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SLEEP INERTIA: IS THERE A WORST TIME TO WAKE-UP?

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SUMMARY

Problem

Sleep inertia is a brief period of inferior task performance and/or disorientation occurring immediately after awakening from sleep. Sleep inertia generally lasts less than 5 min and has no serious negative impact on restarting routine jobs. However, in some military work environments, "on call" or standby individuals may need to be on the job immediately after awakening, despite sleep inertia, exposing them to the danger of accidents.

Objective

The primary objective was to determine the severity of sleep inertia over a 24-hr period, especially evaluating if sleep inertia is circadian rhythmic. If sleep inertia has a circadian rhythm, then there will be a certain time-of-day, compared with other times, when awakening from sleep should be avoided due to prolonged severe sleep inertia.

Approach

A group of nine subjects worked continuously on performance tasks for a 64-hr period, except for 20-min sleeps or naps every 6 hr. Another group of ten subjects stayed awake for a 64-hr period without naps. The differences between these two groups in performance degradation were expected to reveal sleep inertia, superimposed on the background of sleep deprivation. Sleep inertia was measured by performance scores on Baddeley's logical reasoning task.

Results

The effects of sleep inertia were found to be additive to the deterioration due to sleep deprivation. The napped subjects showed inferior logical reasoning performance during a post-nap 6-min period, compared with totally sleep deprived subjects. Thus, sleep inertia affects performance on Baddeley's logical reasoning task for at least 6 min post-nap. Sleep inertia was found not to be circadian rhythmic. Hence, there is no particular time-of-day when sleep inertia effects on logical reasoning performance are disproportionately severe (or mild) compared with other times of day. The severity of sleep inertia depended on the sleep stages from which the subjects were awakened. An extreme form of sleep inertia was observed, unrelated to task performance, where the process of waking up during the circadian body temperature trough became so traumatic that it created "sleep (nap) aversion" in subjects.

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Conclusions

Sleep inertia can be regarded as a "side-effect" of napping, analogous to side effects of a medication. Overall, effects of naps are beneficial, but naps have the side-effect of introducing a short period of performance degradation. An absence of circadian rhythm in sleep inertia means that there is no best (or worst) time-of-day to wake up. This suggests sleep management should advise waiting 10 minutes or longer before resuming work interrupted by a nap.

INTRODUCTION

Sleep is a circadian phenomenon, consisting of the processes of (1) falling asleep, (2) remaining asleep and (3) awakening from sleep. These three processes seem to be independent from each other, as it is known that they are impaired independently in sleep disorders.

The first two processes are rhythmic. Sleep tendency or sleepiness as measured by the Multiple Sleep Latency Test (MSLT) shows circadian influences (1, 2). Detailed analyses of sleepiness reveal a more complex circasemidian (ultradian, 12-hr) component with a major sleepiness peak during the night and a minor sleepiness peak at mid-afternoon (3). In other words, the best time to go to bed and sleep can be specified (4). Circadian control over the process of remaining asleep has been examined in much less detail compared with the process of falling asleep, but daytime sleep of night shift workers is known to be shortened due to circadian influences (e.g., 5).

The critical role of a faulty awakening process in some sleep disorders has been fully explored by Broughton (6). There are also many studies describing how the process of awakening influences moods and performances (see 7). Curiously, no study has examined specifically whether the awakening process is circadian rhythm influenced. Is there a particular time-of-day when awakening is most effective, thus taking the least time to regain full cognitive and psychomotor function?

Sleep inertia is a part of the awakening process. Sleep inertia refers to a short period of confusion and degraded mood/performance immediately following an awakening from sleep. During a period of sleep inertia, subjects show all the signs of being physically awake, but are cognitively still asleep or in an hypnopompic state. The deterioration of various task performances during sleep inertia has been studied and catalogued (7), but none of the studies has focused on whether sleep inertia is influenced by circadian rhythms as is the process of falling asleep.

The primary purpose of this study was to determine whether sleep inertia is a time-of-day or circadian phenomenon. An experiment was designed to maximize the development of sleep inertia by imposing sleep deprivation of 64 hr duration. The circadian nature of sleep inertia was assessed in a group of subjects by placing ten 20-min naps at 6-hr intervals around the clock during this 64-hr period. Another group of control subjects stayed awake for 64 hr without any naps. All subjects completed the logical reasoning task (8) and a visual analog scale for alertness (9, 10).

The logical reasoning task was used for the sleep inertia test, because previous research indicated it to be very sensitive to sleep inertia. Haslam observed that subjects were unable to start logical reasoning test sessions within 5-min of awakening, if the test was conducted at 05:45 after they experienced severe sleep loss (11). The data from the no-nap control group were used to assess the performance and mood deterioration due to sleep loss, whereas the nap subjects were used to evaluate cognitive deterioration due to both sleep loss and sleep inertia. The difference between these two groups in performance degradation was expected to reveal the sleep inertia in which this paper is interested. Another purpose of this study was to explore the pragmatic implication of the after-effects of napping.

MATERIALS AND METHODS

Two groups of young male naval volunteers participated in this study. Two to four subjects at a time were studied simultaneously. They arrived at the sleep laboratory on Monday, and stayed for 5 days and 4 nights until the completion of the experimental protocol Friday morning.

The subjects spent Monday being familiarized with the study protocol and trained on the use of a Psychological Assessment Battery (PAB) which included 20-min and 5-min versions of Baddeley's logical reasoning task (8) and a visual analog scale for alertness (9, 10). Subjects slept about 8 hr on Monday night and were awakened at 0600 Tuesday to start a 64-hr sleep deprivation period.

Fifteen naval volunteers were allowed a 20-min sleep period every 6 hr for a total of ten naps, but were not allowed a regular nocturnal sleep of 8 hr. Two of these volunteers dropped out of the study due to sickness, and four other volunteers opted to withdraw from the study. The remaining nine subjects (average age of 20.0 ± 2.2 yr) completed the experimental protocol, and their data are reported herein. All of the subjects in the 20-min nap group were wired for polygraphic sleep recordings with Medilog recorders during the naps. Figure 1 indicates the timing of the ten naps taken during this study. (The subjects had an additional 20-min nap not shown on Figure 1 at 1605 Monday, to become familiar with the sleep recording procedure. This nap was excluded from the analysis.) No consistent time relation exists between the 20-min logical reasoning session and napping. Hence, these 20-min test sessions cannot be used to measure sleep inertia. For that purpose, special 5-min logical reasoning task sessions (a.k.a., sleep inertia sessions) were run within 27.6 - 52.6 seconds after awakening from the 20-min naps.

Ten additional volunteers (average age of 20.4 ± 1.9 yr) started and completed the protocol requiring them to stay awake for a 64-hr period without any sleep. All of the no-nap subjects completed the study.

All subjects completed a standard PAB session every 3 hr. The 20-min version of the logical reasoning task was used as a part of the standard test session, while the 5-min version was used as a part of the sleep inertia test session. In both versions of the logical reasoning task, the performance measures were (1) the number of problems attempted and (2) percent correct. Nap subjects were awakened from naps by the ceiling light being turned on in the bedroom and being told loudly to "Wake up." If necessary, they were vigorously shaken. After awakening, they walked a short distance across a hallway to a test room and completed a sleep inertia test session. No-nap subjects took the same "sleep inertia" tests at approximately the same time period as the napped subjects.

Polygraphic nap data were visually evaluated using Rechtschaffen and Kales scoring system (12) to yield several measures of sleep: sleep stages, sleep latency

PROBLEMS ATTEMPTED

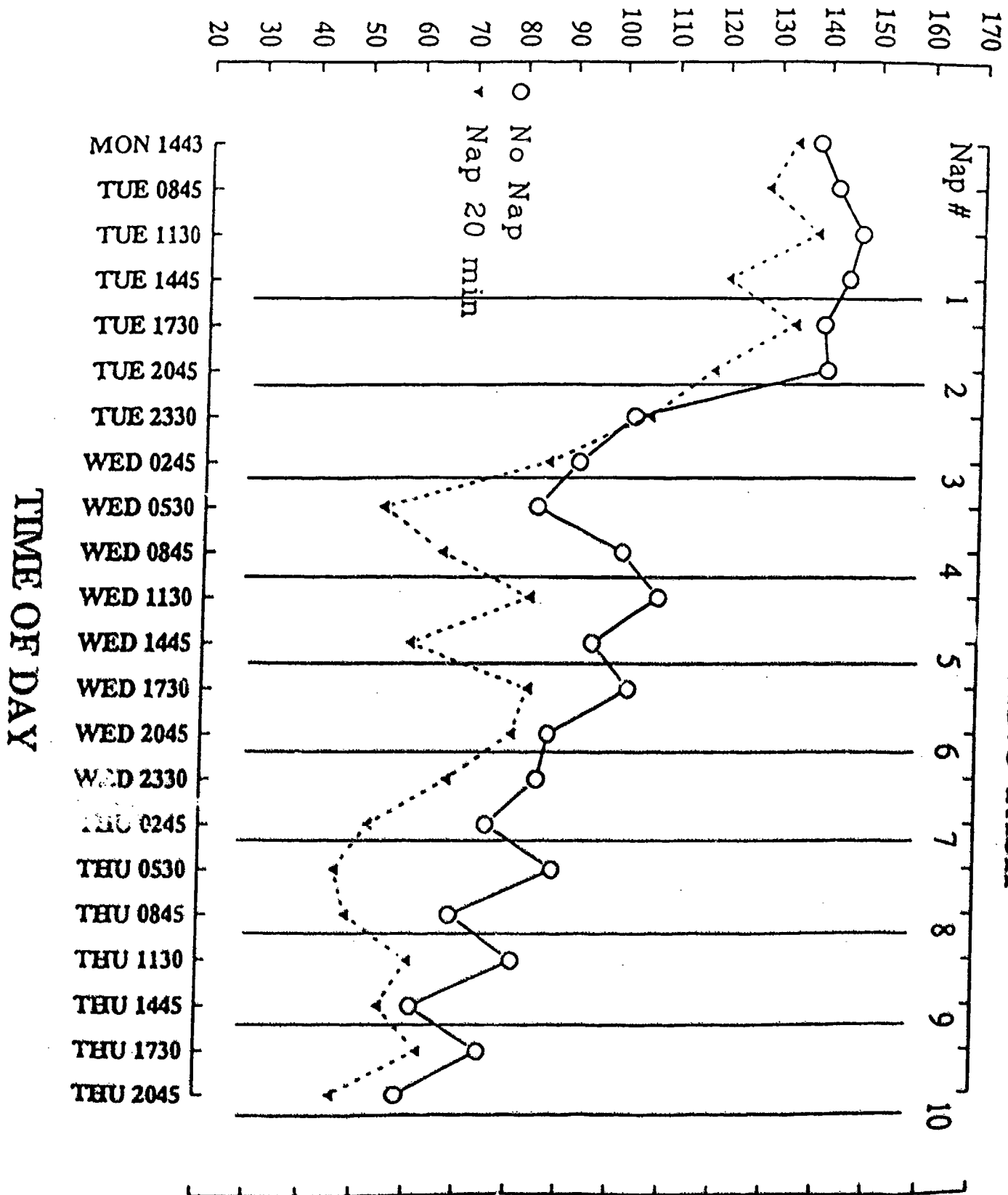


FIGURE 1

(to sleep stage 2) and sleep efficiency (i.e., percent of time spent in sleep stages 2, 3, 4 and REM during the 20 minute period allocated as the "bedtime.").

Because of wide individual variations in performance after the naps, raw performance scores were individually adjusted by (1) selecting the scores obtained during the test session held after being awakened from nap 2 (21:45 Tuesday) as the "baseline" value, then (2) converting the other scores into the percentage change from that baseline. Nap 2 was selected as the "baseline," because nap 1 reflected the difficulties of subjects going to sleep in the unfamiliar laboratory environment wired up for a sleep recording for the first time. These difficulties have been known as the "first night effect." The eight remaining raw performance scores for each subject were expressed as percent increase or decrease from the baseline. For example, if a subject completed 43 problems during the baseline session, and on the next session he was able to do only 26 problems, then this subject had $(26-43)/43 \times 100 = -39.5\%$ decrement in performance from the baseline. Because the scores from the nap 2 testing session were used for baseline, that session had to be excluded from the statistical analyses. Additionally, data were lost on a number of sessions due to equipment failure.

Since many t tests were calculated in the statistical analysis of data, probability was adjusted by using a sharper Bonferroni procedure (13, 14). Since this study has very few subjects, power statistics were calculated when a borderline level of significance ($.05 < P < .15$) was indicated, using a PC-based computer program (15). The results of power statistics were carefully evaluated in view of the paper by Sedlmeier and Gigerenzer (16) who recommend a cautionary approach in the use of statistical power.

In addition to the logical reasoning task, subjects completed a visual analog scale for alertness, together with body temperature data which were taken with an oral basal temperature thermometer at two hourly intervals. The visual analog scale consisted of a linear scale ranging from "Very Sleepy" to "Very Alert." The subject moved the pointer along the thirty point continuum to a position which represented his current level of alertness.

RESULTS

(1) Oral temperature

Figure 2 shows oral temperature of the nap subjects. The open circles show average oral temperature. Complex demodulation (17-19) was used to extract a trend (filled circles; representing effects of sleep deprivation) and one cycle per day (1 CPD; inverted triangle) rhythmic component from these average temperature data. The horizontal axis shows time-of-day, as well as elapsed time since the beginning of the 64-hr continuous work period. The dark period of the day is indicated by the shaded section. The 1 CPD component seems unaltered by the 64-hr continuous work or napping. A small decreasing trend, i.e., lower temperature, was observed up to 06:00 of the second day of the study, which was followed by a steady up-swing in oral temperature. This up-swing may reflect more computational artifact than an actual increase in body temperature.

(2) Characteristics of nap sleep

There were 72 nap periods during the 64-hr continuous work session (9 subjects x 8 naps). Four subjects could not fall asleep during one or two nap periods. There were a total of five such nap periods in this study. One nap record was not scored due to poor recording quality. Thus data for 66-nap periods were available for analysis (Table 1). The overall sleep efficiency was $80.8 \pm 5.6\%$ (mean $\pm$ standard deviation) for sleep stages 2, 3, 4 and REM combined, an average of 17.9 min out of the allocated 20 min "bedtime." The average amount of Slow Wave Sleep (SWS; sleep stages 3 and 4 combined) was 6.5 ± 1.3 min. There were eleven naps belonging to three subjects, which included REM sleep periods lasting an average of 7.8 ± 5.5 min (range 2.0 to 16.5 min).

The sleep stages from which the subjects were awakened was determined, with distinction made between the cases where subjects were unable to fall asleep (NO SLEEP) and the cases where they spontaneously awoke from naps prior to being awakened by experimenters (W). Out of seventy-two awakenings, 66% were from SWS, 12% from sleep stage 2 and only 6% from REM. All awakenings

BODY TEMPERATURE (NAP 20 min)

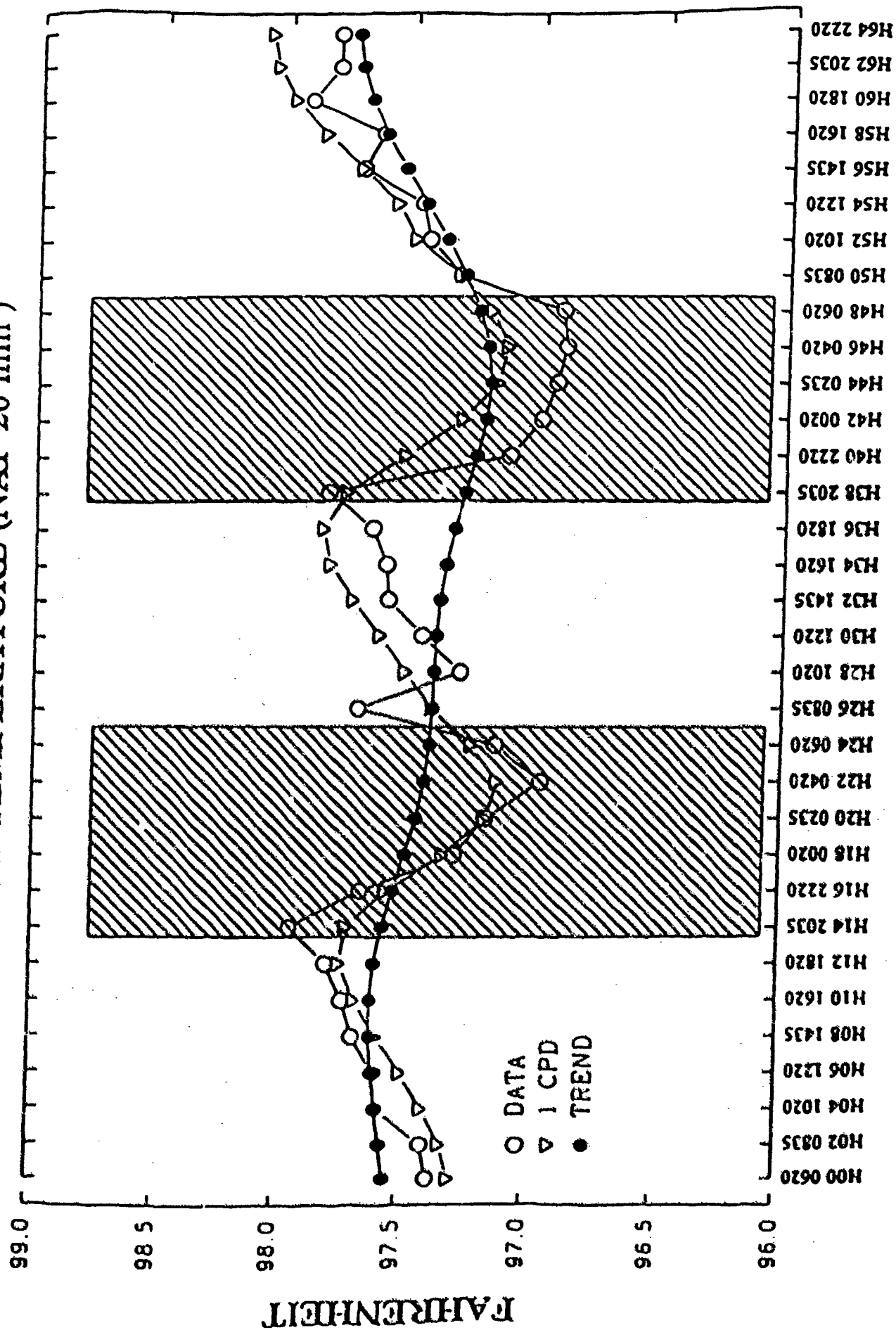


Table 1. SLEEP CHARACTERISTICS DURING 20 MINUTE NAPS

Local Time	Nap ID#	Hours of Wake(hrs)	SL* (min)	TST* (min)	SWS* (min)	SE* (%)
03:45(Wed)	#3	22	3.5(2.1)	18.9(1.2)	6.8(6.6)	83.9(07.5)
09:45(Wed)	#4	28	4.3(3.0)	19.1(2.2)	7.0(5.8)	81.5(10.0)
15:45(Wed)	#5	34	4.8(4.1)	16.7(4.5)	6.5(5.5)	74.6(22.3)
21:45(Wed)	#6	40	3.3(2.0)	17.0(1.9)	6.0(4.9)	82.6(09.9)
03:45(Thu)	#7	46	2.0(0.9)	20.8(1.7)	7.4(7.0)	91.2(03.3)
09:45(Thu)	#8	52	3.4(5.3)	17.4(2.6)	3.6(3.9)	81.7(12.4)
15:45(Thu)	#9	58	4.6(5.3)	17.3(5.2)	7.2(5.2)	76.6(23.8)
21:45(Thu)	#10	64	4.3(2.8)	16.3(5.9)	7.8(5.6)	74.4(26.2)
Mean **			3.8(0.9)	17.9(1.5)	6.5(1.3)	80.8(05.6)

* SL = Sleep latency (to sleep stage 2); TST= Total Sleep Time;

SWS= Slow Wave Sleep; SE= Sleep Efficiency. Numbers represent means and those in parenthesis are standard deviations.

** = Mean across the eight naps.

from REM (6%, or 4 awakenings) occurred in one subject. Six NO SLEEP cases and 5 W cases made up the remaining 16% of awakenings.

(3) Twenty-min logical reasoning task

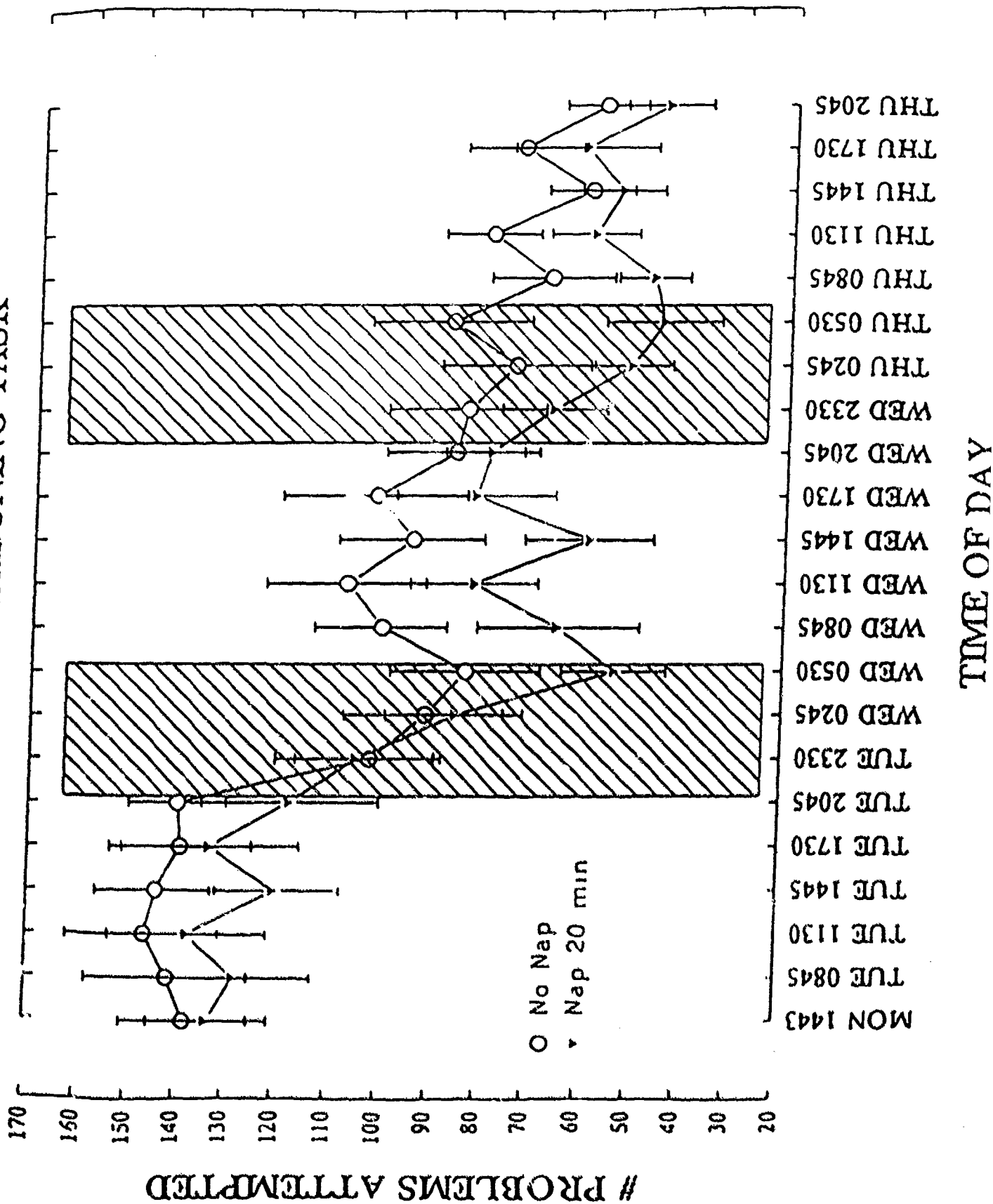
Performance of the 20-min logical reasoning task was evaluated by two measures; the number of problems attempted, and percent correct (Figures 3 and 4). No-nap subjects did as well or better than those who napped. Figure 5 shows the effects of sleep loss and 20-min naps singly or jointly on the visual analog scale for alertness. Figures 3 - 5 show clear circadian components with linearly decreasing trends.

(4) Five-min logical reasoning task

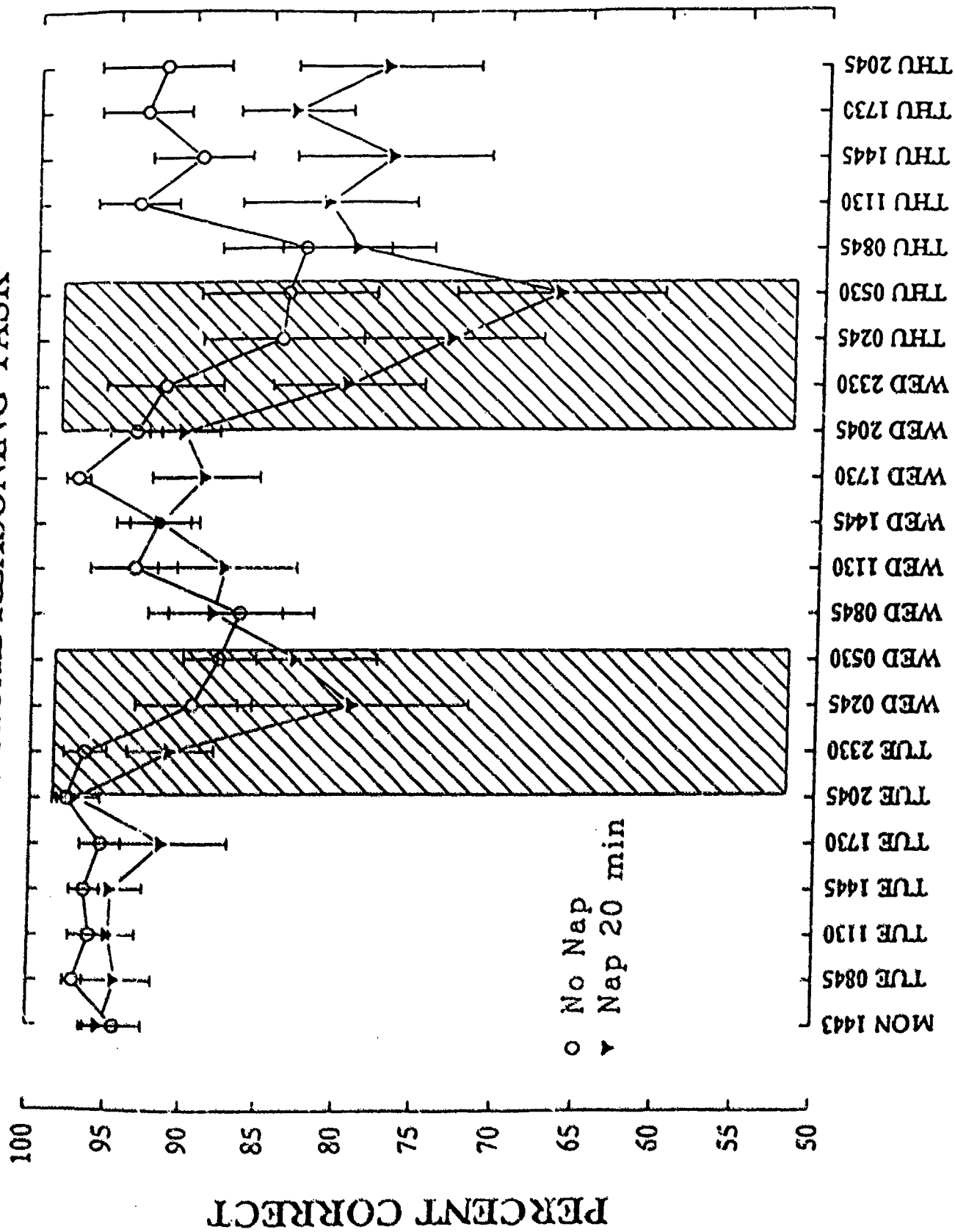
This task started roughly 1-min (average of 41.3 s with a range of 27.6 - 52.6 s) after the subjects were awakened from sleep. Since the logical reasoning task took 5 min to complete, this study covered sleep inertia up to 6 min after the end of the 20-min naps. Those subjects who did not nap took the task approximately the same time of day as the nap subjects. Figure 6 shows clear sleep inertia effects on the number of problems attempted, while Figure 7 shows no evidence of sleep inertia effects on logical reasoning accuracy.

Table 2 lists means and standard deviations of the 20-min nap group and the no-nap group. A considerable amount of data was lost due to equipment failure during the sleep inertia testing. The number of subjects for which data were available on a given session are indicated under N for each group. Table 2 shows the results of between group t tests with p values for the number of problems attempted as a percent change from baseline. During the sleep inertia session after nap #3 (Wed 03:45), the average number of attempted solutions declined by 42.5% from baseline in the nap group, reflecting the combined effects of sleep loss and sleep inertia. In contrast, sleep loss alone caused performance to decline on the average by 10.1% of baseline in the no-nap group. The difference of 32.4% can be attributed to the after-effect of the 20-min nap (sleep inertia).

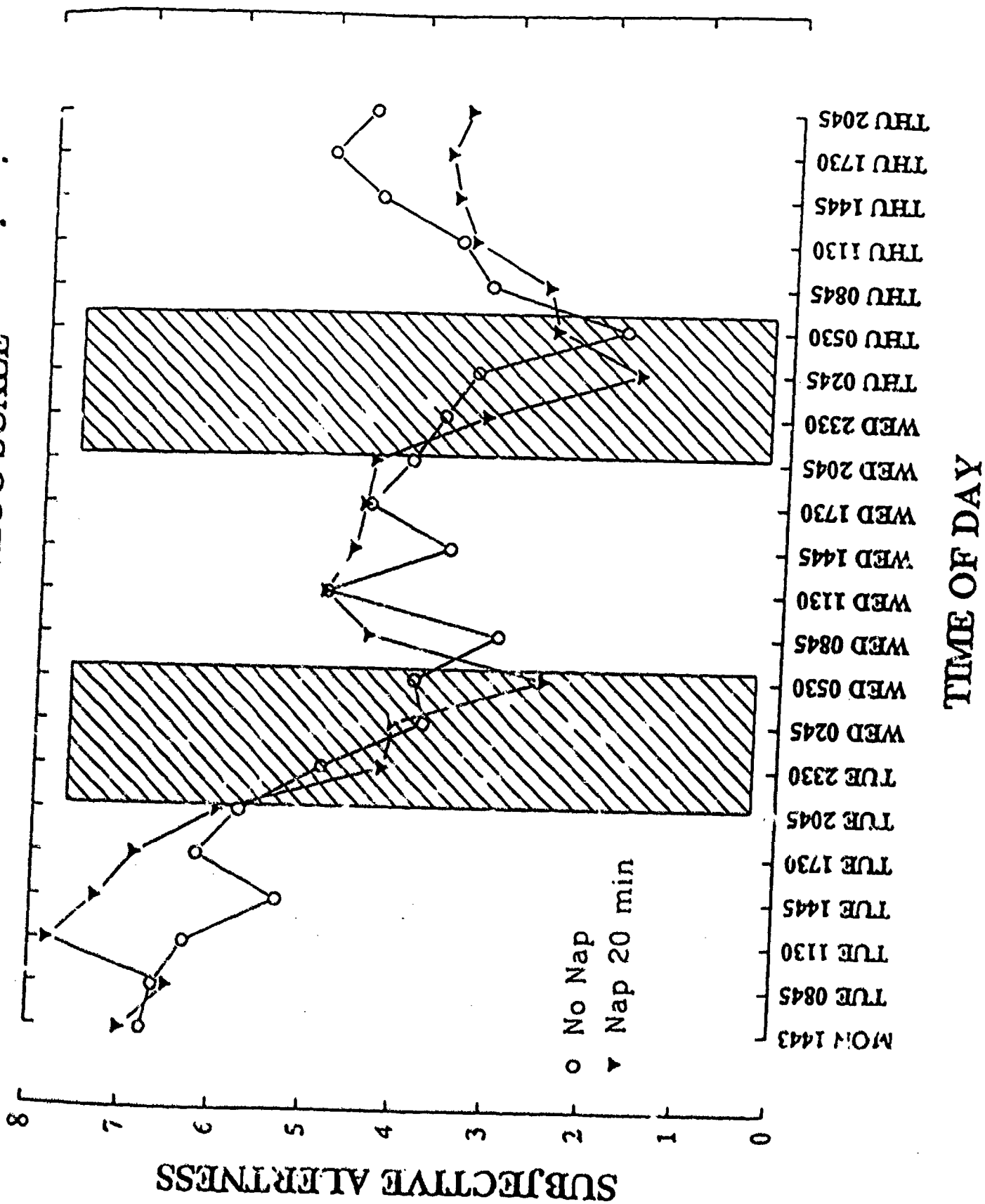
LOGICAL REASONING TASK



LOGICAL REASONING TASK



VISUAL ANALOG SCALE



LOGICAL REASONING TASK (# PROBLEMS ATTEMPTED)

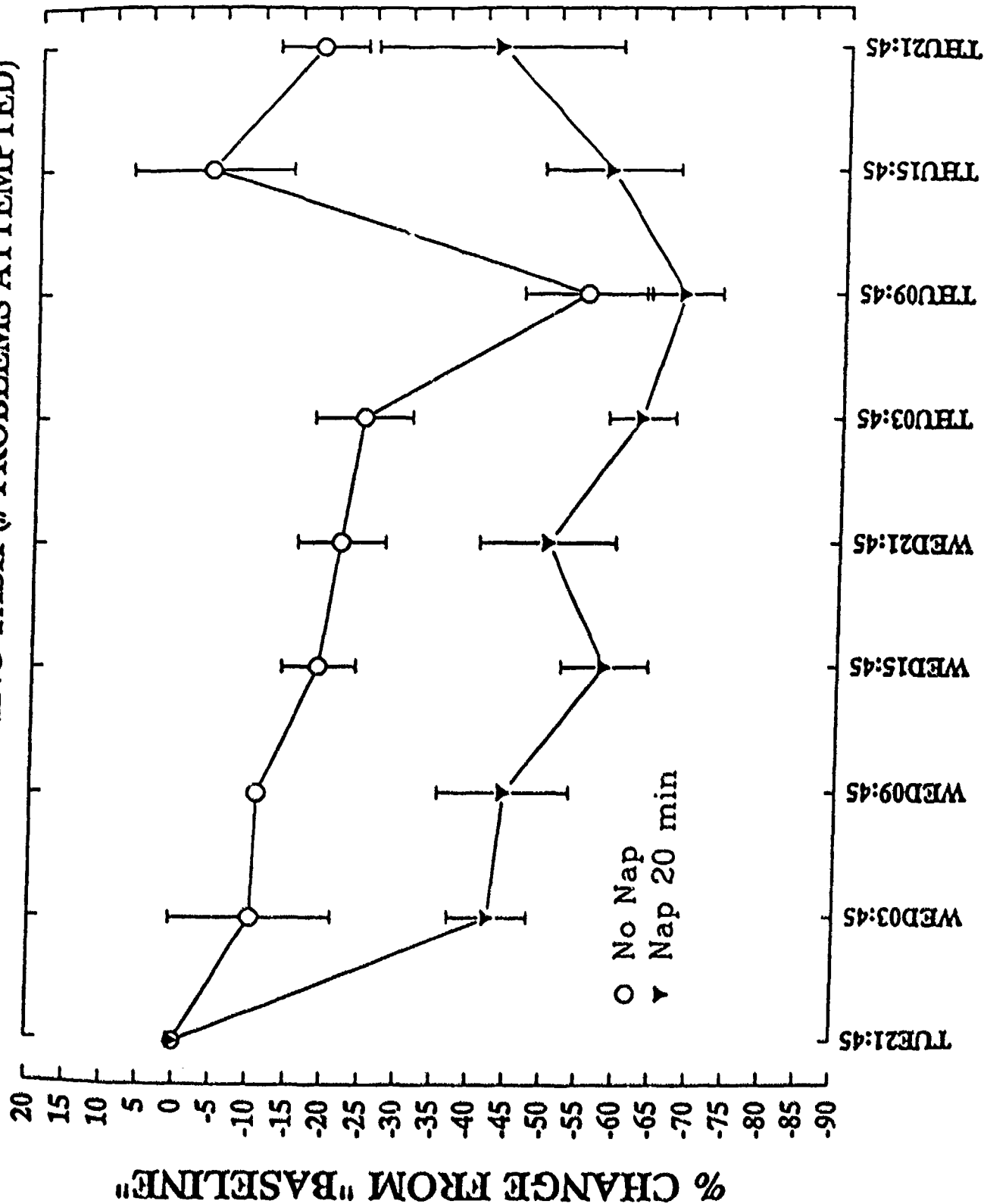


FIGURE 1
TIME OF DAY

LOGICAL REASONING TASK (PERCENT CORRECT)

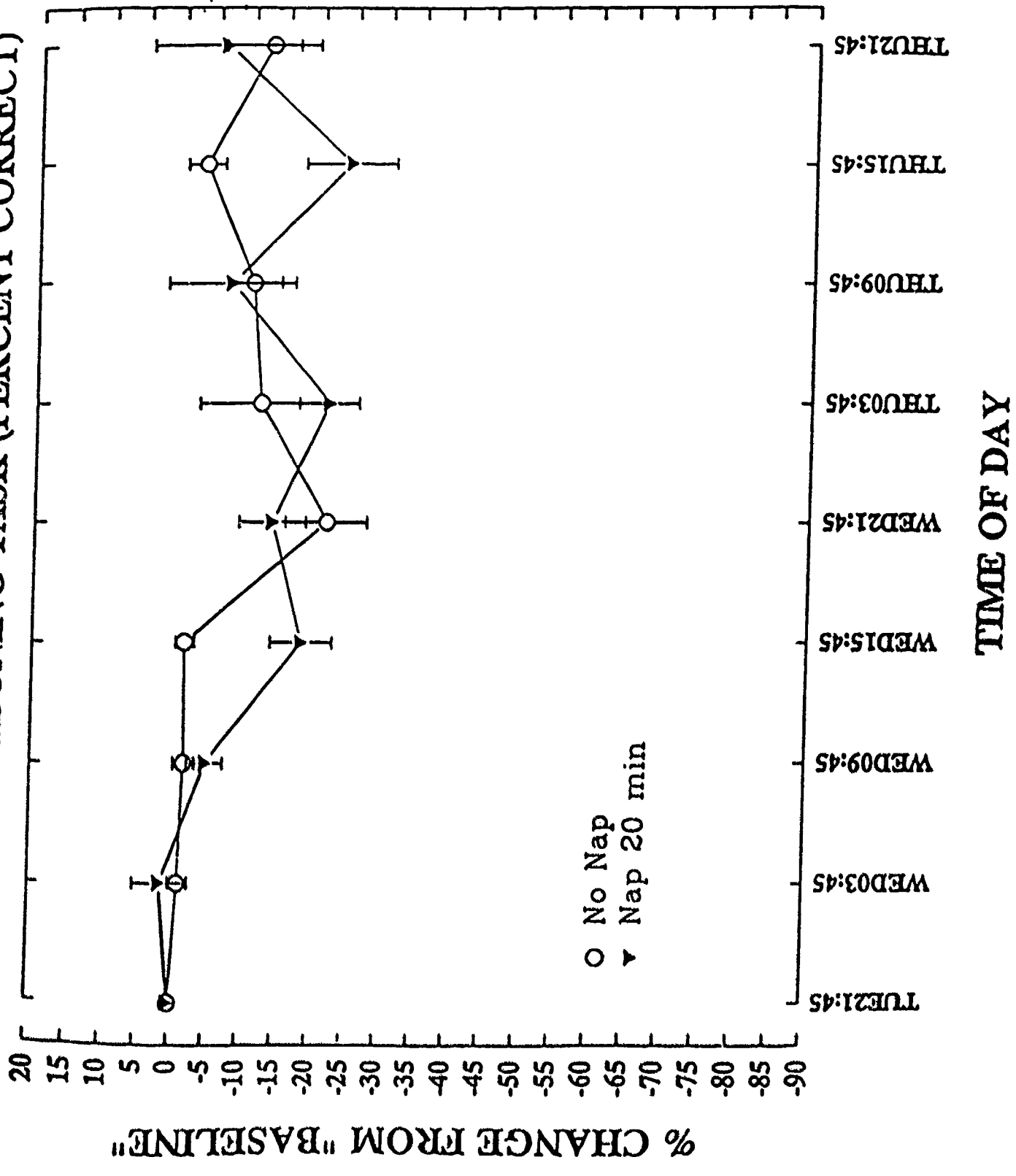


Table 2. COMPARISON OF 20 MINUTE NAP GROUP WITH NO-NAP GROUP IN LOGICAL REASONING TASK: NUMBER OF PROBLEMS ATTEMPTED.

Time	20 Minute Nap Group			No Nap Group			Sig Level	
	Mean	SD	N	Mean	SD	N	t	P
WED 03:45	-42.5	16.3	(9)	-10.1	26.9	(6)	-2.92	0.012
WED 09:45	-44.3	27.2	(9)	-10.7	01.3	(2)	-1.68	0.127
WED 15:45	-57.8	18.1	(9)	-18.7	08.7	(3)	-3.53*	0.006
WED 21:45	-49.7	28.1	(9)	-21.5	11.9	(4)	-1.89	0.085
THU 03:45	-62.2	12.8	(8)	-24.3	14.9	(5)	-4.90*	0.001
THU 09:45	-67.8	14.6	(8)	-54.5	19.6	(5)	-1.40	0.188
THU 15:45	-57.5	27.9	(9)	-03.3	26.6	(6)	-3.77*	0.004
THU 21:45	-42.0	47.1	(8)	-17.9	13.3	(5)	-1.10	0.295

The nap group performance was degraded by both sleep inertia and sleep loss effects, while the no nap group experienced degradation due only to sleep loss. The scores are expressed as the changes from the "baseline" performance which were arbitrarily set to be the scores obtained during the task session held shortly after being awakened from Nap #2, i.e., the Tuesday 21:50 session.

* The t ratios with 5% or better level of significance using Hochberg's sharper Bonferroni procedure (13, 14).

Figure 6 shows a plot of the results tabulated in Table 2. The t tests indicated that 4 out of 8 differences were significant at 5% level of significance, and 3 (t-ratios marked with * in Table 2) out of 8 were significant with sharper Bonferroni correction for multiple comparisons (13, 14).

As Table 2 shows, two t ratios with borderline significance (between 5 and 15% level of significance) were based on samples with very few subjects (listed under N) because of data lost due to equipment failure. Significant group differences might have been observed with larger samples sizes. How many more subjects per group would be needed to give at least a 90% chance of detecting the observed between-group differences to be significant at 5% or better? To find the answer to this question, power statistics were calculated with a PC-based computer program (15). In the Wednesday 09:45 session, the between-group difference was not significant ($p = 0.1274$), meaning that there was no sleep inertia. However, there were only two subjects in the no-nap group. To have a 90% chance of finding the observed difference (-44.3 versus -10.7) to be significant at 5% or better, power statistics showed that the total number of subjects must be increased to eight in each group (instead of 9 versus 2). Hence, it seems likely that the difference would have been significant, if data had not been lost on some of the subjects. Another non-significant group difference occurred during the Wednesday 21:45 session ($p = 0.0849$). Power statistics revealed that thirteen subjects are needed in each group to be significant at 5%. More subjects were required in this session, but the required sample size remained reasonably small. Thus, power statistics suggest that two sessions, Wednesday 09:50 and Wednesday 21:50 sessions, might easily show significant sleep inertia effects, if there were a modest increase in the sample sizes.

Figures 6 and 7 were visually inspected to determine if there were two troughs and two peaks over the two 24-hr periods. The presence of troughs and peaks in sleep inertia roughly corresponding to the times of the low and high body temperatures would indicate that sleep inertia effects on logical reasoning performance were circadian rhythmic. Neither the no-nap nor the nap group

showed obvious rhythmic fluctuation. Among the nap subjects, there seems to be a small decreasing trend in the number of problems attempted from nap #3 to nap #9, and an improving performance trend afterward. However, an application of rank-order test (20) to nap #3 through nap #9 did not show a significant linearly decreasing trend.

(5) Sleep inertia and sleep stage at awakening

The relationship between sleep inertia and the sleep stages from which the subjects awakened was evaluated for the two performance measures, the number of problems attempted and the percent correct. In this analysis, Stage W and NO SLEEP were combined as "Wake" state, because there were too few subjects in each category to justify a separate statistical analysis. Zero-mu t tests were calculated to evaluate whether the subjects showed a greater performance degradation in logical reasoning scores after being awakened from SWS in comparison with the scores after "Wake" state. Two more zero-mu t tests were calculated (1) to compare performance scores after awakening from SWS with those after sleep stage 2, and (2) to compare the scores after sleep stage 2 with those after "Wake" state. One tailed tests were used as previous studies indicated that awakening from slow wave sleep consistently causes the most severe sleep inertia (7, 21). Since there was only one subject who awakened from REM sleep during the 20 minute naps, no statistical evaluation could be made of REM sleep awakenings.

None of the comparisons were significant in relation to the number of "problems attempted" measure. However, accuracy was lowered to -24.3% of baseline after awakening from SWS, compared with a -5.9% decrease after "Wake" state. The difference was significant ($t(5) = 4.91, p = 0.008$). Other comparisons between sleep stages were not significant.

DISCUSSION

Even though performance on the 20-min logical reasoning task showed a clear circadian rhythm (Figures 3 & 4), effects of sleep inertia on performance appeared not to show circadian time effects. This was a surprise, since the process of falling asleep shows a high degree of circadian control (1, 2). It was anticipated that, since there is a best time to fall asleep quickly (4, 7, 21), there must be a best time to wake up quickly. Findings do not support such a "symmetry" hypothesis. Unfortunately, the sampling of sleep inertia in 6-hr intervals is too coarse to definitively assess whether sleep inertia is circadian rhythmic.

Since only the logical reasoning task was used as a sleep inertia measure, it could not be established whether a different outcome would be observed on a different task such as the four-choice serial reaction time task. As was previously reported (19), 20-min napping improved performance on the four-choice serial reaction time task. In contrast, as shown in Figures 3 and 4, logical reasoning performance was degraded by naps, perhaps the four-choice task would show no sleep inertia effects.

The performance degrading effect of sleep inertia on logical reasoning is substantial, and it is additive with sleep loss induced performance degradation. Severity of sleep inertia seems not to be circadian rhythmic. It is increased by awakening from SWS, but only for the percent correct measure, not for the number of problems attempted. There is no particular time-of-day when cognitive awakening can be obtained rapidly and efficiently following a short nap.

An additional concern of this study was to determine the performance maintenance power of an ultra-short sleep/wake cycle (20-min Sleep/340-min Wake; 22) repeated for a period of 64 hr. Our subjects replaced the normal 8 hr/16 hr sleep-wake pattern with the ultra-short sleep-wake cycle. Under this work schedule, we have noted that: (1) a 20-min nap every 6 hr could not maintain logical reasoning performance for more than 12 hr, (2) subjects exhibited lower sleep efficiency during these naps than we have previously observed during a

regular nocturnal sleep of 7 - 8 hr in our laboratory (80.8% vs 90% plus sleep efficiency), (3) profound sleep inertia persisted for at least 6 min after awakening, and (4) a "nap avoidance or aversion" occurred among the subjects.

What is sleep aversion? In the present study, we asked the subjects to switch immediately from an 8/16 work/rest schedule to a 20-min/340-min ultrashort sleep-wake schedule for 64 continuous hr. As subjects began to accumulate sleep debt, they began to experience difficulty in awaking from the 20-min naps, especially during the early morning hours. While they desired the nap because of mounting sleepiness, it is conjectured that they developed nap aversion because of the objectionable process of waking-up. Four out of fifteen volunteers in the 20-min nap group withdrew from the study because they found it intolerable, and an additional 2 withdrew because they felt ill. All of these subjects withdrew shortly after the 0345 nap Thursday morning. In contrast, 10/10 in the no-nap group completed the 64-hr total sleep deprivation, and in many other studies in our laboratory involving similar durations of sleep deprivation without naps we almost never have had a subject withdraw.

Perhaps, long-term training in taking many short naps or polyphasic sleep to replace the regular 7 - 8 hr of nocturnal sleep might overcome nap aversion. Spiegel (23) suggested the importance of habitual napping for benefit from naps. The implication of this paper's observation is that there are no particular times of day or night when we can be suddenly awakened and quickly regain full psychomotor and cognitive functions, at least under the conditions of this study. However, there appear to be some times when it is better not to be awakened suddenly, because of motivational effects which may be due to our psychological reactions to the painful awakening process. There is a need for more studies to find and refine techniques to shorten this period of psychological suffering and the duration of sleep inertia (12, 14, 15) and to understand the spontaneous waking process, as well as the performance impact of forceful intrusion of the Wake System in sleeping subjects.

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FIGURE LEGENDS

Figure 1.

Times of the ten naps in relation to the 20 minute logical reasoning task.

Figure 2.

Average body temperature of the napped subjects. The results of complex demodulation show persistence of a circadian component during a 64-hour sleep deprivation.

Figure 3.

Number of problems attempted on the 20 minute logical reasoning task. Figure shows the means ± 1 standard error. Performance shows clear circadian troughs with sleep loss effects.

Figure 4.

Percent correct on the 20 minute logical reasoning task, showing the means ± 1 standard errors. Performance shows clear circadian troughs and their interaction with sleep loss. The napped subject generally do more poorly than the no-nap control subjects.

Figure 5.

Scores on a visual analog scale measuring subjective alertness. Both the nap and no-nap groups show clear circadian troughs. There are no group differences. The standard error bars are not shown to avoid confusion.

Figure 6.

Differences between the nap and no-nap groups in performing the 5 minute logical reasoning task (Number of problems attempted). Performance scores of an individual subject are expressed as percent change from the baseline. For nap subjects, the entire nap inertia session was completed within 6 minutes after awakening.

Figure 7.

Differences between the nap and no-nap groups in performing the 5 minute logical reasoning task (Percent Correct Measure). The scores have been adjusted as for Figure 6.

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