Caffeine Gum Does Not Improve Marksmanship, Bound Duration, Susceptibility to Enemy Fire, or Cognitive Performance During Tactical Combat Movement Simulation

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ABSTRACT

Background: Military personnel supplement caffeine as a countermeasure during unavoidable sustained wakefulness. However, its utility in combat-relevant tasks is unknown. This study examined the effects of caffeinated gum on performance in a tactical combat movement simulation. **Materials and Methods:** Healthy men (n = 30) and women (n = 9) (age = 25.3 ± 6.8 years; mass 75.1 ± 13.1 kg) completed a marksmanship with a cognitive workload (CWL) assessment and a fire-and-move simulation (16 6-m bounds) in experimental conditions (placebo versus caffeinated gum, 4mg/kg). Susceptibility to enemy fire was modeled on bound duration during the fire-and-move simulation. **Results:** Across both conditions, bound duration and susceptibility to enemy fire increased by 9.3% and 7.8%, respectively (p = .001). Cognitive performance decreased after the fire-and-move simulation across both conditions (p < .05). However, bound duration, susceptibility to enemy fire, marksmanship, and cognitive performance did not differ between the caffeine and placebo conditions. **Conclusion:** These data do not support a benefit of using caffeinated gum to improve simulated tactical combat movements.

KEYWORDS: *caffeine gum; marksmanship; bound duration; enemy fire; cognitive performance; tactical combat movement simulation*

Introduction

In combat, warfighters are involved in direct-fire engagements that are responsible for nearly half of all casualties.[1] Performance during direct-fire engagements is critical and requires soldiers to perform repeated high-intensity sprints. Additionally, Soldiers deliver suppressive fire to protect friendly units advancing on hostile forces during recovery periods.[2–9] Multiple stressors act on warfighters that deteriorate physical and cognitive performance. These stressors, in turn, decrease combat effectiveness.[3,10–12] Countermeasures to restore warfighter performance in austere conditions have used pharmacological substances such as caffeine.[13–16]

Caffeine is an ergogenic aid that improves both physical and cognitive performance.[17–22] Emerging evidence suggests that caffeine improves repeated sprint performance, which deteriorates during direct-fire engagements.[3,4,23–25] Additionally, caffeine improves muscular strength and power, which may help soldiers tolerate heavy personal protective equipment worn during direct-fire engagements.[7,18,26] Last, caffeine also improves marksmanship accuracy and reaction time, which both depreciate in stressful environments.[11,13,15,27–30] While caffeine represents a viable ergogenic target to support soldiers, it is unclear if caffeine can increase soldier survivability during direct-fire engagements.

Blount and colleagues developed a model to predict susceptibility to enemy fire during tactical combat movements such as direct-fire engagements.[13] The susceptibility to enemy fire model was predicated on a soldier's bound duration and exposure to enemy fire (e.g., longer bound duration, longer exposure, and increased susceptibility to enemy fire).[31] Physical fatigue accumulates rapidly during repeated high-intensity sprints and exposure time progressively increases during direct-fire engagements.[3,4,32] However, caffeine may mitigate performance decrements during direct-fire engagements by sustaining bound durations.

To the best of our knowledge, the effects of caffeine supplementation on marksmanship and susceptibility to enemy fire during a tactical combat movement, simulating a direct-fire engagement, remain unknown. We hypothesized that performance would deteriorate during a tactical combat movement simulation resulting in significant decrements in marksmanship, cognition, and susceptibility to enemy fire. Additionally, we hypothesized that caffeine supplementation would significantly attenuate performance decrements in marksmanship, cognition, and susceptibility to enemy fire during the tactical combat movement simulation.

Methods

Design

The study was approved by the Kansas State University Institutional Review Board (#9821). Subjects attended four laboratory visits. Subjects were informed of the study procedures, provided written consent, completed baseline measures, and were familiarized with the tactical combat movement simulation during the first laboratory visit. Subjects were randomized in a double-blind, counterbalanced, crossover design to determine the effects of caffeine on performance during the tactical combat movement simulation. The second laboratory visit served as a baseline (BL) control with no supplement provided to the subject before completing the tactical combat movement simulation. The effects of caffeine (CAF) versus placebo (PLA)

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were evaluated with order randomized between participants on the third and fourth laboratory visits. Laboratory visits 1, 2, and 3 were separated by at least 48 hours. Laboratory visits 3 and 4 were separated by at least 96 hours for a washout period. All trials occurred indoors in temperature-controlled conditions set to 22°C as previously described.[33] Subjects were asked to maintain their physical activity and dietary habits throughout the study. They were also asked to abstain from vigorous physical activity 24 hours before testing, and from caffeine and alcohol 12 hours before testing.

Subjects

Participants were recruited using flyers, in-person presentations, social media, and email listservs surrounding the greater Kansas State University and Fort Riley area. In an attempt to recruit military personnel, focus was placed on recruiting in areas with higher proportions of military groups (e.g., ROTC buildings, veteran centers, and military installations). Civilians, including college-aged students, were also permitted to be in the study based on inclusion and exclusion criteria. Subjects completed a screening questionnaire to ensure that they were in good health, non-tobacco-users, did not possess a condition that would be worsened by physical activity, and reported regular caffeine use (≥50mg per day of caffeine).[34] Daily caffeine consumption was evaluated using a 7-day caffeine recall.[35] A Snellen Visual Acuity Test was used to verify that subjects had at least 20/30 vision.[27] Corrective lenses were allowed during the visual acuity test and required for all testing. Laboratory personnel verified that all inclusion and exclusion criteria were satisfied before experimentation. Subjects also demonstrated proficiency with marksmanship by either providing evidence of a military rifle qualification in the last 12 months (n = 8), or by successfully engaging 12 targets with at least 75% accuracy using a modified M4 device (n = 31). Thirty-nine subjects qualified for the study (age 25.3 ± 6.8 years; height 177.1 ± 21.6 cm; mass 75.1 ± 13.1 kg; body fat percent 20.8 ± 8.2%; fat-mass 15.8 ± 7.2 kg; fat-free mass 59.3 ± 10.7 kg; men n = 30). Height was measured using a stadiometer. Body mass, body fat percentage, fat-mass, and fat free mass were determined using bioelectrical impedance analysis in standard mode (TBF-300A; Tanita, Japan).

Supplementation Protocol

Subjects chewed approximately 4mg/kg body mass of caffeinated Military Energy Gum (Market Right Inc., https://militaryenergygum.com/) or placebo gum during sessions 3 and 4. The mode of delivery and dose was selected based on use in the military and previous research.[16,36] Each piece of gum contained 100mg of caffeine. Pieces of gum were cut in half to achieve approximately a 4mg/kg body mass dose to the closest 50mg increment. The placebo gum was provided by the manufacturer to replicate the color, taste, size, and texture of the caffeinated gum. Subjects chewed two boluses of gum similar to what was described by Lane and colleagues.[37] Each bolus of gum was chewed for at least 10 minutes based on the buccal absorption of caffeine.[38] Subjects initiated a standardized warm-up 10 minutes after the second bolus of gum, followed by the tactical combat movement simulation. Subjects returned after a minimum of 96 hours and performed the tactical combat movement simulation with the opposite gum.[24,25,39]

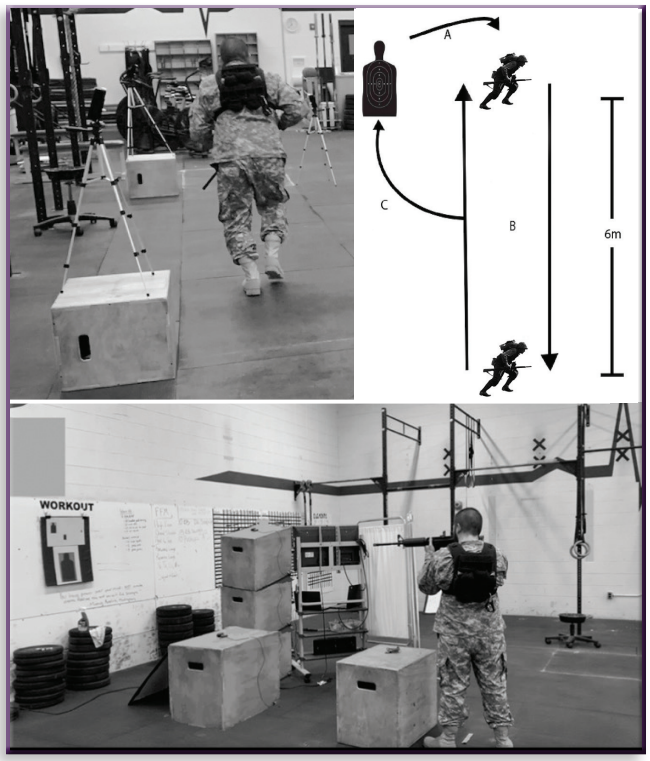
Tactical Combat Movement Simulation

The tactical combat movement simulation required subjects to engage a series of targets with a modified M4 under physical and cognitive workloads (Figure 1). Subjects wore a 25-kg weight vest during the tactical combat movement simulation to replicate a combat load.[3] Subjects wore exercise attire during the familiarization period (i.e., visit 1). Subjects wore a military issued combat uniform and boots during all other sessions (i.e., visits 2–4). The tactical combat movement simulation initiated with a marksmanship and cognitive workload protocol. An M4 was modified with a shot, indicating resetting trigger automatic rifle bolt (SIRT-AR Bolt, Next Level Training, https://nextleveltraining.com/product/sirt-bolt/), so squeezing a trigger emitted a laser from the M4. Laser Activated Shot Reporter software (Shooter Technology Group, https://lasrapp.com/) was used to acquire marksmanship data. The marksmanship with cognitive workload protocol was modified from the Army Research Laboratory to reflect simulated shooting.[40] Four targets were mounted to the wall to simulate distances of 18, 100, 150, and 200 meters. All targets were E-type target silhouettes and had colored backgrounds of yellow, red, green, or blue. The L.A.S.R. software randomly called out a target color every 4 seconds until 12 targets were announced. Target callouts were announced electronically using an external speaker. Subjects were asked to aim the modified M4 and engage the targets by squeezing the trigger as quickly and as accurately as possible. The modified M4 had an iron sight aiming platform that subjects used for accuracy. All subjects confirmed the iron sight's accuracy before each simulation. Subjects were allowed one trigger squeeze per target callout. The number of correctly engaged targets (i.e., marksmanship accuracy) was scored by the L.A.S.R. software. The L.A.S.R. software also reported the time series data for target engagement. The duration between the first target call-out and the first target engagement was the first shot reaction time. The average duration between all target call-outs and target engagements was the marksmanship reaction time. The four target configurations were generated, randomly assigned, and counterbalanced across sessions.

Cognitive workload was induced with a mathematical problem-solving task similar to that of the Army Research Laboratory.[40] An auditory message was presented to the subjects through the external speaker. The auditory message was delivered in between target callouts and contained mathematical problems that were moderate in difficulty and consisted of addition and subtraction of single and double-digit numbers. Subjects verbally answered the mathematical problems before engaging the next target callout. Twelve auditory messages were presented to the subject. The number of correctly answered mathematical problems was used as an index of cognitive performance. Four sets of mathematical problems were generated, randomly assigned, and counterbalanced across sessions.

After answering the last mathematical problem, subjects transitioned to a fire-and-move simulation to induce a combat-relevant physical workload. The fire-and-move simulation protocol was modified from Silk and Billing's protocol, which is used in the Australian Army Combat Arms Physical Employment Standards Assessment.[2,41] Subjects performed 16 × 6 meter bounds on a 20 second cycle. Subjects carried a separate modified M4 to ensure the modified M4 used for marksmanship-maintained calibration. An auditory message was used to instruct subjects to initiate each bound. All bounds started from the prone position and terminated in the kneeling position. Subjects readopted the prone position before initiating the subsequent bound. The duration of each

FIGURE 1 TOP LEFT: *Image of subject performing the fire-and-move portion of the tactical combat movement simulation.* **TOP RIGHT:** *Diagram of the tactical combat movement simulation. The protocol began with the marksmanship with cognitive workload (CWL) assessment* **(A)**, *then transitioned to the fire-and move simulation by performing 16 bounds* **(B)**, *and returned to the marksmanship with CWL assessment* **(C)**. **BOTTOM:** *Image of a subject performing the marksmanship with CWL assessment.*



bound was determined with the Position Fitness infrared timing gate system (Position Fitness, https://positionfitness.com/products/infrared-sport). The infrared timing gates that indicated bound completion were placed at shoulder height.[39] The infrared timing gates that indicated bound initiation were started by the investigator due to subjects lying in the prone position.[42] The average bound duration and fastest bound duration were determined for each condition. Subjects returned to the marksmanship with cognitive workload after the final bound was completed. Subjects were again presented with 12 target call-outs every 4 seconds that were interspersed with 12 mathematical problems.

Modeling Susceptibility to Enemy Fire

The model developed by Blount and colleagues was used to determine susceptibility to enemy fire.[31] The average bound duration from the fire-and-move simulation was used to determine exposure time to enemy fire. This was achieved by using the following equation with the reaction time of enemy forces set at 1 second.

$$\text{Exposure Time} = \text{Bound duration} - \text{Reaction Time of Enemy Forces}$$

The number of shots from enemy forces was determined using the following equation with shooting cadence set to 1.3 shots/second.

$$\text{Shots} = \text{Exposure Time} \times \text{Shooting Cadence}$$

Susceptibility to enemy fire was determined using the following equation with the accuracy of enemy forces set to 10%.

$$\text{Susceptibility to Enemy Fire} = 1 - (1 - \text{Accuracy})^{\text{shots}}$$

Assessment of Treatment Blinding

Subjects were sent an electronic survey (Qualtrics Labs Inc., https://www.qualtrics.com/) after the third and fourth visits to determine if they perceived an effect from the supplement they were provided (yes /no/not sure).

Statistical Analysis

An a priori power analysis determined that a minimum of 39 subjects was required to achieve 80% power, $\alpha < .05$, and a moderate effect size.[43] Complete data were acquired from 31 subjects. Incomplete data were available from eight subjects due to injury not associated with the study (n = 1), failure to comply with the testing timeframe (n = 1), scheduling conflicts (n = 1), failure to follow-up (n = 2), loss of student housing due to COVID-19 outbreak (n = 2), and COVID-19 illness (n =1). Data were analyzed for subjects with complete data using SPSS version 25.0 (IBM, https://www.ibm.com/products/spss-statistics). All descriptive and dependent variables were assessed for normality using a Kolmogorov-Smirnov test and boxplot analysis. All analyses were conducted with and without outliers. Two-way repeated-measures ANOVA tests were used to determine the main effects of condition (PLA versus CAF) and time (pre-/post-fire-and-move simulation) for marksmanship accuracy, first shot reaction time, marksmanship reaction time, and cognitive performance. Two-way repeated-measures ANOVA tests were also used to determine main effects of condition (PLA versus CAF) and time (first three/last three bounds of the fire-and-move simulation) for the bound duration, exposure time, shots, and susceptibility to enemy fire. Significant main effects were followed by post hoc pairwise comparisons (Bonferroni test). Post hoc values were reported as estimated marginal means ± standard error of means. A paired sample *t*-test was used to determine the effect of condition (PLA versus CAF) on the fastest bound duration. Statistical significance was set at $p < .05$. Eta squared (η^2) was used to indicate effect size.

Results

Marksmanship

Figure 2 shows reaction time pre-/post- fire-and-move simulation, first shot reaction time, and marksmanship accuracy between conditions. No main effect was found for condition ($p = .592$) or time ($p = .424$) on marksmanship reaction time. No main effect was found for condition ($p = .601$) or time ($p = .350$) on first shot reaction time. No main effect was found for condition ($p = .960$) or time ($p = .127$) on marksmanship accuracy.

Cognitive Performance

No main effect was found for condition ($p = .280$) on cognitive performance. A significant main effect was found for time [$F = (1,29) = 4.678$, $p < .05$, $\eta^2 = .13$) on cognitive performance. The total number of correct answers to math problems was lower (9.0 ± 0.4) after the fire-and-move simulation compared to before the fire-and-move simulation (9.6 ± 0.4).

Modeling Susceptibility to Enemy Fire

Figure 3 shows the parameters from modeling susceptibility to enemy fire for the first three and last three bounds of the

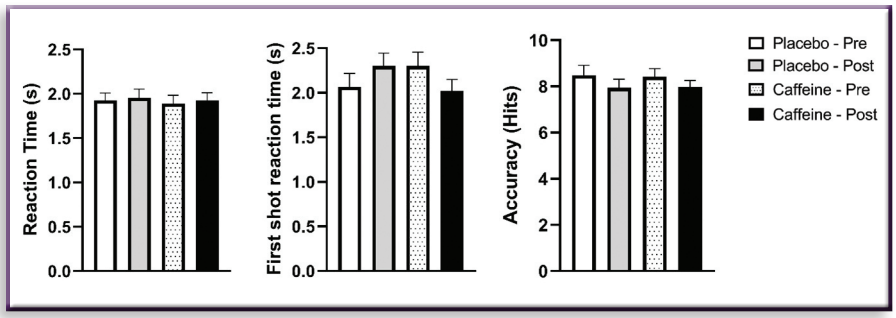
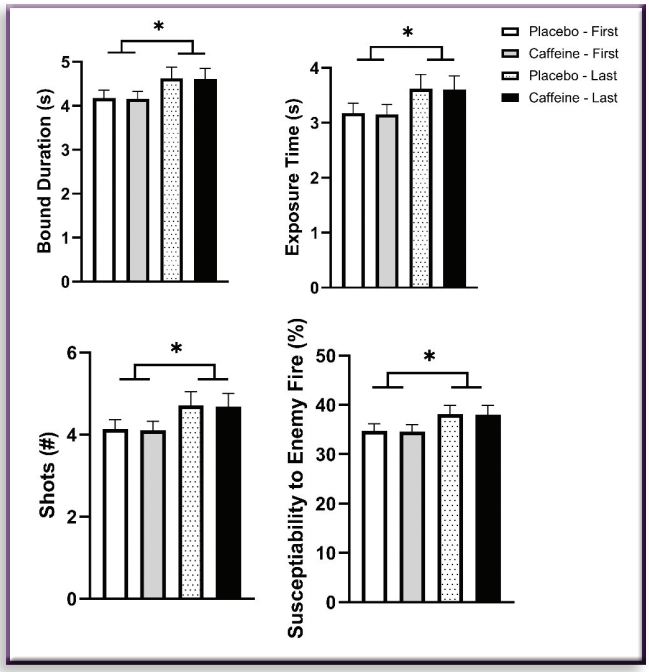


FIGURE 2 *Differences in marksmanship parameters pre-/post- fire-and-move simulation between conditions (N = 31).* **LEFT:** *Marksmanship reaction time between pre-/post-fire-and-move simulation.* **MIDDLE:** *First shot reaction time between pre-/post-fire-and-move simulation.* **RIGHT:** *Marksmanship accuracy between pre-/post-fire-and-move simulation. Data are presented as means ± SEM. No significant differences were found for condition or time.*

FIGURE 3 *Differences in susceptibility to enemy fire parameters for the first/last three bounds of the fire-and-move simulation between conditions (N = 31).* **TOP LEFT:** *Bound duration between conditions.* **TOP RIGHT:** *Exposure time between conditions.* **BOTTOM LEFT:** *Shots between conditions.* **BOTTOM RIGHT:** *Susceptibility to enemy fire between conditions. Data are presented as mean ± SEM.*



*Denotes significant differences ($p < .05$) in first and last three bounds of the fire and move simulation.

fire-and-move simulation across conditions. A significant main effect was found for time [F (1,30) = 20.2, $p < .001$, $\eta^2 = .403$], but not condition on bound duration ($p = .795$). Bound duration was significantly longer in the last three bounds of the fire-and-move-simulation compared to the first three bounds (4.62 ± 0.25 seconds versus 4.17 ± 0.17 seconds, $p < .001$). A significant main effect was found for time [F (1,30) = 20.23, $p < .001$, $\eta^2 = .403$] on exposure time to enemy fire, but not condition ($p = .795$). Exposure time to enemy fire was significantly longer in the last three bounds of the fire-and-move simulation compared to the first three bounds (3.62 ± 0.25 seconds versus 3.17 ± 0.17 seconds, $p < .001$). Caffeine did not improve the fastest bound duration [t(30) = 0.642, $p = .526$].

A significant main effect was found for time [F (1,30) = 20.23, $p < .001$, $\eta^2 = .403$], but not condition ($p = .795$) on the number of shots from enemy forces. The number of shots were significantly higher in the last three bounds of the fire-and-move simulation compared to the first three bounds (4.7 ± 0.32 shots versus 4.1 ± 0.22 shots, $p < .001$). Finally, a significant main effect was found for time [F (1,30) = 25.4, $p < .001$, $\eta^2 = .459$], but not condition ($p = .820$) on susceptibility to enemy fire. Susceptibility to enemy fire was significantly higher in the last three bounds of the fire-and-move simulation compared to the first three bounds (38.1 ± 1.8% versus 34.7 ± 1.4%, $p < .001$).

Assessment of Treatment Blinding

The blinding questionnaire had an 83.9% response rate (n = 26). Approximately 19.4% (n = 6) and 48.4.% (n = 15) of subjects perceived an effect of the supplement during the placebo and caffeine conditions, respectively. Over 35% (n = 11) and 16.1% (n = 5) of subjects did not perceive an effect of the supplement during the placebo and caffeine conditions, respectively. Over 22% (n = 7) and 25.8 (n = 8) were unsure of any effects from the supplement during the placebo and caffeine conditions, respectfully.

Discussion

The purpose of our investigation was to determine the ergogenic properties of caffeine on marksmanship, cognition, and susceptibility to enemy fire during a tactical combat movement simulation. We hypothesized that performance would deteriorate during the tactical combat movement simulation resulting in significant decrements in marksmanship, cognition, and susceptibility to enemy fire. We found that susceptibility to enemy fire and cognitive performance deteriorated from the tactical combat movement simulation, but marksmanship did not. Additionally, we hypothesized that caffeine supplementation would significantly attenuate performance decrements in marksmanship, cognition, and susceptibility to enemy fire during the tactical combat movement simulation. Caffeine did not significantly improve bound duration, marksmanship, cognitive performance, or susceptibility to enemy fire during the tactical combat movement simulation.

Deterioration of sprint ability is a common feature during successive repeated sprint efforts during running and tactical combat movement simulations.[3,4,23,39,44] Our findings support the importance of repeated sprint ability in soldiering tasks and the presence of physical fatigue, as highlighted by Hunt and colleagues during tactical combat movement simulations.[4] Fatigue during tactical combat movement simulations is exacerbated by increasing combat loads. In fact, exposure time increases by 1.1% for each kilogram increase in load.[3] The combat load used in our investigation was similar to other investigations; however, heavier loads may continue to exacerbate fatigue during tactical combat movements and increase susceptibility to enemy fire.[3,4] Load carriage increases the work of respiratory muscles, which decreases blood flow to working locomotor muscles. This can then cause reductions in exercise tolerance.[45,46] Some investigations have documented

that caffeine may increase blood flow and muscle tissue saturation that may increase lower-body muscle function.[47–49] We found no significant effect of caffeine on fire-and-move simulation performance (i.e., repeated sprints), corroborating the results of others.[24,44,50–55] It is possible that providing subjects with a substance that potentially had an active-ingredient elicited an ergogenic response.[56] However, this explanation is unlikely since nearly half of the subjects reported no perceived effect from the placebo supplement. Alternatively, it is possible that the familiarization session was unsuccessful in mitigating a learning effect.

Stressful environments are reported to cause decrements to aspects of lower cognitive function and decision-making.[10–12] The fire-and-move simulation deteriorated cognitive performance, but not marksmanship. This is perhaps because it did not provide enough stress to deteriorate marksmanship.[57,58] Stress-induced cognitive decline, such as sleep deprivation, is often mitigated with caffeine supplementation in soldiers.[22] Caffeine also improves complex soldier tasks such as marksmanship reaction time. However, the effects of caffeine on marksmanship accuracy are not well documented.[59]

Our analysis revealed that neither cognitive performance, marksmanship reaction time, nor marksmanship accuracy were different between placebo and caffeine conditions. Our results confirm previous reports documenting no improvements in marksmanship accuracy after caffeine supplementation when protocols elicit a stressful environment without sleep deprivation.[28,60–63] Additionally, this is the first study to document the effects of caffeine supplementation on marksmanship reaction time during a fire-and-move simulation without sleep deprivation. Our findings suggest that caffeine supplementation does not improve marksmanship reaction time. Thus, caffeine's ergogenicity on marksmanship parameters may only be revealed in sleep-deprived subjects.[29,64,65] Collectively, our findings suggest that caffeine was not an effective ergogenic aid during a simulated tactical combat movement in rested subjects. However, understanding the effects of caffeine on performance during direct-fire engagements while sleep-deprived may have implications to soldier survivability during sustained operations and presents an avenue for future investigations.

The current investigation was strengthened by a robust study design with subjects serving as their own controls in a double-blind, counterbalanced, crossover design that determined the effects of caffeinated gum. This study also utilized a combat-relevant protocol that induced both physical and cognitive stressors. Yet, our study does not go without limitations. Our study included research volunteers who were active-duty military personnel with a rifle qualification or civilians. Our subjects, however, exceeded the US Army standards by successfully engaging at least 75% of targets. Also, since there is no difference in combat simulation performance between civilians and military personnel, the authors did not feel that this influenced our outcomes or interpretations.[66] Our study did not include invasive measures of plasma caffeine concentration, which limited our ability to confirm that caffeine levels significantly increased after chewing the caffeinated gum. However, ingestion of caffeine may not be necessary to elicit an ergogenic response as evidenced by rinsing caffeinated fluids.[25] Eight subjects did not complete the study, which, in part, was due to the COVID-19 outbreak. Thus, a fully powered study may have provided different results. The effect size of the condition on susceptibility to enemy fire was exceptionally low ($\eta^2 = .001$) and would have required many subjects (approximately 200) to detect statistical significance. Lastly, tactical combat movements are conducted with multiple soldiers and units. Thus, our findings may not translate when multiple soldiers work together during direct-fire engagements.[8]

Conclusion

Our investigation determined the effects of caffeinated gum on marksmanship, cognition, bound duration, and susceptibility to enemy fire during a tactical combat movement simulation. The authors found that susceptibility to enemy fire increased, and that cognitive performance decreased during the tactical combat movement simulation. However, caffeine did not change marksmanship, cognition, bound duration, or susceptibility to enemy fire. Significant increases in bound duration indicates that susceptibility to enemy fire increased during the repeated bounds, which, in turn, may decrease soldier survivability. While caffeine was not effective at maintaining bound duration or changing marksmanship or cognitive performance, the authors cannot discount the possibility of improvements in performance from caffeine after sleep deprivation.

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The authors have indicated they have no financial relationships relevant to this article to disclose.

Author Contributions
JAS, JAD, TCH, and K. M. Heinrich conceived the study concept. JAS and TCH obtained funding. JAS recruited participants and coordinated and collected data, JAS, JAD, CMB, CDB, K. M. Holte, and BKK acquired data. JAS analyzed data and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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