatre. It was hypothesized that caffeine would improve rifle firing engagement times, but possibly impair marksmanship due to a potential augmentation of physiological tremor.

2. Methods

2.1. *Participants*

Thirteen rifle-trained male military reservists (mean $\pm$ SD of age = 28 $\pm$ 9 years, stature = 179 $\pm$ 5 cm, and mass = 83 $\pm$ 14 kg) participated in this study, as approved by the institute ethics committee on human experimentation. Prior to participation, the participants were medically screened and a full explanation of the procedures, discomforts, and risks were given before written informed consents were obtained.

2.2. *Protocol*

The participants attended three sessions. The first session consisted of a medical screening, the signing of an informed consent, completion of a caffeine consumption and tobacco use questionnaire, familiarization with the subjective questionnaires, and measurement of basic anthropometric characteristics. The subsequent sessions were the experimental trials whereby participants ingested either a placebo (P) or caffeine (C) encapsulated in gelatin. Trials were double-blind and counterbalanced. Drug and placebo trials were separated by a minimum of one day and were conducted at the same time of day. All shooting engagements occurred on the ATS live-fire range at CFB Edmonton. Daily ambient temperatures ranged from -3–5°C (mean $\pm$ SD of $2.8 \pm 3.8^{\circ}$C) for the morning sessions and 8–14°C ($10.8 \pm 2.5^{\circ}$C) for the afternoon sessions.

Participants were asked to refrain from caffeine and exercise for 12 h and from alcohol for 24 h prior to all trials. Upon arrival at the ATS range, participants calibrated their rifles (i.e. zeroing and grouping) before ingesting either the P or C capsule. A light snack (muffin and juice) was provided 30 min after the ingestion of caffeine. No other food was consumed during the trial period although participants were allowed to drink water *ad libitium* from their canteens between shooting sequences. One hour post-ingestion of the capsule, participants

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completed questionnaires on thermal sensation, tiredness, and debilitating symptoms. A blood sample was then taken and the participants commenced the 2.5-h shooting session. Participants dressed according to combat fighting orders and assumed a prone shooting posture using sandbags to aid rifle support. Since the trials took place outdoors, the participants were allowed to vary their combat attire accordingly. Participants were allowed to stretch and/or slightly adjust their position after each shooting sequence. Each trial ended with the completion of the aforementioned questionnaires in addition to one involving task performance.

2.3. *Drug ingestion*

Participants ingested two unlabelled gelatin capsules containing either the placebo or caffeine 1 h prior to the shooting session. The placebo and caffeine capsules contained Metamucil® (a dietary fibre) and 300 mg of caffeine, respectively, the latter approximating 2–4 regular-sized cups of coffee depending upon strength. The experimental dose of caffeine is effectively cleared from the body after 48 h of ingestion (Graham 2001).

2.4. *Blood samples*

A blood sample of 3 ml was taken from a vein of the non-dominant forearm (that holding the rifle stock) just prior to the start of the shooting session. Samples were used to determine plasma levels of caffeine, cortisol as a stress indicator, and testosterone as a possible correlate to discrimination scores. Plasma caffeine levels were determined by gas chromatograph-mass spectrometry analysis. Cortisol and testosterone levels were determined using radioimmunoassay kits (Clinical Assays Gamma Coat Cortisol 125I RIA Kit, DiaSorin Inc., Stillwater, MN, USA and DSL – 4000 Active® Testosterone Coated-Tube RIA Kit, DSL Inc., Webster, TX, USA, respectively).

2.5. *Questionnaires*

Participants were queried on their thermal sensation (TS), rating of tiredness (RT), and debilitating symptoms [environmental symptoms questionnaire (ESQ)] approximately 1 h following capsule ingestion and immediately following the 2.5 h shooting session. TS is a modified version of the Gagge *et al.* (1967) rating of thermal sensation from extremely cold to extremely hot on a scale from 0 to 10. RT is a customized rating of tiredness from not tired to extremely tired, also scaled from 0 to 10. The ESQ (version IV; (Sampson *et al.* 1994)) is composed of 68 questions involving the presence of various symptoms, and participants were instructed to choose either 0 = not at all, 1 = slight, 2 = somewhat, 3 = moderate, 4 = quite a bit, or 5 = extreme. Composites of certain questions were grouped to obtain indices of the following symptoms: subjective heat illness, cold discomfort, muscle discomfort, cardiopulmonary discomfort, and well-being. Participants also completed a self-assessment task load index (TLX) questionnaire of how well they performed at the end of the shooting session. TLX (Hart and Staveland 1988) is composed of six questions involving mental demand, physical demand, temporal demand, performance, effort, and frustration. Participants were instructed to mark their responses on a continuous line labelled low and high on opposite ends, and these responses were assigned a numerical value based on a linear scale from 0 to 10.

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2.6. *Shooting session*

Participants used the C7 rifle with the C79 scope and engaged conventional pop-up targets (49 × 103 cm Kneeling Man Dartarg Type-E Cat. No. 110-066, ATA, Columbia, SC, USA) at 200 m for all shootings during the 2.5 h session. Grouping and zeroing were conducted before the ingestion of the gelatin capsules. Participants began and ended their sessions with two 4-min sequences of friend-foe (FF) discrimination. The mid 2-h period was divided into four 30-min sequences of vigilance (VIG) testing. Herein 'engagement' refers to shooting a single target, 'sequence' refers to a series of engagements within a task (FF or VIG), and 'session' refers to one complete set of sequences (FF1→2 + VIG1→4 + FF3→4).

Each FF task involved 25 foe and 15 friendly targets, randomly dispersed in time and each appearing for 4 s (including the pop-up time of ~1 s) within a 4-min period. All FF sequences were unique to achieve different, but balanced target presentations. The orientation of a square-wave grating pattern was used to distinguish the foe from the friendly target such that foes were indicated by three thick diagonal white stripes running from the bottom right to upper left and friendly targets were striped in the opposite direction. Different combat markings and colours were purposely avoided to impose a recognition challenge based only on pattern. Participants were instructed to fire a single round at each foe target as soon as they perceived to have the best chance of a central hit. Participants were to hold their fire when a friendly target appeared.

The VIG task involved only non-striped targets randomly dispersed in time and also appearing for 4 s (including the pop-up time). Fifteen targets appeared within each 30-min period over the 2 h to achieve four balanced sequences. Participants were instructed to fire a single round at each target as soon as they perceived to have the best chance of a central hit. Target sequences were varied for the four FF tasks and for the four VIG tasks to achieve an overall counterbalanced design. Target sequences were also distributed between trials to avoid repetition without changing the level of difficulty.

2.7. *Performance measures*

Performance on the FF tasks was based on engagement time for the foe targets, a total count of responses, a discriminatory index, a hit/miss ratio, and marksmanship. Performance on the VIG tasks was based on engagement time, a hit/miss ratio, and marksmanship.

Engagement time (ET) was captured from digital video and audio recordings, and represented the time between the appearance of the target and the first round fired. The total count (TC) was the sum of shots fired at foe targets and fire-holds on friendly targets for a maximum score of 40 per sequence. The discriminatory index (d′) provides a measure of discrimination based on signal detection theory (Macmillan and Creelman 1991) using the equation $d' = Z(\text{false alarms}) - Z(\text{hits})$, where Z represents the location on a normal curve that divides the area under the curve into two parts, depicting the hits and misses, or false alarms and correct rejections. d′ is the difference between the two peaks of the superimposed curves and a value of 1.0 indicates reasonable discrimination. The hit/miss ratio represents the number of hits to number of shots fired (NH/NS), thus providing a measure of firing efficiency where higher values are deemed better. NS and NH were also separately analysed.

The ATS captured the displacement (x and y coordinates) of each round fired. These data were used to assess marksmanship during each sequence. Marksmanship was based on a total point score, accuracy (or shot distance from the target centre of mass (CM)), and precision (or shot group tightness). The total point score (TPS) was the sum of 5 points for hits within the 100 mm target circle, 3 points for hits between the 100 and 150 mm circles, and 0 points for all other shots (B-GL-382-002/PT-001, 2000). Accuracy was measured by the constant error (CE; displacement between centre of impact (CI) and CM) and by the shooting error (SE; mean displacement between each shot and CM). These metrics were assessed for the shots fired at the foe targets during each 4 min sequence of the FF task and on the shots fired during each 30 min sequence of the VIG task. Precision was measured according to the shot mean radius (MR; mean displacement between each shot and CI), the horizontal (R_H) and vertical (R_V) ranges, and the area (A) and diagonal (D) of the shot group dispersion. All formulae pertaining to the measures of accuracy and precision were adopted from Johnson (2001).

2.8. *Data analyses*

Statistica® software was utilized to perform all statistical analyses with acceptance at $p < 0.05$. The TLX scores and the blood variables were analysed using a 1 factor (DRUG (2 levels)) within-subjects repeated measures analysis of variance (RM-ANOVA). The ESQ, TS, and RT scores were analysed using a 2 factor (DRUG (2) × TIME (2)) RM-ANOVA. All measures of performance for both the FF and VIG tasks were analysed using a 2 factor (DRUG (2) x SEQUENCE (4)) RM-ANOVA. The Newman-Keuls means comparison test was used for *post-hoc* analyses where main differences were found. Unless otherwise reported, all data in the text and tables are reported as mean ± SD and in figures as mean ± SE.

3. Results

3.1. *Blood samples*

As anticipated, plasma caffeine levels were higher ($p < 0.004$) during C (2098 ± 1908 ng ml^{-1}) compared to the P trial (550 ± 710 ng ml^{-1}). There were no differences in cortisol (10.71 ± 4.79 vs. 12.39 ± 5.73 μg dl^{-1}) and in total testosterone (3.99 ± 1.03 vs. 4.22 ± 0.68 ng ml^{-1}) levels between P and C, respectively.

3.2. *Questionnaires*

The mean scores for all subjective data are summarized in table 1. There was a main effect of time ($p < 0.042$) for TS whereby participants felt warmer prior to than at the end of the shooting session. There was also a marginal main effect of drug ($p < 0.049$) for TS, with the C trials appearing warmer than the P trials. There was a significant drug × time interaction ($p < 0.019$) for RT. Tiredness increased over time during P (i.e. from pre- to post-shooting), but remained unchanged during C.

There were no differences in any of the TLX indices over time and between trials. However, there was a main effect of time for well-being, cold discomfort, subjective heat illness, and muscular discomfort symptoms of the ESQ ($p < 0.034$, 0.001, 0.001, and 0.003, respectively). All of these symptoms increased from pre- to post-shooting (paradoxical increases in well-being and subjective heat illness will be explained later). *Post-hoc* analysis of cold discomfort revealed that the participants experienced more cold-related symptoms during P than during C ($p < 0.024$).

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Table 1. Mean ± SD of the TS, RT, TLX, and ESQ responses pre- and post-shooting for the placebo and caffeine trials ($n = 13$). TS scores of 0 and 10 represent extremely cold and extremely hot, respectively; RT scores of 0 and 10 represent not tired and extremely tired, respectively.

Subjective indices	Placebo (pre)	Placebo (post)	Caffeine (pre)	Caffeine (post)
TS	4.30 ± 1.89	3.10 ± 1.79*	5.00 ± 1.22†	3.46 ± 1.56*†
RT‡	1.09 ± 0.83	2.63 ± 1.80	1.92 ± 1.89	1.38 ± 1.89
TLX				
Mental		4.16 ± 2.57		4.96 ± 2.39
Physical		3.37 ± 2.77		3.13 ± 3.31
Temporal		3.11 ± 2.40		3.07 ± 2.42
Performance		4.39 ± 2.22		3.99 ± 2.25
Effort		5.41 ± 2.88		5.19 ± 3.05
Frustration		3.89 ± 2.59		4.39 ± 2.52
ESQ				
Subjective heat illness	1.92 ± 2.02	7.15 ± 4.00*	3.00 ± 4.97	7.23 ± 6.11*
Cold discomfort‡	0.31 ± 1.11	9.77 ± 5.31*	0.54 ± 1.20	6.77 ± 6.48*
Muscle discomfort	1.08 ± 1.32	5.85 ± 6.14*	0.62 ± 1.19	5.23 ± 4.27*
Cardiopulmonary discomfort	0.08 ± 0.28	0.77 ± 2.24	0.00 ± 0.00	1.23 ± 3.11
Well-being	6.31 ± 4.97	6.53 ± 4.39	5.00 ± 4.60	8.38 ± 4.50*

*Denotes a significant sequence effect; †denotes a significant drug effect; and ‡denotes a significant drug × sequence interaction.

3.3. *Performance*

Complete data were obtained for all participants ($n = 13$) except for ET, TC, and d′ during the FF task ($n = 12$), and for ET, NS, and NH/NS during the VIG task ($n = 10$, 11, and 11, respectively). Missing data were due to difficulties with the recording equipment during certain sequences. No main effect of caffeine ingestion for any of the marksmanship measures (TPS, accuracy, and precision) was found.

3.3.1. *Friend-foe discrimination*: There was a main effect of sequence ($p < 0.004$) for ET (see figure 1). Engagement times were shorter in the third and fourth friend-foe sequences (FF3 and FF4; 2.00 ± 0.24 and 2.05 ± 0.31 s, respectively) than in first and second sequences (FF1 and FF2; 2.20 ± 0.28 and 2.24 ± 0.31 s, respectively). Discrimination was good overall and there were no differences for d′ across drug treatments or sequences (5.40 ± 0.94 and 5.31 ± 0.96 for C and P, respectively). There was, however, a main effect of sequence for NH ($p < 0.026$) and NH/NS ($p < 0.043$). There were fewer hits and the number of hits to shots ratio was smaller during FF3 and FF4 than during FF1 (see table 2; recall that each FF task comprised 25 foe and 15 friendly targets).

There was a main effect of sequence on the following marksmanship measures: CE, SE, MR, A, D, and R_H. CE was larger during the FF3 sequence than during FF1 ($p < 0.043$). All other variables were larger during FF3 and FF4 compared to FF1 ($p < 0.009$, 0.018, 0.007, 0.006, and 0.014 for SE, MR, A, D, and R_H, respectively; see table 3). There was also a significant drug × sequence interaction for CI in the vertical direction ($p < 0.010$). Its value for the FF3 sequence during the P trial (− 17.60 ± 14.36 cm) was farther from the target's CM than during the FF2

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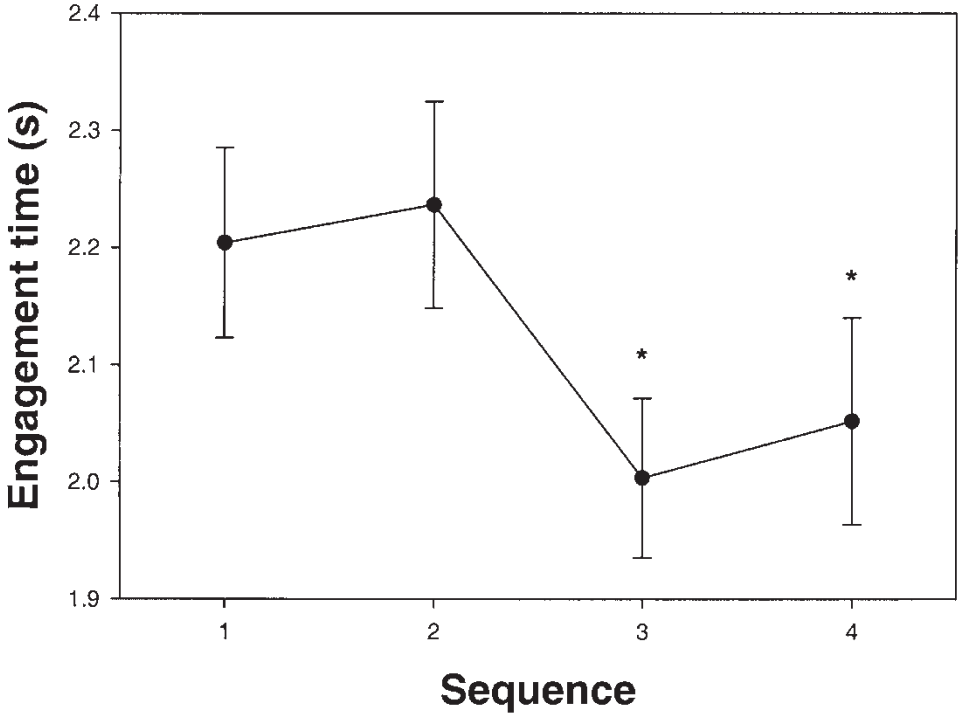

Figure 1. Mean ± SE of engagement time for the friend-foe sequences ($n = 12$); *denotes significance. Engagement times were shorter during the final two sequences (i.e. FF3 and FF4).

Table 2. Mean ± SD of NS, NH, NH/NS for the friend-foe sequences ($n = 13$).

Performance measure	FF1	FF2	FF3	FF4
NS	25.0 ± 1.2	24.7 ± 0.8	24.7 ± 0.9	24.6 ± 1.2
NH	23.8 ± 2.9	21.9 ± 4.2	20.7 ± 4.7*	20.5 ± 5.1*
NH/NS	0.94 ± 0.10	0.88 ± 0.16	0.83 ± 0.18*	0.82 ± 0.19*

*NH and NH/NS were statistically smaller in FF3 and FF4 than in FF1.

(− 3.87 ± 16.96 cm) and FF4 (− 0.11 ± 15.74 cm) sequences of the P trial, and the FF2 (− 8.48 ± 22.00 cm) and FF4 (− 8.59 ± 21.94 cm) sequences of the C trial (a negative value indicates that the participants were firing below the CM). There was no significant difference in the vertical range of MR across sequences. Figures 2 and 3 illustrate the effect of sequence on SE and MR. These measures were selected for illustration as they represent primary measures of marksmanship accuracy and precision, respectively.

3.3.2. *Vigilance*: There was a main effect of sequence ($p < 0.002$) on ET (see figure 4). *Post-hoc* analyses revealed that ET was faster during the second vigilance sequence (VIG2; 2.18 ± 0.64 s) and the fourth (VIG4; 1.92 ± 0.63 s) than during the first (VIG1; 2.66 ± 0.61 s). As well, ET during VIG4 was faster than during VIG3

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Table 3. Mean ± SD of CE, SE, MR, A, D, and R_H for the friend-foe sequences ($n = 13$). All values are expressed in cm, except for the shot group dispersion area (A), which is expressed in cm^2.

Measure	FF1	FF2	FF3	FF4
CE	13.73 ± 9.01	17.70 ± 11.08	20.67 ± 10.07*	19.77 ± 9.54
SE	17.33 ± 7.42	21.31 ± 9.86	24.33 ± 8.90*	23.69 ± 8.32*
MR	9.22 ± 1.70	10.65 ± 2.70	11.61 ± 4.40*	11.82 ± 3.87*
A	1964 ± 962	2698 ± 1685	3146 ± 1827*	3397 ± 2464*
D	45.90 ± 10.55	53.42 ± 17.01	58.78 ± 20.78*	61.80 ± 26.61*
R_H	33.66 ± 9.38	39.11 ± 14.63	40.86 ± 16.06*	43.51 ± 19.66*

*Denotes statistical differences from the first friend-foe sequence (i.e. FF1).

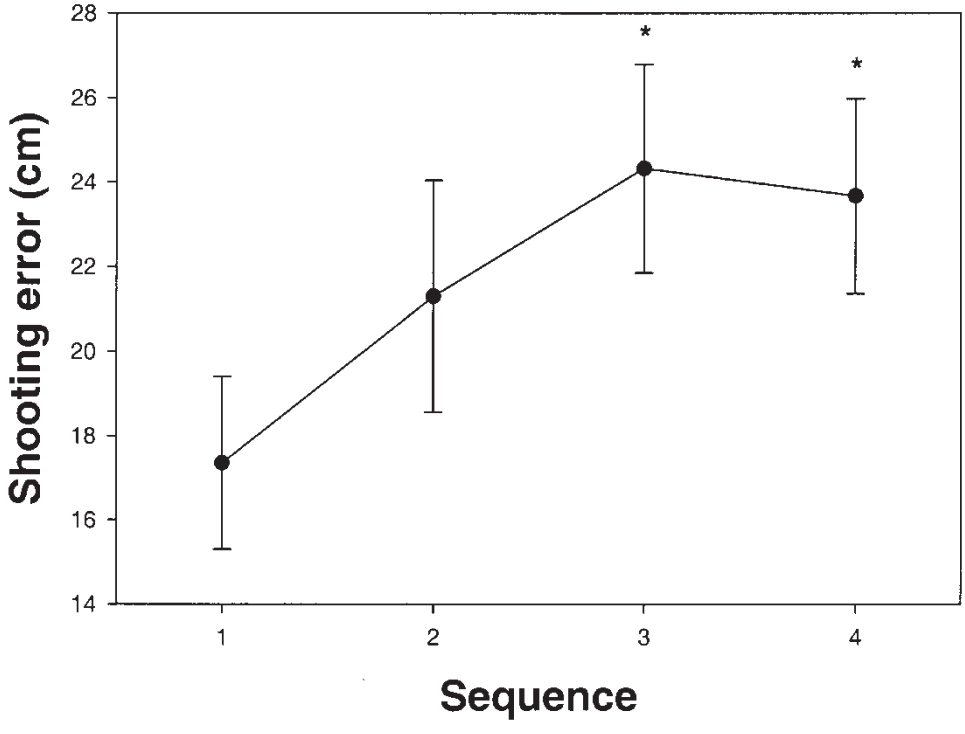

Figure 2. Mean ± SE of shooting error for the friend-foe sequences ($n = 13$); *denotes significance. Shooting error was larger in the final two sequences than in the first sequence, indicating that accuracy declined throughout the shooting sessions.

(2.42 ± 0.57 s). There was no difference in TPS across sequences or drug trials. A significant drug × sequence interaction was indicated for NH ($p < 0.026$) and NH/NS ($p < 0.016$). However, no interactions for NH were identified through *post-hoc* analyses. NH/NS was significantly lower during VIG4 than during VIG3 for the C trial (0.66 ± 0.23 and 0.84 ± 0.17, respectively), but no differences were found across sequences for the P trial.

There was a main effect of sequence for the following marksmanship measures: MR, A, and D. MR was larger during VIG4 (15.10 ± 5.06 cm) than during VIG1,

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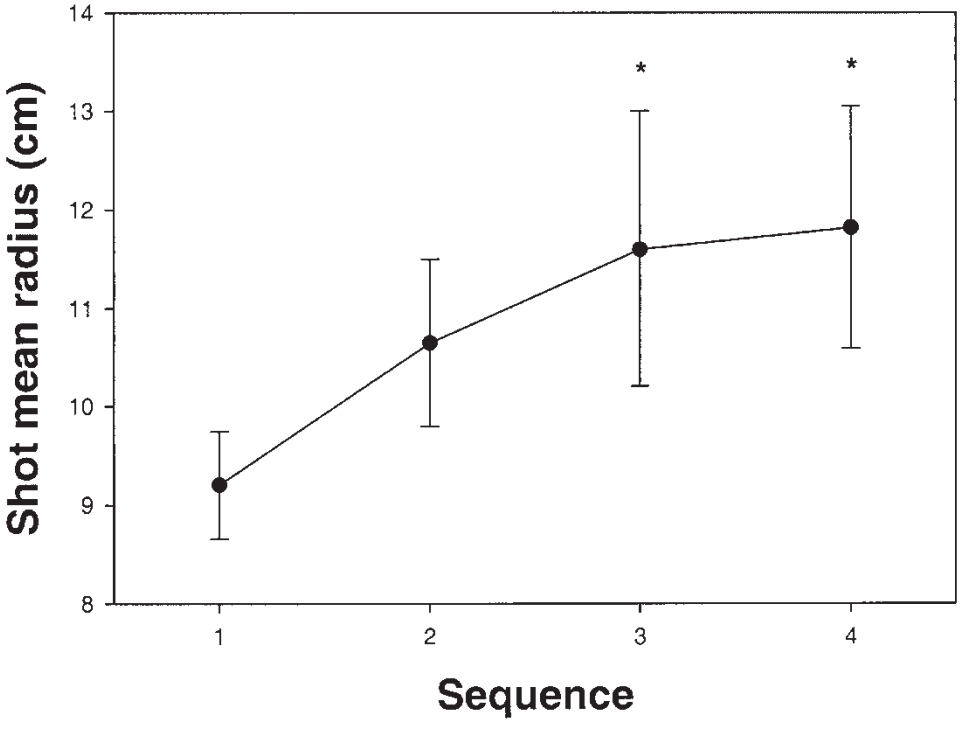

Figure 3. Mean ± SE of shot mean radius for the friend-foe sequences ($n = 13$); *denotes significance. Shot mean radius was larger in the final two sequences than in the first sequence, representing a decline in precision throughout the shooting sessions.

VIG2, and VIG3 (12.67 ± 3.94, 12.36 ± 4.48, and 13.08 ± 4.39 cm, respectively; $p < 0.005$), indicating poorer shot group performance. Shot group dispersion area was larger during VIG4 than during VIG3 (3636 ± 2455 and 2485 ± 1393 cm^2, respectively; $p < 0.034$). D was larger during VIG4 than during VIG2 (63.92 ± 21.57 and 51.57 ± 19.82 cm, respectively; $p < 0.048$). There was a significant drug × sequence interaction for the centre of impact in the horizontal direction ($p < 0.002$). Its value was closer to the target's CM during VIG4 in the P trial (− 2.86 ± 9.81 cm) than during VIG3 and VIG4 of the C trial (5.19 ± 10.65 and 6.15 ± 11.24 cm, respectively). Figure 5 demonstrates the effect of sequence on the shot mean radius for the vigilance sequences.

4. Discussion

The present study investigated the efficacy of caffeine ingestion (300 mg) on shooting performance in a group of CF reservists on a live-fire ATS. Although previous investigations have reported enhanced target detection times with caffeine, it was important to re-examine these claims in a live-fire scenario to determine if caffeine would continue to exert its beneficial effect outside the conditions of a well-controlled laboratory. Also, verification was sought that purported detection time improvements do indeed result in faster engagement times and that caffeine ingestion improves target discrimination without adversely affecting marksmanship during live fire.

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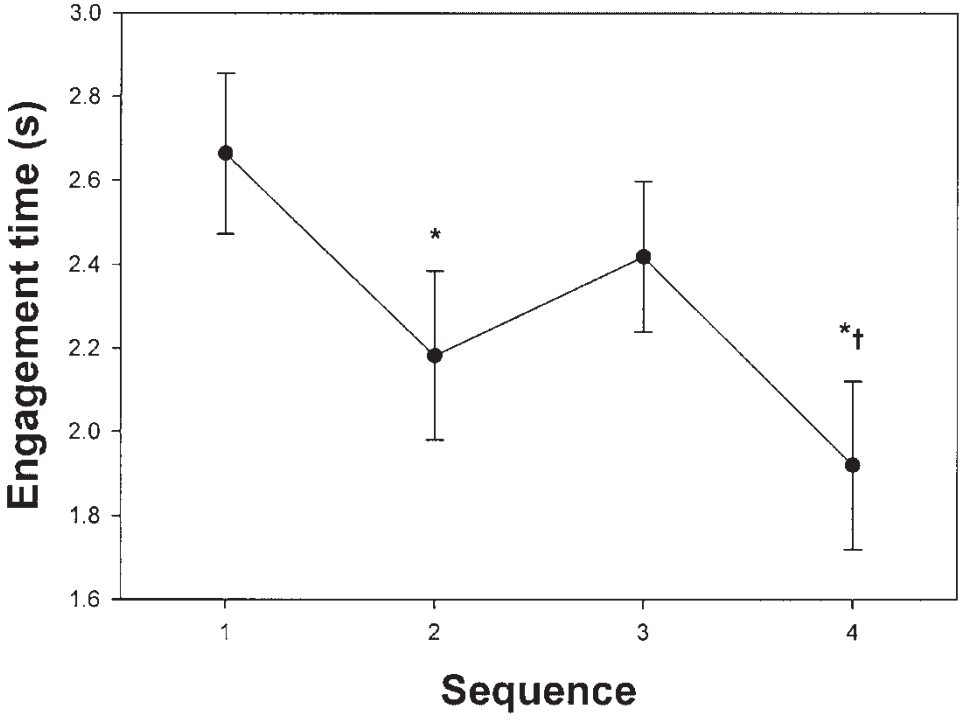

Figure 4. Mean ± SE of engagement time for the vigilance sequences ($n = 10$); *denotes significant differences from VIG1; and † denotes significant differences from VIG3. Engagements times were shorter during the fourth sequence than during the first and third sequences, and shorter during the second sequence than during the first sequence. There were no statistical differences between the second and fourth sequences.

It was not surprising that both the ESQ cold and muscular discomfort symptoms increased with time. Since the study took place outside in a temperature range of − 3 to 14°C, it was expected that cold stress would result in mild discomfort in the participants. Furthermore, although participants were given the opportunity to stretch between shooting sequences, muscular discomfort should nonetheless be anticipated as the participants were expected to maintain a static posture over most of the 2.5 h shooting period. The concomitant increase in both subjective heat illness (SHI) and well-being from pre- to post-shooting was unexpected, especially given the seemingly contradictory findings on cold and muscular discomfort. This might be explained, however, in terms of the types of statements utilized to determine the various symptoms. That is, the statement 'I had a muscle cramp' is used to formulate the SHI score (Sampson *et al.* 1994); however, it is possible that this sub-symptom might result from muscle discomfort and a prone, static posture.

Similarly, the statement 'I felt wide awake' is used to formulate the well-being score, yet such a statement may very well be associated with an increase in arousal and/or alertness due to the mild cold stress present throughout the trials. This was confirmed when examining the subsets of statements individually. Although 22 out of the 68 symptoms were utilized to compute the SHI score, subsequent analyses showed that only five of these symptoms were statistically significant over time.

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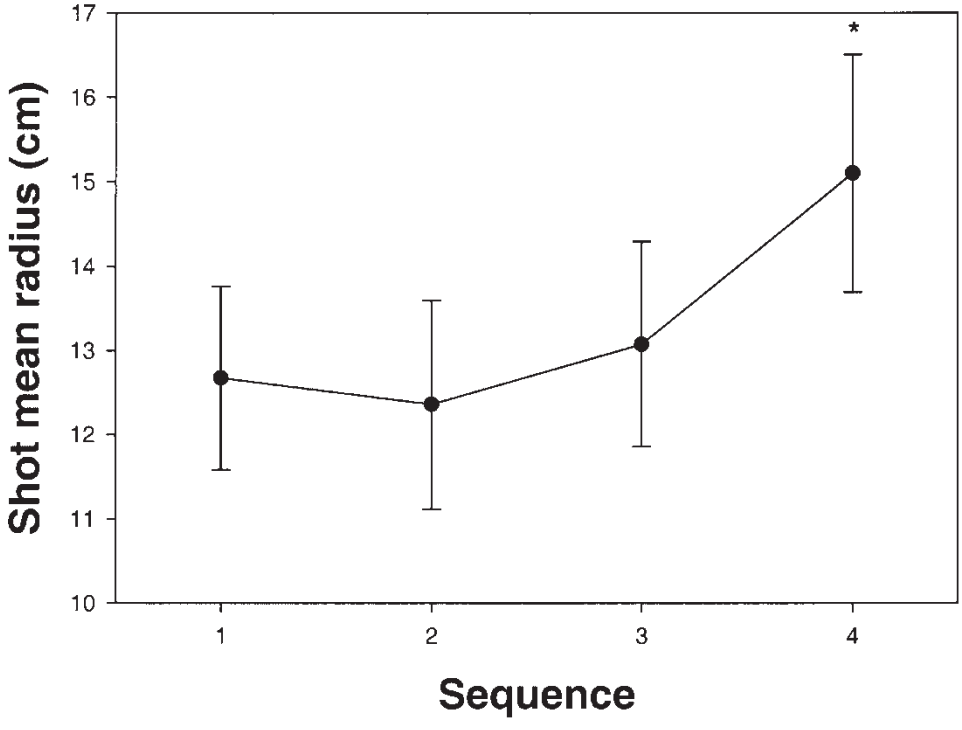

Figure 5. Mean ± SE of shot mean radius for the vigilance sequences ($n = 13$); *denotes significance. Shot mean radius was larger during the fourth sequence than during the first, second, and third sequences, indicating a deterioration of precision by the end of the sessions.

These symptoms were 'My coordination was off', 'I had a muscle cramp', 'Parts of my body felt numb', 'My vision was blurry', and 'I felt restless'. Clearly, such symptoms may be related to other components of the experimental trials and may not be indicative of heat stress *per se*. Similarly, only one of the three symptoms used to compute well-being was significantly affected by time. The symptom 'I felt wide awake' increased following the shooting sequences, indicating that participants felt more awake at the end of the trials. Again, this finding may represent alternate feelings, including increased arousal due to the mild cold stress, than that of general well-being. Given these findings, it is not surprising that SHI and well-being increased over the shooting period, even when cold and muscular discomfort resulted in similar increases. Nevertheless, that the cold stress actually affected the participants was verified by the thermal sensation results, which indicated that the participants felt colder following the shooting session than before they began.

Thermal sensation was also affected by caffeine ingestion. Participants were colder during the placebo trial than during the caffeine trial. The higher number of cold-related symptoms experienced during the placebo trial substantiated this finding. Caffeine ingestion has been shown to increase energy expenditure in humans exposed to thermoneutral temperatures (Acheson *et al.* 1980, LeBlanc *et al.* 1985). Thus, if enhanced energy expenditure occurred in the participants with caffeine ingestion, it is likely that the elevated heat production was responsible for the warmer sensation

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during the caffeine trial. In addition, the RT results indicated that tiredness increased from pre- to post-shooting for the placebo trial, but remained unchanged throughout the caffeine trial. This is consistent with the stimulatory action associated with caffeine ingestion.

Engagement times improved with subsequent sequences for both the FF and VIG tasks. This was unexpected given previous findings that target detection times deteriorate over time for shooting and other vigilance-type tasks (Wilkinson 1969, Johnson and McMenemy 1989, Johnson and Merullo 1996). One possible explanation for this disparity is that while target detection times may indeed decline with time, the participant's ability to detect the target, properly align the sight with the target, and squeeze the trigger (i.e. engagement time in the present context) actually improves over time. In the previous studies (Johnson and McMenemy 1989, Johnson and Merullo 1996), detection time was limited to the time taken to depress a button (not the trigger) and excluded the time to aim and fire a shot. Despite the requirement that all participants had a minimum shooting qualification level as a condition for acceptance in the present study, it is possible that the participants became increasingly familiar with the shooting process itself and that it is the somatic component of shooting that improved rather than the perceptual component. Another plausible explanation is that the subjective cold strain experienced by the participants induced sufficient arousal to improve performance on this particular measure. Tikuisis *et al.* (2002) found that shot group tightness, as measured by MR, was enhanced in participants experiencing cold strain as compared to a thermo-neutral condition. Although these researchers did not measure engagement times, they did suggest that a beneficial arousing effect of the cold might have been responsible for their findings. Further study is needed to determine the direct effects of cold ambient conditions upon marksmanship performance. Detection/engagement time differences will be further addressed below.

The number of hits achieved and the shooting efficiency of the participants (i.e. NH/NS) declined with increasing sequences for the FF task, but not for the VIG task. With respect to vigilance, Johnson and McMenemy (1989) and Johnson and Merullo (1996) found similar results whereby shooting performance, as measured by the number of hits, did not change over time. Marksmanship accuracy and precision, however, were affected by time on the task. CE and SE deteriorated over time during the FF task, while MR deteriorated during both the FF and VIG tasks. These measures provide a more complete assessment of the dynamics of shooting and how a particular stressor and/or enhancement might affect it.

It is not surprising that marksmanship deteriorated over time, especially as the participants reported increased muscular discomfort with time. During the FF task, efficiency, accuracy, and precision were all poorer during the final two sequences, which were performed following the VIG task, at a time when muscular discomfort and fatigue would be expected and confirmed by the subjective ratings. It is also noteworthy that a speed-accuracy trade-off appears to have occurred during both shooting tasks. Engagement times improved while marksmanship deteriorated over the 2.5 h shooting period. It is conceivable that the participants were inclined to fire more quickly at the expense of marksmanship induced by a combination of mild cold stress and muscular discomfort. Indeed, performance research supports this interpretation. According to arousal theory, a stressor such as cold may alter the participant's strategy, leading to faster but less accurate performance (Ellis 1982, Enander 1989).

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The ability to discriminate friend from foe targets was unaffected by both sequence and caffeine ingestion. Performance research has shown that ingestion of 200 mg of caffeine improves the ability to detect an infrequent stimulus amongst a series of frequent, known stimuli (Fine *et al*. 1994). Also, Johnson and Merullo (1999, 2000) found that the same dose of caffeine can reduce friend–foe discrimination errors and reduce the likelihood of failing to fire at an enemy target. The lack of similar improvements in friend–foe discrimination in the present study may have been due to a number of factors, including the discriminatory features of the targets and/or the conditions of the live-fire range. Although the same identification scoring system as utilized by Johnson and Merullo (1999) was applied, the targets used here were quite different. Johnson and Merullo used a 1-s light stimulus adjacent to the target to designate friendly status whereas the present study utilized a different grating pattern to distinguish targets. Perhaps the briefness of the light stimulus presented a greater discriminatory challenge than the different grating pattern, as the participants had 4 s to make their decision in the present study. The requirement for faster perceptual processing may have led to the higher number of friend vs. foe errors in the previous study, thereby providing an opportunity for caffeine to exert its ergogenic effect. Furthermore, it is possible that the realism of the ATS and the cold-induced arousal helped to reduce friend–foe discrimination errors, thus attenuating any potential improvements with caffeine ingestion.

The ingestion of 300 mg of caffeine did not affect any of the marksmanship measures recorded in either the FF or VIG sequences. This result was unexpected and contrasted the hypotheses that caffeine ingestion would improve engagement times, while impairing marksmanship capabilities. Further, the results challenge the generality of the reports of previous authors, who reported improved response times with caffeine ingestion (Johnson 1991, Johnson and Merullo 1996, Tharion *et al*. 1997). There are several possible explanations for the discrepancies in these findings. As already noted, the engagement time measured in the present study was more complex than simply target detection, as measured in the cited studies. These previous studies reported detection times that are more representative of simple reaction time tasks (Johnson and Merullo 1996) and therefore may be more likely to be affected by the ergogenic action of caffeine. The present findings suggest that the effect of caffeine ingestion cannot be extrapolated across the entire process of target engagement. That is, ET comprises a series of actions that collectively might be less affected by caffeine ingestion than the single action of detecting the target (Johnson and McMenemy 1989, Fine *et al*. 1994).

Second, Johnson and Merullo (1996) found that 200 mg of caffeine eliminated the decrement in target detection time associated with time on the task. However, caffeine did not improve target detection times above that of baseline performance. Perhaps caffeine exerts its action by reducing the duration and frequency of lapses, which are very brief periods when performance falters or stops (Bergstrom 1972). If the participants in the present study did not experience lapses, possibly due to the arousing effect of the cold, then caffeine would not have had as great an opportunity to exert its ergogenic effect.

A third reason for the discrepant findings may be the level of caffeine present in the participants. Although the plasma caffeine concentration was significantly higher during the caffeine trial, the mean level of caffeine (i.e. 2098 ng ml^{-1}) was lower than would be expected with the 300 mg dose (Tarnopolsky 1994). Reanalysis of the blood samples, as well as of the capsules to verify the amount of caffeine provided,

waived any concerns regarding miscalculations during the spectrometry analysis and the preparation of the capsules. Additionally, the researchers were present during capsule handling and ingestion, assuring that capsule administration was correct. Accordingly, no plausible explanation can be given to explain the lower than expected levels of caffeine observed in the participants. Nonetheless, the marksmanship studies cited above administered 200 mg of caffeine, a lower dose than utilized in the present study. Unfortunately, Johnson (1991) and Johnson and Merullo (1996, 1999) did not measure the level of plasma caffeine and, thus, the findings cannot be compared in this context. However, Tharion *et al.* (1997, 2003) did measure salivary caffeine levels and reported a mean caffeine concentration of 2940 ng ml^{-1} 1–1.5 h post-200 mg ingestion. This reported value is well within the standard deviation of the mean plasma caffeine concentration reported in the present study. Therefore, although the plasma caffeine concentration reported in the present study was lower than expected, previous research has demonstrated beneficial caffeine effects upon response time and sighting time (i.e. with respect to marksmanship versus computerized task performance) with moderate caffeine concentrations.

Although no differences in marksmanship were noted with caffeine ingestion, the efficiency of shooting during the vigilance task did decline during the final 30-min sequence for the caffeine trial only. Figure 6 illustrates this decline, while also demonstrating the tendency for shooting efficiency to be lower in the placebo trial than the caffeine trial during the mid two sequences. Thus, caffeine may have exerted a stimulating effect upon marksmanship ability between 2.0–2.5 h post-ingestion, when circulating levels of the drug were likely to be at their peak (Graham 2001), followed by a disruption in marksmanship as drug levels began to decline and the

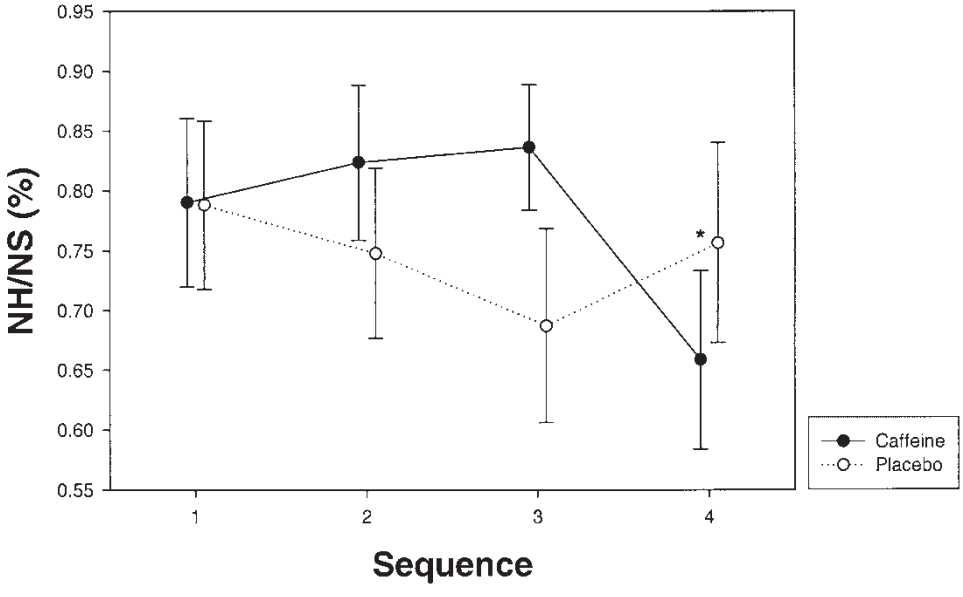

Figure 6. Mean ± SE of NH/NS for the vigilance sequences. Shooting efficiency was lower during VIG4 than during VIG3 for the caffeine trial only, as indicated by *. NH/NS tended to be lower for VIG3 during the placebo than for VIG3 during the caffeine trial ($p < 0.098$).

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initial stimulating effect began to weaken. Conversely, the participants were not under the influence of a drug during the placebo trial, thus explaining the relatively consistent performance throughout the sequences, maintained by the arousing effect of the cold.

Data from the caffeine consumption and tobacco usage questionnaire were documented for all but one participant. Of these participants, three were light caffeine users (i.e. the equivalent of one cup of coffee per day or less), eight were moderate users (2–4 cups), and one was a heavy user (five or more cups). In addition to the planned analyses presented earlier, these participants were divided into two groups, those who consumed the equivalent of less than three cups of coffee per day (LOW, $n = 5$) and those who consumed more (HIGH, $n = 7$). A 3 factor (GROUP (2) × DRUG (2) × SEQUENCE (4)) ANOVA, with a between-subjects GROUP factor, was then used to determine any differences between the two groups on the engagement times and marksmanship performance. Only one variable was affected by caffeine usage. The LOW group attained a higher total point score during the vigilance task than the HIGH group, in both the caffeine and placebo conditions ($p < 0.034$). This occurred during the VIG2, VIG3, and VIG4 sequences of C, and for the VIG1 and VIG4 sequences of P. The TPS is a reference score used by the CF to assess marksmanship accuracy and pertains to the 'kill zone' of a target. It is not apparent why this particular group difference occurred other than statistical coincidence, especially when no other measures of performance were affected.

Three of the above participants were also regular tobacco users while the others were non-users. These participants were similarly divided into two groups and a three factor (GROUP (2) × DRUG (2) × SEQUENCE (4)) ANOVA, with a between-subjects GROUP factor, was used to determine any differences between the two groups on the engagement times and shooting performance. There were marginal main effects of group for shot mean radius ($p < 0.048$), shot group dispersion area ($p < 0.049$), and shot group diagonal ($p < 0.039$) during the FF sequences, indicating that the tobacco users were consistently less precise than the non-users throughout these sequences. Although not significant, there was a similar trend for the vigilance sequences, where the shot mean radius and shot group dispersion area tended to be larger for the tobacco users ($p < 0.056$ and $p < 0.059$, respectively). As well, efficiency during the VIG sequences was lower for the tobacco users than the non-users (0.54 and 0.80, respectively; $p < 0.039$). Due to the study location (i.e. live-fire range), participants were restricted from smoking during the 2.5 h shooting sessions and none elected to chew tobacco during this period. Therefore, it is plausible that the tobacco users experienced withdrawal symptoms throughout the duration of the session, which resulted in poorer performance outcomes. However, these findings are statistically limited due to the number of tobacco users and to a lack of baseline performance data (i.e. without tobacco restrictions). Nonetheless, they concur with expectation and suggest that future studies should more closely consider the relationship between tobacco use and marksmanship.

The present findings provide further insight into the effects of caffeine ingestion on target detection and rifle marksmanship. Although previous researchers have endorsed the use of caffeine for improvements in target detection and reaction time tasks, the present findings reveal that such benefits do not always translate into improvements when the task demands and/or complexity is altered, as in the present

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study under more realistic target engagements and cold conditions. These findings highlight the necessity for future studies to evaluate live-fire vs. simulator performance and to determine the effect of caffeine ingestion on live-fire engagements when various other levels of combat and operational stressors (i.e. heat stress, physical and mental fatigue, and sleep deprivation) are also present.

5. Conclusions

In the present live-fire study, the ingestion of 300 mg of caffeine neither influenced the time taken from target detection to firing a rifle nor affected marksmanship capabilities. These findings refute our hypotheses that caffeine ingestion would improve engagement times and impair marksmanship. Time on the task, however, did result in improved engagement times, while impairing rifle firing accuracy and precision. These findings may be explained in terms of an arousal hypothesis, whereby the cold discomfort experienced by the participants led to an inclination to fire more quickly at the expense of rifle marksmanship. These results are contrary to certain previous studies where target detection and marksmanship were tested under less realistic conditions. Further research is required to clarify the role of caffeine during complex task performance and to determine its efficacy during combat situations involving various stressors, either separately or in combination, and at different intensities.

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