Maintenance of Alertness and Performance by a Brief Nap After Lunch Under Prior Sleep Deficit

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Abstract: We examined the effects of a 15-min nap after lunch on subsequent alertness, performance, and autonomic function following a short sleep the preceding night. Subjects were 12 healthy students who had slept for only 4 hours the night before being tested. They experienced both nap and no-nap conditions in a counterbalanced order, at least a week apart. The nap condition included a 15-min nap opportunity (12:30-12:45) in bed with polygraphic monitoring. We measured the P300 event-related potential, subjective sleepiness (Visual Analog Scale), and electrocardiogram (ECG) at 10:00, 13:15, and 16:15, and task performance (logical reasoning and digit span) at 10:00, 11:30, 13:15, 14:45, 16:15, and 17:45. Mean home sleep measured by actigraphy was 3.5 hours under both conditions. At 13:15, the P300 latency after the nap was significantly shorter than after no nap, but its amplitude was not affected by napping. Subjective sleepiness at 13:15 and 14:45 was significantly lower, and accuracy of logical reasoning at 13:15 was significantly higher after the nap than after no nap. No other performance measures or the ECG R-R interval variability parameters differed significantly between the nap and no-nap conditions. Mean total sleep time during the nap was 10.2 min, and no stage 3 and 4 sleep was observed. The above results suggest that under prior sleep deficit, a 15-min nap during post-lunch rest maintains subsequent alertness and performance, particularly in the mid-afternoon.

Key words: Nap; partial sleep deprivation; alertness; performance, autonomic function

INTRODUCTION

THE AVERAGE DURATION OF SLEEP OF JAPANESE WORKERS HAS GRADUALLY BEEN DECREASING. National surveys in the past five years have shown a 7% increase in the number of workers sleeping six hours or less and a 9% decrease in those sleeping seven hours or more.[1] Decreased nocturnal sleep can lead to sleepiness, errors, and accidents during the daytime.[2] Even after a normal sleep at night, the mid-afternoon period (around 14:00) is characterized by decreased alertness, poor performance, and frequent errors in the workplace; or what has been recognized as the "post-lunch dip."[3-5] Thus, it is important to seek practical solutions to diminished daytime function resulting from less sleep.

Recent research has documented that naps of less than 30 minutes are a promising strategy for counteracting the effects of a short sleep period of 4—5 hours the preceding night.[6-9] This research evaluated the roles of repeated (polyphasic) naps or a single nap taken in the morning or mid-afternoon. Such patterns of napping, however, seem unfeasible in most work settings, because of the obvious conflict with work schedules. In a previous study, we hypothesized that a post-lunch rest is an appropriate time to take a nap in the workplace, and therefore investigated the effects of a 15-minute nap taken at 12:30.[10] The results showed greater alertness and performance after the 15-minute nap than after no nap or a 45-minute nap. These findings are in agreement with the latest evidence showing improved alertness after a 20-minute nap scheduled at 12:20 in a study in which the effects of meals and time cues were controlled.[11] However, since the subjects in both studies had a normal sleep the night before testing, the effects of a post-lunch nap following a short sleep remain to be determined.

The purpose of the present study was to examine whether a 15-minute nap taken during post-lunch rest improves subsequent alertness and performance under prior sleep deficit. The effects of the nap were assessed by the P300 event-related potential (ERP) and neurobehavioral tasks. We also investigated the autonomic effects of the nap by measuring the electrocardiographic (ECG) R-R interval variability.

METHODS

Subjects

Twelve healthy students served as subjects for this experiment (7 males and 5 females, mean age 22.1±1.6 SD years). None of them reported sleep complaints or any history of medical disorders. Their habitual sleep duration was

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6.9±0.5 hours. Eleven of the subjects were intermediate type and one was moderately evening type, as assessed by the Japanese version of Morningness-Eveningness Questionnaire.[12] Before the study, the subjects were instructed that the purpose of the study was to determine whether a brief nap after lunch improves, has no effect on, or worsens subsequent alertness and performance after a short sleep at night. The experimental protocol was approved by the ethics committee of our institute. All subjects gave their written informed consent and were paid for their participation in the study.

Procedure

Subjects were instructed to sleep for only four hours at home the night before testing by delaying their bedtime. Home sleep was monitored by wrist actigraphy (Actillume, Ambulatory Monitoring, USA), and the actigraphic data were scored for sleep with software provided by the manufacture (Action 3). Each subject was exposed to both nap and no-nap conditions, once each, in a counterbalanced order. The mean length of the interval between conditions was 18 days (range 7—63). When the subjects reported to the laboratory in the morning on the first test day, they were told which of the two conditions they would be subjected to first. The nap condition included a nap opportunity of 15 minutes (12:30—12:45) in bed after lunch, with electroencephalogram (EEG), electromyogram (EMG), electrooculogram (EOG), and ECG monitoring during the 15-minute period. The corresponding time period under the no-nap condition and the testing intervals involved reading in the laboratory under surveillance by the experimenter. We measured the P300 ERP, subjective sleepiness, and 5-minute sitting ECG at 10:00, 13:15, and 16:15, and performance of neurobehavioral tasks (logical reasoning and digit span) at 10:00, 11:30, 13:15, 14:45, 16:15, and 17:45. Electrophysiological signals were recorded on an electroencephalograph (EEG-4217, Nihon Kohden, Japan) and stored on an FM tape recorder (XR-7000L, TEAC, Japan). Subjects were given training sessions for all tasks on the day before the experiment.

P300 ERP and Subjective Sleepiness

The P300 ERP was elicited by binaural presentation of 1000 and 2000 Hz tones (60 dB SPL, 100 ms duration) at an inter-stimulus interval of 1.5 s. The tones were presented through a headphone, with the 1000 Hz tone as the non-target stimulus and the 2000 Hz tone as the target stimulus. Subjects pressed a button with the thumb of their preferred hand as quickly as possible whenever they detected a target tone. Reaction time (RT) was measured as the interval between stimulus onset and key-pressing. Two blocks of 150 trials, each containing 30 random target stimuli, were recorded for each subject.

The EEG activity was recorded at the Fz, Cz, and Pz electrode sites according to the International 10-20 system, and referred to linked mastoid electrodes with a forehead ground. The inter-electrode impedance was less than 5 kΩ. Horizontal and vertical EOG activities were also recorded. EEG and vertical EOG were digitized on-line at 1 ms per point for 1100 ms, including a 100-ms pre-stimulus baseline. The waveforms were averaged off-line (Evoked Potential Analyzer, Medical Research Equipment, Japan). Trials in which the EEG or EOG exceeded ±50μV and those with erroneous responses were excluded from averaging. The P300 amplitude was identified as the largest positive peak occurring between 250—500 ms post-stimulus, relative to the average of the corresponding 100-ms pre-stimulus baseline. The P300 latency was measured as the time point of the largest P300 amplitude from stimulus onset. To check for experimenter bias, we blindly analyzed a subset of randomly selected P300 data.

A 100-mm visual analog scale (VAS) was used to obtain ratings of subjective sleepiness.[13]

Neurobehavioral Tasks

Performance was evaluated by using two different neurobehavioral tasks: logical reasoning[14] and digit span.[15] These tasks were administered and scored with a personal computer. The logical reasoning task was coupled with each of three memory loads (two-four-six letter strings). After presentation of each memory load, subjects determined whether a sentence describing a relationship between the two letters (e.g., A is preceded by B) satisfied the following letter pair (e.g., A B) as quickly as possible. Then, they recalled the pre-loaded letter strings. Sixteen trials were administered for each memory load. The number of errors and mean response time for correct judgements were recorded, in addition to the percentage of correct recalls of the memory load. For the digit span task, subjects recalled the randomly generated digits in the appropriate order. In each trial, the length of the initial digit sequence was four, and its length was subsequently increased by one digit at a time until incorrect recall occurred. Five trials were performed, and the mean number of digits correctly recalled in the five trials was recorded.

ECG R-R Interval Variability

We described the procedure used for analysis of the R-R interval variability in our previous report.[16] Briefly, 256-second consecutive R-R intervals during each 5-minute ECG recording, interpolated linearly, were subjected to spectral analysis by the fast Fourier transform. Powers at low-frequency (LF) and high-frequency (HF) ranges were calculated by integrating corresponding powers over 0.05—0.15 Hz and over 0.15—0.5 Hz, respectively. Each absolute power was normalized as the percentage of the total power integrating over 0.02—0.5 Hz, namely %LF and %HF. The LF/HF ratio and the mean of the 256-second R-R intervals (mean RR) were calculated.

Polygraphic Recording of a 15-minute Nap

The EEG, EMG, and EOG recorded during the nap were visually scored in 20-second epochs according to the criteria of Rechtschaffen and Kales.[17]

Statistical Analysis

The latency and amplitude of P300 were analyzed by three-way analyses of variance with repeated measures (ANOVAs). Factors analyzed included condition (nap and no-nap), time of measurement (10:00, 13:15, and 16:15), and electrode site (Fz, Cz, and Pz). Scores on the neurobehavioral tasks were transformed into differences from the score at 10:00 to minimize individual variation. Next, data from the logical reasoning task were analyzed by three-way ANOVAs, with condition, time of measurement (11:30 through 17:45), and memory load (two-four-six letter strings) as factors. Condition×time of measurement ANOVAs were performed on the mean RT and error responses on the P300 measurement, subjective sleepiness, digit span, and R-R interval variability parameters. P-values are reported after the Greenhouse-Geisser epsilon correction[18] with the original degrees of freedom. Post-hoc comparisons were made by using the Newman-Keuls test.

To further assess the implications of a post-lunch nap under prior sleep deficit, we compared the results obtained for the nap condition in the present study with our previously published data.[10] Our previous data analyzed here were obtained from 10 subjects who did not take a 15-minute nap after lunch (prior sleep = mean 7.6 hours) and another 10 subjects who did (prior sleep = mean 7.2 hours). The dependent variables compared included P300 latency and amplitude, subjective sleepiness, and R-R interval variability parameters, since these variables were measured in both studies. The Scheffé's test was used to compare the three conditions at the following measurement times: before (at 10:00), 30 minutes after (at 13:15), and 3.5 hours (at 16:15) after napping or no napping. The SAS software (Release 6.12, SAS Institute, USA) was used for all statistical analyses.

RESULTS

Prior Nocturnal Sleep

The actigraphic data indicated that equivalent amounts of sleep were obtained on the night preceding testing under both the nap and no-nap conditions (3.5±0.3 vs. 3.5±0.5 hours).

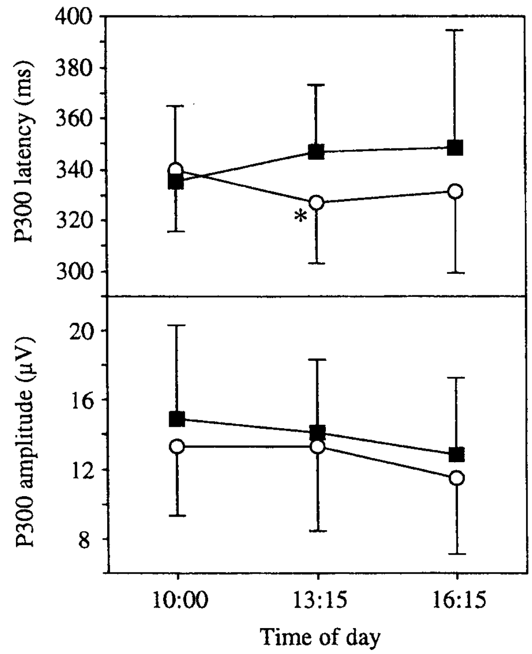

Figure 1—Means (±SD) of the P300 latency and amplitude at the Pz electrode site under the nap (○) and no-nap (■) conditions. * Significantly different from no nap at p<0.05.

P300 and Subjective Sleepiness

Shorter latency and larger amplitude of the P300 were found at the Pz electrode site than at either the Fz or Cz electrode site by three-way ANOVAs (main effects of electrode site for the latency: F[2,22]=3.24, p=0.0831, and for the amplitude: F[2,22]=21.65, p<0.0001). For this reason, we used the P300 latency and amplitude at the Pz electrode site for subsequent ANOVAs, with condition and time of measurement as factors. A significant interaction between condition and time of measurement was found for the P300 latency (F[2,22]=3.68, p=0.0489). The main effect of condition tended to be significant (F[1,11]=3.54, p=0.0865). The Newman-Keuls test confirmed that the P300 latency 30 minutes after the nap (at 13:15) was significantly shorter than after no nap (327±24 vs. 347±26 ms, p<0.05, Figure 1). Shorter P300 latency was also observed 3.5 hours after the nap (at 16:15), but the difference was not statistically significant. Only the main effect of time of measurement was significant for the P300 amplitude (F[2,22]=4.87, p=0.0281), and no significant differences were observed between the nap and no-nap conditions (Fig. 1). The blinded analysis of the subset of P300 data showed no differences from the results obtained from the entire data set described above (unblinded analysis). The ANOVAs failed to show any significant results for either the mean RT or error responses on the P300 measurements.

The main effects of both condition and of time of measurement were significant for subjective sleepiness (F[1,11]=10.84, p=0.0072; F[5,55]=10.71, p<0.0001), but

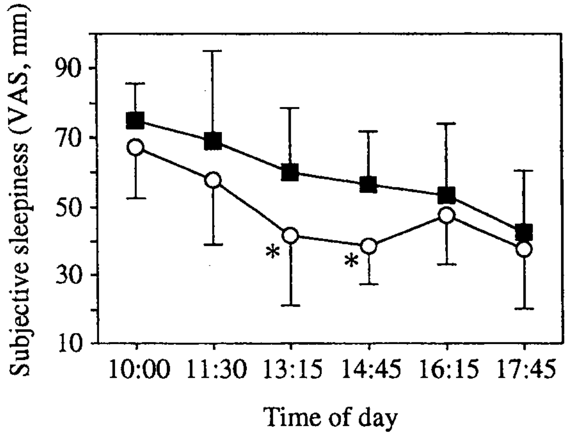

Figure 2—Means (±SD) of the subjective sleepiness measured by the Visual Analogue Scale under the nap (○) and no-nap (■) conditions. * Significantly different from no nap at p<0.05.

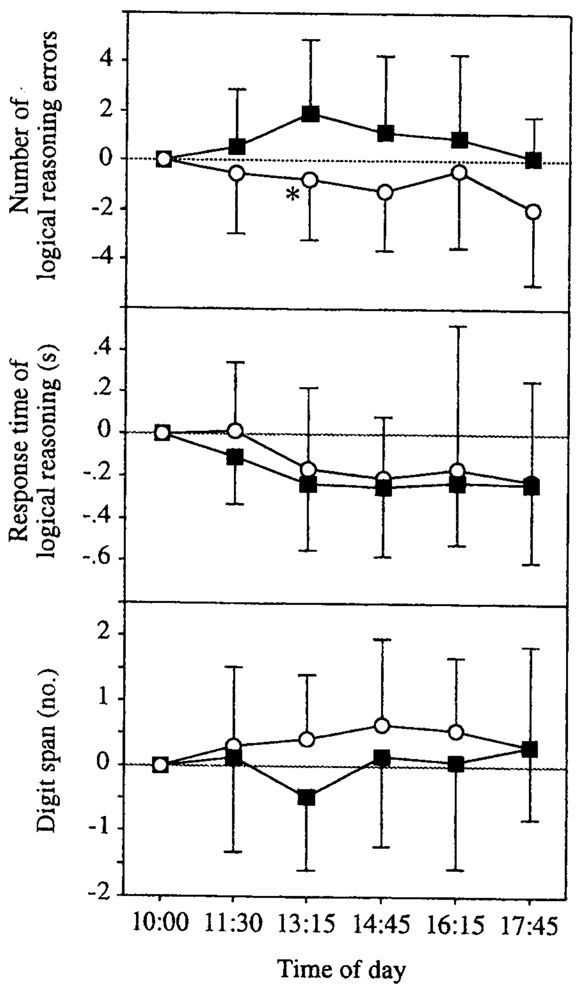

Figure 3—Means (±SD) of the total number of errors and average response times on the logical reasoning task and digit span under the nap (○) and no-nap (■) conditions. Data are expressed as differences from the score at 10:00. * Significantly different from no nap at p<0.05.

the interaction between the two factors was not significant. Figure 2 shows the significantly reduced subjective sleepiness at 13:15 and 14:45 after the nap as compared with no nap (ps<0.05).

Performance Measures

Neither main effect nor interactions concerning memory load were found for any scores on the logical reasoning task. Therefore, the number of errors was summed across the three levels of memory load, and the mean response time and the percentage of correct recall were averaged. The data were then submitted to the condition×time of measurement ANOVAs. The main effect of condition was significant for the total number of errors ($F[1,11]=4.86$, $p=0.0498$). As presented in Figure 3, the logical reasoning errors at 13:15 ($p<0.05$) and at 14:45 (NS) decreased after the nap as compared with no nap. No significant effects were observed for either the averaged response time or the averaged percentage of correct recall. Digit span appeared to be increased after the nap as compared with no nap, especially at 13:15 (Fig. 3), however, ANOVA failed to reveal any significant differences (ps>0.2).

R-R Interval Variability Parameters

No significant differences in any parameters of R-R interval variability were found between the nap and no-nap conditions (Fig. 4). Only the main effects of time of measurement were significant for the mean RR ($F[2,22]=13.90$, $p=0.0009$) and %HF ($F[2,22]=4.46$, $p=0.0334$).

Sleep Data During the Nap

As summarized in Table 1, mean total sleep time was 10.2 minutes, and sleep latency was 3.8 minutes. The nap contained exclusively stage 1 and stage 2 sleep, with no deep non-rapid eye movement (NREM) sleep (stage 3 and stage 4 sleep) being detected.

Comparison of the Brief-nap Effects With and Without Prior Sleep Deficit

Figure 5 shows the time courses for the P300 latency and amplitude, as well as subjective sleepiness for the 15-minute nap condition with and without prior sleep deficit and for the no-nap condition after a normal sleep. Significantly longer P300 latency ($p<0.05$) and higher subjective sleepiness were observed in the morning after sleep deficit than after no sleep deficit. Neither measure, however, was significantly different after the nap with prior sleep deficit from the value after no nap without prior sleep deficit. The P300 latency after the nap with prior sleep deficit was significantly longer than after the nap without prior sleep deficit (ps<0.05), and similar results were obtained for subjective sleepiness. However, the P300

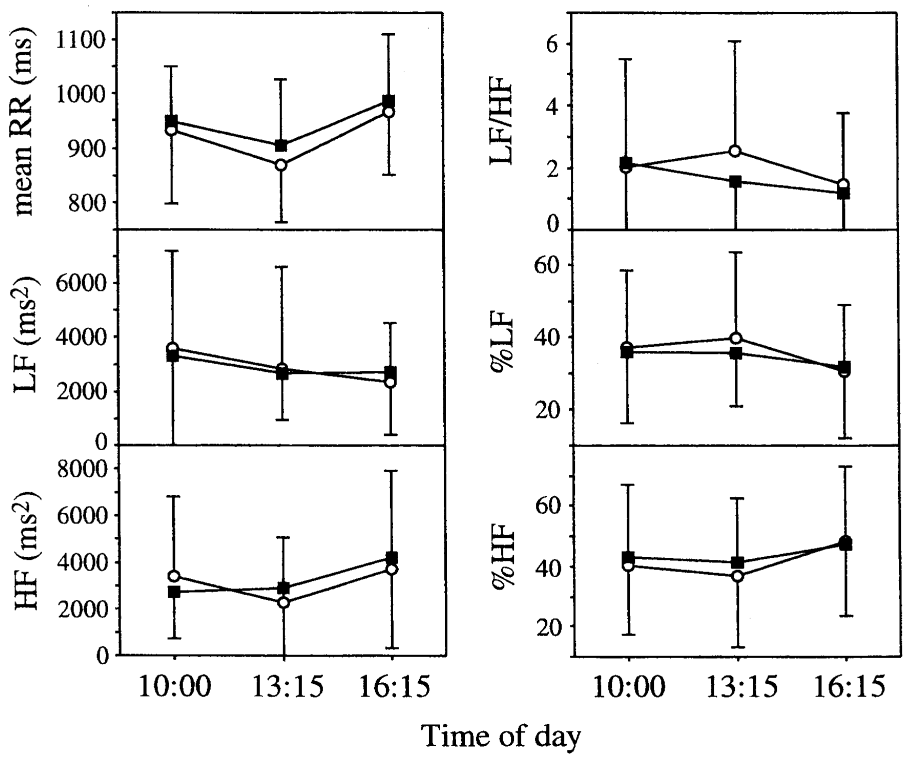

Figure 4— Means (±SD) of the R-R interval variability measures under the nap (○) and no-nap (■) conditions; mean RR, LF, HF, LF/HF, %LF, and %HF.

amplitude with prior sleep deficit was significantly reduced throughout the measurement period as compared with no sleep deficit. No significant differences were observed for any of the R-R interval variability parameters.

DISCUSSION

The results of the present study indicate that a 15-min nap after lunch maintains subsequent alertness and performance even in subjects who sleep for only 4 hours the night before. The benefits of napping as measured by P300 latency, subjective sleepiness, and logical reasoning were more apparent in the period between 13:15 and 14:45. Since errors and accidents during this period may further increase after loss of sleep,[4, 19] our results demonstrate that the post-lunch nap may alleviate such unfavorable consequences. A 15- to 30-minute nap taken at times of day other than 12:30 has been shown to attenuate decrements in alertness and performance following partial sleep deprivation,[7-9] but not following total sleep deprivation.[20] Hence, it is reasonable to conclude that taking a brief nap has a beneficial effect on subsequent waking function, provided the prior loss of sleep is only partial.

Table 1—Sleep data during the 15-minute nap

	Mean (min)	SD (min)
Total sleep time	10.2	3.0
Sleep latency	3.8	3.0
Stage Wake	1.0	1.6
Stage 1 sleep	5.5	2.0
Stage 2 sleep	3.5	3.7
Stages 3+4 sleep	0.0	0.0
Stage REM sleep	1.1 #	2.7

n=2

No significant differences were found in P300 latency or subjective sleepiness after napping under prior sleep deficit as compared with no nap under prior normal sleep. These results must be evaluated carefully, because of the slight differences in experimental procedure between the previous[10] and present studies. The recuperative effects of napping observed, however, are supported by the findings of Gillberg et al.[7] that subjective sleepiness and vigilance performance after a 30-minute nap following prior four-hour sleep were similar to those after no nap following prior 7.5-hour sleep. As shown in Figure 5, the 15-minute nap after lunch did not completely reverse the impact of sleep deficit, and the invigorating effect of a nap after sleep deficit was less than after no sleep deficit. Nevertheless, the data obtained in the current study suggest that the post-lunch nap may be effective in lowering potential of sleep-related problems during subsequent working hours.

We found that the brief nap significantly shortened the P300 latency as compared with no nap, but did not affect its

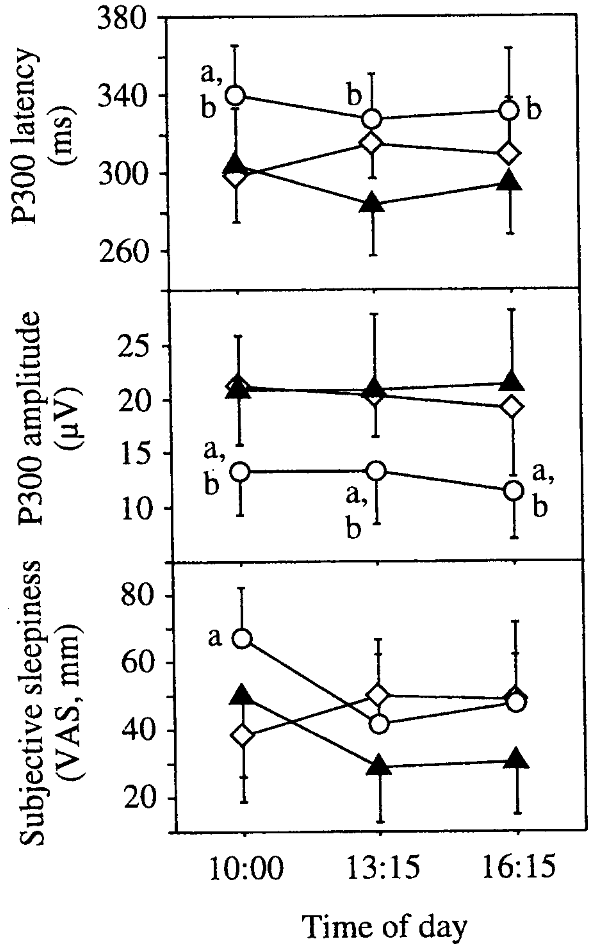

Figure 5—Means (±SD) of the P300 latency, P300 amplitude, and subjective sleepiness under the 15-min nap condition with prior sleep deficit (Nap-deficit, ○, n=12), the 15-min nap condition after a normal sleep (Nap-normal, ▲, n=10), and the no-nap condition after a normal sleep (No-nap-normal, ◇, n=10). The latter two sets of data (Nap-normal and No-nap-normal) were taken from our previous study.[10] The protocol of the previous study was essentially the same as that of the current one. **a** Significantly different from No-nap-normal at p<0.05. **b** Significantly different from Nap-normal at p<0.05.

amplitude, as in our previous study, in which the nap was taken after a normal sleep.[10] P300 is thought to be sensitive to the level of alertness;[21] yet, the nap-induced changes in alertness appeared to be reflected selectively in P300 latency, independent of prior sleep length. This finding is similar to those in previous reports showing that the latency of P300, rather than its amplitude, is altered in a consistent manner by sleep deprivation, excessive daytime sleepiness, and administration of barbiturate hypnotics.[22-25] However, the consistently smaller P300 amplitude in the sleep deficit group presented here, combined with the lack of nap effects, implies that the P300 amplitude may represent an aspect of reduced alertness, which does not benefit from the brief nap.

Significantly fewer errors were observed in the logical reasoning task after the nap than after no nap. However, no effects of the nap were observed on speed of response. These results may have been attributable in part to an instruction given to the subjects that emphasized the speed of judgment. Another important factor may be related to the strategy the subject used in solving the task. In effect, the nap may have led to a change in strategy to one that favored increased accuracy. If that were the case, greater accuracy would be accompanied by slower responses, and thus a speed-accuracy trade-off would occur. This relationship has been observed in earlier studies that used the logical reasoning task.[26-28] In contrast, the current results failed to show such a trade-off in the nap condition. A brief nap after a short sleep may thus play a role in maintaining subsequent performance at a more accurate level without any accompanying loss of response speed. Our finding is consistent with that of Hayashi et al.,[29] who demonstrated improved task accuracy, not improved speed, as a result of a 20-minute nap taken at 14:00 following a normal nocturnal sleep.

Our results show that alertness and performance after napping were not impaired by sleep inertia.[30, 31] Because the measurements were made 30 minutes after the nap, there is a possibility that the effects of sleep inertia had become negligible by that point. In addition, the sleep data showed that no deep NREM sleep occurred during the nap (Table 1). The amount of deep NREM sleep is known to be positively correlated with the severity of sleep inertia.[30-32] We anticipated that the restricted nocturnal sleep would increase the deep NREM sleep during the nap, thereby producing greater sleep inertia. A nap duration of 15 minutes, however, may not have been long enough to produce this effect.

None of the parameters of R-R interval variability after the nap were found to be significantly different from those after no nap. This was true even when subjects had slept normally on the preceding night.[10] Although the autonomic effects of the brief nap would be expected to be more pronounced after sleep restriction, our finding implies that no alteration of activity of the autonomic nervous system[33] occurred in response to napping, regardless of the duration of sleep the night before.

This study, as most previous nap studies,[7-11, 20, 27, 29] was not conducted with a blind design. It cannot therefore exclude the possibility that the differences between conditions were overestimated by expectation and knowledge of the experimental condition by the subjects and experimenters. However, the data were collected in an identical manner under both the nap and no-nap conditions. Furthermore, a subset of the P300 data that was randomly selected was analyzed blind to the experimental conditions, and the results were consistent with those obtained from the entire data set. Based on these facts, the effects of bias mentioned above seem unlikely in our study. Nevertheless, a great effort to provide blinding should be made in future research.

The young students in the current study experienced partial sleep deprivation for a single night. Repeated restriction of nocturnal sleep, a situation that is probably experienced by many workers, has been reported to cause cumulative decrements in daytime alertness and performance.[34] Further study is required to verify the present findings for a brief nap in a real work setting.

In conclusion, our results demonstrate that a brief nap during post-lunch rest contributes to maintaining subsequent alertness and performance even after a short sleep the night before. The benefits of napping are evident in the mid-afternoon.

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