A Brief Afternoon Nap Following Nocturnal Sleep Restriction: Which Nap Duration is Most Recuperative?

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Study Objectives: The purposes of this study were to compare the benefits of different length naps relative to no nap and to analyze the electroencephalographic elements that may account for the benefits.

Design: A repeated-measures design included 5 experimental conditions: a no-nap control and naps of precisely 5, 10, 20, and 30 minutes of sleep.

Setting: Nocturnal sleep restricted to about 5 hours in participants' homes was followed by afternoon naps at 3:00 PM and 3 hours of postnap testing conducted in a controlled laboratory environment.

Participants: Twenty-four healthy, young adults who were good sleepers and not regular nappers.

Measurements and Results: The 5-minute nap produced few benefits in comparison with the no-nap control. The 10-minute nap produced immediate improvements in all outcome measures (including sleep latency, subjective sleepiness, fatigue, vigor, and cognitive performance), with some of these benefits maintained for as long as 155 minutes. The 20-minute nap was associated with improvements emerging 35 minutes after napping and lasting up to 125 minutes after napping. The 30-minute nap produced a period of impaired alertness and performance immediately after napping, indicative of sleep inertia, followed by improvements lasting up to 155 minutes after the nap.

Conclusions: These findings suggest that the 10-minute nap was overall the most effective afternoon nap duration of the nap lengths examined in this study. The implications from these results also suggest a need to consider a process occurring in the first 10 minutes of sleep that may account for the benefits associated with brief naps.

Keywords: Brief naps, napping, acute sleep restriction, alertness, performance

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INTRODUCTION

GLOBAL TRENDS OF INCREASED WORK, DOMESTIC AND SOCIAL DEMANDS, AND ASSOCIATED NOCTURNAL SLEEP REDUCTION AND DAYTIME SLEEPINESS HAVE stimulated research interest into countermeasures of this daytime sleepiness. One countermeasure that has received attention in recent years is brief napping.

Naps as brief as 19.8,[1] 10.8,[2] 10.2,[3] 10,[4,5] and 9.1 minutes[6] have been shown to improve alertness and performance following restricted nocturnal sleep. Similar benefits have also been observed after normal nocturnal sleep from brief naps of mean durations of 20,[7,8] 15,[9] and 7.3[10] minutes. In addition, brief workplace naps during a night shift have also been shown to be beneficial.[11,12]

Brief naps have been shown to be at least as restorative as longer naps.[4,10] Comparing a 15-minute nap opportunity (mean sleep duration 7.3 minutes) with a 45-minute nap opportunity (mean sleep duration 30.1 minutes) after a night of normal sleep, Takahashi et al[10] observed significantly improved alertness 30 minutes after the 15-minute nap opportunity and comparable improvements for the 2 nap conditions 3 hours after napping. Under conditions of mildly restricted nocturnal sleep, Tietzel and Lack[4] found that an afternoon nap of precisely 10 minutes' sleep was at least as recuperative as a 30-minute nap in terms of improved alertness and performance for an hour following the napping.

However, it is important to recognize the limitations of these studies. In terms of the Takahashi et al study,[10] dependent measures were administered only twice. In the Tietzel and Lack[4] study, postnap testing was limited to 1 hour. Hence, the longer nap may have ultimately shown greater benefits had greater time been allowed for postnap testing. In fact, after a night of total sleep loss, longer naps (i.e., 1 to 2 hours) have been shown to be more alerting than brief naps for at least 3 hours after napping.[13,14] Although longer naps may be recuperative, especially following total sleep deprivation, any benefit of longer naps must be weighed against their practical disadvantages of greater length of time consumed by the nap and greater sleep inertia after the nap and their possible detrimental impact on subsequent nocturnal sleep.

Sleep inertia refers to a period of disorientation, confusion, and sleepiness that an individual may experience immediately upon awakening from sleep.[15,16] Since sleep inertia appears to be directly related to duration of slow-wave sleep during a sleep episode, it follows that sleep inertia will be greater following longer naps that typically contain more slow-wave activity than shorter naps.[17-19] Even naps with as much as 30 minutes of sleep show the negative effects of sleep inertia.[4]

Considering that there have been no studies comparing more than 2 nap lengths, there is clearly a need to measure the effects of several different length naps over an extended postnap period. Therefore, the present investigation examined the 3-hour time course of effects following 5-, 10-, 20-, and 30-minute naps after a night of mildly restricted sleep. A practical aim of this study was to provide information that would allow a more informed decision regarding the most effective nap duration for improving alertness and cognitive performance in the afternoon.

In addition to this practical consideration, a careful examination

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of the time course of nap effects could have theoretical implications. The napping research appears to challenge 1 postulate of the homeostatic model of sleep (Process S), that sleep propensity reduces as a function of the accumulation of slow-wave activity during the sleep episode.[20] That is, Process S would predict minimal benefits resulting from brief naps without slow-wave activity and greater restorative benefits from longer naps with substantial slow-wave activity. Even a more cautious formulation of Process S based on total sleep rather than slow-wave activity would predict benefits proportional to the length of nap sleep.

If, however, longer naps do not produce greater benefits than shorter naps, it may be necessary to reconsider the adequacy of the homeostatic model of sleep in accounting for the beneficial effects of brief naps. Tietzel and Lack[5] recently postulated that the onset of stage 1 sleep may be the operative mechanism determining brief nap benefits, as opposed to amount of sleep or slow-wave activity (Process S). In order to test this hypothesis, naps of 30 seconds, 90 seconds, and 10 minutes of sleep were compared with a no-nap control condition. Tietzel and Lack[5] found that the 'ultra-brief' 30-second and 90-second naps produced no significant postnap benefits and, therefore, concluded that the onset of stage 1 sleep did not appear to be the mechanism underlying the benefits of brief naps. Since, in this study, a 10-minute nap again produced significant benefits,[5] it would be valuable to investigate processes occurring in the first 10 minutes of sleep.

Just recently, Hayashi et al[6] showed that a 9.1-minute nap including 3 minutes of stage 2 sleep was better than a 4.5-minute nap of only stage 1 sleep for improving some performance and sleepiness measures. Their data suggested no specific benefit from the nap if it only included the onset of stage 2 (first sleep spindle). They suggested, instead, that the napping benefits derived from the accumulated 3 minutes of stage 2 sleep per se. However, their results do not preclude the possibility that the napping benefits arose from more total sleep rather than stage 2 sleep. Therefore, the benefits of brief naps may require the accumulation of a brief fixed amount of stage 2 sleep or a brief fixed period of total sleep of any stage between 90 seconds and 10 minutes in duration. The present study tested some of these possible sources of the benefits from brief naps.

METHODS

Participants

Participants included 12 male and 12 female university students (mean age = 22.50 years, SD = 3.86) recruited from the Flinders University Employment Service (each receiving monetary payment of A$215). For inclusion in this study, participants were required to be nonhabitual nappers (i.e., less than 1 nap per week), nonsmokers, self-reported good sleepers (i.e., sleep latencies less than 30 minutes and no history of sleep complaints), and low consumers of caffeine (i.e., less than 3 cups of caffeinated beverages per day). The study received approval from the Flinders University Social and Behavioural Research Ethics Committee.

Design

The study employed a repeated-measures design comprising 5 experimental conditions: no-nap control, 5-minute nap, 10-minute nap, 20-minute nap, and 30-minute nap. Out of 120 possible permutations of order for 5 conditions, 24 orders were selected at random. Subjects were randomly allocated an order such that each nap condition occurred an approximately equal number of times in each position order. (There was no greater than a 9% variation from the mean in frequency of occurrence of any condition, and the average variation was 4% across the 5 positions of order.)

Prior to the Laboratory Session

Participants were required to maintain regular bed times for the period commencing 1 week prior to the initial laboratory session until participation was completed, with the exception of the evening preceding each of the laboratory sessions. On the evening prior to each session, participants limited their sleep period to the hours between 2:00 AM and 7:00 AM. To prevent the accumulation of sleep debt, at least 2 intervening nights (typically 1 week) of normal nocturnal sleep were scheduled between these nights of sleep restriction. Sleep-wake diaries and activity monitors were used throughout the experimental period to confirm compliance with these instructions. In addition, compliance with sleep-restriction instructions was monitored on the night prior to each laboratory session with time-marked telephone calls to the sleep laboratory at 2:00 AM and 7:00 AM.

Further instructions given to participants included refraining from alcohol and caffeine consumption for 3 days prior to and including laboratory sessions, consuming a normal-size lunch within the hour prior to arriving at the sleep laboratory, and refraining from vigorous mental or physical activity for at least 30 minutes prior to a session. Thus, all practical measures were taken to reduce the potential sources of random variance in the outcome alertness and performance variables.

The Laboratory Session

Participants reported to the laboratory at 1:00 PM, were equipped with electroencephalogram (Cz to Oz), electrooculogram, and electromyogram electrodes for standard recording and were then confined to bed until the completion of the laboratory session (6:00 PM). External time cues were eliminated, light intensity was maintained at 50 lux between sleep-latency trials, and bedroom temperature was maintained at 22ºC.

Figure 1 outlines the scheduling of napping and testing during the 5 laboratory sessions. Each session comprised 5 periods of testing and 4 sleep-latency trials. Baseline testing occurred at 2:00 PM, with postnap testing beginning at 5, 35, 95, and 155 minutes after awakening from the nap. The prenap sleep-latency measure was the latency to sleep onset of the nap itself, with postnap sleep-latency trials conducted 65, 125, and 185 minutes after napping. In between periods of electrode attachment, testing, and sleep-latency trials, participants engaged in quiet activity in constant environmental conditions (e.g., reading magazines or novels or watching videos in a near-supine position in bed) to ameliorate the possible arousing effects of the testing procedures. As depicted in Figure 1, the onset of nap periods was staggered for the different nap conditions in order to align the clock time of postnap testing and, therefore, minimize circadian-rhythm differences between conditions. Lights were turned out at 2:30 PM for the 30-minute nap, 2:40 PM for the 20-minute nap, 2:50 PM for the 10-minute nap, 2:55 PM for the 5-minute nap, and 3:00 PM for the no-nap condition. The mean time of awakening from the naps was 3:04 PM (SD = 2.83 minutes). This mean awakening time indicated that sleep latencies for the naps were short and that, once

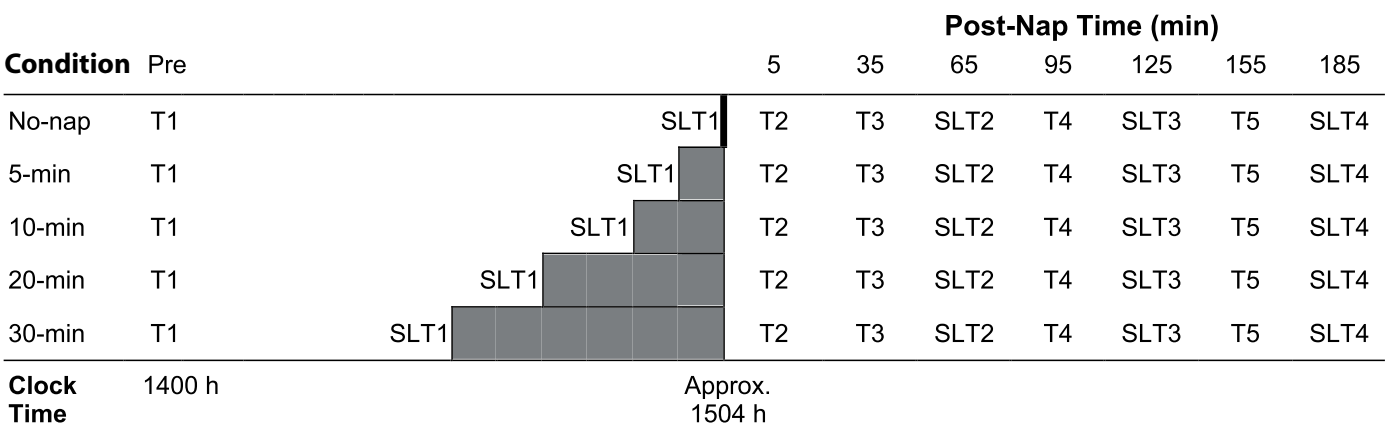

Figure 1—Schematic diagram of the experimental protocol (not to scale). Each session comprised 5 periods of testing (T) and 4 sleep latency tests (SLT). The shaded horizontal bars represent sleep.

sleep was initiated, it invariably continued uninterrupted to the completion of required nap length.

Test Instruments

The test battery included the Stanford Sleepiness Scale,[21] fatigue and vigor subscales of the Profile of Mood States,[22] Symbol-Digit Substitution Task (SDST), Letter Cancellation Task (LCT), and a simple visual reaction time (RT) task. The RT task had 80 stimuli spaced randomly in time (interstimulus interval from 3 to 9 seconds) over about 8 minutes. With respect to the SDST, participants were presented with a key of 9 novel symbols paired with the digits between 1 and 9 and a random sequence of these symbols with instructions to identify and copy the digit corresponding to each symbol as quickly and accurately as possible. The LCT involved participants searching for and marking 2 target letters in a matrix of alphanumeric stimuli. The outcome measure derived from the SDST and LCT was the mean number of correct responses within a 90-second period (SDST) or 2-minute period (LCT). Parallel forms of both tasks provided novel forms for each testing occasion. The outcome measures derived from the RT task were median RT (milliseconds) and number of RT lapses (RT > 500 milliseconds).

Sleep-Latency Measure

Sleep latency was used as an objective measure of alertness. The baseline sleep-latency measure was the latency to the nap sleep, with postnap sleep-latency trials conducted 65, 125, and 185 minutes after napping. A fixed period of 20 minutes was allocated to each sleep-latency trial to ensure fixed scheduling of postnap testing. When participants met sleep-onset criteria prior to the completion of this 20-minute period, they were awakened and had additional quiet activity for the remainder of the 20-minute period. Sleep-latency trials with a failure to initiate sleep were counted as a 20-minute latency. These were rare, accounting for fewer than 4% of all latencies and occurring about equally between conditions, mainly in the last 2 latency trials at 5:00 PM and 6:00 PM.

Sleep latency was determined using customised computer software (Laboratory Virtual Instrument Engineering Workbench 5 (LabVIEW5); National Instruments Corporation, Austin, TX). The software contained a power spectral analysis program, that quantified on-line electroencephalogram alpha (8-12 Hz), theta (4-7 Hz), and delta (0.5-4 Hz) power for every 30-second epoch of each sleep-latency trial and displayed these power values graphically in real time. A delta-wave movement artifact, associated with adjustment to the sleeping position, always occurred in the 30-second epoch following lights out. Following this artifact, a 50% alpha baseline was calculated for each sleep-latency trial by averaging the alpha power of the 2 epochs with the highest amount of alpha power (invariably occurring in the first few epochs immediately following the movement artifact) and dividing the average alpha power by 2. Sleep latency was defined as the latency (in minutes) from the termination of delta-wave movement artifact to the first of 3 consecutive 30-second epochs below the 50% alpha baseline. This method of determining sleep latency was used for its quantitative precision and need to limit sleep-latency trials to precisely 3 epochs of sleep. The method, when used for sleep-latency measurement across all circadian phases, has been shown to have high interrater reliability (r = +.99) and validity with latency on the standard Multiple Sleep Latency Test determined from raw electroencephalogram, electrooculogram, electromyogram measures(r = +.90).[23]

Nap Sleep Determination

The LabVIEW5 software was also used for monitoring the nap sleep period. In the no-nap condition, participants were awakened following 3 consecutive 30-second epochs below the 50% alpha baseline, in order to obtain a sleep-latency measure. Importantly, this procedure for obtaining a sleep-latency measure (containing only 90 seconds of sleep) does not alter subsequent alertness.[5] In each of the other nap conditions, the nap period commenced at the first of 3 consecutive epochs below the 50% alpha baseline. Participants were awakened from naps after they had obtained precisely 5, 10, 20, or 30 minutes of sleep.

For purposes of analyzing nap sleep infrastructure the nap period was also recorded using a portable polysomnography-recording system. An experienced polysomnography technician, who was blinded to condition, scored the sleep stages retrospectively using the conventional Rechtschaffen and Kales[24] sleep-scoring criteria. The first onset of any delta-wave electroencephalographic activity (amplitude > 75 μV, 0.5 < Hz < 4.0) was also identified in the raw electroencephalogram of each nap.

Data Screening and Preliminary Analyses

For the 5 evenings of enforced sleep restriction, a 1-way repeated-measures analysis of variance (ANOVA) performed on actigraph-derived mean total sleep times revealed no significant overall difference between conditions ($F_{4,92} = 0.93$, $p > .20$). Further pair-wise comparisons with Bonferroni correction (family wise $\alpha = .05$) showed no significant differences in total sleep time (hours) between the nocturnal sleep prior to the no-nap (mean = 4.81, SD = 0.17), 5-minute nap (mean = 4.73, SD = 0.20), 10-minute nap (mean = 4.75, SD = 0.25), 20-minute nap (mean = 4.82, SD = 0.17), and 30-minute nap (mean = 4.78, SD = 0.19) conditions. Hence the same degree of sleep restriction preceded each nap condition. Since the mean (SD) total sleep time during the normal intervening nights was calculated from sleep diaries as 7.32 (0.35) hours, there was a mean reduction of about 2.5 hours sleep for the nights preceding the laboratory sessions.

One-way repeated-measures ANOVAs also revealed no significant condition differences in prenap baseline scores for all outcome measures (all p values > .10). Posthoc analyses were also conducted to examine possible order effects for each of the measures. One-way repeated-measures ANOVAs revealed no significant variations for any of the measures (all p values > .10) in prenap scores across the order of administration.

Statistical Analyses

For all dependent (outcome) measures (e.g., sleep latency, subjective alertness, performance measures), 2-way repeated-measures ANOVAs were conducted on the raw data with the main factors of nap length and postnap testing time. Simple within-subjects planned contrasts were then conducted to test the prediction that alertness and performance measures would increase between before and after the nap for particular nap lengths compared to no nap. Given that the planned contrasts performed were orthogonal and that the number of contrasts did not exceed the degrees of freedom (i.e., sleep latency = 12, other dependent measures = 16), an uncorrected per comparison p level of .05 was utilized, as recommended by Keppel.[25]

For the objective alertness (sleep latency) variable, the 2-way repeated-measures ANOVA comprised 5 levels on the factor nap length (no-nap, 5-, 10-, 20-, and 30-minute naps) and 4 levels on the factor time (prenap and 65, 125, and 185 minutes after nap). Because so many sleep latencies were short, these distributions had significant ($p < .05$) positive skew. Transformation techniques failed to significantly reduce the skew. Although ANOVA is robust to violation of normality, one should still be cautious in interpreting the ANOVA results for this measure. For the remaining alertness and performance variables, there were 5 levels on the factor time (prenap and 5, 35, 95, and 155 minutes after nap). The overall main differences between conditions and time were not relevant to testing the aims of this study. The interest was in the relative changes from before to after nap between the no-nap control and other nap lengths, as investigated by examining the interaction effects between nap lengths and postnap time.

RESULTS

Table 1 shows the results of 2-way interactions and simple planned contrasts against the no-nap control for all outcome measures. For the 5-minute nap, the only significant planned contrast of interaction effects with the no-nap condition were improved LCT performance 35 and 95 minutes after the 5-minute nap (see Table 1). However, following the 10-minute nap, there were significant improvements for all outcome variables. The 10-minute nap showed lengthened sleep latency 65 minutes after the nap. To summarize the changes in the other 7 subjective and performance measures following the 10-minute nap, there were significant improvements in 5 measures at 5 minutes, 7 at 35 minutes, 6 at 95 minutes, and 4 at 155 minutes after the nap. The 20-minute nap resulted in lengthened sleep latencies 65 minutes and 125 minutes after the nap. However, in the 7 other measures, none were significant after 5 minutes, only 2 after 35 minutes, 2 after 95 minutes, and none after 155 minutes. After the 30-minute nap, sleep latency was also lengthened at 65 minutes and 125 minutes after the nap. However, none of the other 7 measures were significant at 5 minutes after the nap, 1 at 35 minutes, 2 at 95 minutes, and 3 at 155 minutes after the nap.

Figure 2 (a) graphically illustrates the change in mean sleep latency following all nap lengths over time. This shows the general increase of sleep latency 65 minutes following all naps, with a regression toward the no-nap control by 3 hours after nap. Figure 2 also shows the mean changes from prenap baseline as a percentage of the total ranges in the measures of (b) Subjective Alertness (SSS), (c) Fatigue, (d) Vigor, (e) SDST performance, (f) LCT performance, and (g) median RT performance across all postnap times for all nap lengths. This method of illustration highlights the relative changes following different length naps from prenap (with all values zeroed) to all postnap times. Because percentage change could not be calculated for the lapses data, Figure 2 (h) shows the difference in the mean number of lapses compared with baseline. Of note, because higher scores on the SSS, Fatigue scale, RT, and RT lapses represents reduced alertness, the y axes for these variables were reversed so that figures reflected "improvement" in the positive direction for all outcome measures. Error bars and indicators of points of significant interactions were not included for purposes of visual clarity. However, in all cases, the significant interactions between the control and any specific nap length occurred at time points in the figures of greatest deviation from the control values.

Posthoc Examination of Sleep Inertia

Sleep inertia is evident following the 30-minute nap in this study. It is indicated graphically in Figure 2 as relatively reduced values 5 minutes after the nap and increased values later. One way to examine possible sleep-inertia effects statistically in this study was to test the relative reduction in subjective alertness and performance immediately following the 20- and 30-minute naps compared with later test periods. Posthoc 2-way repeated-measures ANOVAs were performed, with 2 levels on the factor Nap Length (e.g., no-nap, 30-minute nap) and 4 levels on the factor Time (5, 35, 95, and 155 minutes after the nap). In the event of a significant interaction effect, simple within-subjects planned contrasts were then performed to compare the no-nap and 30-minute conditions between 5 minutes after the nap and the 3 subsequent test times, with Bonferroni adjusted ($p = .017$) due to the exploratory nature of this analysis. As indicated in Table 2, significant interactions between the no-nap and 30-minute nap conditions were observed between 5 and 35 minutes after the nap (i.e., SDST and LCT performance) and between 5 and 155 minutes after the nap (i.e., Subjective Alertness and SDST performance). On the Fatigue variable, the interaction between the 2 nap conditions

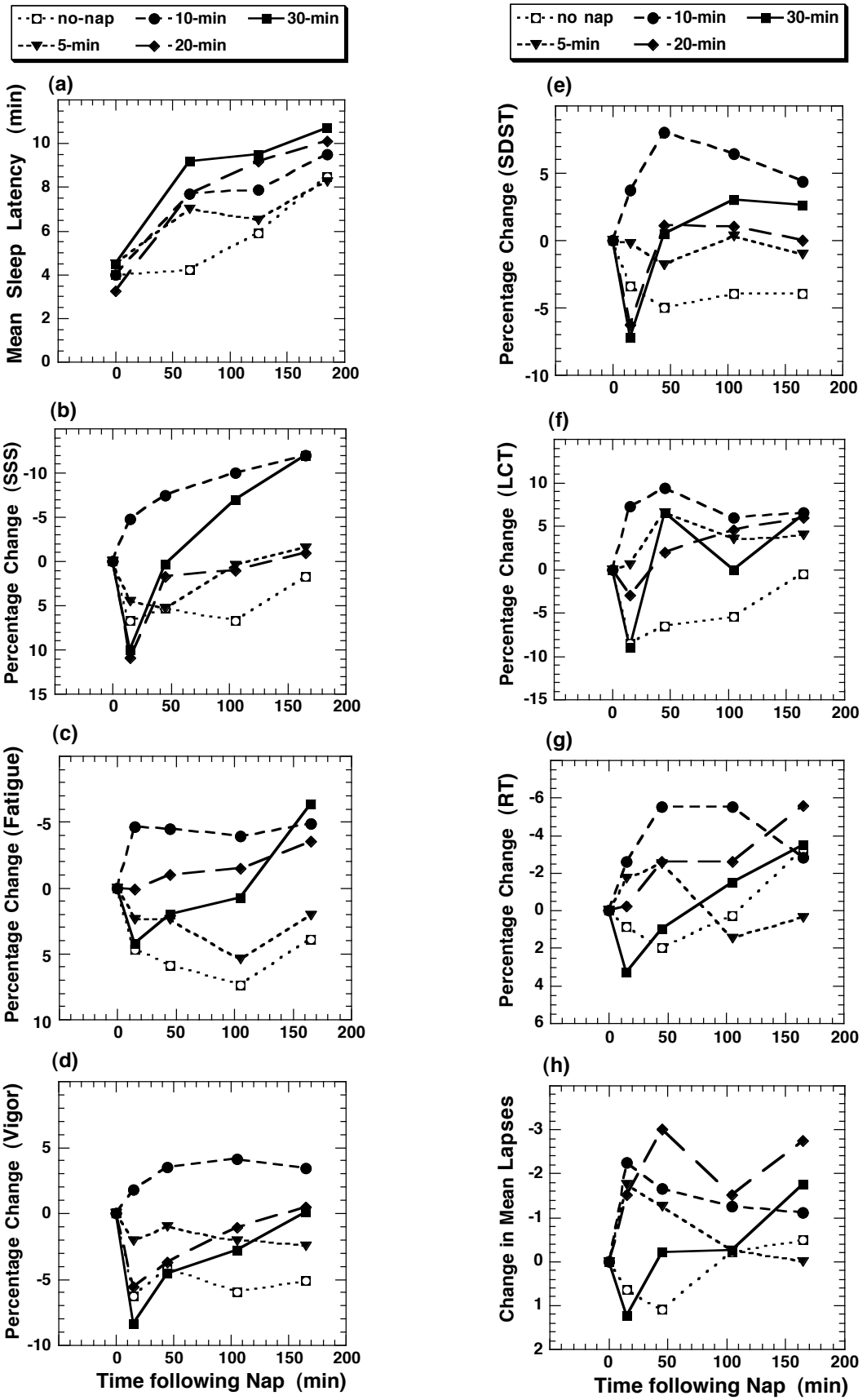

Figure 2—(a) Mean sleep latency for the nap and 3 postnap times; change from baseline as a percentage of total range of scale in (b) Subjective Alertness (Stanford Sleepiness Scale [SSS]), (c) Fatigue, (d) Vigor; (e) Symbol Digit Substitution Task (SDST) performance, (f) Letter Cancellation Task (LCT) performance, and (g) median reaction time (RT) performance and changes in (h) mean number of RT lapses following no nap and the 5-, 10-, 20- and 30-minute naps. Note, because higher scores on (b) SSS, (c) Fatigue, (g) RT, and (h) lapses represent reduced alertness, the y axes for these variables were reversed, so that figures reflected "improvement" in the positive direction for all measures.

Table 1— Two-Way ANOVA Interaction Effects and Planned Within-Subjects Contrasts for Condition (No-nap vs Other Nap Condition) by Time (Prenap vs Postnap Time) for All Dependent Variables

Variable	ANOVA		Condition	Planned Contrasts: Time		
				Prenap vs 65 min post	Prenap vs 125 min post	Prenap vs 185 min post
	df	F		F		
Objective Alertness Sleep Latency	6.86, 157.84	1.93	No-nap vs 5-min nap	2.60	0.00	0.11
			No-nap vs 10-min nap	5.42*	1.85	0.59
			No-nap vs 20-min nap	11.84**	6.97*	2.42
			No-nap vs 30-min	12.29**	5.53*	2.13

				Time			
				Prenap vs 5 min post	Prenap vs 35 min post	Prenap vs 95 min post	Prenap vs 155 min post
	df	F		F			
Subjective Alertness SSS	7.90,181.66	1.86	No-nap vs 5-min nap	0.09	0.12	0.83	0.20
			No-nap vs 10-min nap	4.54*	4.12[c]	7.89*	5.69*
			No-nap vs 20-min nap	0.48	0.21	0.70	0.14
			No-nap vs 30-min nap	0.25	0.63	4.60*	4.11[c]
Fatigue	7.43,170.99	1.82	No-nap vs 5-min nap	0.55	1.05	0.43	0.11
			No-nap vs 10-min nap	7.93*	5.76*	9.63**	4.05*
			No-nap vs 20-min nap	2.11	2.56	4.82*	2.83
			No-nap vs 30-minv	0.01	0.77	3.23	4.01[e]
Vigor	7.79,179.20	1.35	No-nap vs 5-min nap	0.97	0.52	0.83	0.31
			No-nap vs 10-min nap	8.19**	4.06[d]	8.29**	4.52*
			No-nap vs 20-min nap	0.32	0.15	1.59	2.13
			No-nap vs 30-min nap	0.28	0.01	0.65	1.17
SDST Performance	7.71, 177.34	2.76***	No-nap vs 5-min nap	0.84	0.98	2.63	0.78
			No-nap vs 10-min nap	3.25	17.78***	10.73**	6.04*
			No-nap vs 20-min nap	0.52	5.33*	3.22	2.75
			No-nap vs 30-min nap	1.43	3.55	4.55*	4.26[a]
LCT Performance	16,368	1.99*	No-nap vs 5-min nap	2.02	5.52*	4.96*	0.18
			No-nap vs 10-min nap	11.39**	8.21**	5.02*	0.78
			No-nap vs 20-min nap	2.20	3.71	7.49*	2.29
			No-nap vs 30-min nap	0.04	7.89*	1.89	1.30
Median RT Performance	6.78, 155.85	2.07[b]	No-nap vs 5-min nap	0.61	3.16	0.07	1.37
			No-nap vs 10-min nap	2.60	11.05**	7.59*	0.02
			No-nap vs 20-min nap	0.20	3.05	1.27	1.21
			No-nap vs 30-min nap	0.41	0.31	0.36	0.05
RT Lapses	4.42,101.55	1.54	No-nap vs 5-min nap	3.07	3.58	0.00	0.16
			No-nap vs 10-min nap	5.12*	7.07*	0.67	0.17
			No-nap vs 20-min nap	0.72	5.80*	0.65	1.39
			No-nap vs 30-min nap	0.10	1.29	0.02	1.51

ANOVA refers to analysis of variance; SDST Symbol Digit Substitution Task; LCT, Letter Cancellation Task; RT, reaction time. All df = 1,23; [a]p = .051, [b]p = .052, [c]p = .054, [d]p = .056, [e]p = .057, *p < .05, **p < .01, ***p < .001

between 5 and 155 minutes approached significance. The same analysis on the no-nap versus 20-minute nap comparison found no significant interaction effects across the postnap test sessions. Thus, there was some statistical support for the presence of detrimental sleep-inertia effects 5 minutes following the 30-minute nap for 4 of the outcome measures but no statistical evidence of sleep inertia following the other naps.

A Comparison of the 10- and 30-Minute Nap Conditions

The relative benefits following the 10- and 30-minute naps were compared with posthoc analyses. For all outcome measures, 2-way repeated-measures ANOVAs were performed with factors Nap Length (10-minute nap, 30-minute nap) and Time (e.g., prenap and 5, 35, 95, and 155 minutes after the nap). In the event of an overall significant interaction term, planned contrasts were undertaken to compare the simple interaction effect of changes in the 10- and 30-minute nap lengths, between prenap and each postnap testing period, with the criterion Bonferroni adjusted (p = .013). As indicated in Table 3, the 10-minute nap produced significantly greater benefits 5 minutes after napping than did the 30-minute nap for SDST and LCT performance, whereas changes in Subjective Alertness and RT approached significance. While all the other comparisons up until 155 minutes after the nap tended to favor the 10-minute nap, none of these interaction effects were statistically significant.

Nap Sleep Infrastructure

Table 4 summarizes information about the sleep infrastructure

Table 2—Two-way ANOVA and Planned Within-Subjects Contrasts for Condition (No-Nap vs 30-Minute) by Time for the Dependent Variables

	ANOVA		Planned Contrasts		
			Time		
			5-min post vs 35 min post	5-min post vs 95 min post	5-min post vs 155 min post
Variable	df	F		F	
Subjective Alertness	1.95, 44.83	5.54*	3.63	6.18[c]	13.94*
Fatigue	3, 69	2.87*	1.08	2.78	6.40[b]
Vigor	3, 69	2.16	-	-	-
SDST Performance	2.30, 52.84	5.17*	9.16*	7.05[a]	11.54*
LCT Performance	3, 69	2.97*	9.12*	2.46	2.73
RT Median	2.27, 52.24	0.78	-	-	-
RT LAPSES	1.57, 36.07	0.79	-	-	-

SDST refers to the Symbol Digit Substitution Task; LCT, Letter Cancellation Task; RT, reaction time. Analyses of variance (ANOVA): *p < .05 (Greenhouse-Geisser ε corrected). Simple contrasts: all degrees of freedom/ (df) = 1,23; *p < .013, [a]p = .014, [b]p= .019, [c]p = .021

Table 3—Two-Way ANOVA and Planned Within-Subjects Contrasts for Time (Prenap vs Postnap Time) by Condition (10-Min vs 30-Min) for the Dependent Variables

	ANOVA		Planned Contrasts			
			Time			
			Prenap vs 65 min post	Prenap vs 125 min post	Prenap vs 185 min post	
Variable	df	F	F			
Objective Alertness	3, 69	0.33	-	-	-	
			Prenap vs 5 min post	Prenap vs 35 min post	Prenap vs 95 min post	Prenap vs 155 min post
Variable	df	F	F			
Subjective Alertness	4, 92	2.76*	6.46[b]	2.76	0.27	0.00
Fatigue	2.75, 63.26	2.42	-	-	-	-
Vigor	2.50, 57.47	2.33	-	-	-	-
SDST Performance	4, 92	3.57*	8.17*	3.10	0.84	0.11
LCT Performance	4, 92	3.64*	8.20*	0.17	0.51	0.09
RT Median	4, 92	2.87*	6.56[a]	3.64	2.60	0.08
RT Lapses	4, 92	2.39	-	-	-	-

SDST refers to the Symbol Digit Substitution Task; LCT, Letter Cancellation Task; RT, reaction time. Analyses of variance (ANOVA): *p < .05 (Greenhouse-Geisser ε corrected). Simple contrasts: all degrees of freedom (df) = 1,23; *p < .013, [a]p = .017, [b]p = .018.

during the naps, as derived from Rechtschaffen and Kales' conventional sleep stage-scoring criteria.[24] Data from 1 participant were unavailable for analysis due to technical failure during recording. The total sleep time allocated for each nap length included the 3 epochs (1.5 minutes) of sleep criteria confirming the onset of sleep. Thus the no-nap condition, in fact, allowed 1.5 minutes of sleep. The Table 4 row labeled "delta onset" refers to the number of subjects who showed, during sleep free of movement artifact, at least 1 complete delta wave form that may or may not have met criteria for stage 3 or 4 sleep. Analysis of these sleep-infrastructure differences may provide a clue to the sleep processes underlying the benefits arising from the 10-minute nap.

The total amount of stages 2, 3, and 4 sleep and the number of participants achieving these stages increased with increasing nap length. Repeated 1-way ANOVAs showed that total stage 2 sleep was significantly greater between each consecutively longer nap condition (e.g., between 5 and 10, 10 and 20, etc., all p values < .001). Total time in stages 3 and 4 sleep also significantly increased between all nap conditions (all p values < .05). For example, compared with the 10-minute nap, the 20-minute and 30-minute naps had more than 6 and 12 times, respectively, the minutes of stages 3 and 4 sleep.

Increasing nap lengths resulted in increasing numbers of participants achieving the different stages of sleep. Significantly more participants initiated stage 2 sleep in each nap length than in the no-nap control (p < .05) but with no difference in frequency between the 4 nap lengths. The number of participants initiating delta-wave activity significantly increased between the no-nap, 5-minute nap, and 10-minute nap condition (p < .001), after which there was no further increase. The number achieving stage 3 sleep increased significantly from the 5-minute nap to the 10-minute nap, to the 20-minute nap (p < .001), after which there was no further increase at the 30-minute nap.

To focus on the infrastructure variable—the onset of delta activity—further analyses were conducted. Whereas the 10-minute nap, in which 20 participants had some delta activity, resulted in improvements in all measures, the 5-minute nap, in which only 12 participants had delta onset, resulted in improvements in only 1 measure. Two groups were formed on the basis of achieving (n = 12) or not achieving delta onset (n = 11) in the 5-minute nap. The

Table 4—Summary of Sleep Infrastructure for Each Nap Condition in 23 Subjects

	Nap condition				
	No-nap	**5-min**	**10-min**	**20-min**	**30-min**
Sleep stage	Minutes per sleep stage				
1	1.13 ± 0.48	0.63 ± 0.64	0.67 ± 0.49	0.63 ± 0.57	1.00 ± 1.16
2	0.37 ± 0.48	4.30 ± 0.75	8.37 ± 1.90	13.24 ± 5.15	17.43 ± 7.38
3	-	0.02 ± 0.10	0.91 ± 1.84	4.71 ± 4.25	8.09 ± 5.38
4	-	-	-	1.00 ± 1.95	3.28 ± 5.09
REM	-	-	-	-	-
	Number of participants reaching sleep stage 2 or 3 or delta onset				
2	10	23	22	23	23
Delta Onset	1	12	20	23	23
3	0	1	5	16	21

Data are presented as mean ± SD or number. Delta Onset refers to minimum of 1 complete delta-wave form, determined from raw electroencephalogram, which may or may not have met criteria for stage 3 or 4 sleep.

2 groups were then compared in posthoc exploratory analyses. The results for all 8 variables were in the predicted direction (i.e., subjects with delta onset in the 5-minute nap condition showed trends of greater benefit relative to those with no delta onset). Assuming each comparison would, by chance according to the null hypothesis, have a 0.5 probability of showing greater benefit for the 5-minute delta-onset condition, the 1-tailed probability that all 8 comparisons would show this difference in the predicted direction would be p = .004 according to the sign test.[26] In this sense, the obtained pattern of results is of a significantly greater benefit from the 5-minute nap if it achieved delta onset.

Discussion

The present investigation compared naps of 5, 10, 20, and 30 minutes of sleep with a no-nap control, with a view to determining the time course of nap effects and the most effective nap duration for improving alertness and performance following restricted nocturnal sleep. A comparison of the current findings with earlier empirical studies of similar protocols (i.e., afternoon naps following mild sleep restriction) will lead the discussion.

The present results showed a lengthening of the sleep latency at 65 minutes after the 10-, 20-, and 30-minute naps. The results replicate our previous findings, which showed improved objective alertness following 10-minute[4,5] and 30-minute naps[4] an hour after napping. In the present study at the second postnap assessment (i.e., 125 minutes after napping), the 20- and 30-minute naps continued to show significant improvements of sleep latency, whereas the 10-minute nap no longer showed a statistically significant benefit. At 185 minutes after napping, there were no significant improvements of sleep latency in any of the nap conditions compared with the no-nap control. The lack of significance at this time, particularly following the 20- and 30-minute naps, may be due, at least partly, to some truncation of the range of latency values by the 20-minute time limit on sleep-latency trials. In other words, if longer trials had been used (e.g., 30 minutes), we might have found a significant lengthening of sleep latency at 3 hours following the 20- and 30-minute naps.

With regard to subjective alertness (SSS), the 5- and 20-minute naps showed no significant benefits compared with the no-nap condition. On the other hand, the 10-minute nap showed significantly improved subjective alertness immediately after napping that was maintained for the following 2.5 hours. This finding conforms to previous research that has shown improved subjective alertness subsequent to naps of comparable duration.[2-6] The 30-minute nap resulted in a period of reduced subjective alertness immediately after napping, followed by improved subjective alertness 95 and 155 minutes after napping relative to the no-nap condition. That is consistent with Tietzel and Lack,[4] who found significant subjective-alertness benefits emerging 65 minutes after a 30-minute nap.

Changes in Fatigue and Vigor were comparable to those changes in subjective alertness. Significantly improved Fatigue and Vigor were demonstrated across all postnap testing occasions following the 10-minute nap, whereas a significantly improved Fatigue was also found 95 minutes after the 20-minute nap. The 30-minute nap showed evidence of a period of sleep inertia followed by a marginally significant improvement in Fatigue 155 minutes after napping. No other significant changes in Fatigue or Vigor were observed. Tietzel and Lack[4] observed similar patterns of change in the hour of postnap testing following 10- and 30-minute naps.

The 5-minute nap showed significantly improved LCT performance 35 and 95 minutes after napping but no improvements on the other performance variables. In contrast, following the 10-minute nap, all performance measures evidenced similar patterns of improvement that were statistically significant 5 (LCT and RT lapses), 35, 95 (SDST, LCT and RT), and 155 (SDST) minutes after napping. These findings are consistent with (1) Tietzel and Lack,[4] who also observed significantly improved SDST and LCT performance in test sessions beginning 5 and 35 minutes after napping; (2) Tietzel and Lack[5] and Hayashi et al,[6] who also found significantly improved SDST performance 35 minutes after 10-minute naps; (3) Horne and Reyner,[2] who found improved performance on a 1-hour simulated driving task beginning 5 minutes after a 15-minute nap opportunity (mean = 10.8 minutes); and (4) Takahashi and Arito,[3] who observed improved logical reasoning performance 30 minutes after a brief nap (mean duration 10.2 minutes).

The 20-minute nap produced significant improvements in cognitive performance emerging 35 (SDST and RT lapses) and 95 (LCT) minutes after napping. Gillberg et al[1] also found significant performance benefits in their first test period beginning 30 minutes after a nap of similar mean duration. The 30-minute nap indicated a period of sleep inertia immediately after napping, with no improvements in the first postnap test session. However, 35 minutes after the 30-minute nap, LCT performance was improved; 95 minutes after napping, subjective alertness and SDST performance were improved; and 155 minutes after the nap, subjective alertness, fatigue, and SDST were improved. Tietzel and Lack[4]

also observed sleep-inertia effects in their cognitive-performance measures immediately following a 30-minute nap, with evidence of a recovery in SDST and LCT performance 35 minutes after napping. In summary, the effects found in the present study are consistent with those found in past studies for which there were similar nap lengths and postnap testing intervals.

GENERAL DISCUSSION

We now turn to the first general aim of the study, specifically, the 3-hour time course of effects following different length naps. The 5-minute nap showed a general trend of improvement resembling the 10-minute condition for at least an hour after napping, although, generally, benefits associated with the 5-minute nap did not reach statistical significance. The 10-minute nap produced a pronounced increase in alertness and performance immediately after napping (approximately twice that of the 5-minute nap for the first hour) that, for most outcome measures, was maintained for the duration of postnap testing. However, some of these effects diminished by the end of the 3-hour testing period.

The 20-minute nap produced instances of significantly improved alertness and performance across postnap testing but not until at least 35 minutes following the nap. Finally, the 30-minute nap produced several improvements of alertness and performance but, again, not until at least 35 minutes after the nap. This suggested an immediate period of sleep inertia following the nap, perhaps resulting from the greater amount of total sleep or greater amount of deeper stages 3 and 4 sleep in the 30-minute nap. Following this sleep-inertia effect, there was an overall increase in alertness and performance after 3 hours, to about the same extent as that of the 10-minute nap.

It appears that the 10-minute nap generally produces greater benefits than the other naps over the 3-hour period following the naps. We restricted the postnap testing period to 3 hours following the naps because, for practical purposes, the nap timing was aimed to occur around the period of the "postlunch dip" and the nap effects would then be tested through to the completion of the typical workday. Although the 30-minute nap still showed significant alertness benefits 3 hours after the nap for 3 of the 8 measures, it was no greater than that following the 10-minute nap. Nevertheless, it is still possible that a period of postnap testing longer than 3 hours may have found greater sustained benefit from the longer nap on some of these measures. However, on the grounds of both brevity of implementation and total benefit over a 3-hour testing period, the 10-minute nap should be recommended for improving afternoon alertness and performance following restricted nocturnal sleep.

The possible detrimental impact of the naps on subsequent nocturnal sleep was not assessed in this study. However, one indicator of impact would be a lengthened sleep latency. This occurred 1 hour after the 10-, 20-, and 30-minute naps, as well as 2 hours after the 20- and 30-minute naps. By 3 hours after the nap (apart from the possible caveat due to truncated range of data) sleep latency was no longer lengthened significantly above the no-nap control condition for any of the nap lengths used in this study. Therefore, none of these brief nap lengths (5-30 minutes) following prior nocturnal sleep restriction would be expected to have an impact on subsequent nocturnal latency to sleep onset in the order of 7 to 8 hours after the brief nap. Nevertheless, future studies should assess the effects on subsequent nocturnal sleep of these relatively brief naps. as well as of longer naps, in order to evaluate the total costs and benefits of daytime napping.

Considering the differential pattern of results for each of the nap lengths, it is plausible to infer that the effectiveness of a nap reflects 2 opposing processes—1 beneficial and another adverse. One adverse effect of napping, particularly seen in the 30-minute condition in this experiment, is relatively short term and, considering the nap sleep-infrastructure data presented, is most appropriately explained by sleep inertia resulting from the 30-minute nap containing more total sleep or stages 3 and 4 sleep.[15-19]

A convergence of evidence supports the finding of sleep inertia following the 30-minute nap. Firstly, the 30-minute nap did not produce any significant benefits relative to no nap, in the first postnap test period. Secondly, for at least 4 of the outcome measures, there were significant improvements following this first postnap test period. Finally, if one assumes that the 10-minute nap is free of sleep inertia and that an alerting process benefits the 30-minute nap to the same extent as the 10-minute nap, then the difference between the 10-minute nap and the 30-minute nap would reflect the extent of sleep inertia associated with the longer nap and its dissipation over postnap testing. One could, therefore, assume that the sleep-inertia effects associated with the 30-minute nap are strongest immediately following the nap and dissipate within 35 minutes (for most measures). This is consistent with a general review of sleep-inertia effects.[15] While the 20-minute nap produced no significant benefits in the first test period, suggesting some immediate sleep inertia, it was less robust than that following the 30-minute nap.

The pattern of significant improvements in alertness and performance arising from these brief naps, particularly the 10-minute nap, suggests some sleep process contributing to these benefits. Our earlier study had found no benefit from naps consisting of only 30 seconds or 90 seconds of stage 1 sleep, which ruled out the simple act of stage 1 sleep onset as the beneficial process in napping.[5] Hayashi et al[6] recently found that up to 5 minutes of stage 1 sleep is of limited benefit but that an additional 3 minutes of stage 2 sleep generally had recuperative benefits. Their analysis also discounted the onset of stage 2 (first sleep spindle) as a contributor to the benefits. Therefore, they suggested that 3 minutes of stage 2 sleep is the important contributor. However, all participants in the present 5-minute nap study reached stage 2 sleep and obtained an average of 4.3 minutes of stage 2 sleep but with few beneficial effects on alertness. Therefore, considering both the recent Hayashi et al[6] study and the present study, it appears that neither the initiation of stage 2 sleep nor obtaining 3 to 4 minutes of stage 2 is a strong contributor to napping benefits.

On the other hand, since the 10-minute nap (with 8.4 minutes stage 2 sleep) showed benefits to all 8 outcome measures in the present study and the Hayashi et al[6] beneficial stage 2 sleep condition contained 9.1 minutes of total sleep (3 minutes of stage 2 sleep), the napping benefits may arise from obtaining in the range of 3 to 8 minutes of stage 2 sleep or at least 9 to 10 minutes sleep of any stage. This would be consistent with a number of other brief (7- to 15-minute) nap studies. However, in the present study with a sleep infrastructure analysis of 4 different nap lengths, we were able to consider other possible contributors to napping benefits. Since the 20- and 30-minute naps had more total sleep, stage 2 sleep, and stage 3/4 sleep, yet had no greater benefits than the 10-minute nap, even after the probable dissipation of sleep inertia, it seems unlikely that more of these aspects of sleep beyond

10 minutes contribute to the napping benefits.

While there may be other differences between the nap conditions that were not measured in the present study, another possible contributor arising from the infrastructure analysis is the onset or first appearance of delta-wave activity. Table 4 shows an increase in the number of participants achieving delta onset from the control condition to the 5-minute nap to the 10-minute nap with no further increase for the 20- and 30-minute naps. Furthermore, posthoc exploratory analyses of the 5-minute nap showing greater benefits to those participants who had some delta onset lend support to this possibility. However, beyond initiating delta activity (10-minute nap mean amount of stage 3/4 sleep = 0.91 minutes) the accumulation of more stage 3/4 sleep in the longer 20- and 30-minute naps provided no further benefit. Compared with the 10-minute nap, the 20- and 30-minute naps comprised over 6 and 12 times more stage 3/4 sleep, respectively, and 2 and 3 times more total sleep, respectively. Therefore, the results of the present study suggest the onset of some delta-wave activity as a relatively important contributor to the alertness and performance benefits accruing from brief naps.

Overall, the 10-minute nap was the most effective afternoon nap duration (of those investigated) for improving alertness and performance following mild nocturnal sleep restriction. Furthermore, it is proposed that the beneficial effects of napping in the conditions of this experiment may be due to the onset of delta-wave activity or the accumulation of a fixed, relatively brief, duration of stage 2 sleep or total sleep. Further research may determine more precisely the physiologic concomitant of the sleep process producing the alertness and performance benefits following brief naps.

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