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Effects of caffeine and menthol on cognition and mood during simulated firefighting in the heat

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ABSTRACT

This study examined the separate effects of caffeine and menthol on cognition and mood during simulated firefighting in the heat. Participants ($N = 10$) performed three trials in a counterbalanced order, either with 400 mg caffeine, menthol lozenges, or placebo. The simulated firefighting consisted of 2 bouts of 20-min treadmill exercise and one bout of 20-min stepping exercise in the heat with two brief 15-min rest periods between each exercise phase. Exercise induced significant dehydration (>3%) and elevated rectal temperature (>38.9 °C), for all three conditions. Neither caffeine nor menthol reduced perceived exertion compared to placebo ($p > 0.05$). Mood ratings (i.e., alertness, hedonic tone, tension) significantly deteriorated over time ($p < 0.05$), but there was no difference among the three conditions. Simple reaction time, short-term memory, and retrieval memory did not alter with treatments or repeated evaluations. Reaction accuracy from a math test remained unchanged throughout the experimental period; reaction time from the math test was significantly faster after exposure to the heat ($p < 0.05$). It is concluded that, exhaustive exercise in the heat severely impacted mood, but minimally impacted cognition. These treatments failed to show ergogenic benefits in a simulated firefighting paradigm in a hot environment.

1. Introduction

While the physiological consequences of firefighting have been extensively studied, less is understood about how cognition and mood would be affected during firefighting in harsh and demanding environments. Firefighters are often exposed to multi-stressors, including intense and sustained physical tasks, environmental extremes, anxiety, uncertainty, and obligations of victim rescue. There is considerable anecdotal documentation of these multi-stressors negatively impacting on the ability to process cognitive information and act quickly, effectively, and decisively (Grandjean and Grandjean, 2007; Hancock and Vasmatzidis, 2003). Furthermore, a firefighting job is characterized by shift work which can contribute to episodic sleepiness, and may cause deterioration of alertness and operational efficiency. A recent article highlighted sleep disruption, heat, and smoke on physical and cognitive performance encountered by wildland firefighters (Aisbett et al., 2012). Impaired cognition and mood would likely increase risks of injuries and accidents.

Caffeine and menthol might provide a practical intervention to preserve sufficient mental efforts during firefighting missions. The behavioral effects of caffeine as a stimulus are well known. Following crossing the blood-brain barrier, caffeine binds to adenosine receptors and exerts centrally psychostimulant effects through antagonism of adenosine A1 receptors. Caffeine's well-documented stimulating effect on human cognition and mood include increased alertness, attention, vigilance, and memory (Lieberman, 2001; Nehlig, 2010). For shift workers, use of caffeine products are likely to be encouraged for prevention of work errors and possible injuries resulted from fatigue and sleepiness (Ker et al., 2010). The beneficial effects on cognitive information processing likely contribute to the widespread use of this drug. Menthol has a mild arousal effect. When applied to the skin and mucous surfaces, menthol induces subjective

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sensation of coolness, the underlying mechanism being a stimulating action on peripheral cold receptors (Eccles, 2003). Nasal inhalation or oral administration of menthol brings perceived sensation of breathing cool and fresh air and of improved airflow; it has been suggested this cool sensation influences arousal and alertness levels (Eccles, 2000). Mints and lozenges with menthol additive are frequently used in situations where a mild stimulus is required to maintain alertness. Interestingly, Mündel and Jones (2009) studied swilling menthol solution during exercise in a hot environment and it was found endurance capacity was enhanced by an average of 9% with menthol. They suggested that change in the sense of effort (average of 15% reduction in ratings of perceived exertion) partially accounted for the improvement in heat tolerance. Thus, effects of stimulus such as caffeine and menthol might be expected, especially when individuals experience low arousal and high fatigue levels, or in tasks requiring explicit and sustained cognitive processing, or in situations of high demand on controlled mood. Therefore, for firefighters experiencing dehydrated, hyperthermic, and exhausted states, caffeine and menthol might offer simple solutions for combating fatigue and preserving cognitive information processing and mood.

Failure to detect any dangerous situations can be critical and life-threatening. Therefore, this study examined the separate effects of caffeine and menthol on cognition and mood during a simulated firefighting exposure. We hypothesized that in a heat stress prolonged exercise condition, caffeine and menthol would increase cognitive performance and improve mood across time relative to placebo. Administrators need to be aware of the potential for mental efforts deficits in highly stressful situations and seek potential interventions to mitigate adverse effects.

2. Material and methods

2.1. Participants

Ten males, unacclimatized to heat, volunteered to participate in this study. They were confirmed to be regular coffee drinkers, consuming at least one cup of regular coffee per day. Their physical characteristics were age: 24 ± 4 yr, height: 179 ± 6 cm, weight: 76.3 ± 15.3 kg, percentage of body fat: 8 ± 5%, and maximal oxygen uptake: 52.8 ± 5.3 ml kg^{-1} min^{-1}. This study was approved by the university's Institutional Review Board for protection of human subjects.

2.2. Experimental design

This study used a placebo-controlled, counter-balanced cross-over repeated measures design. This study required participants to complete four laboratory visits. Experimental trials were conducted once per week. The first visit consisted of preliminary testing, workload assessment, and familiarization. The remaining three visits were experimental trials with placebo, caffeine, or menthol treatments. For the caffeine trial, caffeine was administered in capsule form (400 mg of caffeine) ten minutes prior to the 1st treadmill exercise. For the menthol and placebo trials, participants took menthol lozenges (10-mg menthol, 6-mg benzocaine) (Chloraseptic, Prestige Brands, USA), or placebo lozenges (6-mg benzocaine) (Cepacol Fizzlers, Combe Inc., USA). Each of the three trials consisted of a baseline assessment of cognition and mood (described below) followed by repeated post-treatment assessments. Before each experimental day, participants were asked to refrain from strenuous exercise and consuming any caffeine-containing drinks or food from 8 P.M. the previous evening until completion of the trial during the experimental day.

The first visit was to determine individual's maximal oxygen uptake and maximal heart rate from a graded treadmill test, and the consequent individual workloads. Each experimental trial consisted of two treadmill exercises and one stepping exercise with brief rest periods between the each exercise phase. For the treadmill exercise, participants performed 4 bouts of 4 min of walking on a motor-driven treadmill to elicit a metabolic rate of 60% maximal oxygen uptake followed by 1 min of 15 arm curls (bar weighing 4.5 kg). For the stepping exercise, participants performed 4 bouts of 4 min of constant cadence stepping exercise at a cadence of 25 steps per min (using a metronome) on a 40-cm high platform followed by 1-min 15 arm curls. Participants were required to complete this familiarization trial to ensure that they were acquainted with the exercise regime, equipment, and measurement scales. Three sample sets of cognition and mood tests were also introduced and practiced during the familiarization period to reduce learning effects. Participants verbally confirmed their confidence with all experimental protocols after the initial visit.

During the experimental days, participants were asked to provide a urine sample to verify the hydration status prior to the trials. Participants were not tested if they were dehydrated (urine specific gravity >1.020). Participants' nude body weight (shorts only) was measured on a calibrated scale (Detecto Scales Inc., USA). Participants then self-inserted a rectal thermocouple (Physitemp, USA) and the rectal temperature was monitored with a portable system (Physitemp Thermalert model TH-8, USA). Participants donned a Polar heart rate monitor (Polar, USA). During the experimental trials, participants wore firefighter protective clothing (i.e., turnout coat/pants made of Nomex fiber out shell with Goretex barrier (LION, USA) and gloves (American Firewear Inc., USA)), a self-contained breathing apparatus tank (Survivair Respirators Inc., USA), and a helmet (E.D. Bullard Co., USA). Instead of firefighting boots, athletic shoes were worn to avoid unnecessary discomfort. The total weight of the personal protective equipment was approximately 19.1 kg.

The environmental chamber setting for three 20-min exercise periods was 35 °C wet bulb global temperature (wet: 31 °C, dry: 45 °C, globe: 43 °C; 40% relative humidity). During two 15-min rest periods, participants were seated in the main laboratory room where the ambient temperature was 21 ± 1 °C (45% relative humidity). Participants took either one menthol lozenge (menthol trial) or placebo lozenge (caffeine and placebo trials) and entered the environmental chamber. They first completed a set of cognition tests (i.e., simple reaction test, followed by a short-term memory test, and math test) and a mood assessment. Then participants completed the 1st 20-min treadmill exercise, exited the environmental chamber, and completed the 1st 15-min rest period. Water was freely available during rest periods and volume consumed was recorded. A 2nd lozenge was taken prior to the 2nd treadmill exercise. Then participants repeated the 2nd 20-min treadmill exercise. Immediately after the 2nd treadmill exercise, participants completed another set of cognitions tests and mood assessment in the environmental chamber. Then participants exited the environmental chamber and completed the 2nd 15-min rest period. A 3rd lozenge was provided prior to the stepping exercise. Participants re-entered the environmental chamber and performed the stepping exercise. Immediately after the stepping exercise, participants completed the final set of cognition tests and a mood assessment in the environmental chamber. Upon doffing all gear except shorts, participants were weighed again at the end.

2.3. Measurements

2.3.1. Rectal temperature, heart rate, body weight loss, rating of perceived exertion

Rectal temperature and heart rate were monitored and recorded every 5 min throughout the experimental periods. Body weight loss was calculated as change in pre-trial and post-trial nude body weight adjusted by total fluid volume taken during rest periods.