Recuperative Power of a Short Daytime Nap With or Without Stage 2 Sleep

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Study Objectives: The recuperative effect of a nap of less than 30 minutes has been confirmed. Such naps consist mainly of stages 1 and 2 sleep. The present study examined whether sleep stage 1 or 2 contributed to the recuperative effect of a short nap.

Design: Repeated-measurement within-subject design. After sleep was restricted to 1.5 hours less than their usual nocturnal sleep, participants took a rest (No-nap condition) or a nap at 2:00 PM. In the nap condition, they were awakened after 5 minutes of stage 1 sleep (S1-nap condition) or 3 minutes after stage 2 sleep appeared (S2-nap condition).

Setting: University sleep laboratory.

Participants: Ten healthy university students (aged 19 to 24 years).

Measurements: Subjective mood, performance on visual detection and symbol-digit substitution tasks, and the number of slow eye movements during a performance task were measured before and after the nap or rest.

Results: In the No-nap condition, subjective mood and performance deteriorated, and Slow eye movements increased during mid-afternoon, suggesting that the post-lunch dip occurred. In contrast, subjective alertness and performance improved and slow eye movements rarely occurred in the S2-nap condition. Although subjective sleepiness and fatigue improved, performance deteriorated and slow eye movements increased in the S1-nap condition.

Conclusion: A daytime short nap containing 3 minutes of stage 2 sleep has recuperative effects, whereas these effects are limited following only stage 1 sleep.

Keywords: Short nap, stage 2 sleep, sleep inertia, sleepiness, alertness

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INTRODUCTION

THE IMPORTANCE OF SLOW-WAVE SLEEP (SWS) DURING NOCTURNAL SLEEP IS WIDELY CONFIRMED. THE FACT THAT THE RATES OF CEREBRAL NEURAL FIRING are lowest during SWS, the length of SWS is correlated with the length of prior wakefulness, and the cerebrum is isolated from sensory input and from subcortical structures suggests that SWS is associated with tissue restitution.[1] Recently, the recuperative effects of SWS have also been observed in a daytime nap. It has been found that a daytime nap that contained SWS improved perceptual learning.[2,3]

However, because of the homeostatic nature of SWS,[4] the occurrence of SWS during a daytime nap induces a decrease of SWS in the subsequent night sleep,[5] so that sleeplessness during the night occurs. In addition, SWS during a nap leads to sleep inertia,[6] that is, deterioration of performance or sleepiness immediately after awakening.[7,8] Stampi et al[6] have shown that 5 polyphasic 50-minute daytime naps after 4 hours of night sleep caused severe sleep inertia and have stated that this occurred because participants were awakened from SWS. They also showed that the shortest nap condition (20 minutes), which was virtually without SWS (only 4%), was the most effective in facilitating performance compared with longer naps (50 and 80 minutes). Tietzel and Lack[9] have reported that sleep inertia occurs after a 30-minutes nap, while this is not the case for a 10-minute nap.

Short daytime naps of less than 30 minutes, which rarely contain SWS, have been shown to have positive effects on daytime alertness.[10] This has been experimentally confirmed after a normal night of sleep in young adults[11-17] and elderly individuals,[18-21] after a restricted night of sleep,[6,9,22-28] and during prolonged sustained performance.[29]

Table 1 shows the sleep variables of daytime short naps that have been reported in previous studies to have positive effects. These short naps are mainly composed of sleep stages 1 and 2. The shortest naps were reported by Takahashi and colleagues.[16,25] After normal nocturnal sleep (7.2 hours; Takahashi et al),[16] a 7.3-minutes nap was the shortest, which was composed of 5.2 minutes of stage 1 and 2.1 minutes of stage 2 sleep. After restricted nocturnal sleep (3.5 hours; Takahashi and Arito),[25] a 10.2-minutes nap was the shortest, which was composed of 5.5 minutes of stage 1 and 3.5 minutes of stage 2 sleep. Their results suggest that the occurrence of 5 minutes of stage 1 and 3 minutes of stage 2 sleep have recuperative effects. However, it is not clear which sleep stage mainly contributes to the recuperative effects of a daytime short nap, since these naps contained both sleep stages 1 and 2.

Tietzel and Lack[26] examined whether 30 seconds or 90 seconds of stage 1 sleep had recuperative effects and found that these ultrabrief naps had no recuperative power. They also found that a 10-minutes brief nap had a recuperative effect, suggesting that the recuperative power of a short nap depends on stage 2 sleep, not stage 1. However, they did not show the sleep variables of the 10-minutes nap.

The present study examined which sleep stage (1 or 2) provides the recuperative effects of a nap. After restricted nocturnal sleep, daytime alertness was studied after taking a nap in which the participants were (1) awakened 3 minutes after stage 2 sleep occurred (S2-nap condition) or (2) awakened 5 minutes after stage 1 sleep occurred (S1-nap condition), and (3) after taking a rest without a nap (No-nap condition).

Disclosure Statement

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Table 1—Sleep Variables of Short Naps (< 30 Minutes) With Recuperative Effects Reported In Previous Studies*

Author	Sleep variables of naps (min) Total Sleep Time	S1	S2	SWS	REM	Sleep Latency Time	Nap Start Sleep (h)	Prior Nocturnal	Mean Ages
Takahashi et al.[16]	7.3	5.2	2.1	0.0	0.0	6.7	12:30	7.2	20-30
Present study (S2-nap condition)	9.1	6.0	3.0	0.0	0.0	2.1	14:00	5.1	21.6
Takahashi & Arito [25]	10.2	5.5	3.5	0.0	1.1	3.8	12:30	3.5	22.1
Horne & Reyner[23]	10.8	NA	NA	NA	NA	7.4	15:00	5.0	28.0
Kaida et al.[27]	12.9	9.8	3.1	0.0	0.0	1.6	14:00	7.8	21.6
Hayashi et al.[14]	14.8	8.6	6.2	0.0	0.0	4.8	12:40	7.3	21.1
Kaida et al.[28]	18.3	7.6	10.7	0.0	0.0	1.7	14:00	7.7	21.3
Gillberg et al.[22]	19.8	7.1	9.0	3.7	0.0	10.1	10:45	3.75	32.0
Hayashi et al.[12]	19.9	6.1	9.9	0.0	3.9	6.7	14:00	7.8	20.6
Hayashi et al.[11]	20.2	5.6	10.4	0.8	3.4	4.4	12:20	7.7	20.7
Tamaki et al.[18]	24.2	9.4	14.4	0.5	0.0	4.5	13:00	6.8	73.0
Mean (except for the present study)	15.5	7.2	7.5	0.5	0.9	5.0			
Mean (total)	14.9	7.1	7.1	0.4	0.8	4.8			

*Mean values were calculated from the total number of the participants in these studies.

METHOD

Participants

Ten university students (7 women and 3 men, 19 to 24 years of age, mean age 21.6 years) with good health participated in the study. They completed the sleep-wake habit inventory and the morning-evening questionnaire.[30] They reported that they slept 6 to 8 hours nightly, had normal sleep-wake habits, and did not complain of sleep-wake problems. They took naps less than once per week. They were not excessive morning types, nor evening types. They were all right-handed. They gave informed consent prior to participation.

Tasks

The participants performed 2 cognitive tasks: visual detection and symbol-digit substitution tasks. These tasks were displayed on a computer screen. The participants were seated 60 cm away from the computer screen and instructed to respond with their right hand as quickly and accurately as possible.

The visual detection task was experimenter paced. A numeral was set as a target stimulus and was displayed for 1.0 seconds at the start of the task. Four seconds later, the individual numerals in random order were displayed for 200 milliseconds each at intervals of 1.0 to 1.4 seconds (mean 1.2 seconds). The visual-angle size of the stimuli was 0.86° wide and 1.24° high. The participants were required to press a button as soon as the target numeral appeared. One hundred trials were presented per session during which 10 target stimuli were presented in random order. The mean reaction time to the target stimuli and number of misses of the target stimuli were calculated.

The original digit-symbol substitution task was revised as a computer-based symbol-digit substitution task for this experiment. This task was participant paced. At the start of the task, 9 pairs of digits (1 to 9) and symbols were displayed at the top of the computer screen. Thereafter, 1 symbol was displayed at the bottom of the screen. The participants were required to tap 1 of the 10 numeral keys on the keyboard corresponding to the symbol. The next symbol was displayed as soon as the participant tapped the key. The number of correct responses within each 90-second session and the mean reaction time were calculated.

Subjective Measures

The participants rated their subjective sleepiness and fatigue using a 100-mm visual analog scale immediately before doing the performance tasks. The values of sleepiness and fatigue ranged from 0 (alert or vigorous) to 100 (sleepy or tired).

Physiologic Measures

Electroencephalograms (EEG) (C3-A2, C4-A1, O1-A2 and O2-A1), horizontal electrooculograms from both eyes and submentalis electromyogram were recorded with an electroencephalograph (Nihonkoden, EEG-1100) throughout the study. Interelectrode impedance was below 5 kΩ. EEG, electrooculograms and electromyograms were amplified using time constants of 0.3 seconds, 1.5 seconds, and 0.03 seconds, respectively. Sleep stages during the nap were scored in 30-second epochs using the standard criteria.[31]

In the present study, slow eye movements frequently occurred when the participants performed the visual detection task. It has been demonstrated that slow eye movements occur during wake-sleep transition,[32] are associated with increasing sleepiness,[33] and are a good indicator of alertness.[34] The number of 15-second epochs in which slow eye movements occurred during the 2 minutes of the visual detection task was counted. Eye movements with amplitudes greater than 50 μV and durations greater than 1 second[35] were judged as slow eye movements.

Experimental Procedure

Before starting the experiment, the participants practiced the tasks. They did not consume any alcohol or caffeine within 12 hours before their participation in the experiment. Napping was prohibited during the experimental period.

All participants participated in all 3 experimental conditions (S1-nap, S2-nap, and No-nap conditions) with intervals of more than 1 day between conditions. The order of the conditions was

Table 2— Sleep Variables and Subjective Ratings of the Nap*

	Condition				Student t test	
	S1-nap		S2-nap		t (9)	p
Sleep variables, min						
Time in bed	6.5	(1.5)	11.4	(2.4)	5.39	< 0.001
Total sleep time	4.5	(0.7)	9.1	(2.4)	6.78	< 0.001
Stage 1	4.5	(0.7)	6.0	(2.4)	2.11	0.064
Stage 2	0.0		3.0	(0.0)		
Stage 3+4			-	-		
Stage REM			-	-		
Waking time after stage 1 onset	0.2	(0.3)	0.3	(0.7)	0.71	NS
Latency to stage 1	1.9	(1.2)	2.1	(1.1)	0.46	NS
Subjective ratings						
Nap time, min	5.9	(3.8)	8.5	(5.7)	2.05	0.070
Sleep latency, min	4.7	(3.0)	3.8	(2.6)	1.03	NS
Depth of the Nap†	3.5	(1.1)	3.8	(1.0)	0.54	NS
Nap satisfaction‡	2.8	(0.9)	2.5	(0.8)	0.82	NS

* Values in parentheses are SD.
†1: light, 5: deep.
‡1: poor, 4: good.

randomized across the participants.

The participants had their nocturnal sleep at home. The night before the experiment, their sleep times were shortened by delaying their bedtime for 2 hours. Their nocturnal sleep was monitored by actigraphic recordings (Actiwatch AW64, Mini-Mitter Co. Inc., Bend, Ore.) and self-rated sleep logs.

They reported to the laboratory at 12:00 noon. After eating lunch, electrodes were attached to monitor EEG, electrooculogram, and electromyogram activities. At 1:40 PM, they sat in a chair in a soundproof and air-conditioned isolation unit and engaged in prenap sessions for 15 minutes (5 minutes × 3 times). Each 5-minute session included subjective ratings of sleepiness and fatigue using the visual analog scale, the 2-minute visual detection task, and the 1.5-minute symbol-digit substitution task.

Participants lay in a bed at 2:00 PM in both the S1-nap and the S2-nap conditions. In the S1-nap condition, they were awakened by a pip tone (52 dB) when 5 minutes had elapsed from the onset of sleep stage 1.[31] If a sleep spindle appeared before 5 minutes of stage 1, they were awakened immediately at that time. In the S2-nap condition, they were awakened when 3 minutes had elapsed from the first occurrence of a sleep spindle or K-complex. In the No-nap condition, they watched television programs sitting on a semireclining chair for 16 minutes. The duration of 16 minutes was determined to be about equal to the duration of bedrest in the S2-nap condition, that is, the sum of mean sleep latency (5.0 minutes) and mean duration of stage 1 sleep (7.2 minutes) in the previous short nap study (Table 1) and 3 minutes of stage 2 sleep.

Immediately upon waking from the nap, they sat in a chair and answered the questionnaires about their estimated nap time (minutes), sleep latency (minutes), depth (1, light to 5, deep) and satisfaction of the nap (1, poor to 4, good). They engaged in postnap sessions for 30 minutes (5 minutes × 6 times) starting 1 minute after waking from the nap.

Statistical Analysis

Sleep variables of the naps in the S1-nap and the S2-nap conditions were compared using Student *t* tests. The values of the following variables were analyzed using the average of every 3 sessions (15 minutes): subjective ratings of sleepiness and fatigue, number of misses and reaction time in the visual detection task, number of correct responses and reaction time in the symbol-digit substitution task, and the number of 15-second epochs with slow eye movements during the visual detection task. Three 15-minute blocks (0-15 minutes before the nap and 0-15 and 15-30 minutes after the nap) were analyzed by 2-way (3 [conditions] × 3 [time: blocks per 3 sessions]) analyses of variance with repeated measures. To adjust for interparticipant variations, the data was transformed with the mean values of 15-minute prenap sessions set to 0. The degrees of freedom were adjusted to reduce type I error using Huynh and Feldt's ε[36] for small samples. The posthoc comparisons were performed using the Newman-Keuls procedure.

Performance on the above measures was better following a S2-nap compared with the No-nap condition. However, it is possible that the recuperative power of the S2-nap depended on total sleep time or total amount of stage 1 sleep rather than the 3 minutes of stage 2 sleep. To examine whether total sleep time and stage 1 sleep contributed to the recuperative effects of a nap, Pearson's product moment correlation coefficients were calculated between the sleep variables and the differences in the values of the subjective mood, performance, and slow eye movements between the S2-nap and No-nap conditions (n = 10).

RESULTS

Nocturnal Sleep Time Before the Experimental Day

Actigraphic recordings confirmed that the participants slept for 5.0 hours before the experimental day (S1-nap: 5.2 ± 1.0 hours; S2-nap: 5.1 ± 0.7 hours; No-nap: 4.8 ± 0.7 hours). The lengths of the previous nocturnal sleep were not significantly different among the conditions ($F_{2,16}$ = 1.31, ε = 1.0, NS). They slept 6.5 hours (SD = 0.97) 2 to 7 days before the experimental days. Thus their experimental sleep time was 1.5 hours shorter than their usual sleep time.

Sleep Variables of the Nap

The sleep variables of the nap are shown in Table 2. Latency to stage 1 sleep was approximately 2.0 minutes and was not significantly different between the S1-nap and the S2-nap conditions.
In the S1-nap condition, 6 of the 10 participants were awakened when 5 minutes of stage 1 sleep elapsed, while the other 4 participants were awakened at the moment when sleep spindles occurred. The duration of stage 1 sleep of the latter participants was 3.5 minutes (2 participants) and 4.0 minutes (2 participants). Mean total sleep time in the S1-nap condition was 4.5 minutes, and time in bed was 6.5 minutes. The S1-nap consisted only of stage 1 sleep. In the S2-nap condition, the participants slept for 9.1 minutes and were in bed for 11.4 minutes. This nap was composed of 6.0 minutes of stage 1 and 3.0 minutes of stage 2 sleep. Thus, the experimental control over the content of the S1- and S2-naps was successful. Although the subjective estimation of the nap time tended to be longer in the S2-nap condition compared with the S1-nap condition (P = .070), other subjective ratings of the naps were not significantly different between the conditions.

Table 3—Subjective Ratings, Performance, and Number of Slow Eye Movements During Postnap Period over 3 Sessions

	Postnap sessions			
Condition	1-3	(0-15 min)	4-6	(15-30 min)
Sleepiness				
No-nap	7.0	(6.6)[b,c]	17.4	(6.4)[*,b,c]
S1-nap	-13.5	(4.0)[*,a]	-5.2	(5.2)[a]
S2-nap	-16.8	(5.7)[*,a]	-16.2	(7.5)[*,a]
Fatigue				
No-nap	7.7	(2.9)[*,b,c]	17.8	(4.5)[*,b,c]
S1-nap	-9.7	(3.5)[*,a]	-2.9	(4.5)[a]
S2-nap	-3.1	(6.3)[a]	-2.7	(6.1)[a]
Visual detection, no. of misses				
No-nap	0.3	(0.4)	1.4	(0.4)[*,c]
S1-nap	0.4	(0.2)	1.0	(0.5)[*,c]
S2-nap	-0.1	(0.1)	0.1	(0.1)[a,b]
Visual detection, reaction time, ms				
No-Nap	13.0	(6.7)	19.2	(9.8)*
S1-nap	-0.4	(8.2)	8.5	(12.0)*
S2-nap	6.6	(8.2)	16.9	(7.9)*
Symbol-digit substitution, no. of correct responses				
No-nap	-0.9	(1.7)	-5.3	(3.1)[*,b,c]
S1-nap	-1.7	(1.6)	-2.0	(2.0)[a,c]
S2-nap	1.4	(1.3)	4.4	(1.5)[*,a,b]
Symbol-digit substitution, reaction time, ms				
No-nap	38.3	(34.0)	141.5	(88.2)[*,b,c]
S1-nap	18.0	(28.1)	23.5	(32.8)[a]
S2-nap	-18.3	(28.8)	-69.9	(32.2)[a]
Slow eye movements, No. of 15-s epochs				
No-nap	0.4	(0.2)	2.2	(0.8)[*,b,c]
S1-nap	0.4	(0.4)	1.2	(0.5)[*,a,]
S2-nap	-0.2	(0.1)	-0.1	(0.1)[a,b]

The data are expressed as the values of changes from the prenap sessions, calculated by subtracting the mean values of the 3 prenap sessions (SEM). Significantly different from *prenap sessions, [a]no-nap condition, [b]S1-nap condition, and [c]S2-nap condition. Significance level was set at .05.

Subjective Mood

Immediately after napping, sleepiness and fatigue significantly decreased (-19.1 and -8.6, respectively) in the S1-nap condition (sleepiness: t (9) = 3.77, P = .004; fatigue: t (9) = 2.57, P = .030), and sleepiness significantly decreased (-18.6) in the S2-nap condition (t (9) = 3.06, P = .014), in comparison with immediately before napping. In the No-nap condition, no significant difference was observed between immediately before and after resting.

Figure 1 shows the changes of subjective ratings of sleepiness and fatigue and fatigue average every 15-minute. Analyses of variance showed that sleepiness and fatigue were significantly greater in the No-nap condition than the S1-nap and S2-nap conditions (sleepiness: $F_{2,18}$ = 7.15, ε = 1.00, P = .005; fatigue: $F_{2,18}$ = 11.01, ε = 1.00, P = .001). There were no significant differences between the S1-nap and the S2-nap conditions.

The interaction of condition × time was also significant for both sleepiness ($F_{4,36}$ = 5.30, ε = 1.00, P = .009) and fatigue ($F_{4,36}$ = 9.50, ε = 0.94, P < .0001). In the No-nap condition, sleepiness and fatigue significantly deteriorated during the postnap sessions in comparison with the prenap sessions (Table 3). In the S1-nap condition, sleepiness and fatigue significantly improved during the first half of the postnap sessions. In the S2-nap condition, sleepiness significantly improved throughout the postnap sessions.

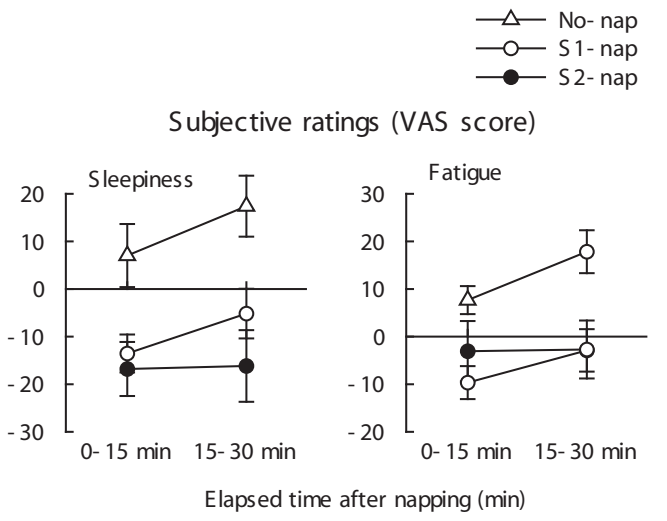

Figure 1—Subjective ratings of sleepiness and fatigue during the postnap sessions. The data are expressed as the values of changes from the prenap sessions, calculated by subtracting the mean values of the three pre-nap sessions. VAS refers to visual analog scale.

Performance

Figure 2 shows the performance on the visual detection task and the symbol-digit substitution task. For the visual detection task, no significant difference was observed between immediately before and after napping. Analyses of variance showed that the number of misses ($F_{2,18}$ = 10.67, ε = 0.98, P = .001) and reaction time ($F_{2,18}$ = 4.24, ε = 1.00, P = .031) significantly increased as time elapsed. The interaction of condition × time was marginally significant for the number of misses ($F_{4,36}$ = 2.15, ε = 0.98, P = .097). In the S2-nap condition, misses of the target stimuli were infrequent during prenap and postnap sessions. In contrast, the number of misses during the last half of the postnap sessions significantly increased in both the No-nap and the S1-nap conditions and were significantly greater than in the S2-nap condition (Table 3)

For the symbol-digit substitution task, no significant difference was observed between immediately before and after napping. The analysis of variance showed that the interaction of condition × time was significant for the number of correct responses ($F_{4,36}$ = 5.42, ε = 0.68, P = .007) and reaction time ($F_{4,36}$ = 3.86, ε = 0.54, P = .036). In the S2-nap condition, correct responses during the latter half of the postnap sessions significantly increased compared with the prenap sessions and were significantly greater than in the No-nap and the S1-nap conditions (Table 3). In the S1-nap condition, correct responses during the postnap sessions did not significantly change compared with the prenap sessions, while they significantly deteriorated in the No-nap condition during the postrest sessions. During the last half of the postnap sessions, reaction time on the symbol-digit substitution task was significantly prolonged in the No-nap condition compared with the prenap sessions and compared with the S1- and S2-nap conditions. Although reaction time was 70 milliseconds shorter for the last half of the postnap sessions in the S2-nap condition than for the prenap sessions, this difference was not significant.

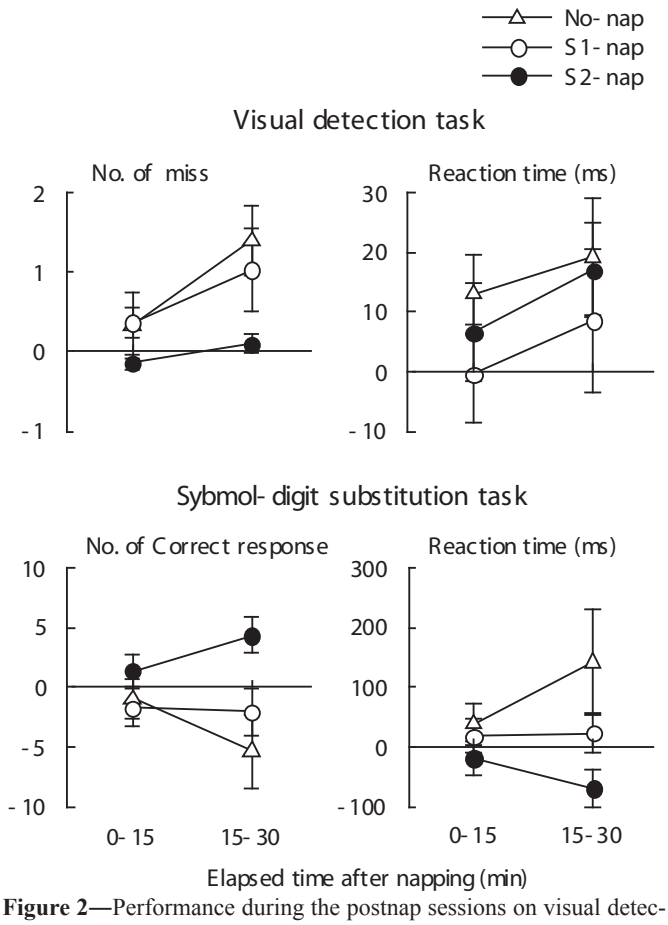

Figure 2—Performance during the postnap sessions on visual detection task (top panels) and symbol-digit substitution task (bottom panels). The data are expressed as the values of changes from the prenap sessions, calculated by subtracting the mean values of the 3 prenap sessions.

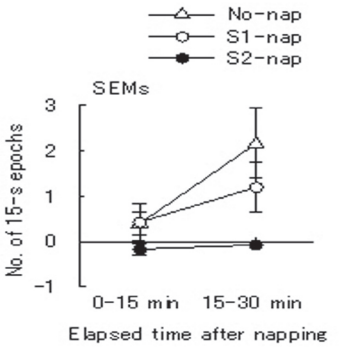

Figure 3—The number of 15-second epochs accompanied by slow eye movements during the visual detection task. The data are expressed as the values of changes from the prenap sessions, calculated by subtracting the mean values of the 3 prenap sessions.

Slow Eye Movements

Figure 3 shows the number of 15-second epochs accompanied by slow eye movements during the visual detection task. Slow eye movements infrequently occurred in the S2-nap condition, whereas they occurred from 5 minutes after the postnap sessions in both the No-nap and the S1-nap conditions. No significant difference was observed between immediately before and after napping. Analysis of variance showed that slow eye movements significantly increased as time elapsed ($F_{2,18}$ = 3.69, ε = 1.00, P = .045). There were also significant differences among the conditions ($F_{2,18}$ = 7.30, ε = 0.76, P = .010) and a significant interaction of condition × time ($F_{4,36}$ = 4.34, ε = 0.76, P = .012). During the last half of the postnap sessions, slow eye movements significantly increased in the No-nap and the S1-nap conditions in comparison with the prenap sessions and were significantly greater than the S2-nap condition (Table 3).

Appearance of Sleep Spindle in the S1-Nap

As described earlier, sleep spindles appeared in the S1-nap condition for 4 of the 10 participants. Because the participants were awakened immediately after the first spindle appeared, the last 30-second epochs of the S1-nap were scored as stage 1 sleep. However, the subjects were apparently awakened at stage 2 sleep; therefore, there remains the possibility that the positive effects of the S1-nap on subjective sleepiness and fatigue might be attributable to the occurrence of the sleep spindle. Therefore, the subjective measures, performance, and slow eye movements were reanalyzed by dividing participants into subgroups for those who were awakened when the first spindle appeared (n = 4) or not appeared (n = 6). The time course of subjective measures, performance, and slow eye movements for the former subgroup were almost the same as for the latter subgroup. Analyses of variance showed that there were no significant differences between the subgroups.

Correlation Between the Measures and Total Sleep Time and/or Stage 1 Sleep

Recuperative effects of the S2-nap were observed, especially during the last half of the postnap sessions. Correlation coefficients for the last half of the postnap sessions were calculated between the total sleep time and/or the total amount of stage 1 sleep and the differences between the S2-nap and the No-nap conditions for the subjective mood, performance, and slow eye movements . Subjective fatigue was negatively correlated with total sleep time (r = -0.26) and the amount of stage 1 sleep (r = -0.33), although these correlations were not significant. No significant correlations were observed for the other measures (r = -0.14 to 0.15).

DISCUSSION

The recuperative effects of daytime naps of less than 30 minutes have been confirmed by earlier research. These naps are mainly composed of stage 1 and 2 sleep. The present study examined whether the recuperative effects of short naps depend upon which of the sleep stages are present in the nap, ie, stage 1 or 2 sleep. After restricted nocturnal sleep, the participants took a rest (No-nap condition) or a nap, which was composed of 5 minutes of stage 1 sleep (S1-nap condition) or an additional 3 minutes of stage 2 sleep (S2-nap condition). In the No-nap condition, subjective sleepiness and fatigue increased, and task performance deteriorated in the mid-afternoon. Slow eye movements also occurred during the visual detection task. In contrast, in the S2-nap condition, there was less subjective sleepiness, performance was improved on the visual detection task and the symbol-digit substitution task, and the occurrence of slow eye movements was suppressed after the nap. In the S1-nap condition, subjective sleepiness and fatigue were improved; however, task performance deteriorated and slow eye movements occurred during the visual detection task. These

results suggest that stage 2 sleep has recuperative power, while these effects are limited in stage 1 sleep.

No-Nap Condition

In the No-nap condition, the participants took a 16minute rest from 2:00 PM and then engaged in the postnap sessions from 2:17 PM to 2:47 PM. During the latter half of the postnap sessions, subjective mood and task performance deteriorated. These results show the "postlunch dip," which would reflect 12-hour biologic cycles of sleepiness.[37]

Monotony and a low-activated environment during the 16-minute rest period might have lowered alertness during the postnap session. If it were the case, then sleepiness, fatigue, performance deterioration, and slow eye movements would have occurred from the beginning of the postnap sessions. However, this was not the case for the No-nap condition. Subjective symptoms and performance did not significantly deteriorate, and slow eye movements did not significantly occur immediately after resting as compared with immediately before resting. Therefore, the deterioration of alertness in the No-nap condition could be caused by post lunch dip, not the 16-minute rest itself. These results suggest that the No-nap condition was appropriate as a control condition.

S1-Nap Condition

In the S1-nap condition, subjective fatigue improved, and sleepiness decreased immediately after napping. However, similar to the No-nap condition, slow eye movements occurred during the visual detection task, and performance on this task deteriorated. Performance on the digit-symbol substitution task was not different from the No-nap condition and was significantly lower than the S2-nap condition. These results showing that the S1-nap had no recuperative effects on performance support the findings of Tietzel and Lack.[26] They showed that ultrashort naps of 30 seconds or 90 seconds of stage 1 sleep had no recuperative effect on performance on the symbol-digit substitution task and on stage 1 sleep latency, used as an indicator of objective sleepiness. In contrast with our study, they also showed that these naps had no recuperative effect on subjective sleepiness.

The discrepancy of the results between their study and the present study may be related to the length of the S1-nap. Stage 1 sleep of 60 to 90 seconds in Tietzel and Lack's study is still the beginning hypnagogic state, corresponding to the stage of disappearance of EEG alpha activities or EEG flattening.[38-39] Although wake-related components attenuate in these EEG stages, sleep-related components do not yet appear.[40] In contrast, 4.5 minutes of stage 1 sleep in the present study is the latter half of the hypnagogic stage, corresponding to EEG stages when vertex sharp waves appear.[40] From this EEG stage, EEG delta and theta activities begin to enhance, suggesting that sleep-related components begin to appear.[41] These findings suggest that the recuperative process might start in the S1-nap with the appearance of sleep-related components. However, the present results also suggest that 4.5 minutes of S1 nap had recuperative effects on subjective symptoms but not on microsleep or lapses of performance after restricted nocturnal sleep.

Sleep spindles appeared in the S1-nap condition for 4 of the 10 participants. However, no significant differences were observed between those who were immediately awakened when the first spindle appeared and those awakened when 5 minutes of stage 1 sleep elapsed. The recuperative power of the daytime short nap would be restricted until the appearance of the first spindle.

S2-Nap Condition

The participants slept for 9 minutes in the S2-nap condition. This nap consisted of 3 minutes of stage 2 and 6 minutes of stage 1 sleep. In this condition, subjective sleepiness and fatigue decreased, performance was enhanced, and slow eye movements did not occur during the task. Thus a 9-minute nap containing 3 minutes of stage 2 sleep was effective for maintaining alertness and prevented the occurrence of microsleep due to restricted nocturnal sleep or postlunch dip. These results are comparable to Takahashi et al,[16,25] Tietzel and Lack,[26] and Horne and Reyne.[23] Takahashi et al[16] have shown that a 7.3-minute nap, consisting of 5.2 minutes of stage 1 and 2.1 minutes of stage 2 sleep, after normal night of sleep has positive effects on subjective sleepiness and performance on a transcription task. After restricted nocturnal sleep (3.5 hours of nocturnal sleep), Takahashi and Arito[25] showed that a 10.2-minute nap, consisting of 5.5 minutes of stage 1, 3.5-minutes of stage 2, and 1.1 minutes of rapid eye movement sleep, improved subjective sleepiness and performance on a logical reasoning task. Although sleep variables, except for total sleep time and sleep latency, were not described, Horne and Reyner[23] have shown that a 10.8-minute nap after 5 hours of nocturnal sleep had positive effects on daytime alertness; the number of incidents during a driving simulation task decreased and EEG theta-alpha band power was suppressed. Tietzel and Lack[26] have also shown that a 10-minute nap after 5 hours of nocturnal sleep improves alertness and cognitive performance.

Total sleep time for the S2-nap was 9.1 minutes, which was 4.6 minutes longer than the S1-nap (4.5 minutes). This undisrupted length of the 9-minute nap, including stage 1 sleep, might influence our results. However, the total sleep time or the total amount of stage 1 sleep in the S2-nap did not correlate significantly with the subjective, behavioral, and physiological measures. Therefore, in the present study, it seems plausible that the main contributor to the recuperative effects on daytime alertness and performance after restricted nocturnal sleep would be the 3 minutes of stage 2 sleep, not the 9 minutes of total sleep time including stage 1 sleep.

Still, it cannot be completely ruled out that the recuperative power of the S2-nap might depend on the length of total sleep time, since the S2-nap had twice as much sleep time as the S1-nap. Additional experimental studies would be necessary to equate the total sleep time in these nap conditions. Perhaps the acoustic stimulation technique[42] could be useful to prevent participants from developing deeper sleep stages, while avoiding awakening, so that the length of total sleep time in the S1-nap could be controlled to be the same length as in the S2-nap condition.

It has been reported that the recuperative effects of sleep depend on SWS and that this is also the case for daytime naps.[3,4] Short naps of approximately 10 minutes do not contain SWS, suggesting that stage 2 sleep during a daytime nap, independent of SWS, has recuperative effects. However, delta- and theta-band EEG activities during the waking-sleeping transition period intensify rapidly during stage 2 sleep.[43] It could be argued that background EEG delta activity during stage 2 sleep might contribute to the recuperative effects of the daytime short nap. Spectral analysis of EEG during the nap might be required.

Several possibilities remain that the effects of the S2-nap might be attributed to a bed-rest effect or the undisrupted length of the nap, not to the stage 2 sleep itself. The total time in bed for the S2-nap was 11.4 minutes, which was 5 minutes longer than the S1-nap (6.5 minutes). Daiss et al[44] have found that after 7 to 8 hours of nocturnal sleep, 1 hour of bedrest without sleep improves mood, as does a 1-hour daytime nap. In a daytime short-nap study, Horne and Reyner[23] have also found that their participants who cannot sleep during the nap period report an improvement of mood. The participants in the present study took a rest sitting in a reclining chair, not a rest on a bed without sleep, so the bedrest effect cannot be completely ruled out. Further studies are needed to examine the effects of brief bedrest.

In the present study, the effects of the nap were measured for only 30 minutes after napping. This might be too short to fully evaluate the effects of the nap. In our previous studies, a daytime 20-minute nap taken at noon[11] or midafternoon[12] improved subjective sleepiness for 2 to 3 hours. However, when the effects of a short nap taken at 2:00 PM were evaluated every 15 minutes, the differences between the nap and the no-nap conditions in subjective sleepiness and reaction time on the performance task were maximal 15 to 30 minutes after the nap.[14] These results suggest that a short daytime nap has maximum recuperative benefit at the time when afternoon sleepiness is greatest. It was not clear in the present study whether sleepiness was greatest 30 minutes after resting in the No-nap condition. However, subjective sleepiness in the S2-nap condition reached plateau immediately after napping (Figure 1), suggesting that alertness would not be enhanced for more than 30 minutes after napping. Further studies would be required to examine the duration of the effects of the S2-nap.

CONCLUSION

Short daytime naps of less than 30 minutes, which rarely contain SWS, have been widely reported to have positive effects on daytime alertness.[6,9-29] These short naps are mainly composed of stage 1 and 2 sleep (Table 1). The present study confirmed that stage 2 sleep plays an important role in the restorative function of sleep and that a minimum of 3 minutes of stage 2 sleep had recuperative effects on daytime alertness and performance after restricted nocturnal sleep, while these effects were limited in stage 1 sleep.

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