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Research report

# Comparing the benefits of caffeine, naps and placebo on verbal, motor and perceptual memory

Sara C. Mednick[a,*], Denise J. Cai[c], Jennifer Kanady[a], Sean P.A. Drummond[b]

[a] University of California, San Diego, Department of Psychiatry and Veterans Affairs San Diego Healthcare System, Research Service, United States
[b] University of California, San Diego, Department of Psychiatry and Veterans Affairs San Diego Healthcare System, Psychology Service, United States
[c] University of California, San Diego, Department of Psychology, United States

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ABSTRACT

Caffeine, the world's most common psychoactive substance, is used by approximately 90% of North Americans everyday. Little is known, however, about its benefits for memory. Napping has been shown to increase alertness and promote learning on some memory tasks. We directly compared caffeine (200 mg) with napping (60–90 min) and placebo on three distinct memory processes: declarative verbal memory, procedural motor skills, and perceptual learning. In the verbal task, recall and recognition for unassociated words were tested after a 7 h retention period (with a between-session nap or drug intervention). A second, different, word list was administered post-intervention and memory was tested after a 20 min retention period. The non-declarative tasks (finger tapping task (FTT) and texture discrimination task (TDT)) were trained before the intervention and then retested afterwards. Naps enhanced recall of words after a 7 h and 20 min retention interval relative to both caffeine and placebo. Caffeine significantly impaired motor learning compared to placebo and naps. Napping produced robust perceptual learning compared with placebo; however, naps and caffeine were not significantly different. These findings provide evidence of the limited benefits of caffeine for memory improvement compared with napping. We hypothesize that impairment from caffeine may be restricted to tasks that contain explicit information; whereas strictly implicit learning is less compromised.



## 1. Introduction

Caffeine, the world's most widely consumed stimulant [1], is an active ingredient in coffee, tea, chocolate, sodas, and energy drinks (the fastest growing sector of the American beverage industry) [2]. Modern times have led to an increase in daily, often multiple doses of caffeine, a rise in the coffee business, and the addition of caffeine to common beverages such as soda, bottled water, and even chewing gum. Based on the available product usage and food consumption data, Barone and Roberts [3] estimated the mean daily intake was 4 mg/kg body weight (approximately 280 mg for a 155 pound person; 16 ounces of Starbucks coffee contains 372 mg). For the 90th percentile of caffeine users, intakes approximated 5–7 mg/kg body weight (approximately 300–500 mg).

This increasingly common use of caffeine in our society coincides with an increasingly common trend of individuals obtaining insufficient sleep on a regular basis. While it is difficult to ascertain the exact number of individuals who use caffeine as a substitute for sleep in society, the 2005–2007 National Sleep Foundation's annual Sleep in America polls strongly suggest that Americans regularly consume caffeine as a substitute for sleep and/or as a result of insufficient sleep [4–6]. These polls report consistent associations between low quantity or quality of sleep, decreased daytime functioning, and increased daytime caffeine consumption.

A number of studies have examined the benefits of daytime caffeine consumption in non-experimentally sleep-deprived individuals [7–19]. The performance tasks used in these studies measure reaction time and motor speed, speed of information processing, vigilance and attention, immediate and delayed verbal memory, as well as mood and alertness (for review see [10,18]. Generally, caffeine enhances mood and alertness [8,14], vigilance and attention [8,9], speed of information processing [14,19], reaction time and motor speed [8,9,14,19]. One study found 200 and 300 mg of caffeine benefited visual vigilance, choice reaction time, repeated acquisition, and self-reported fatigue and sleepiness, but did not improve marksmanship, a task that requires fine motor coordination and steadiness [16,17]. Dimpfel et al. measured the effects of placebo, 200 and 400 mg of caffeine on human

* Corresponding author at: University of California, San Diego, Laboratory of Sleep and Behavioral Neuroscience, Department of Psychiatry, 9116a, 9500 Gilman drive, La Jolla, CA 92093, United States. Tel.: +1 858 552 8585x42895; fax: +1 858 458 4201.
*E-mail address:* smednick@ucsd.edu (S.C. Mednick).

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electroencephalogram (EEG) patterns at rest and during mental concentration tests. In addition to the finding that the effects of caffeine can be quantified with EEG spectral densities, they also found that subjects achieved the best results on concentration tests when given 200 mg of caffeine. In fact, subjects given 400 mg tested below subjects in the placebo condition. Other studies have found similar improvements on cognitive tasks with as little as 70 mg of caffeine administration compared to placebo [20].

While these studies show caffeine can enhance wakefulness and performance on attention and concentration tasks, little agreement can be found in the literature on caffeine and memory [7,19,21]. In their review, Nehlig et al. [10] write "In man, memory per se is not improved but response tends to be quicker and keener [with caffeine]". An alternative explanation for the negative findings is that only a limited number of memory processes have been examined. A thorough examination of the effect of caffeine across a wide range of memory processes has not been completed. Thus, it is still an open question whether caffeine improves learning and memory [1,12], either more generally or in specific memory domains.

Naps, in contrast to caffeine, have been shown to enhance not only alertness and attention, but also some forms of memory consolidation. In particular, naps (daytime sleep between 5 and 90 min) appear to improve performance on non-medio-temporal lobe dependent, procedural skills [22–25]. Mednick et al. reported that a mid-day nap can also reverse perceptual deterioration that builds with repeated within-day testing [22]. They further showed that naps with SWS and REM produced improvements in performance equivalent to that of a full night of sleep, whereas naps with only SWS restored deteriorated performance to baseline levels [23]. Walker and coworkers have demonstrated that naps improve procedural motor skill learning to the same degree as a full night of sleep, and that improvement on this task was correlated with Stage 2 and sleep spindle activity [25,26]. Tucker compared naps with non-REM sleep to a no-nap condition on a procedural memory task and a declarative, verbal-paired-associates task. They found that the non-REM naps produced improved performance in the declarative, but not the procedural task [27]. This is evidence that non-REM in naps can produce similar declarative memory improvements as nocturnal non-REM sleep [28].

Prior studies of performance during nightshift work have directly compared caffeine and napping in on a variety of tasks [29,30]. For example, recently, Sagaspe et al. compared the effects of a single 200 mg dose of caffeine to a 30 min nap and placebo on nocturnal driving in young and middle-aged participants. They found that both interventions significantly improved performance in both age groups, although napping was even more effective in younger compared to older participants. There are no studies, however, directly comparing the effects of caffeine and naps during the day in normally rested individuals, and few that have compared caffeine and sleep at any time for cognitive processes beyond attention, vigilance, or driving. Here, we compared the effects of caffeine, a daytime nap, or placebo on three distinct memory processes: declarative verbal memory, procedural motor skills, and perceptual learning. For verbal memory, we tested recall and recognition in two different phases: 7 h retention with a between-session intervention (caffeine, placebo or nap), and 20 min retention for a different list of words post-intervention. The non-declarative tasks (finger tapping task (FTT) and texture discrimination task (TDT)) were trained before the intervention and then retested afterwards.

## 2. Methods

### 2.1. Subjects

61 adults between ages 18–39 with no personal history of neurological, psychological or other chronic illness (non-smoking) gave informed consent to participate in the experiment, which was approved by the institutional review boards of the University of California San Diego. Subjects were low to moderate caffeine drinkers (no more that two cups of coffee per day). Since restricted nighttime sleep can have a deleterious effect on performance [31], we required that subjects maintain a sleep schedule for one week prior to the study. For seven nights prior to the study, subjects were instructed to go to bed no later than midnight and to get up no later than 8 a.m. They were asked to spend at least 8 h in bed each night. Subjects filled out sleep diaries and wore actigraphs as subjective and objective measures of sleep–wake activity. Subjects were restricted from consuming caffeine and alcohol 24 h prior to and during the experimental day.

An uneven number of subjects were run in all three tasks due to technical error, subjects misunderstanding the task which led to unusable data, and adding the verbal task midway through the study. For the Verbal task, 11 placebo, 12 nappers and 12 caffeine subjects were run. For the Motor task, 18 placebo, 13 nappers and 18 caffeine subjects were run. For the Perceptual task, 19 placebo, 18 nappers and 18 caffeine subjects were run.

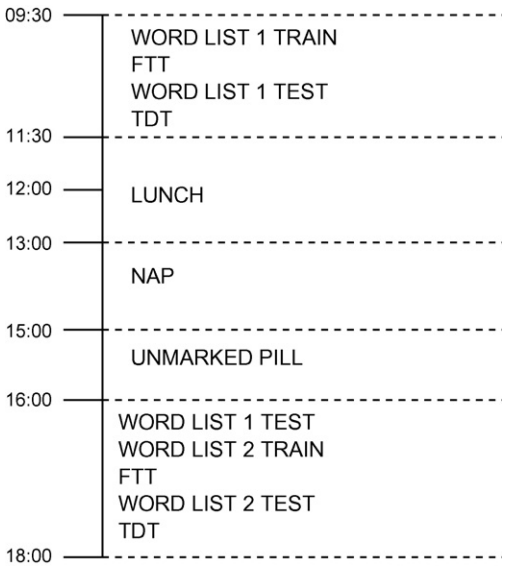


**Fig. 1.** Experimental timeline. All subjects tested on Word List 1 in the morning. At 1 p.m., nappers slept with PSG monitoring. At 3 p.m. non-nappers received an unmarked pill (200 mg of caffeine or placebo). All subjects retested on Word List 1 after 7 h retention interval. All subjects were then trained and tested on Word List 2 with a 20 min retention interval.

### 2.2. Study procedures

Fig. 1 shows study timeline (an example task order scenario). Task order was counterbalanced across subjects. Subjects were in the lab under supervision during the entire experimental day. Subjects' knowledge of testing procedure was limited to being told that they would be tested in the morning and afternoon on the all three tasks. At 09:30, subjects were administered the initial verbal task and were trained on the finger tapping task and texture discrimination task (Session One). Lunch was served at noon. At 13:00, subjects were randomly assigned to a nap or a drug group. Subjects either took a polysomnographically (PSG) recorded nap (90-min of sleep maximum or up to 2 h in bed) or listened to a book on tape with PSG monitoring. A summary of nap PSG can be found in Table 1 At 15:00, subjects in the drug groups were given an unmarked pill (200 mg caffeine or placebo). Sixty minutes later (Session Two), subjects were tested on all three tasks, as described below.

In addition, subjective sleepiness was measured before and after each test session with the Karolinska Sleepiness Scale (KSS). The KSS assesses subjects' momentary state of alertness/sleepiness on a 1–9 scale ("extremely alert" to "extremely sleepy"). Before the first test session subjects also completed the Epworth Sleepiness Scale. The Epworth assesses trait daytime sleepiness with eight questions, each scored with a degree of severity ranging from 0 to 3. A score less than 10 is considered normal. Table 2 shows the demographic information, Epworth

**Table 1**
Polysomography of naps (mean and standard deviation)

| TST | Stage 1 | Stage 2 | SWS | REM |
|---|---|---|---|---|
| 69.38 ± 23 | 6.38 ± 4.1 | 41.57 ± 14 | 12.55 ± 13 | 8.88 ± 12 |