CAFFEINATED GUM MAINTAINS VIGILANCE, MARKSMANSHIP, AND PVT PERFORMANCE DURING A 55 HOUR FIELD TRIAL

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INTRODUCTION

In a 2001 report the Committee on Military Nutrition Research (CMNR) stated that military personnel are often placed in unique situations in which extended alertness is required. This is most evident in situations involving sentry duty, radar monitoring, communications, long-range air support missions, and logistical supply requirements as well as in combat itself. In addition, personnel are often required to forgo sleep in order to meet mission requirements and this inevitably leads to various degrees of sleep deprivation. It is well accepted that restricted and/or total sleep deprivation will result in a concomitant impairment in cognitive performance (for reviews see Angus et al., 1992; Dinges and Kribbs, 1991).

Caffeine's ability to maintain or improve mental performance in rested, fatigued, and/or sleep deprived individuals has been well documented (for reviews see Fredholm et al., 1999; Lieberman et al., 2001; and Smith, 2002) and the CMNR (2001) has recommended caffeine for use as a fatigue countermeasure. Two important areas of concern with caffeine are how it can be delivered and the duration of its effects. Kamimori et al. (2002) have demonstrated that caffeine, administered in a chewing gum formulation, can be delivered three times faster in comparison to a capsule formulation. Additional studies using this chewing gum formulation have shown that a multiple dose administration paradigm (200 mg/2 hr)can effectively maintain vigilance for six hours in the early morning hours following a night without sleep (Kamimori et al., 2003) and have identified the effects of habitual high consumption with the same administration paradigm (Kamimori et al., 2004). Although these and other studies have provided a wealth of information on the ability of caffeine to sustain performance during sleep deprivation, few studies have examined its effectiveness in the performance of military tasks and under field conditions. Consequently, this study was designed to evaluate the effect of caffeine, administered in a chewing gum formulation, on vigilance and accuracy in a live fire marksmanship task and in a field observation task during a 55 hr training exercise with restricted sleep. The secondary goal was to compare performance on a standardized laboratory Psychomotor Vigilance Test (PVT), designed for use in the field, with performance on these militarily relevant tasks.

METHODS

Subjects.

Thirty healthy male soldiers from four sections with mean ± SD values for age (23.6± 4.5 yr), height (181 ± 6 cm) and body mass (81.8 ± 10.3 kg) participated in this study. Each section was assigned a number (1-4) and two of the sections were selected to receive CAF (n = 15) and the other two a placebo (PLA, n = 15) in a double-blind manner. Since all tasks could not be evaluated at the same time for all subjects (see below), one CAF and one PLAC section were grouped together to control for order effects. All subjects were certified field-fit by their base Medical Officer prior to participation and Weapons Test qualified for the use of the C7 rifle and C79 scope. The soldiers were fully informed of the details, discomforts and risks associated with the experimental protocol during an initial briefing, and written informed consent was obtained. Volunteers were not selected if they

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were taking any medication or if they had given blood within 30 days of the study. The study was granted approval by the human ethics review committee of Defence R&D Canada, Walter Reed Army Institute of Research and the Therapeutics Protection Directorate of Health Canada.

Baseline Testing.

Day 1 was the base line day. Soldiers reported to the drill hall at 08:00 hr where they were briefed by the scientific staff about experimental procedures. After the briefing, the soldier's coffee/tea consumption for the morning and daily consumption habits was recorded on a caffeine questionnaire and they were restricted from any caffeine use for the remainder of the study period. The soldiers had consumed their normal morning coffee or tea consumption prior to the briefing.

At approximately 09:00 hr the baseline five km run was conducted. Just prior to the run the soldier's height and weight were measured. After the run the soldiers underwent training on the psychomotor vigilance task (PVT) as described below. Following lunch, soldiers reported with all personal equipment necessary for a 48 hr operation. All subjects then completed an 11 km forced march to the target range. They set-up camp for the night and weapons were zeroed in preparation for the night control shoot. Smoking or chewing of tobacco was not allowed between 18:00 and 23:00 h but otherwise its use was not restricted during Day 1.

Sections1 and 3 reported to the target range at 19:00 h where they completed the baseline cycle of PVT and control marksmanship testing (as described below). Since the number of lanes on the range was limited, all soldiers in the two sections could not perform the marksmanship task at the same time. Thus, approximately half of the soldiers from each section performed the marksmanship task first while the others remained in the range shack and performed a PVT every 15 minutes. After these tasks had been completed, the soldiers switched tasks. Two hours later the other sections began their cycle of PVT and marksmanship testing. Once these sections had finished the marksmanship testing a final PVT was performed by all soldiers. Subjects were kept awake until 02:00 hr of Day 2 at which time they began a three hr sleep period in the range hut.

Soldiers were awakened at 05:00 hr and following breakfast performed a second forced march of five km to the Fighting In Built Up Areas (FIBUA) site. For the remainder of the morning the sections fortified and set-up sandbag defensive positions in and around the building that would be used during the evening's vigilance testing. In the afternoon the soldiers conducted a live-fire simunitions exercise.

Experimental Testing.

At 19:30 hr subjects were briefed on the sequence of testing that would occur during the overnight period. Smoking or chewing of tobacco was not allowed between 20:00 hr and 06:30 hr the next morning but its use was not restricted at other times of the day.

The testing was divided into an early (2200 hr of Day 2 to 0200 hr of Day 3) and late session (0200 to 0600 h of Day 3). Within each test session the soldiers completed the PVT and marksmanship task and the FIBUA vigilance task. Sections 1 and 3 completed the PVT and marksmanship task first while sections 2 and 4 completed the FIBUA task first in both the early and late test sessions. Prior to beginning the early phase of testing all soldiers chewed one stick of gum for five minutes. A further two sticks of gum were chewed for five minutes after completing the first task and before switching to begin the other task at approximately midnight of Day 2. Each piece of the gum contained either 100 mg of caffeine or no caffeine. This sequence of testing and caffeine or placebo administration was repeated during the late phase of testing. The total dose of caffeine administered during the night was 600 mg. After the late phase of the testing was completed soldiers were transported to the drill hall where a repeat of the initial five km run was performed starting at 09:00 hr. Prior to beginning this five km run, soldiers chewed on a cotton stick for three minutes to provide a saliva sample that was later analysed for caffeine. After the final five km run, a short debriefing occurred after which soldiers were transported to their place of residence for recovery sleep.

Marksmanship Vigilance and Accuracy.

The marksmanship task was completed on an outdoor range and consisted of two components. The first was a vigilance task lasting 40 minutes followed by an accuracy task which lasted five minutes. Subjects were directed to fire a single shot at any target which appeared in their lane and to expect between two and five targets. The range was unlit and upper body targets were raised in each lane at a random interval with four total targets per lane per test. The targets were lit from below as they were raised above ground and remained above ground for a period of four seconds.Targets appeared in each lane four times randomly sequenced during the 40-minute period and were illuminated from below; otherwise this task was conducted in total darkness. A maximum of two points was awarded for each target; one for recognizing the target and firing the rifle, and one for hitting the target.

The second component was an accuracy task which followed the vigilance session. The range was lit by para-flares and soldiers had five minutes to fire the remaining rounds in their clip (they began the vigilance task with 10 rounds) at a new target. Each shot that hit the target was awarded one point. No specific firing instructions were given other than to hit the target.

Fighting in Built Up Area (FIBUA).

At the FIBUA site each subject was assigned an observation position in a window or doorway and directed to observe and record any actions (time, location, event) occurring in and around a building on the opposite side of the street (~15 M). The soldiers were to record the where, when and what of any activity that occurred in and around this building. The nature of the activities (such as a person opening and closing shutters, coming out of a door, a pen light being turned on to simulate reading a map, or someone walking from a corner of the building to enter the building) and the time that they appeared throughout the 90 min observation period were randomized such that one activity occurred randomly within each ten min block for a total of nine activities over the 90-minute period. Prior to the start of this activity soldiers synchronized their watches and were given a flashlight, clipboard and pen to record their observations. Each activity was awarded a maximum of three points; one for recording the appropriate time of the activity, one point for describing the whole activity accurately and a third point for stating accurately where the activity happened. Thus, the total number of points awarded for this activity was 27 and scores were expressed as a percentage.

Psychomotor Vigilance Task (PVT).

The PVT is a computerized vigilance test with a reaction time component that is administered on a hand held palm pilot. Subjects press a button each time a bull's-eye appears on the screen. Test presentation occurs with 1-5 sec interstimulus interval and the test is five min in duration. The data collected included reaction time (RT, speed), minor lapses (RT > 500 msec) and major lapses (RT > 3000 msec). In addition to the PVT test session in each test period, PVTs were also administered prior to and after the completion of the marksmanship and UOVT.

Measurements.

Saliva samples were assayed for caffeine concentration using gas chromatograph-mass spectrometry electron impact single ion monitoring (model MSD 5970a Hewlett Packard, Palo Alto, Ca).

Statistics.

An analysis of variance with one repeated factor (time) and one grouping factor (drug) was used to determine differences between and within groups. To correct for the violation of the sphericity assumption with the repeated factor, a Huynh-Feldt correction was applied to the F-ratio. When a significant group and time interaction occurred, a Newman-Keuls post-hoc analysis was performed to isolate differences among treatment means. For all analyses, an alpha level of ≤ 0.05 was used for statistical significance. Regression analyses were conducted to determine the relationships between PVT and Marksmanship and FIBUA task performance. For each variable in each comparison, groups (PLA and CAF) and sessions (early and late) were combined but matched accordingly.

RESULTS

Daily Caffeine Consumption.

Two soldiers in the CAF group and 4 in PLA were nonusers of caffeine. For the remaining soldiers, caffeine consumption ranged from a low of 42 to a high of 1823 $\mathrm{mg} \cdot \mathrm{day}^{-1}$. Daily caffeine consumption was not different between the CAF ($698.4 \pm 493.1\ \mathrm{mg \cdot day^{-1}}$) and PLAC ($400.9 \pm 456.4\ \mathrm{mg \cdot day^{-1}}$) groups.

Caffeine Concentration.

One saliva sample was lost for a soldier in the PLA group but for the remaining soldiers in this group there was no measurable trace of caffeine in their saliva. In contrast, saliva concentrations of caffeine measured 9.9 ± 6.0 µM for the CAF group.

Marksmanship.

There was no significant decline in marksmanship vigilance during the early test session on Day 2 in either the placebo or caffeine groups. However, in the late session there was a significant decrease in vigilance in PLA while vigilance was maintained in CAF (See Figure 1). There was no significant difference between PLA and CAF in any test session.

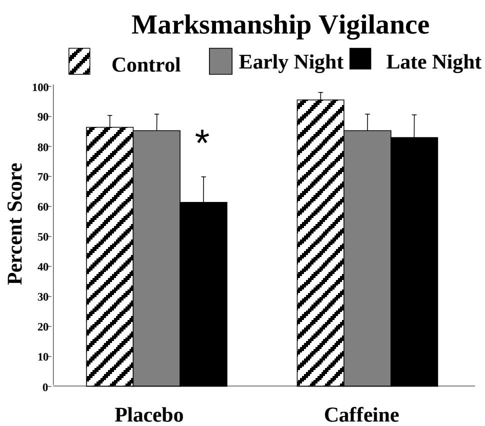

Figure 1. Effect of caffeine on marksmanship vigilance. * = significant difference compared to control.

As illustrated in Figure 2, there was a trend toward decreased marksmanship accuracy over time in PLA which was significantly reduced relative to both the control and early test sessions. Accuracy was maintained with CAF across all test sessions.

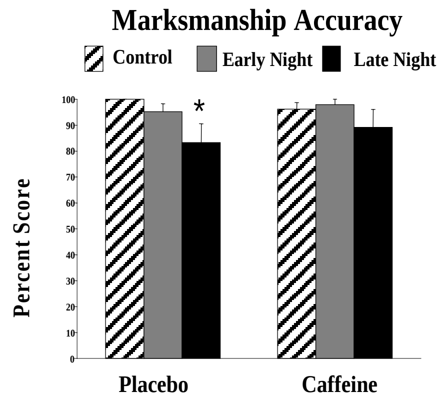

Figure 2. Effect of caffeine on marksmanship accuracy at three different time points. * = significantly different from control and early night.

FIBUA.

Performance on the FIBUA task was significantly impaired in PLA between the early and late test sessions (82 to 44%) while performance was maintained in CAF (See Figure 3.). In addition, in the late test session (0200-0400 hr) performance in PLA was significantly impaired relative to CAF.

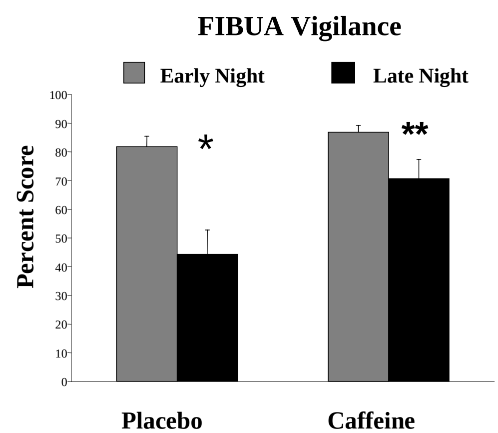

Figure 3. Effect of caffeine on performance in the FIBUA vigilance task. * = significant difference between early and late. ** = significant difference between PLA and CAF.

PVT.

Reaction time significantly increased and the number of minor and major lapses was significantly increased over time. There was a three fold increase in the number of minor lapses in the early test session but this was not significant. However in the late session the number of minor lapses was significantly higher than control and CAF (See Figure 4). Although there were very few major lapses during the study, the results mirrored those observed for minor lapses (See Figure 5).

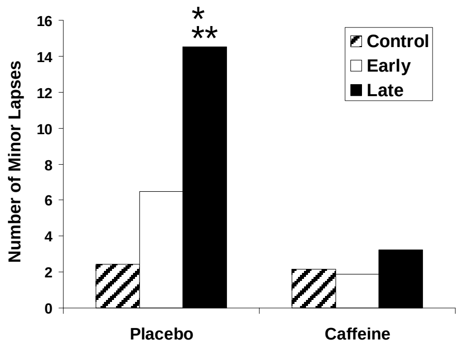

Figure 4. Number of minor lapses on the PVT in relation to marksmanship vigilance. * = significant difference from control. ** = significant difference from CAF

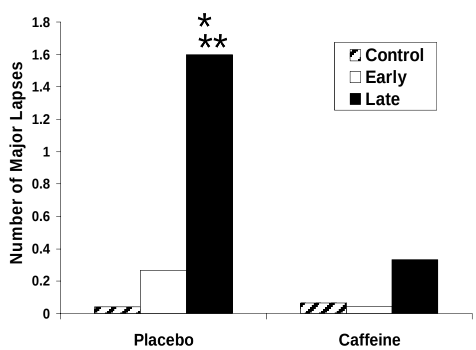

Figure 5. Number of major lapses on the PVT in relation to FIBUA performance. * = significant difference from control. ** = significant difference from CAF

Comparison of Military Tasks vs PVT. As presented in Table 1 there was a significant correlation between the number of major or minor lapses and vigilance on the marksmanship task and for FIBUA performance. However, marksmanship accuracy did not correlate with PVT performance.

Table 1. Correlations between marksmanship vigilance and accuracy and FIBUA performance and the PVT.

	Marksmanship Vigilance	Marksmanship Accuracy	FIBUA
PVT Major Lapses > 3 sec	$R^2 = 0.26$ $p < .000$	$R^2 = 0.006$ $p > .05$	$R^2 = 0.26$ $p < .000$
PVT Minor Lapses 0.5-3.0 sec	$R^2 = 0.24$ $p < .000$	$R^2 = 0.002$ $p > .05$	$R^2 = 0.22$ $p < .000$

DISCUSSION

The results of this study demonstrate that sleep deprivation has a profound negative effect on performance of military tasks that include a vigilance component. Marksmanship vigilance and accuracy, FIBUA, and PVT performance were all compromised by sleep deprivation. Multiple small doses of caffeine (100-200 mg), administered in a chewing gum formulation, maintained performance on all of these tasks during the 55 hr operation. These findings provide support for the fielding of caffeine as an effective fatigue countermeasure in the operational environment. Finally, the significant correlations identified between marksmanship vigilance and the FIBUA task with the field laboratory task (PVT) will facilitate development of a model to predict performance in the field based on laboratory results.

The ability of caffeine to maintain cognitive function during periods of sleep deprivation have been well documented in the laboratory (Beaumont et al., 2001; Kamimori et al., 2000; Penetar et al., 1993; Wesensten et al., 2002) using a variety of computer based tests. These studies have shown that the benefits of caffeine are proportional to the extent of the performance degradation observed during the period of sleep deprivation, with consistent positive effects on reaction time, vigilance and alertness tasks. In one of the few studies to examine performance in a field environment, Lieberman et al. (2002) determined the effectiveness of caffeine on cognitive function during a stressful military training exercise. Following 72 hours of sleep restriction either caffeine (100-300 mg doses) or placebo was administered and cognitive function was assessed 1 and 8 hours later. Improvements in vigilance, reaction time, attention, mood and sleepiness were reported and the degree of improvement was related to the dose of caffeine administered. These results are consistent with those of the aforementioned laboratory-based studies.

Previous studies using firearms training simulators (Tharion et al., 2003; Tikuisis et al., 2004) have shown that sleep deprivation slows target engagement time and impairs marksmanship accuracy. Tharion et al. (2003) reported that caffeine improved target engagement time while Tikuisis et al. (2004) showed that engagement time was restored to baseline levels with caffeine. Both of these studies reported that the impaired marksmanship accuracy associated with sleep deprivation was not restored with caffeine ingestion. In addition, Tikuisis et al. (2004) reported that caffeine restored target detection vigilance which increased during sleep deprivation. In the present study, both marksmanship vigilance and accuracy were significantly compromised by sleep deprivation while performance was maintained in the caffeine group. It is important to note that although marksmanship accuracy declined in both groups during the late session the effects only reached significance for the placebo group. The present data, collected on a live-fire range, are consistent with those of previous studies (Tharion et al., 2003; Tikuisis et al., 2004), that used firearms simulators and support the use of caffeine for maintaining shooting performance in the operational environment as there were no significant negative effects on accuracy.

Sleep deprivation had a significant negative effect on performance of the FIBUA task, which was expected as it is very similar to a number of standard laboratory vigilance tasks. Reaction time and the number of minor and major lapses on the PVT were significantly increased over time with sleep deprivation in the placebo group whereas caffeine maintained performance on all of these measures. These results are consistent with those reported in laboratory studies and also with more recent studies (Kamimori et al., 2003; Kamimori et al., 2004) in which a similar multiple dose administration paradigm was used in the laboratory. More importantly, the significant correlation between PVT performance (number of minor and major lapses) with marksmanship vigilance and FIBUA performance demonstrate that laboratory based tasks can be used to predict performance on military task in the operational environment.

In summary, this study demonstrates the effectiveness of caffeine for maintaining the performance of military tasks during a period of sleep deprivation. Vigilance and accuracy in a live-fire marksmanship task and in an extended vigilance task (FIBUA) was maintained at baseline levels with the administration of multiple small doses of caffeine ingested over an eight hour period. These results support the recommendation that during periods of unavoidable sleep loss the use of caffeine can extend the period of operational effectiveness during the conduct of military operations. In addition, this data will be instrumental in the development of models to predict field performance from laboratory results.

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