Impact of Naps and Caffeine on Extended Nocturnal Performance

M. H. BONNET1 AND D. L. ARAND

Dayton Veterans Administration Medical Center, Wright State University, and Kettering Medical Center, Dayton, OH

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BONNET, M. H. AND D. L. ARAND. Impact of naps and caffeine on extended nocturnal performance. PHYSIOL BEHAV 56(1) 103-109, 1994. — It was hypothesized that alertness and performance would be improved by an afternoon nap and the subsequent use of caffeine during the night. Twelve young adults received a 4-h afternoon nap and caffeine during the night during one session and four 1-h naps during the night in a second session. After an afternoon nap, subjects had increased objective and subjective alertness, increased oral temperature, and increased performance on complex tasks like logical reasoning and correct additions when compared to the condition that allowed four nighttime naps. It was concluded that the specific scheduling of a nap period in preparation for an all-night work shift where sleep would not be allowed could result in increased alertness and performance as well as a less conflicted work situation.

Shift work  Sleep deprivation  Nap  Work scheduling  Circadian rhythm  Psychomotor performance
Caffeine  Sleep inertia

IN recent years, there has been growing concern about the ability of individuals to maintain adequate levels of performance over long work shifts, particularly when those shifts span nighttime hours (1,5,25). In hospital settings, where it has been common practice for residents to frequently work 36-h shifts, legal challenges, legislative input, resident spokesmen, and hospital administration have begun a difficult debate concerning work schedules (18,31). Many shift schedules exist and many new schedules have been proposed by several of these groups. However, discussions to date concerning changes in schedules have not relied significantly on empirical data.

There is a growing consensus, both from applied work in hospital settings and laboratory studies, that significant sleep reduction will lead to decline in ability to perform many tasks. Empirical studies of young adults suggest that alertness and performance deficits can be measured on the day following a reduction in sleep to 2-4 h per night on an acute basis (7,10,19,35) or a reduction to 5-5.5 h on a chronic (2-60 days) basis (9,33,35). A number of studies have examined sleep, mood, and performance in doctors at various levels of training [reviewed in (7,21)]. Of 11 studies that examined performance or mood in doctors who had slept an average of 2.8 h compared with recent baseline sleep amounts of 7.1 h, nine studies reported significantly worse performance on at least one test. One study that was unable to demonstrate significant changes in performance after reduced sleep did show that mood, as measured by the Profile of Mood States (POMS), became more negative after sleep reduction (14). As might be expected, the studies suggested that performance decrement was more likely to be found on reasoning tasks (3,11,20,23), on nonstimulating tasks (16,25), and in doctors with less experience (22). The performance impact was less than accompanying changes in mood (17). The two studies that did not demonstrate changes in performance used small groups and did not control the time of testing closely (14,24). One study reported that baseline sleep amounts in doctors were reduced about 1 h compared with their prehospital baseline sleep amounts (23). This implies that the baseline comparison may have included some chronic partial sleep reduction. As expected from the empirical studies, the reduction of sleep to the 3-h range in the applied medical setting is sufficient to demonstrate a decline in performance. Despite findings of decreased performance ability, previous studies have not examined physician performance in the 0400-0600 h time period, where it would be predicted that the maximal impact of sleep loss would be found.

Relatively few studies have applied our knowledge concerning the impact of reduced sleep and circadian rhythm on performance to maintain nocturnal performance at higher levels. In hospital on-call situations, it is common for doctors to attempt to sleep for periods of time during the night when their immediate presence is not required. The amount of sleep possible is widely variable and the ambiguity of the situation, which presumably conflicts the doctor's desire and need for sleep with his patient care responsibilities, is less than ideal. Because the work/rest schedule is by nature ill-defined, doctors are unlikely to have the option of using caffeine to maintain alertness because caffeine might interfere with the ability to fall asleep, if an opportunity should arise. The standard on-call/sleep schedule is also less than ideal because it is the rule that doctors are not wakened until needed. Performance immediately after arousal from sleep will frequently be poor because it can take up to 30 min to overcome ...

1 Requests for reprints should be addressed to Michael H. Bonnet, Ph.D. (1511N), VA Hospital, 4100 W. Third Street, Dayton, OH 45428.
the negative effects of sleep inertia (12, 28). During the night, circadian effects add to sleep deprivation to compound sleep inertia. Although this reasoning indicates that individuals allowed relatively short intervals of sleep across an all-night work period should be less alert and should perform more poorly than individuals who have had naps at earlier times, empirical comparisons of such schedules have not been done.

Several recent studies have shown that the placement of sleep periods and the use of caffeine can be beneficial in helping to maintain performance over shorter periods of sleep loss (up to 52 h of wakefulness). Specifically, the placement of a variable-length nap in the late afternoon before a 24-h continuous operation had a direct linear impact on alertness and performance during that operation (6). Performance during the first night was significantly improved in groups of subjects who had received 3.5 or more hours of sleep in the afternoon compared to a group that did not receive a nap (6). Administration of caffeine (4.0 mg/kg) at 2230 h had approximately the same significant beneficial impact on alertness over the following 8-h period as did a 3.5-h afternoon nap (30, 32). Another study has shown that the combination of caffeine administration during the night following a 4-h afternoon nap resulted in further significant improvement in alertness and performance over a 24-h test period compared to a 4-h nap period matched with placebo administration (8). These studies have clearly documented declining performance across the night of work in individuals who have not slept, and minimal change in performance and alertness in groups who have had either substantial afternoon naps or less substantial naps in combination with the use of caffeine during the night. However, it is not known to what extent the afternoon nap plus nocturnal use of caffeine combination provides improved alertness and performance compared to the currently common practice of allowing variable-length naps to occur during the course of an on-call night of work.

In the current study, a group of normal young adults participated in two (counterbalanced) continuous work periods. In one schedule, subjects (Ss) were allowed to take two 1-h naps during the nocturnal part of a 24-h work period. In the other schedule, Ss took a prophylactic 4-h nap before the 24-h operation and received caffeine during the night. The empirical intent of this design was to compare a simulated on-call schedule allowing naps during the night to the empirical schedule that has been shown in the literature to be most effective in maintaining alertness and performance (8) during the night. It was hypothesized that a prophylactic nap and caffeine would allow maintenance of the baseline level of alertness and performance across the night and following day. It was hypothesized that naps during the night would permit normal circadian drops in temperature, alertness, and performance.

METHOD

Subjects

Subjects were 12 healthy, 18-30-year-old males without significant history of sleeping problems, shift work, or frequent naps. Subjects were primarily undergraduate students from a nearby state university. Potential Ss using more than 250 mg of caffeine equivalent per day were excluded. All subjects completed an informed consent after the study had been explained to them and were paid for their participation in the study. Subjects also completed a 4-h session of practice on tests to be used in the study before starting the study.

Design

Subjects were scheduled for a laboratory adaptation night, which was preceded by additional test practice. After the adaptation night, a final 90-min test practice session was followed by an adaptation nap latency test. The study proper involved spending 3 consecutive nights and 2 days in the laboratory (usually Thursday night through Sunday morning) for 2 consecutive weeks. A study timeline is presented in Fig. 1. The initial night was a baseline sleep night scheduled according to the subject’s habitual sleep/wake time. On the following morning, subjects completed baseline testing on all performance and mood measures and had their baseline nap latency test between 0800 and 1200 h. During 1 week, subjects were allowed to leave the laboratory until 1500 h, when they returned to the lab to be readied for a 4-h nap, which began at 1600 and ended at 2000 h. On the other (counterbalanced) week, Ss returned to the lab at 1900 h. Beginning at 2000 h, all subjects followed the same schedule of alternating performance test blocks, Multiple Sleep Latency Test (MSLT) observations, and meals/breaks for 24 h before being allowed a night of recovery sleep scheduled at their normal sleep time. The differences in conditions were that Ss in the condition that did not have a nap between 1600 and 2000 h were allowed to stay in bed for 1 h on each of their first four MSLT observations and Ss in the other condition were awakened at sleep onset.
PROPHYLACTIC VS. NOCTURNAL NAPS

For the 1-h and 4-h naps, Ss were required to remain in bed for the allotted time even if unable to sleep. All Ss in both conditions received pills at 0130, 0730, 1330, and 1930 h. For Ss in the 4-h afternoon nap condition, the pills administered at 0130 and 0730 h contained 200 mg of Eleveine, a sustained release formulation of caffeine. All other pills were placebos. In the condition with four 1-h naps during the night, all pills were placebos. The Ss were unaware of when caffeine might be administered and reported no consistent expectations about afternoon or evening naps being better.

All subjects were assigned their own room for the course of the study. Each room contained a standard hospital bed and furniture, including a desk with an Apple IIGS computer. Subjects participated in the study in groups of one to four individuals. Subjects completed all tests and questionnaires at their individual computer workstation in their room under technician observation. Nonstartling procedures, such as calling the subject’s name, were used by the technicians to awaken faltering subjects. Meals and breaks were scheduled in another area of the laboratory, which was also within technician observation. Caffeinated beverages were not available. This study was approved by the Hospital Institutional Review Board.

Tests

Performance and mood were assessed with a battery of measures including logical reasoning (a 30-min version of the modified Baddeley task (23), digit span task from the WAIS (34), hand tremor (2-min insertion of a stylus into a 4-mm opening with percent of side touching time measured), the digit symbol substitution task from the WAIS (5 min) (34), tapping (preferred rate for 10 min), computer-modified William Word Memory Test of immediate free recall (37), computer-modified Wilkinson Addition (60 min) (36), visual vigilance (60 min) (26), subjective sleepiness/alertness (10-point analog scale), Profile of Mood States. Oral temperature was also included as a part of the performance battery because it is easily measured and is a frequent physiological correlate of performance. The tests were administered in repeated batteries across the 24-h operation.

For all subjects on all measures except MSLT, performance during continuous operations was automatically scored by the computer and was output in a format suitable for statistical analysis. The MSLT was scored for the latency to stage 1 sleep to maximize the sensitivity of the test during the relatively short sleep loss with prior sleep and possible caffeine.

EEG Recordings

Four-channel sleep recordings (LE-A2, RE-A2, C3-A2, OZ-A1) were made during nocturnal sleep periods, naps, and MSLT evaluations. Standard sleep stage percentages were calculated. Additionally, the number of sleep stage shifts, awakenings, and brief EEG arousals (per hour of sleep) were calculated. Sleep efficiency was calculated as total time asleep divided by total time in bed minus initial sleep latency. Ten MSLT evaluations were made during the study proper. The first occurred at 1000 h on the baseline day. The remaining nine MSLT tests began at 2200 h that night (following the prophylactic nap) and continued at 3-h intervals until 2200 h 1 day later.

Analyses of Performance Data

All performance and physiological variables except sleep EEG and MSLT values were analyzed and are expressed as the proportion of change from baseline (i.e., observation divided by baseline score) to help control for individual differences. Data for these variables were analyzed by ANOVA with terms for condition (1 df), time of test (df dependent upon number of administrations of a given test), and interaction. Pairwise comparisons were performed with the Newman–Keuls test at the 0.05 level using the Greenhouse–Geisser degrees of freedom. All reported results in the text will refer to statistically significant differences unless noted otherwise. Results on the many performance tests were similar. Therefore, only data from MSLT, vigilance, additions, logical reasoning, tremor, subjective sleepiness/alertness, POMS subjective fatigue, and POMS subjective vigor will be presented in this report.

RESULTS

Sleep

Sleep data are presented in Tables 1 and 2. Table 1 shows baseline sleep stage data. Significant differences from one baseline week to the next were found for total minutes of wake time during the night (24 vs. 11 min) and sleep efficiency (94% vs. 98%). However, these sleep efficiency values are within normal limits (38). Data from the 4-h nap and the four 1-h naps are found in Table 2. Although total sleep time in the two 4-h periods did not differ, there were significant differences in the distribution of sleep stages. These differences reflected the timing and length of the nap sleep periods. Fifty-eight minutes of wake during sleep in the 4-h nap was offset by four 12-min sleep onset latencies (total of 47 min) in the 1-h naps. Slow wave sleep was increased in the nighttime naps compared to the prophylactic nap. Despite the 4-h sleep periods, the recovery night of sleep demonstrated decreased sleep latency, increased sleep efficiency, and increased stage 4 sleep. These changes are usually seen following sleep loss (7). However, there were no statistically significant differences between the 4-h nap and the four 1-h nap conditions in the recovery sleep.

Psychomotor Performance

A summary of performance tests, mood scores, and physiological measures can be found in Table 3. Statistically significant

| TABLE 1 |
| BASELINE NOCTURNAL SLEEP STAGE FOR THE 4-H PROPHYLACTIC NAP AND THE FOUR 1-H NAP CONDITIONS |
|-------------------|-------------------|-------------------|-------------------|
|                  | 4-h Nap (min)     | 4 x 1-h Naps (min) |
|                  | Mean   | SD     | Mean   | SD     | t     | p     |
| Total sleep time | 439    | 52     | 423    | 58     | 1.57  | NS    |
| Stage 1 (%)      | 10.3   | 5.3    | 9.0    | 5.5    | 0.82  | NS    |
| Stage 2 (%)      | 43.1   | 11     | 40.7   | 11     | 1.32  | NS    |
| Stage 3 (%)      | 7.0    | 3.0    | 7.0    | 2.2    | 0.00  | NS    |
| Stage 4 (%)      | 16.7   | 7.8    | 17.2   | 8.8    | 0.49  | NS    |
| Stage REM (%)    | 19.6   | 7.9    | 19.5   | 5.2    | 0.10  | NS    |
| Stage movement (%) | 0.8  | 0.8    | 0.9    | 0.9    | 0.56  | NS    |
| Sleep latency   | 12.1   | 7.5    | 24.5   | 28     | 1.41  | NS    |
| Wake time       | 11.0   | 19     | 24.4   | 30     | 2.48  | 0.03  |
| Stage changes   | 115    | 25     | 115    | 25     | 0.00  | NS    |
| Time in bed     | 462    | 56     | 472    | 33     | 1.27  | NS    |
| Sleep efficiency | 0.98   | 0.04   | 0.94   | 0.06   | 2.46  | 0.03  |
| No. of awaken    | 6.0    | 5.7    | 13.7   | 17     | 1.85  | 0.1   |
| Latency to REM  | 108    | 42     | 139    | 66     | 1.49  | NS    |
| Arousal index   | 7.5    | 1.1    | 7.0    | 2.0    | 1.11  | NS    |
FIG. 2. Correct addition values (proportion of presudy baseline) for caffeine and placebo groups. Significant differences are noted (*).

FIG. 3. Oral temperature values (proportion of presudy baseline) for caffeine and placebo groups. Significant differences are noted (*).

FIG. 4. Multiple sleep latency test values for caffeine and placebo groups. Significant differences are noted (*).

total sleep time allowed in each condition the same. The early evening nap with later caffeine was chosen as a comparison because it has been previously tested against other nap conditions and found to be the most beneficial (5,6,8) and because the availability of daytime staff to cover admissions or emergencies can allow a 4-h block of time in the late afternoon or early evening in many environments. Planned afternoon nap opportunities allow several other advantages compared to napping on-call at night. Those advantages include:

1. a well-defined work situation for everyone;
2. removal of the moral or ethical conflict of interest (should I stay awake and help patients or sleep and help myself?);
3. employees can plan on remaining awake and are therefore able to use caffeine if they wish.

The data from the current study indicate that individuals who take a prophylactic nap and use caffeine during their work shift will have significantly increased objective and subjective alertness, increased oral temperature, and increased performance on complex tasks like logical reasoning and on general productivity as measured by correct additions. The 15% increase in reasoning and addition problems could justify planned prophylactic naps simply based on productivity, and there is also the additional benefit of increased alertness and ability to make complex decisions. It would be predicted that the potential for a catastrophic mistake would be the greatest when an employee was awakened and immediately forced to make an important decision. Although such a situation was not explicitly measured in the current study, it is common that individuals allowed to sleep during work situations will specifically be awakened when an emergency occurs. Several studies have indicated that performance is worse immediately after awakenings during nocturnal sleep periods (12,28). Sleep inertia effects are increased after awakenings from SWS (4) and have been found in many tasks, including simple and choice reaction time (15,27), short-term memory (4,29), and letter substitution (13). In the current study, 60% of nocturnal naps (vs. 10% of prophylactic naps) ended in SWS. This figure is probably a low estimate for the real world where on-call situa-
of sleep inertia, sleep deprivation, and declining circadian rhythm.

The performance, alertness, and temperature differences shown in the current study were unlikely to be based upon differences in performance ability, differences in underlying circadian rhythm, or other factors because 1) there were no significant differences in the prenap baseline performance values on any of the performance measures or MSLT when the 4-h nap condition values were compared to the 4 X 1-h nap condition values; and 2) the study design was within-subject with a balanced order of conditions.

The present study could be criticized because a combination of prophylactic nap and caffeine was compared to the nocturnal naps. This particular combination was chosen a) because a series of previous studies using the same design and tests has shown significantly decreased performance across the night when sleep was not allowed (6); significantly improved performance and alertness across the night when prophylactic naps were given (6); and significantly improved alertness and performance across the night when a combination of a shorter nap and caffeine was given (8); and b) because it is unlikely that an individual working at night, who is allowed to sleep at unspecified times during that night, will ingest caffeine to maintain alertness (i.e., a nocturnal nap plus caffeine condition is not of practical use). However, it is likely that an individual working at night and not allowed to nap during the night will consume caffeine.

This study indicates that individuals who nap during the night in their work situation and who are awakened frequently or accumulate less than 4 h of sleep will perform more poorly than individuals who take an afternoon nap and remain awake during the night. In addition to the overall 15% performance benefit associated with remaining awake during the night, individuals will avoid larger performance deficits (15—24% or more) associated with immediate awakening from sleep. In terms of practical use, the results suggest that taking a nap prepares individuals to deal with the sleep loss that occurs during nocturnal work periods and that caffeine probably reverses some of the normal circadian decline in nocturnal alertness. The effect of caffeine may be either a function of its central stimulating effect or through a secondary increase in body temperature.

A large and apparently controversial literature exists dealing with the extent to which physicians are impaired on various tasks after varying periods of sleep deprivation. Several published studies used small groups of subjects (14), did not control for the time of testing (14,24), or used tests that were either too brief (11) or had not been shown to be sensitive to sleep deprivation (14,24) and found small effects. In addition, none of the published studies examined performance at 6400 h, when negative effects are greatest. In this study, if no testing had been done prior to 0900 h, the largest group differences would have been missed. Smaller groups and insensitive tests easily could have reversed the results reported here. In this study, the figures and Table 3 provide performance and mood data as a percent of baseline. As such, numbers less than 1.0 indicate a decrease in performance compared to baseline (despite any learning that may have taken place). For several variables, performance in the nocturnal nap condition reached or averaged about 80% of baseline.

The results of the current study suggest that knowledge of the effects of sleep loss, and circadian rhythms can be used in the design of work schedules that can increase work efficiency and quality.

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