

CIRCADIAN CYCLES AND RESTORATIVE POWER OF NAPS

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8 am (50 hours of sleep loss) --- Thought it was all over until about 3:30 when we finally got a sing-along, a Sorry game, and finally a bridge game going. Tiredness is definitely here and we'll have to evolve methods to deal with it. It seems to come in waves. --- One effect all of us have noticed is a tendency to forget names. Just now, I had the damndest time remembering Hav's name. After five days we should know each other's name at least.

From the diary of a subject in a 205-hour sleep deprivation study conducted at UCLA in 1966.

Sleep-deprived men and women show deterioration in mood and behavioral efficiency. A nap is viewed by many as having recuperative power, reducing fatigue and sleepiness. Taub and Berger (1973) have reported, however, that if a subject does not habitually nap, the initial effects of a nap would be detrimental to mood and task performance. For accustomed nappers, afternoon napping improved subjects' performance and mood within a 1.5- to 2-hour time period after awakening from the nap (Taub, 1979; Taub et al., 1976, 1977). Taub et al. also observed that accustomed naps early in the morning (0935-1135) and late at night (2135-2335) were "to some extent (but not completely)" equally beneficial as the afternoon nap (1500-1700). They found that the recuperative power of habitual napping was observed in more rapid psychomotor performance, improved short-term memory, reduced sleepiness, and more positive affective states.

Lubin et al. (1976) and Hartley (1975) reported that naps were usually beneficial in maintaining task performances and mood in laboratory studies. In a field study, Opstad et al. (1978) noted that naps, cumulating to a total of 3-6 hours in the middle of 92-120 hours of continuous combat training, significantly reduced the profound loss in behavioral efficiency of the cadets. Haslam (this volume) similarly noticed the recuperative power of small amounts of sleep in maintaining job performance.

Although naps may help in maintaining performance over long periods, the immediate performance upon awakening from a nap may show no improvement and often may be lower than pre-nap levels. Since Langdon and Hartman (1961) reported on loss of performance efficiency after sudden awakening from nocturnal sleep, "sleep inertia" has been extensively studied. Sleep inertia has been observed in simple, as well as complex, reaction time tasks (Goodenough et al., 1965; Wilkinson & Stretton, 1971), grip strength (Jeanneret & Webb, 1963), short-term memory (Stones, 1977; Åkerstedt & Gillberg, this volume), and in complex visual and cognitive tasks (Seminara & Shavelson, 1969; Scott & Snyder, 1968; Pritchett, 1964). Sleep inertia is usually short-lasting, and is quickly followed by the recuperative phase of a nap. Sleep inertia has been estimated to last about 15 minutes after awakening (Wilkinson & Stretton, 1971). Webb and Agnew (1974) observed that sleep inertia disappeared in 1-5 minutes

after awakening from an afternoon nap. But it is quite possible that a nap taken after a prolonged period of wakefulness would cause a more severe and longer period of sleep inertia, making the nap disadvantageous for behavioral efficiency.

The primary purpose of this study was to determine the recuperative power of a 2-hour nap after either 45 hours (Phase 1 of this study) or 53 hours (Phase 2) of a vigil. The recuperative power was simply defined as those beneficial effects that restore human behavioral efficiency and subjective feelings of vigor and arousal. This study also attempted to answer whether the recuperative power of a nap would depend on the time of day it was taken. If sleep inertia reflects difficulty in becoming fully awake and mobilizing mental and physical energy, then it might be anticipated that basic circadian mechanisms controlling the level of arousal would be closely involved in determining the severity and duration of sleep inertia. This would, in turn, limit the beneficial effects of the nap. To evaluate the potential circadian effect on the recuperative power of a nap, naps were taken at the early morning hours of 0400-0600 and at the midday hours of 1200-1400. The early morning nap corresponded to the nadir of many human circadian rhythms, and the midday nap occurred at the slowly rising pre-peak circadian phase. Circadian rhythms in mood, fatigue, sleepiness, and task performances were carefully analyzed both during the baseline and vigil phases to establish their phase relations to the naps.

Methods and Materials

Experimental Design. Fifteen sailors (average age 21.5 years old, ranging from 18-30) were in Group 1 and participated in Phase 1. Eight sailors (average age 18.6 years old, ranging from 18-21) were in Group 2 and completed Phase 2 (Figures 1 & 2). The experiment required all subjects to live, two at a time, in a sleep laboratory for 6 consecutive days.

Phase 1. The period of continuous work was 45 hours for this group. The continuous work started on awakening at 0700 on Tuesday (Day 2) and continued until 0400 on Thursday (Day 4), representing 2 days and 2 nights of sustained wakefulness. Then the subjects were allowed to nap for 2 hours, from 0400 to 0600, on Thursday. The selection of a 2-hour nap was based primarily on the previous studies of Wilkinson (1970), Hamilton et al. (1972), Johnson and Naitoh (1974), Hartley (1974), Friedmann et al. (1977), Opstad et al. (1978), and Haslam (this volume); all had suggested that a 2-hour nap would be the minimal sleep duration to expect some recuperation. Time of the early morning nap was set to coincide with the troughs of circadian rhythms for most physiological and psychological variables. The recuperative power of this early morning nap was evaluated every 2 hours from the time of subjects' awakening until noon, 6 hours after being awakened. From 1200-1400, the subjects took their second 2-hour nap. After the second nap, the subjects were asked to resume their tasks for an additional period of 10 hours until bedtime at midnight. On Friday (Day 5), the subjects continued to work on their tasks until 1600, the end of this study. Polygraphic records for sleep-staging (Rechtschaffen & Kales, 1968) were obtained on baseline nights, naps, and on the recovery night (see Figures 1 & 2).

**ACTIVITY SCHEDULE FOR FRAGMENTED SLEEP STUDY
PHASE 1**

	Baseline Monday	Baseline Tuesday	Vigil Wednesday	Fragmented Sleep Thursday	Recovery Friday		
0000	Sleep	Sleep			Sleep		
0030							
0100							
0130							
0200						Bio-17	Bio-29
0230						Chore 5	Chore 9
0300						Bio-18	Bio-30
0330							
0400							Sleep ₁
0430							
0500							
0530							
0600			Bio-19	Bio-31			
0630							
0700			Chore 6	Chore 10			
0730							
0800		Bio-8	Bio-20	Bio-32	Bio-41		
0830	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast		
0900	Orientation	Watch 2a	Watch 4a	Watch 6a	Watch 8a		
0930							
1000		Bio-9	Bio-21	Bio-33	Bio-42		
1030							
1100				Bio-34			
1130	Bio-1	Bio-10	Bio-22	Lunch	Bio-43		
1200	Subject pick-up and orientation	Lunch Aud. Vig. Tng.	Lunch	Lunch	Lunch		
1230							
1300				Sleep ₂			
1330							
1400	Dema. ques. FRT and MAST trg	Bio-2	Bio-11	Bio-23	Bio-35	Bio-44	
1430							
1500	Chore 1	Chore 3	Chore 7	Chore 11	Chore 13		
1530	Bio-3	Bio-12	Bio-24	Bio-36	Bio-45		
1600							
1630	Dinner	Dinner	Dinner	Dinner	Debriefing Return to base		
1700							
1730	Bio-4	Bio-13	Bio-25	Bio-37			
1800							
1830	Chore 2	Chore 4	Chore 8	Chore 12			
1900	Bio-5	Bio-14	Bio-26	Bio-38			
1930							
2000	Watch 1a	Watch 3a	Watch 5a	Watch 7a			
2030							
2100							
2130	Bio-6	Bio-15	Bio-27	Bio-39			
2200							
2230							
2300	Bio-7	Bio-16	Bio-28	Bio-40			
2330							

Figure 1. Experimental schedule for Group 1. Shaded areas show sleep (including two 2-hour naps) periods.

**FRAGMENTED SLEEP ACTIVITY SCHEDULE
PHASE 2**

	Sunday	Baseline Monday	Baseline Tuesday	Vigil Wednesday	Fragmented Sleep Thursday	Recovery Friday	
0000							
0030							
0100							
0130							
0200		Sleep	Sleep	Bio-17	Bio-20	Sleep	
0230					Chore 5		Chore 9
0300					Bio-18		Bio-30
0330							
0400							
0430							
0500					Bio-18A		Bio-30A
0530							
0600					Bio-19		Bio-31
0630							
0700			Chore 6	Chore 10			
0730							
0800			Bio-8	Bio-20	Bio-41		
0830		Breakfast	Breakfast	Breakfast	Breakfast		
0900		Orientation	Watch 2a	Watch 4a	Watch 6a	Watch 8a	
0930			Bio-9	Bio-21	Bio-33	Bio-42	
1000							
1030							
1100					Bio-34		
1130		Bio-1	Bio-10	Bio-22	Lunch	Bio-43	
1200	Subject pick-up and orientation Demo. ques. FRT and MAST tng	Lunch Aud. Vig. Tng.	Lunch	Lunch	Sleep_{F2}	Lunch	
1230							
1300							
1330			Bio-2	Bio-11	Bio-23	Bio-35	Bio-44
1400			Chore 1	Chore 3	Chore 7	Chore 11	Chore 13
1430		Bio-3	Bio-12	Bio-24	Bio-36	Bio-45	
1500							
1530							
1600							
1630	Dinner	Dinner	Dinner	Dinner	Dinner	Debriefing Return to base	
1700							
1730			Bio-4	Bio-13	Bio-25		Bio-37
1800			Chore 2	Chore 4	Chore 8		Chore 12
1830			Bio-5	Bio-14	Bio-26		Bio-38
1900							
1930			Watch 1a	Watch 3a	Watch 5a		Watch 7a
2000							
2030							
2100			Bio-6	Bio-15	Bio-27		Bio-39
2130							
2200							
2230							
2300		Bio-7	Bio-16	Bio-28	Bio-40		
2330							

Figure 2. Experimental schedule for Group 2. Shaded areas show sleep (including one 2-hour nap) periods.

Phase 2. In Phase 2, the early morning nap was omitted and the 8 subjects continued to work for 53 hours until time for the midday nap. This group, thus, provided control data to establish whether the early morning nap improved mood and behavioral efficiency when compared with subjects who remained sleepless. Group 2 was allowed to nap from 1200-1400 after 53 hours of continuous work (in contrast to 45 hours of continuous work for Group 1). The dependent variables observed during the post-midday nap period in Group 2 were compared with those in the post-early morning nap period for Group 1, to reveal any differences in recuperative power between the early morning and midday naps. These comparisons gave only a rough estimation of the recuperative power of the early morning nap in reference to the midday nap because Group 2 experienced 8 hours of additional wakefulness. Similarly, performance and mood following the two 2-hour naps in Group 1 could be compared to performance and mood after the single midday nap of Group 2. If there were no differences in the recuperative power between the two 2-hour naps and the one midday nap, then the 2-hour early morning nap could be considered not to have contributed significantly to the recuperative power. Except for the difference in nap schedules, the subjects in Group 2 were treated in much the same way as those in Group 1. No polygraphic sleep records were obtained from this group.

Description of Tests. During Sunday and Monday, all subjects were trained to obtain oral temperature, pulse rate and some performance measures, and how to complete adjective checklists. Also, during these two days, they received extensive training on psychological tasks so that they would be performing these tasks near the asymptotic level before the start of Tuesday (Day 2), the second baseline day.

Three kinds of task sessions were used: (1) 45 bio-sessions; (2) 13 chore-sessions, and (3) 8 watch-sessions. For Group 1, the bio-sessions were repeated every 2 hours during the day on Monday, Tuesday, and Friday, and every 2 hours, both day and night, on Wednesday and Thursday. Group 2 had the same bio-sessions as Group 1, except a four-choice serial reaction time task was added. The tasks used in the bio-, chore-, and watch-sessions are listed in Table 1. Table 1 shows the tasks in the exact sequence presented to the subjects.

Sleep Logs were modeled after the one developed by Hartman and Cantrell (1976). The subjects completed it upon awakening from the major sleep period. Sleep Logs questioned not only sleep duration, but also trouble going to sleep, how well-rested they felt following sleep, and need for more sleep.

Oral temperature was measured by an electronic digital thermometer. Three readings were obtained at each bio-session. Pulse rate was measured by a photo-electrical device which detected pulsations of the middle finger. Blood pressure was measured with an automatic device which sensed Korotokoff sounds. A Jamar dynamometer was used to measure the grip-strength of the dominant hand. Spiral aftereffect was measured by asking the subjects to look at a rotating disk with an Archimedes type spiral. The details of grip-strength and spiral aftereffect will not be discussed in this paper.

The Memory and Search Test (MAST), designed by Folkard et al. (1976), consisted of searching line after line, through lines of 20 letters, for the lines containing letters of a specified target. The target letters (2, 4, or

Table 1

List of Tasks Used in This Study

<u>Tasks to be Performed</u>	<u>Approximate Time to Complete*</u>
<u>45 Bio-Sessions/Two Hourly</u>	
1. Sleep Logs ^{1†}	30 sec.
2. Oral Temperature	30 sec./reading:Three readings
3. Pulse rate	30 sec. - 1 min.
4. Blood pressure	1 - 2 min.
5. Grip strength [†]	30 sec.
6. Spiral Aftereffect Test [†]	5 min. (Timed) ²
7. Memory and Search Task (MAST)	2 min./test:6 min. total (Timed)
8. NIRC Mood Scale	1 - 2 min.
9. Stanford Sleepiness Scale (SSS)	1 min.
10. SAM Subjective Fatigue Checklist	1 - 2 min.
11. Thayer's AD-ACL	2 min.
12. Humphries Response Alternation	6 min. (Timed)
13. Fitt's Reciprocal Tapping	1 min. (Timed)
14. Four-Choice Serial Reaction Time	6 min. (Timed) ³
<u>13 Chore Sessions/4 - 8 Hourly</u>	
1. Four-Choice Serial Reaction Time	16 min. (Timed)
2. Short-Term Memory	3 min./Timed Recall:10 min. total
3. Miller's Reading (Reading)	10 min. (Timed)
Miller's Reading (Examination)	Approximately 5 min.
4. Wisher Eye Movements Task ^{4†}	Approximately 30 min.
<u>8 Watch Sessions/12 Hourly</u>	
1. Wilkinson's Auditory Vigilance test	50 min.

* For single subject. † Results were discussed elsewhere. 1. Recorded only after awakening from major sleep periods. 2. The task was timed by experimenter. 3. Only for Group 2. 4. Only for Group 1.

6 letters) were listed at the top of each test sheet. The subjects were asked to place a check mark along the line containing the target letters, and an X mark for the remainder. Each test with 2, 4, or 6 target letters was timed to last for 2 minutes. The score was the total number of lines scanned in 2 minutes (which included both correctly and incorrectly evaluated lines). Only the results of the MAST with 2 target letters are reported in this paper because the MAST task with 4 or 6 letters yielded similar results.

The NHRC Mood Scale (also known as the NPRU Mood Scale), developed by Moses et al. (1974), has been reported in some detail by Johnson and Naitoh (1974). Recently, the NHRC Mood Scale was used successfully by Opstad et al. (1978). The scale has two scores: positive and negative moods. Previously, sleep loss was found to increase the negative score and to decrease the positive score.

The Stanford Sleepiness Scale (SSS) was developed by Hoddes et al. (1973) to obtain self-ratings on a 7-point scale of feeling drowsy. The larger the score, the greater the extent of subjectively rated sleepiness.

The School of Aerospace Medicine (SAM) subjective fatigue checklist, developed by Pearson and Byars (1956), has been used extensively to evaluate subjective ratings of fatigue in air crews (e.g., Harris et al., 1971) and in crews working under an atypical demanding work-rest schedule (Storm & Gray, 1978). The scale consisted of ten statements. The score of this scale ranged from 0-20 points, where the lower scores indicated greater subjective feelings of fatigue.

On Thayer's Activation-Deactivation Adjective Check List (AD-ACL) (Thayer, 1967, 1978), subjects described their feelings at the moment by checking off each of 48 adjectives or statements, such as "carefree" and "engaged-in-thought", by selecting one of the four alternatives. The AD-ACL yielded a General Activation score based on the subjects' checking affirmatively on "peppy", "energetic", "vigorous", "lively", "activated", "full-of-pep", and "active".

Humphries' Task of Response Alternation Performance (TRAP) is described by Humphries and Naitoh (in preparation), and was used in a gradual sleep reduction study by Friedmann et al. (1977). This task requires the subjects to press one of two response buttons alternately and repeatedly at a pace set by the subjects. If the inter-tapping interval exceeded 2.5 seconds (i.e., a "lapse" in attention), a buzzing noise was given to the subjects through headphones. The subjects performed this task with their eyes closed. The tapings were recorded on cassette tapes for later analysis. Two response measures were obtained: (1) TRAP 1, the total number of button tapings in 5 minutes, and (2) TRAP2, the 10 percentile of the longest inter-tapping intervals.

Fitts' reciprocal tapping task (Fitts, 1954; Fitts & Peterson, 1964) was modified by Graeber et al. (1977) to be a paper-and-pencil self-administered test. Each subject had a tapping sheet on which was a parallel series of 12 circles separated by 8.75 cm. The subjects were to mark, with a pencil, inside each target circle from left to right down the sheet. Accuracy rather than speed was stressed, but the subjects were to complete this task as rapid-

ly as possible. Any marks outside the circles or any marks extending outside a circle were counted as errors. The subjects used a stopwatch to measure time needed to complete tapping these 12 circles. An "efficiency" of tapping score was defined as the ratio of the total number of successful tappings divided by the number of seconds required to complete the task. A smaller ratio reflected less efficiency in tapping.

The Wilkinson four-choice reaction time task (Wilkinson & Houghton, 1975) consisted of a modified cassette recorder which had a display of four lights arranged in a square. Below this display were four similarly arranged push-buttons. The task required the subjects to press the button corresponding geometrically to the illuminated light. All button-presses were recorded on cassette tapes for later analysis. The task performance was evaluated by two measures: (1) number of both correct and incorrect responses, and (2) 10 percentile of the slowest inter-response intervals.

The short-term memory test (Williams et al., 1966) consisted of 15 tape-recorded words. In performing this task, each word was first pronounced, spelled, and pronounced again. This was followed by 10 seconds of silence during which the subjects wrote the word down. After the list was completed, the subjects had 3 minutes to recall as many words as possible, in any order, and write them down on a recall sheet. Three such lists were used in the chore-session. A misspelled word, if legible, was counted as a correct recall. The score was the percentage of the words correctly recalled.

Details of the Miller Reading Efficiency test and Wisher's eye movement task will be discussed elsewhere.

During the Wilkinson's auditory vigilance task (Wilkinson, 1970), the subject was in bed in a soundproof room and listened to a 600 Hz tone pulse coming from a loudspeaker. This 600 Hz tone lasted for 500 msec and recurred every 2 seconds on a background of white noise. Forty of these tones, occurring randomly ten times in every 15 minutes of the vigilance test, were of slightly shorter duration, 360 msec. The subjects' task was to detect these shorter tones and report them by pressing a button as quickly as possible. Then the subjects were to indicate how confident they were that the tone was indeed a signal by pressing one of three buttons. Background noise was set at about 85 dB. Two measures were used: (1) percent correct signal detection, and (2) average reaction time of all responses.

Results

Statistical Analysis of Data

Statistical analyses were divided into two major parts: (1) quantitative analysis for circadian rhythms for the baseline and vigil data, and (2) statistical evaluation of the recuperative power of the naps.

Circadian analysis. The group mean cosinor analysis, as described by Halberg et al. (1967), was used by programming a PDP-12 computer first to fit a 24-hour/cycle cosinusoidal wave to the data one subject after another, and then to calculate and plot a 95% confidence ellipse for each dependent variable. In fitting a 24-hour/cycle cosinusoidal wave to the data, the "monosin-

usoidal method" by Naitoh et al. (in press) was employed. In the analysis, 11 data points (starting from the 8th bio-session) were grouped together to provide the baseline, and analyzed by the group mean cosinor method. This "baseline" period included 0800 Tuesday to 0400 Wednesday, corresponding to 21 hours of continuous wakefulness. Thus, this baseline was slightly contaminated by data points which could also belong to the vigil time period, i.e., the data obtained at 0200 and 0400 Wednesday. Another 11 data points from the 20th bio-session to the 30th bio-session were analyzed by the group mean cosinor method to represent the time period of sleep loss or vigil. This vigil period was from 0800 Wednesday to 0400 Thursday. Beginning at 0800 Tuesday, there were 45 hours of continuous wakefulness before the 0400 Thursday nap.

To determine if the vigil caused the acrophase angle (or Time-of-Peak, TOP) of the dependent variable to shift from the normally expected time, the Rayleigh test, as described by Batschelet (1965), was used.

Bio-sessions. Only a portion of data from the 45 bio-sessions was used. First, the average of bio-sessions 8 through 16 (0800 Tuesday to 2400 Tuesday) was calculated for each subject and used to represent his baseline score. Another average for bio-sessions 20 through 28 (0800 Wednesday to 2400 Wednesday) was calculated to represent the "vigil" score for each subject. The value observed in bio-session 31 (which occurred after the first nap for Group 1) was used to represent the effects of Nap 1, or a continuous vigil of 47 hours for Group 2. Bio-sessions 32 through 34 were averaged to represent either the period of partial recovery in Group 1 or the continuing vigil in Group 2. Then bio-session 35 was used to represent either the effect of Nap 1 plus Nap 2 for Group 1, or the effect of the first nap for Group 2. Finally, an average of bio-sessions 36 through 40 was used to represent the period of partial recovery for Group 1 and Group 2. Thus, the data obtained in the bio-sessions were grouped into six discrete conditions: C1, the baseline for both groups; C2, the vigil for both groups; C3, Nap 1 for Group 1 and continuing vigil for Group 2; C4, partial recovery for Group 1 and continuing vigil for Group 2; C5, Nap 2 for Group 1 and the single nap for Group 2; and C6, the second partial recovery period for Group 1 and partial recovery for Group 2. Table 2 shows the bio-sessions partitioned into the six conditioned.

Oral temperature can be used to illustrate how the group mean scores were obtained for the six conditions. Oral temperature readings during bio-sessions 8-16 were averaged for each subject, and then the mean of these averages over subjects was computed to get the mean oral temperature for each group for each condition, e.g., $98.06\text{ F} + 0.35\text{ F}$ was the mean baseline oral temperature for Group 1. Similarly, the average for Group 2 for the baseline was 97.84 F (see Table 2).

In the statistical evaluation, only 11 of the 15 subjects in Group 1 had complete data for all of the dependent variables. Thus, the statistical evaluation was based on 11 subjects in Group 1 and 8 subjects in Group 2.

As seen in Table 2, each variable could be subjected to a two-way ANOVA for the "two factor experiment with repeated measures on one factor (Winer, 1971). The two factors were groups and conditions, and the conditions factor was measured repeatedly. In this study, however, the exact multivariate solution for the two-sample multivariate profile analysis of Timm (1975) was

Table 2

Summary of Results of Physiological and Performance Measures and Subjective Ratings

Dependent Measures	Group 1	C1	C2	C3	C4	C5	C6
	Group 2	Baseline Baseline	Vigil Vigil	Nap 1 Vigil	PR 1 Vigil	Nap 2 Nap	PR 2 PR 1
		Bio 8-16	Bio 20-28	Bio 31	Bio 32-34	Bio 35	Bio 36-40
Oral Temperature (F ⁰)							
Group 1		98.06(0.35)	97.86(0.36)	96.69(0.59)*	97.41(0.56)*	97.48(0.71)	98.11(0.36)
Group 2		97.84(0.37)	97.58(0.52)	97.11(0.46)*	97.05(0.55)*	97.39(0.43)	97.64(0.63)
Pulse (BPM)							
Group 1		63.0 (5.9)	66.0 (6.3)	64.2 (10.4)	65.1 (5.0)	67.0 (9.2)	68.3 (3.9)
Group 2		67.3 (5.3)	66.2 (5.8)	59.8 (6.4)	68.8 (6.9)	65.8 (6.5)	66.4 (9.1)
Blood Pressure (mmHg)							
Systolic: Group 1		121.6 (8.8)	122.8 (8.2)	116.3 (8.1)	127.7(11.8)	128.5(12.2)*	114.4 (4.5)
Systolic: Group 2		119.4 (6.2)	118.9 (4.6)	112.5 (8.2)	129.7(9.1)	128.3(11.3)*	110.4 (15.2)
Diastolic: Group 1		69.9 (8.1)	70.5 (5.5)	75.9(10.2)	71.9(7.9)	72.5(9.4)	67.1 (10.3)
Diastolic: Group 2		70.3 (5.6)	69.5 (5.3)	72.8(8.9)	72.7(3.9)	77.0(8.2)	68.1 (7.9)
MAST (2 letters)							
# Lines : Group 1		62.5(18.1)	59.8(16.3)	33.7(8.1)*	59.3(17.7)	54.8(21.6)*	65.4 (6.6)
# Lines : Group 2		51.5(9.5)	45.0(8.3)	32.8(9.3)*	45.6(11.8)	51.8(13.3)*	43.9 (8.8)
TRAP							
# Response: Group 1		1044(273)	1024(288)	783(285)	972(272)	929(310)	1116(276)
# Response: Group 2		1046(210)	1036(189)	854(293)	953(209)	781(260)	1092(149)
10%ile slow: Group 1		497(160)	768(454)	1510(991)*	1055(533)*	844(658)	542(278)
10%ile slow: Group 2		445(83)	754(266)	1292(931)*	1221(687)*	1761(1067)	764(350)
Fitts Reciprocal							
Tappings							
Efficiency: Group 1		1.02(0.41)	0.99(0.42)	0.72(0.44)*	0.93(0.46)	0.93(0.47)	0.98(0.44)
Efficiency: Group 2		1.11(0.21)	1.12(0.27)	1.02(0.33)*	1.11(0.25)	0.90(0.33)	1.14(0.26)
SAM Fatigue Checklist							
Group 1		15.3(1.9)	11.6(3.1)	6.9(4.5)*	8.9(3.6)*	10.2(3.1)*	10.7(2.8)*
Group 2		12.4(1.0)	9.8(1.6)	8.0(3.7)*	9.5(3.4)*	7.9(3.2)*	8.6(3.0)*
SSS							
Group 1		1.99(0.52)	2.74(0.81)*	4.18(1.32)*	3.09(1.01)	3.09(0.94)*	2.64(0.64)
Group 2		2.07(0.59)	2.86(0.63)*	4.38(1.06)*	3.75(1.32)	3.88(0.99)*	3.08(1.21)
MRC Positive							
Group 1		33.4(7.4)	30.8(9.3)	17.0(7.8)*	25.6(9.5)	25.7(8.6)*	28.1(7.6)
Group 2		32.8(5.8)	28.9(7.7)	19.4(10.1)*	27.6(9.0)	22.0(9.9)*	26.3(10.0)
MRC Negative							
Group 1		2.6(3.8)	5.4(4.8)*	9.4(6.2)*	7.9(6.5)	7.8(5.9)	5.4(5.1)
Group 2		2.7(1.9)	5.0(3.2)*	8.9(5.1)*	8.5(7.3)	8.6(7.6)	9.3(8.0)
Thayer's AD-ACL							
GA+: Group 1		2.54(0.47)	2.33(0.60)	1.74(0.82)*	2.11(0.51)*	2.13(0.47)*	2.26(0.61)*
GA-: Group 2		2.53(0.52)	1.88(0.56)	1.79(0.70)*	1.97(0.64)*	1.93(0.64)*	1.84(0.58)*

* = Average of two groups is significantly different from the baseline (average of Bio-sessions 8 - 16).

Nap 1 = The first nap for Group 1. Nap 2 = The second nap for Group 1. Nap = Only nap allowed for Group 2.

For definitions of some dependent measures, see the text. + = General Activation.

used instead of a univariate ANOVA. To supplement the multivariate omnibus Hotelling's T^2 statistics, multivariate simultaneous confidence intervals for 95% confidence levels were generated to determine the loci of the significant omnibus Hotelling's T^2 . Thus, the problem of multiple comparisons was avoided. Also avoided was the assumption of compound symmetry. However, two-sample Hotelling's T^2 assumes homogeneous covariance matrices of the two samples. Hakstian et al. (1979) showed that two-sample Hotelling's T was robust, even when this assumption was violated. A FORTRAN program was written for the PDP-12 to do a two-sample multivariate profile analysis for each of the 13 variables listed in Table 2.

Chore- and watch-sessions. The same multivariate analysis was applied to the data of the four-choice serial reaction time, Williams' Word Memory, and Wilkinson's auditory vigilance (Table 3). The multivariate analysis was repeated five times, once for each dependent variable.

Circadian Rhythms and Vigil

In Table 4 is a summary of the group mean cosinor analysis. Statistically significant circadian rhythms were detected in the baseline data of all of the 12 dependent variables listed in Table 3. The data and cosinor plot of oral temperature, systolic blood pressure, SAM fatigue checklist, SSS, TRAP 1 and TRAP 2 measures are given in Figures 3, 4, and 5.

Each figure shows the chronograms to the left and the group-mean cosinor plots to the right. In the cosinor plot, the 95% confidence ellipse bounded by the longer tangent lines intersecting into the clockface represents the vigil phase. Figures 3, 4, and 5 (top rows only) show that the circadian rhythms of these variables persisted throughout the period of prolonged wakefulness. The circadian rhythm of the TRAP 2 measure, which is shown in the bottom row of Figure 5, was lost during the vigil. In addition to the TRAP 2 measure, diastolic blood pressure and total number of responses in the four-choice serial reaction time task also lost their circadian rhythms during the vigil (see Table 4).

The most consistent change in circadian rhythms observed during the vigil was that the 95% confidence ellipses tended to be larger for data collected during the vigil, suggesting that continuous work caused individual differences to appear in terms of TOP. With the exception of diastolic blood pressure and pulse rate, the TOPs were reliably shifted by sleep loss (see Table 4). The shifts in TOPs were all within 2 hours, the sampling interval used in this study. The absence of large (greater than 2 hours) shifts in TOPs indicates that the values of these variables during the vigil could be compared directly with those obtained during baseline without complex phase-adjustment, as long as these values were observed at the same time during the baseline and vigil. Group TOPs of the TRAP 1 measure and MAST during the vigil were appreciably different from the baseline TOPs, but these changes were not statistically significant using the Rayleigh test.

A measure of percent (Amplitude/Mesor) was computed by dividing the average amplitude by an average mesor, and by multiplying this ratio by 100. Oral temperature, which is highly regulated homeostatically, had a small percent (Amplitude/Mesor), 0.6%. This means that the oral temperature could swing as

Table 3

Performance Measures Taken at Different Test Sessions

		<u>CHORES</u>					
Group 1	Baseline(C5)	Vigil(C8)	Vigil(C9)	Nap 1(C10)	Nap 2(C11)	R(C12)	
Group 2	Baseline(C5)	Vigil(C8)	Vigil(C9)	Vigil(C10)	Nap (C11)	R(C12)	
Four-Choice RT							
# of response:Group 1	507.5(52.0)	476.1(53.6)	465.3(87.7)	400.2(69.3)*	441.9(83.0)	470.2(64.7)	
# of response:Group 2	540.5(88.8)	460.4(89.6)	490.0(87.5)	411.4(115.4)*	443.1(84.9)	483.0(102.4)	
10%ile slow:Group 1	960(317)	1358(778)	1226(422)	2336(967)	1895(1759)	1957(1478)	
10%ile slow:Group 2	956(277)	2023(1372)	1312(765)	4352(6536)	1967(1120)	1524(1027)	
Williams' Word Memory							
% Recall: Group 1	55.1(10.8)	48.3(14.8)	51.8(9.3)	37.8(8.7)*	49.8(13.9)	54.2(14.7)	
% Recall: Group 2	54.7(9.1)	43.9(5.8)	51.4(18.9)	41.1(17.5)*	42.8(12.3)	47.5(9.4)	
		<u>WATCHES</u>					
Group 1	Baseline(W3)	Vigil(W4)	Vigil(W5)	Nap 1(W6)	Nap 2(W7)	R(W8)	
Group 2	Baseline(W3)	Vigil(W4)	Vigil(W5)	Vigil(W6)	Nap (W7)	R(W8)	
Wilkinson's Auditory Vigilance							
% Correct: Group 1	62.4(17.1)	37.5(12.5)*	48.2(14.5)	22.0(12.2)*	50.2(13.2)	38.2(13.7)	
% Correct: Group 2	55.6(11.8)	39.7(9.4)*	39.0(9.4)	20.8(13.1)*	35.5(14.0)	39.1(9.8)	
Average RT:Group 1	525(86)	556(88)	561(81)	511(69)	542(71)	538(98)	
Average RT:Group 2	544(68)	556(69)	569(55)	597(79)	606(55)	624(44)	

C stands for "Chore" in the schedule; W stands for "Watch" scheduled in this study. For details see the text.

* = Average of two groups is significantly different from the Baseline (Chore 5 or Watch 3 session).

Cosinor Summary of Circadian Rhythm During Baseline (B) and Vigil (V) Periods

Variable	Epoch	N	PR	Mesor (SD)	Amplitude Mean (95% C.I.)	Acrophase (hrs min) Mean (95% C.I.)	%(Amp/ Mesor)	Rayleigh Zd
Oral Temp (°F)	B	23	54.5%	97.8(0.3)	0.5(0.4 to 0.7)	1722(1614 to 1819)	0.6%	13.6***
	V	23	43.5%	97.5(0.5)	0.4(0.3 to 0.5)	1641(1504 to 1813)	0.4%	
Blood Press. Systolic (mmHg)	B	19	38.3%	120.3(7.5)	6.9(3.8 to 10.0)	1037(0856 to 1234)	5.8%	10.7***
	V	19	51.2%	120.4(6.4)	9.0(5.6 to 12.5)	1006(0902 to 1119)	7.5%	
Blood Press. Diastolic	B	19	27.7%	71.3(6.4)	2.7(1.0 to 4.6)	0420(0048 to 0605)	3.8%	1.4
	V	19	29.9%	70.2(6.2)	1.8	0550	----	
Pulse (beats/min)	B	19	31.5%	63.7(5.7)	2.8(0.7 to 5.2)	1503(1032 to 1736)	4.4%	2.8
	V	19	37.5%	65.0(5.4)	3.3(1.3 to 5.4)	1525(1306 to 1702)	5.1%	
NHRC +	B	23	47.3%	31.9(7.4)	4.0(2.3 to 5.7)	1432(1231 to 1623)	12.6%	10.8***
	V	23	31.7%	27.5(8.9)	3.2(1.4 to 5.2)	1500(1328 to 1722)	11.7%	
NHRC -	B	22	48.6%	3.5(2.8)	1.6(0.8 to 2.5)	0327(0206 to 0438)	45.7%	6.1**
	V	22	39.2%	6.8(4.0)	1.6(0.8 to 2.5)	0355(0154 to 0638)	23.6%	
SSS	B	22	55.7%	2.3(0.5)	0.7(0.5 to 1.0)	0236(0132 to 0321)	31.3%	8.8***
	V	22	35.7%	3.3(0.8)	0.5(0.3 to 0.8)	0339(0138 to 0538)	16.1%	
SAM Fatigue	B	23	56.1%	12.4(1.6)	2.1(1.3 to 3.0)	1407(1255 to 1504)	17.0%	5.6**
	V	23	35.3%	9.8(2.6)	1.6(1.0 to 2.7)	1511(1308 to 1728)	16.4%	
TRAP 1 (# Responses)	B	19	36.7%	1033.6(237.0)	43.8(24.3 to 66.0)	1946(1741 to 2234)	4.3%	2.5
	V	19	32.6%	1006.9(247.0)	45.7(4.35 to 88.2)	1707(1208 to 2120)	4.6%	
TRAP 2 (msec)	B	19	33.2%	503.9(151.9)	70.0(29.6 to 121.3)	0637(0410 to 1035)	13.9%	1.0
	V	19	24.2%	798.9(372.9)	68.7	0623	-----	
2 MAST (# Lines)	B	19	25.5%	57.2(15.1)	4.3(1.3 to 7.3)	1516(1319 to 1741)	7.5%	2.0
	V	19	24.1%	53.1(15.0)	2.5(0.2 to 4.9)	2045(1931 to 0058)	4.8%	
4-Choice (# Responses)	B	8	36.8%	547.8(59.7)	19.1(4.8 to 42.2)	1837(1445 to 2353)	3.5%	1.1
	V	8	10.2%	489.5(85.5)	3.6	0701	----	

** 1% or better.
*** Better than 1%

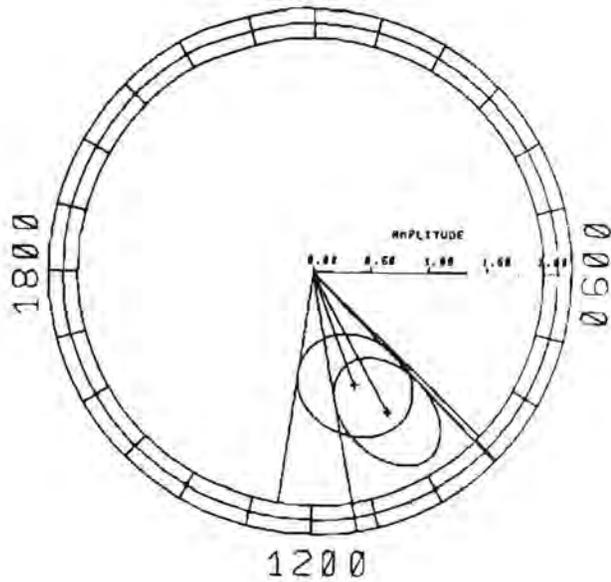
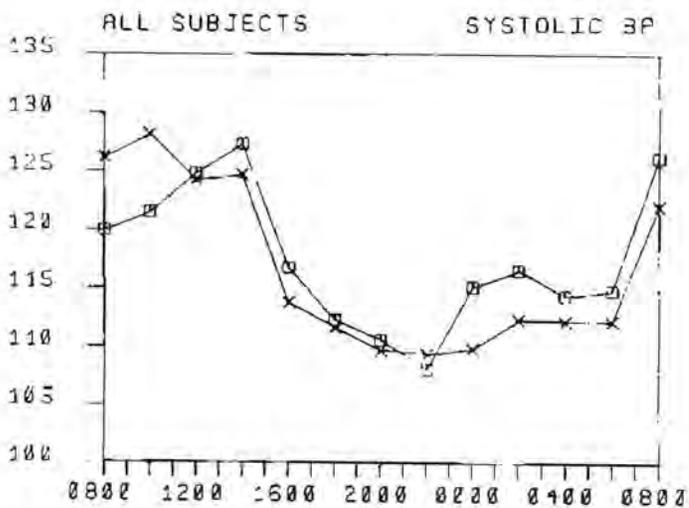
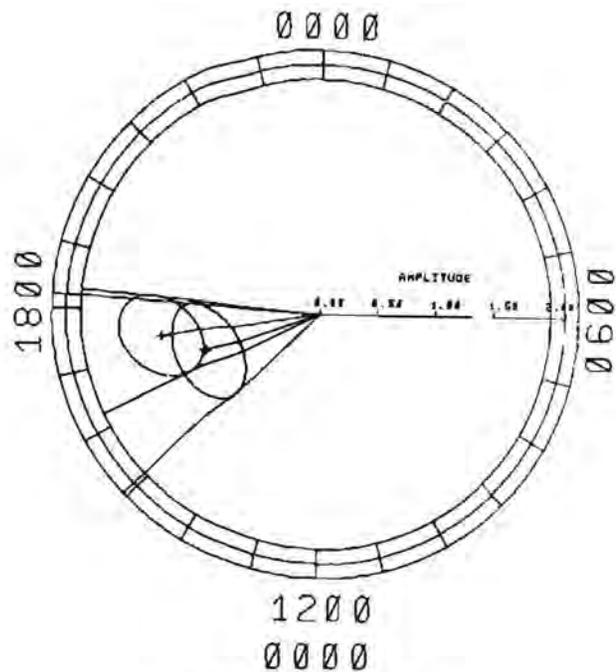
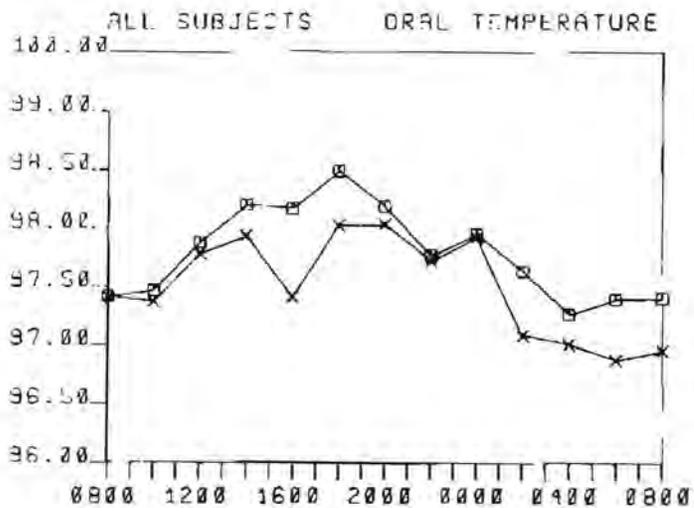


Figure 3. A chronogram (left) and cosinor plot (right) for oral temperature (top row), and for systolic blood pressure (bottom row). A chronogram is a plot of averages across all subjects. The squares identify the values observed during the vigil, and that with shorter lines for the baseline. The same procedures were used for Figures 4 and 5. The X-axis shows time of day. Y-axis for oral temperature is in F degree. Y-axis for systolic blood pressure is in mm Hg.

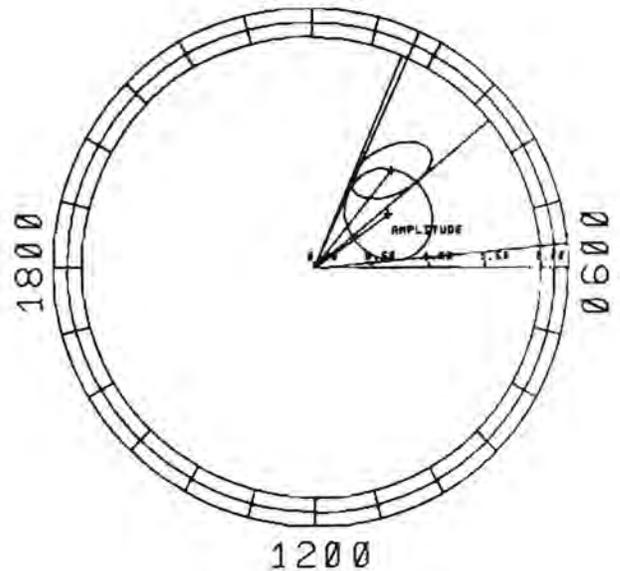
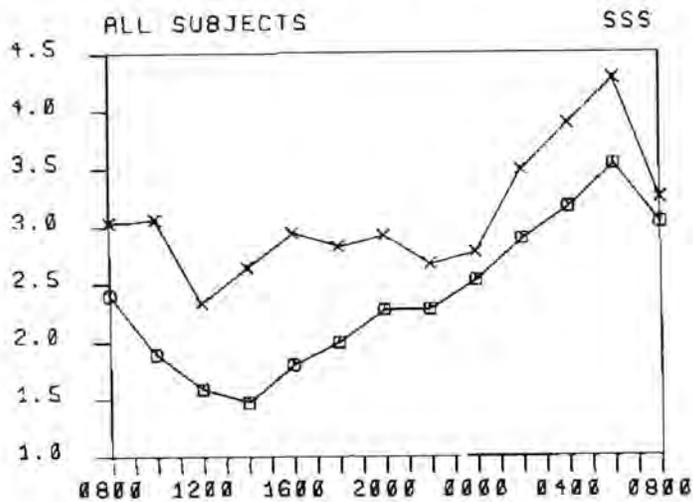
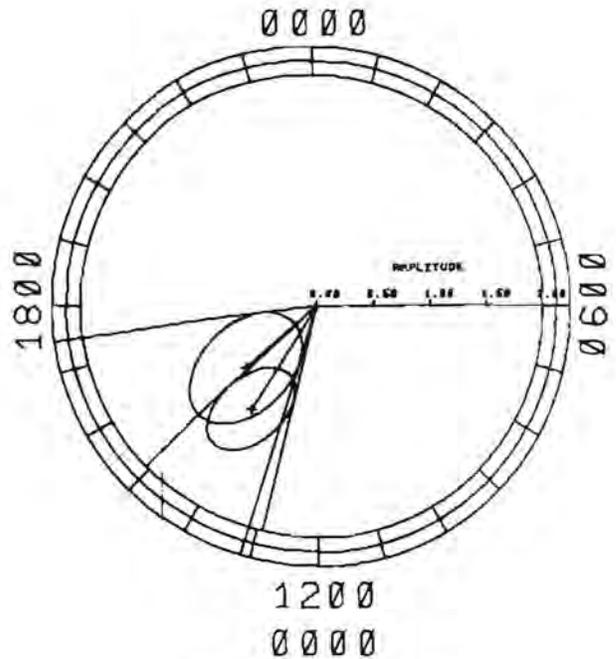
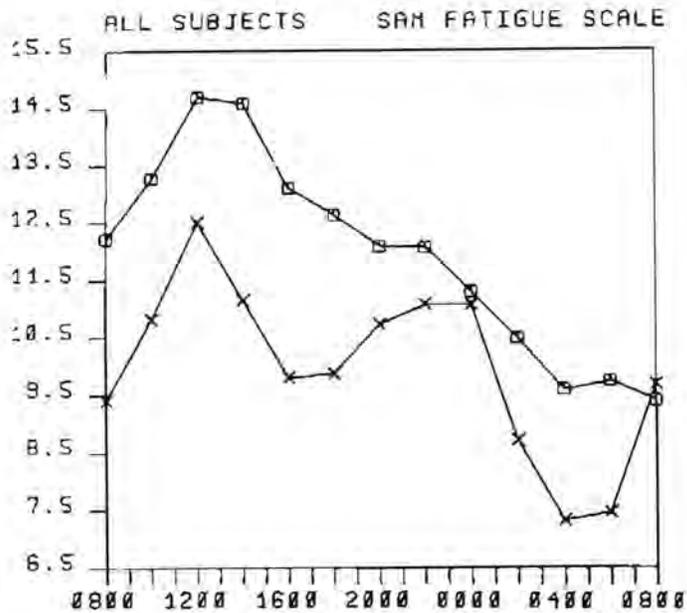


Figure 4. A chronogram (left) and cosinor plot (right) for the SAM subjective fatigue checklist (top row), and for the Stanford Sleepiness Scale (SSS). X-axis is time of day, and Y-axis for SAM subjective fatigue checklist is in an arbitrary scale, ranging from zero to 20. The larger number means less subjectively rated fatigue. Y-axis for chronogram of the SSS is in an arbitrary unit, ranging from zero to seven. The larger number means greater sleepiness.

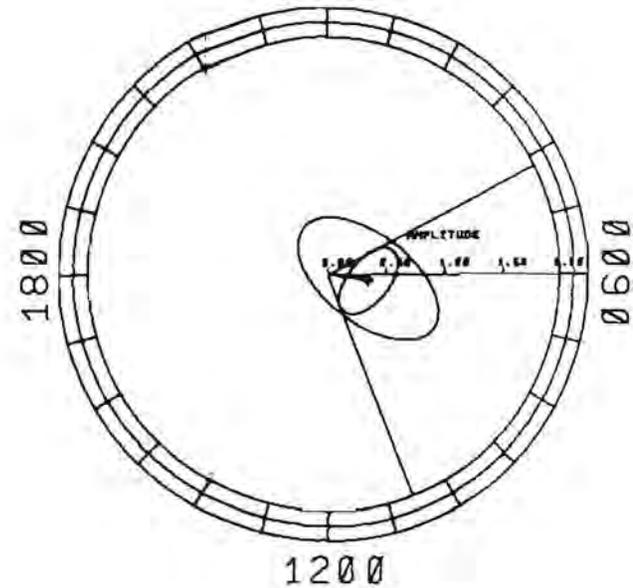
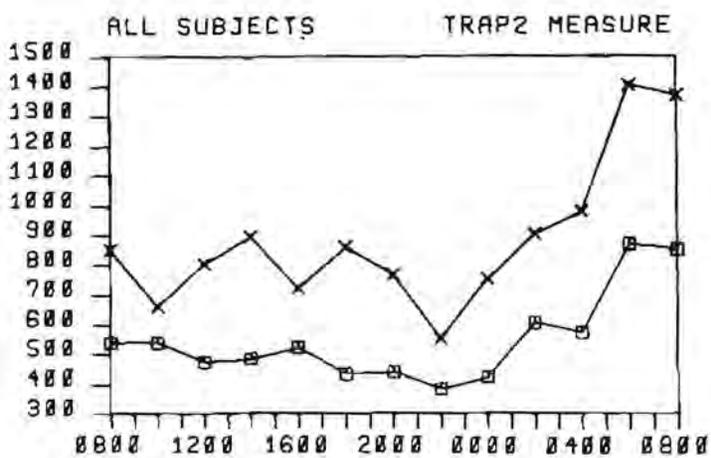
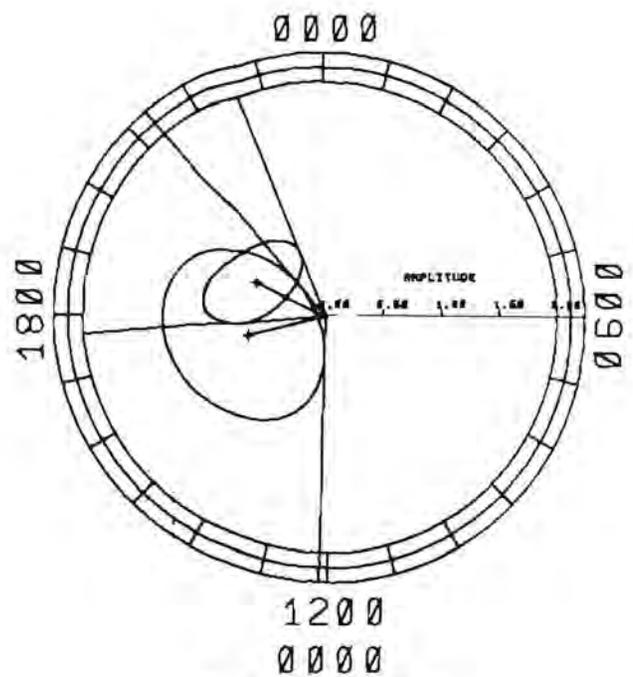
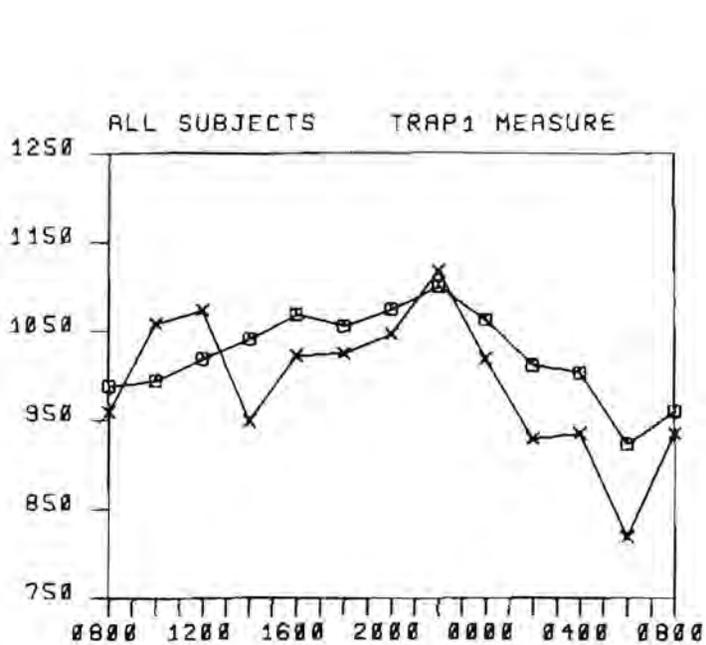


Figure 5. A chronogram (left) and a cosinor plot (right) of TRAP 1 measure (top row), and of TRAP 2 measure (bottom row). Y-axis for TRAP 1 measure is total number of tapings. Y-axis for TRAP 2 measure is 10 percentile of the slowest inter-tapping intervals.

much as 0.6% of its mesor, higher or lower, due to the circadian rhythm. The percent measure was much greater for other dependent variables, especially for mood, sleepiness, and fatigue. For example, the percent value for the NHRC Negative Scale suggested that it oscillated as much as 45.7% of the mesor due to the circadian rhythm. This finding suggests that the circadian rhythm component would be very large for self-ratings of mood, sleepiness, and fatigue.

The data in Table 4 show that the minimum oral temperature occurred at 0441 during the vigil. Systolic blood pressure was minimal at 2206, and pulse minimum occurred at 0325 during the vigil. The minima for subjective ratings for the NHRC Positive Scale, NHRC Negative Scale, SSS, and SAM Fatigue Scale during the vigil were 0300, 0355, 0339, and 0311, respectively. Performance minima for the TRAP 1 measure and MAST were 0507 and 0845, respectively. Thus, Nap 1 of Group 1 was placed near the troughs of many circadian rhythms, especially oral temperature and subjective ratings. Nap 2 of Group 1 and the only nap for Group 2, taken from 1200 to 1400, occurred very close to the TOPs of many circadian rhythms. Thus, these naps were placed at the intended phases of the circadian rhythms.

Recuperative Power of Naps

Groups by conditions interaction. In Tables 2 and 3 are the results of this analysis. The null hypothesis, first tested by multivariate two-sample profile analysis, was that the two groups would have parallel profiles. In a univariate ANOVA, this null hypothesis of parallelism corresponds to a null hypothesis of no interaction between groups and conditions. The differences (e.g., the slopes) of C1-C2, C2-C3, C3-C4, C4-C5, and C5-C6 of Group 1 were tested simultaneously against those of Group 2 to determine if any of these slopes were significantly different.

The null hypothesis of parallelism of the groups' profiles was tested 18 times, one null hypothesis test for each dependent measure (Tables 2 & 3). Using a significance level of 5%, none of the 18 null hypothesis tests for parallelisms could be rejected. For all variables, the two groups had similar profiles which went up or down together. There was no significant group-by-conditions interaction. The similarity of the two groups can be seen in the plots of the group means over experimental days 2 through 5 in Figures 6 through 9. Data obtained in the chore- and watch-sessions were not plotted, but the two groups showed very similar plots.

The second null hypothesis tested by multivariate two-sample profile analysis was that Group 1 did not differ over conditions from Group 2. Again, the null hypothesis was tested for each of the dependent measures. Only the MAST showed a large enough omnibus T^2 value to allow rejection of the null hypothesis. Further analysis with the 95% simultaneous confidence intervals, however, showed that Group 1 and Group 2 differed significantly from the very beginning of the experiment, and they remained different throughout the experiment (see top row of Figure 8).

Comparison over conditions. As the two groups had parallel profiles, they were combined into one group and the null hypothesis that no differences exist among conditions (or flatness hypothesis) was tested 18 times. The omnibus testing of all possible contrasts among the conditions indicated there

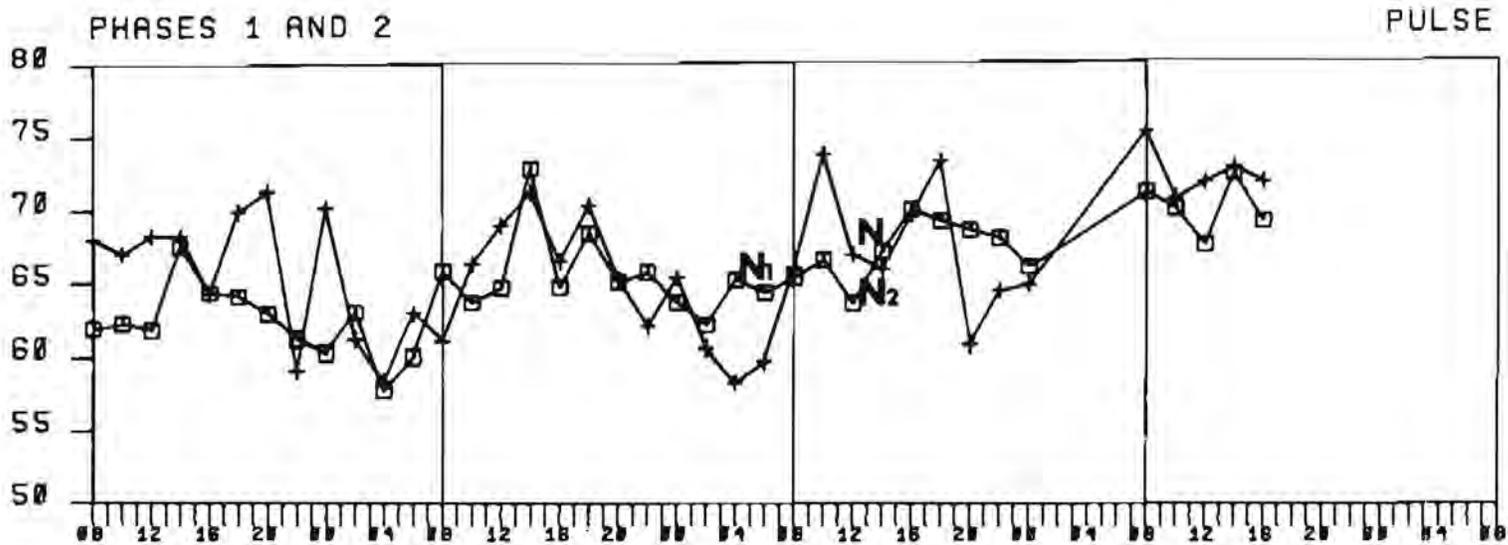
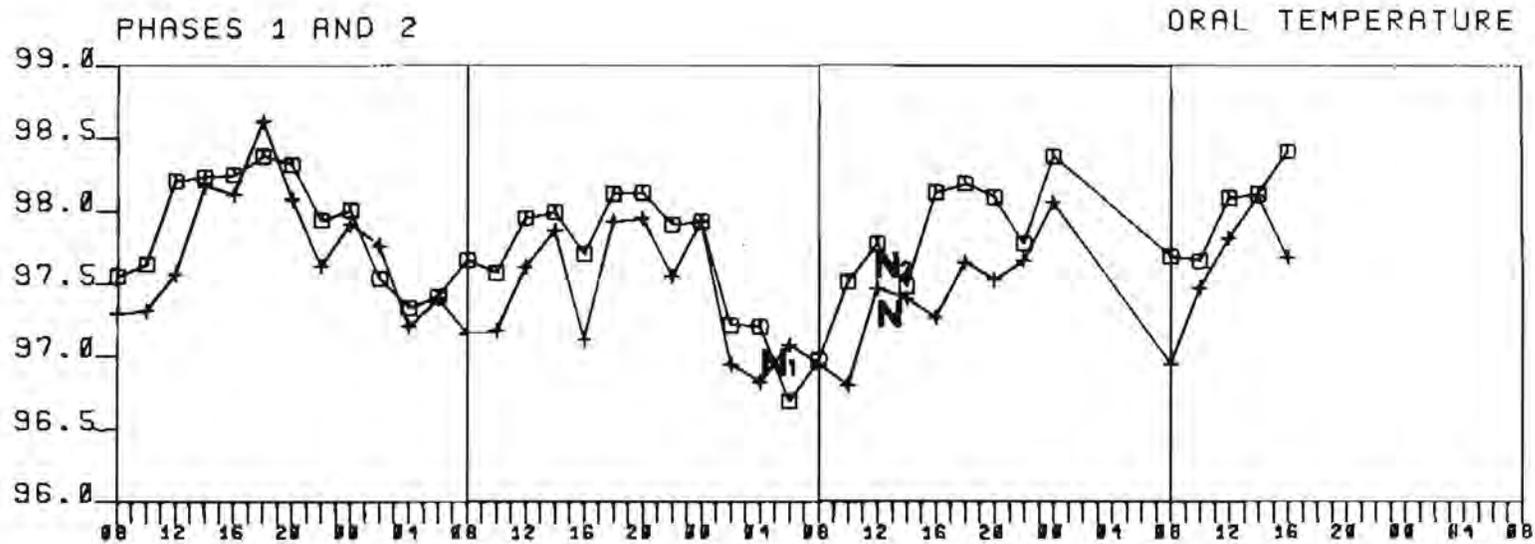


Figure 6. Plots of oral temperature and pulse rate separately for Group 1 and Group 2. Y-axis starts with 0800 Tuesday (Day 2 of the experiment) and continues to the end of the study at 1600 Friday (Day 5). For this and the remaining figures, N and N are the first and second 2-hour naps experienced by Group 1 (identified by the squares). N is the only 2-hour nap allowed for Group 2 (identified by plus [+]). Y-axis for pulse is in beats per minute.

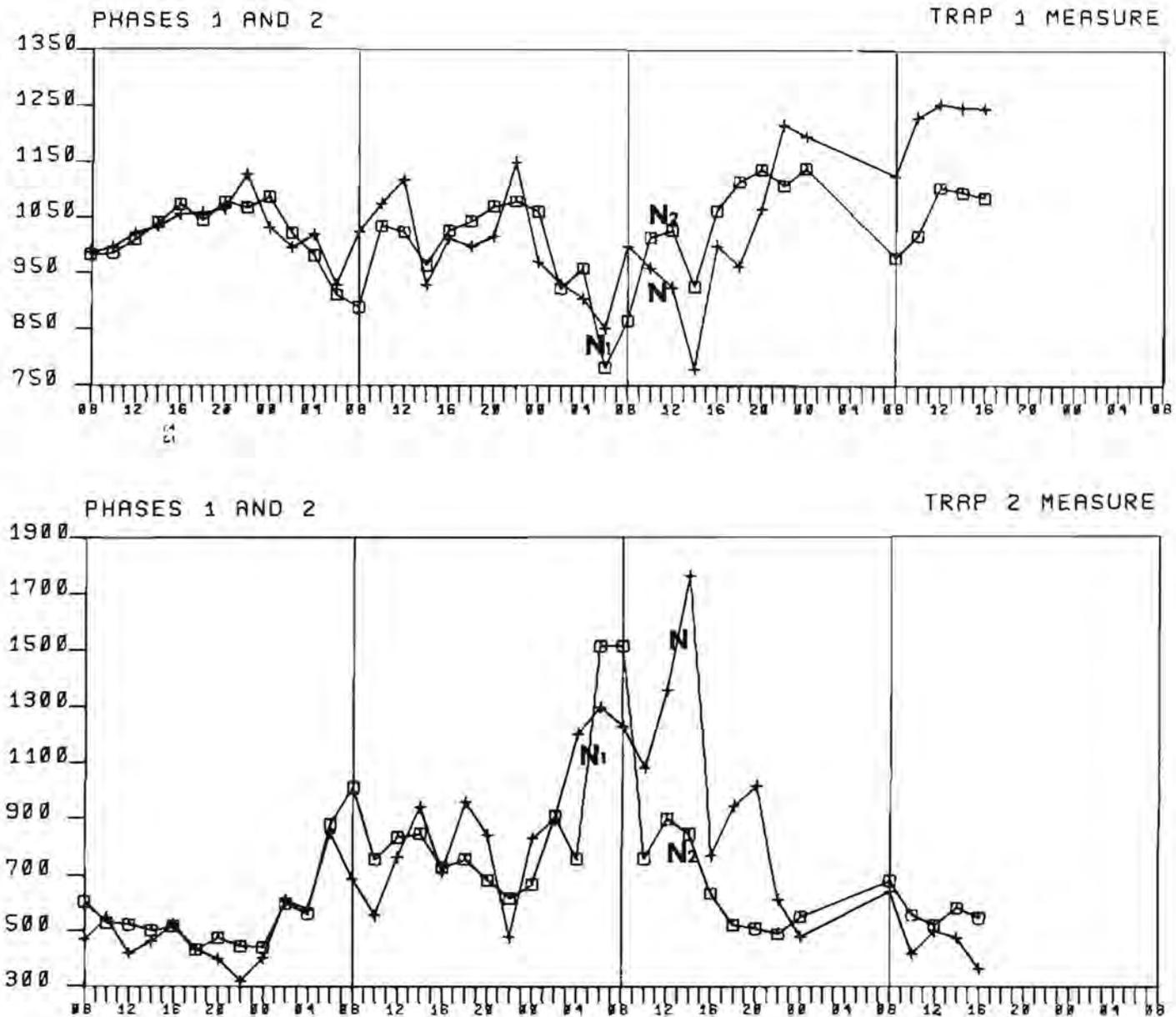


Figure 7. Plots of two measures of TRAP task performance separately for Group 1 and Group 2. TRAP 1 measure is in terms of total number of tappings. TRAP 2 measure is in milliseconds of elapse time between tappings. TRAP 2 measure shows averages of 10 percentile slowest inter-tapping intervals.

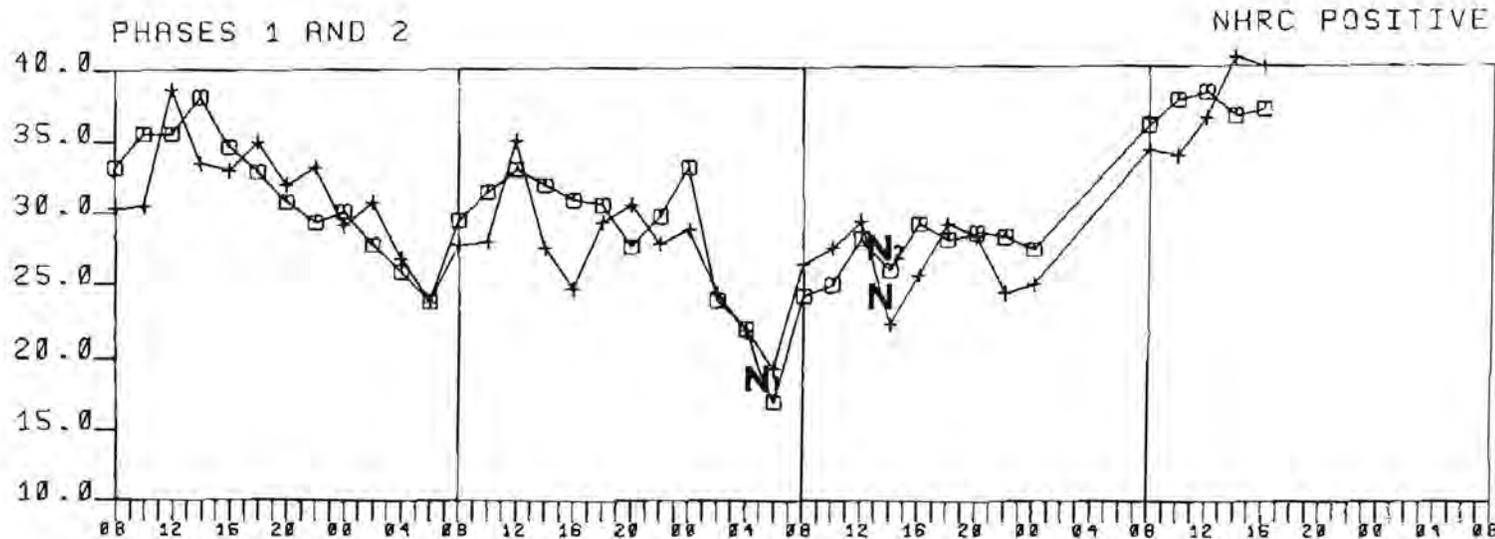
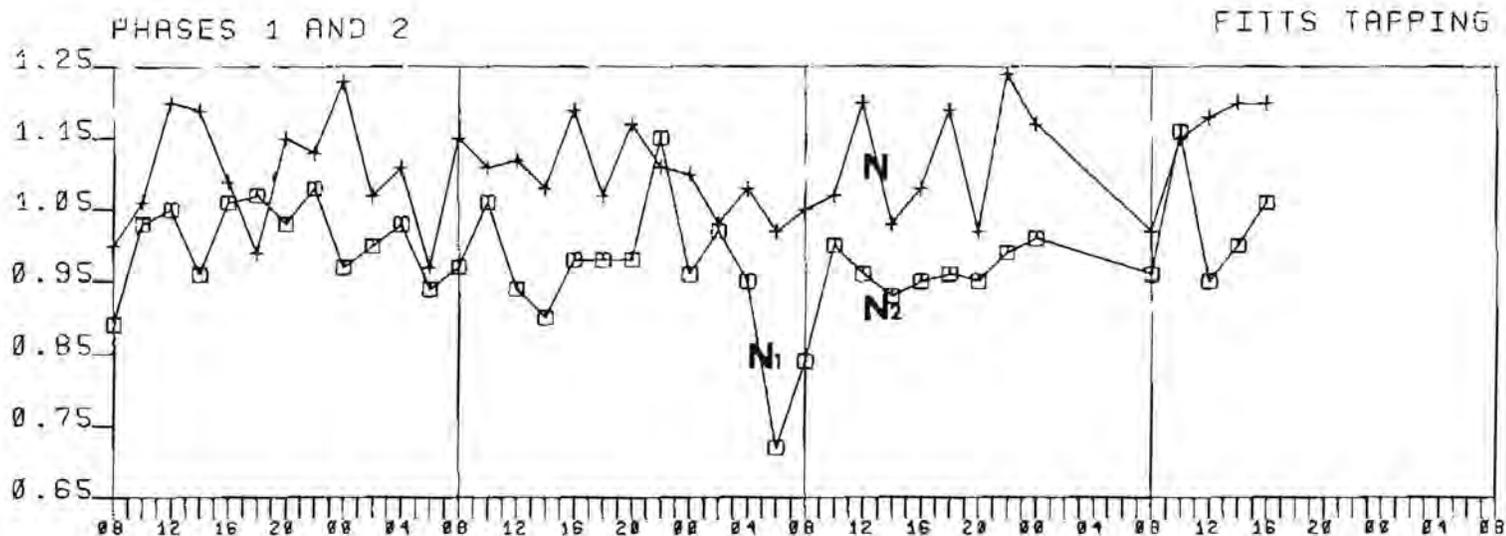


Figure 8. Plots of efficiency score of Fitts' reciprocal tapping task and NHRC positive score separately for Group 1 and Group 2. The efficiency score for Fitts' reciprocal tapping task was derived by dividing the number of successful tapings by time (in seconds) the subjects needed to complete the task. The larger Y-value represents a higher "efficiency". Y-axis for NHRC positive scale is an arbitrary scale, ranging from the minimum of 0 to the maximum of 76. Better mood is shown as a larger value along the Y-axis.

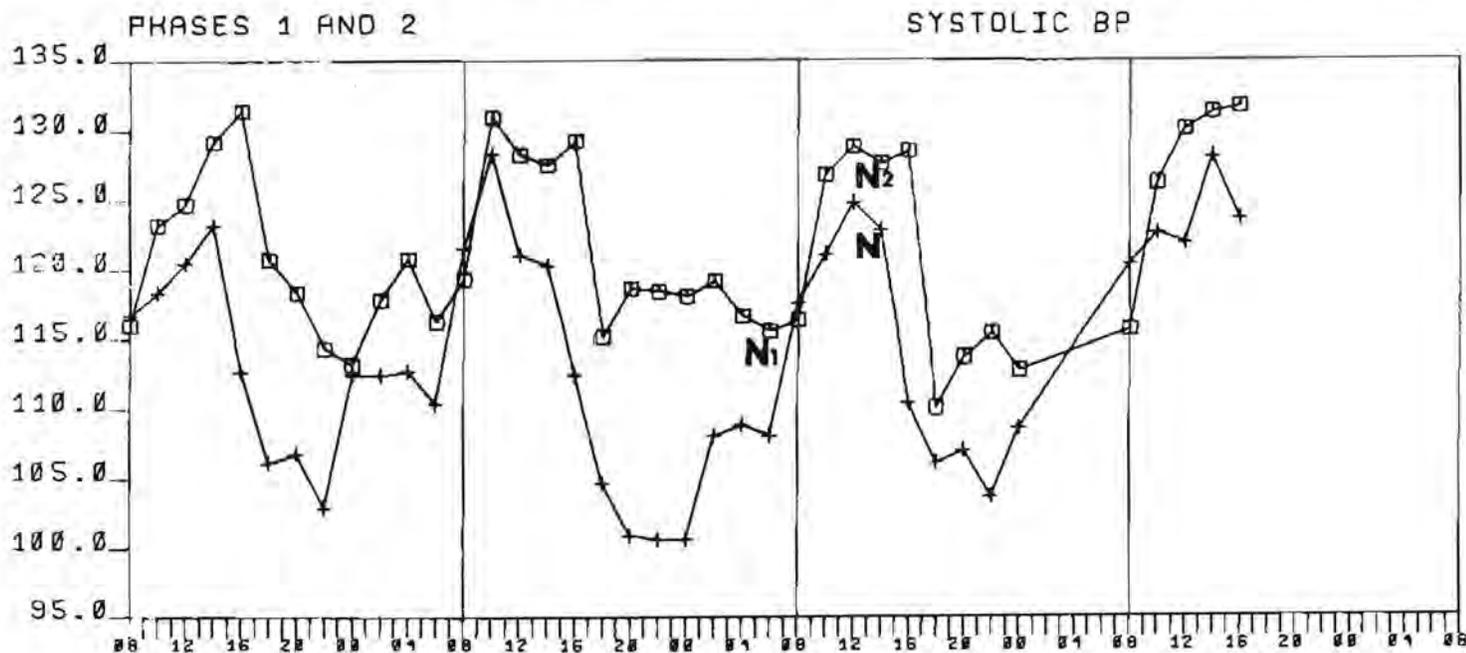
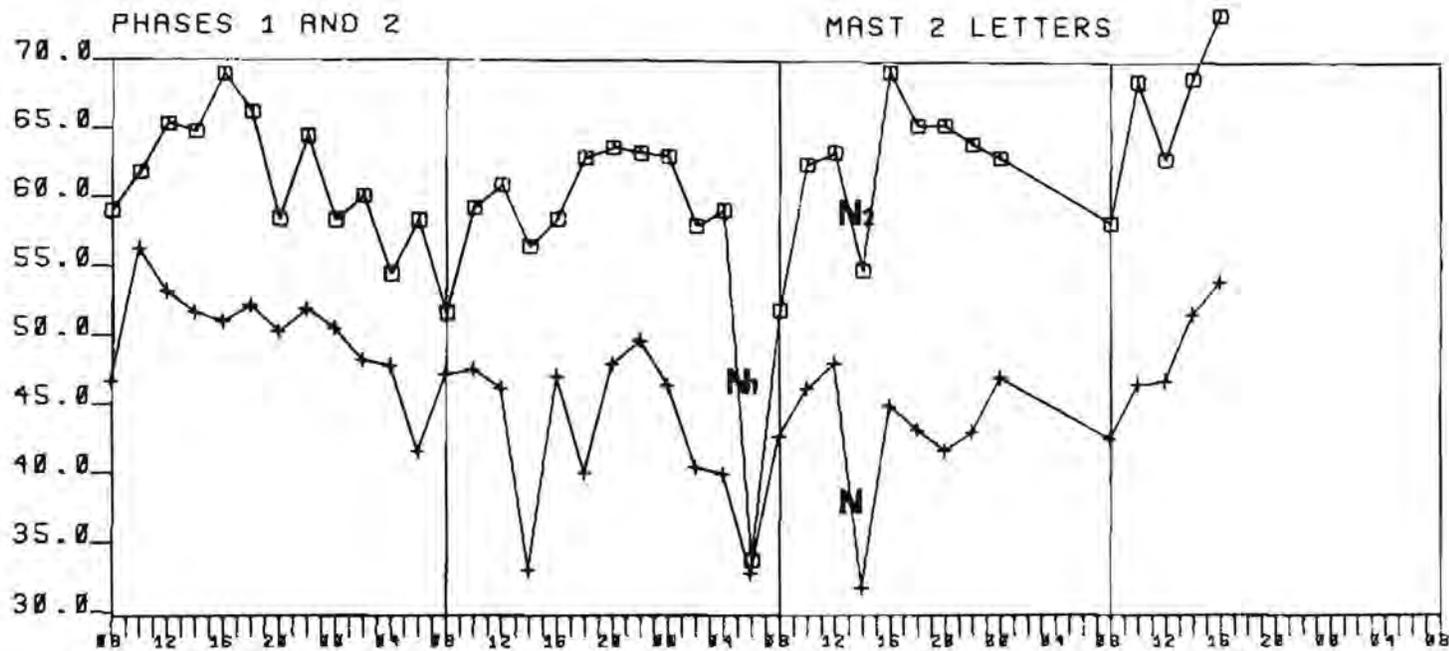


Figure 9. Plots of total number of lines scanned in MAST test (2-letter target) and systolic blood pressure separately for Group 1 and Group 2.

were no significant differences among the conditions for the following dependent measures: (1) pulse rate, (2) diastolic blood pressure, (3) TRAP 1 measure, (4) four-choice serial reaction time (10 percentile of the slowest inter-response intervals), and (5) average reaction time on Wilkinson's auditory vigilance test. These five measures, thus, were not reliably affected by any of the experimental treatments of the prolonged continuous work or of napping. They were not useful in understanding the recuperative power of naps or in detecting the effects of sleep loss. The dependent measure of systolic blood pressure also belongs in this group of non-contributing measures, although the omnibus T^2 for conditions was significant. Further analysis with the 95% simultaneous confidence intervals indicated that systolic blood pressure at bio-session 35 was significantly different from the baseline, C1, simply because of the sampling artifact and the manner in which the bio-sessions were partitioned (see the bottom graph of Figure 8).

The remaining dependent measures showed highly significant T^2 for conditions, and the null hypothesis of flatness was rejected. The results of comparing the baseline (bio-sessions 8-16) with each and every condition with the 95% simultaneous confidence intervals are shown in Tables 2 and 3.

Effects of continuous performance of 45 hours. Forty-five hours of sleep loss produced a significant change from baseline in subjective ratings of sleepiness, SSS (a greater sleepiness with sleep loss), increased negative effect on the NHRC Mood Scale, and reduced percent correct detections on Wilkinson's auditory vigilance task. Performance following Nap 1 for Group 1 and during continuous work for Group 2 showed similar changes from baseline. When C3 performance was compared to baseline for both groups, there was a significant drop in oral temperature, significantly fewer lines were scanned on the MAST, and the inter-response interval on the TRAP was significantly slower. On the four-choice serial reaction time task, both groups had significantly fewer responses, and on the Williams' Word Memory test, both groups showed a significant loss of immediate memory and recall. Finally, the two groups had significantly fewer correct signal detections on Wilkinson's auditory vigilance task during C3. Self-ratings of mood, fatigue, and sleepiness showed declines in mood and increased fatigue and sleepiness.

The similarity of detrimental changes that occurred in both groups during C3 leads to the inescapable conclusion that Nap 1, the early morning nap, had no recuperative power. In contrast, Group 1's performance was the same as the continuing vigil performance of Group 2. The early morning nap after prolonged prior wakefulness of 45 hours was not helpful. Figures 6 through 10 illustrate the ineffectiveness of the one 2-hour early morning nap in restoring performance and mood.

Results comparing baseline data with performance and mood before the mid-day nap (C4) showed that some dependent measures remained significantly deteriorated for both groups. Perhaps the reason for this continued deterioration in Group 1 was that Nap 1 was too short and "sleep inertia" persisted. Group 2 simply failed to show the anticipated circadian up-swing at this time of day due to sleep loss.

The dependent measures that showed significant improvements, from C3, during C4 were the MAST and NHRC Positive Mood Scale scores. These scores during

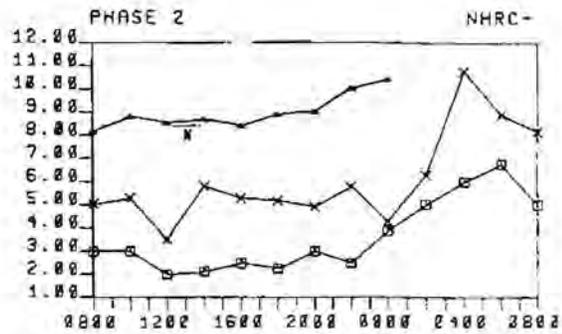
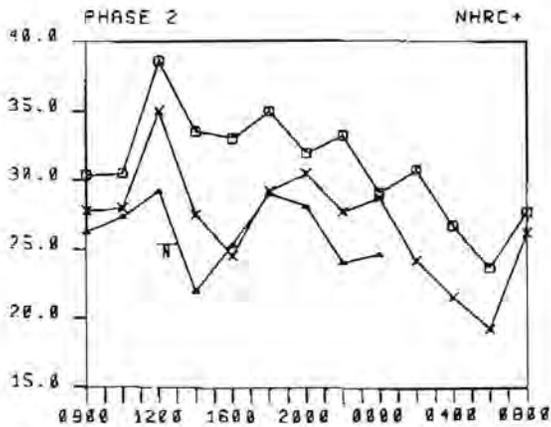
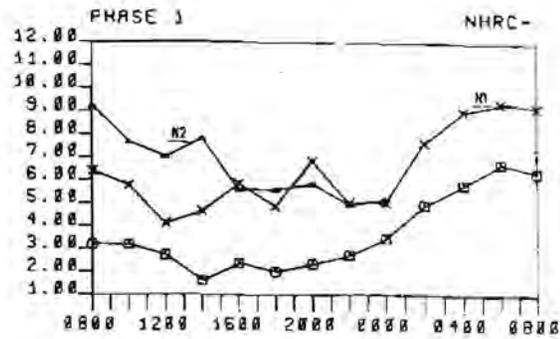
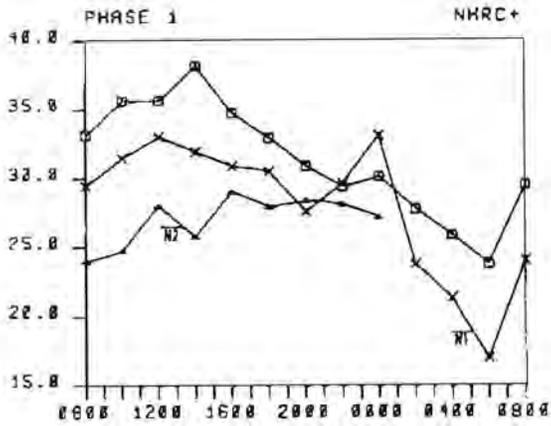


Figure 10. Chronogram plots of NHRC positive scale (the left column) and NHRC negative scale (the right column) to show ineffectiveness of naps to restore mood to the baseline levels. A line marked with squares is for baseline (Tuesday, Day 2). The line marked with x's represents the data for the vigil (Wednesday, Day 3), and the line marked with triangles represents Thursday. Group 1 data are on the top row (i.e., Phase 1 data), and Group 2 data are on the bottom row. Phase 1 = Group 1; Phase 2 = Group 2. X-axis shows the time of day. These lines are continuous. Compare NHRC plot with NHRC Positive plot in Figure 7. Day 5 data are not plotted in this Figure.

C4 did not differ significantly from baseline. The improved scores for Group 2 were probably due to the circadian up-swing. The improved scores for Group 1 could be attributed to Nap 1 or the circadian up-swing. Other dependent variables--Fitts' reciprocal tapping, SSS, and NHRC Negative Scale--were sufficiently improved, from C3, (but not significantly) during C4 so the scores for these variables did not differ significantly from baseline.

Comparisons of C5 with baseline, C1, showed that most dependent measures had recovered to baseline: oral temperature, TRAP 2 measure, Fitts; reciprocal tapping, NHRC Negative Scale, four-choice serial reaction time task (in terms of total number of responses), Williams' Word Memory, and Wilkinson's auditory vigilance. For oral temperature, the midday nap by Group 2 resulted in the same rise in oral temperature as did the combined action of Naps 1 and 2 for Group 1. For performance on the four-choice serial reaction time task, the one 2-hour midday nap taken by Group 2 was as recuperative as were the two 2-hour naps taken by Group 1. The same conclusion can be drawn for Wilkinson's auditory vigilance task, as the midday nap restored percent correct detection in Group 2 to baseline levels. For the TRAP 2 measure, Nap 2 seemed to have improved the inter-response intervals by shortening them, but the single nap appeared detrimental to Group 2 by slowing down their tappings. But the difference between the groups was not significant due to the large standard deviation of Group 2.

The only performance measure which failed to recover to the baseline level was MAST. The gain seen in C4 was lost in C5. The subjective ratings of fatigue, sleepiness, positive mood, and arousal also failed to recover to baseline levels.

The overall conclusion that one 2-hour midday nap was as recuperative as two 2-hour naps seemed to be confirmed by the absence of prolonged sleep inertia during C6. With the exception of the SAM fatigue checklist and Thayer's AD-ACL scores, the values of the dependent measures recovered to baseline during C6.

Discussion

The results of this study suggest that the recuperative or beneficial power of naps depends on three major factors: (1) hours of prior wakefulness, (2) time when nap was taken, and (3) duration of nap. The clearest finding from this study was that if a 2-hour nap is taken early in the morning, 0400-0600, after 45 hours of continuous work without sleep, then task performances and self-rating of mood, fatigue, and sleepiness would remain deteriorated at the level of those who stayed awake. The deteriorated task performances and feelings of greater sleepiness, fatigue, and negative effects could be anticipated immediately after being awakened from short sleep, as it is quite normal to see this sleep inertia. Since the early study of Langdon and Hartman (1961), many have observed that sleep inertia invariably follows awakening from sleep. However, under normal circumstances, where subjects are not deprived of sleep for long periods of time, this sleep inertia is quickly replaced by "more rapid motor responses, higher levels of short-term memory, larger shifts in positive affective states (e.g., cheerful, energetic) and less reported sleepiness (e.g., inert-fatigued, Stanford Sleepiness Scale)" (Taub, 1979, p. 107). Taub (1979) noted that sleep inertia could be seen for

as long as 2 hours. What is unusual about the finding of this study is that beneficial effects of the early morning nap were not observed during the first 2 hours, and up to 6 hours afterward, in some dependent measures. An early morning nap taken after prolonged wakefulness can cause sleep inertia for a long period of time after awakening.

This long sleep inertia was not observed when a nap of the same duration as the early morning nap was taken at 1200-1400, after 53 hours (instead of 45 hours) of continuous wakefulness. Following this midday nap, performance on some dependent measures exhibited signs of sleep inertia, but it was replaced by improvements. Similarly, subjects in Group 1 showed some sleep inertia after their second nap (i.e., from 1200-1400), but it disappeared within 1 hour after awakening. Comparison of post-midday nap self-ratings and task performances of Group 2 with those of Group 1 revealed that the two groups recovered almost to baseline with no significant differences between groups. This finding suggests that one midday nap taken after 53 hours of wakefulness was as recuperative as the combined action of the early morning nap plus midday nap taken after a shorter period of wakefulness. This finding further suggests that the early morning nap was not helpful and the midday nap was the only nap that contributed substantially to recuperation. Thus, the local time of day when a nap is taken seems to be an important factor in determining the duration of sleep inertia; hence, how quickly the recuperative powers of a nap would be felt.

The effects of sleep loss and nap inertia varied from one dependent measure to another. The self-ratings of fatigue, sleepiness, positive and negative mood, and arousal were profoundly influenced by sleep loss and sleep inertia, and some of these dependent measures recovered only after 7 hours of recovery sleep (see bottom graph of Figure 7). These subjective measures of feeling tones may be used as sensitive measures of the recuperative power of naps.

In this study, sleep records were obtained to see if the subjects slept well during the assigned sleep periods. Sleep-stage analysis of the two naps taken by Group 1 showed, as expected, highly elevated amounts of stages 3 and 4, slow wave sleep (SWS). Recovery sleep obtained from 2400 Thursday to 0700 Friday showed a typical SWS increase over the baseline level by about 22%. This SWS "rebound" can be contrasted with an expected SWS rebound of 50% in those who stayed awake for 40 hours. Thus, two 2-hour naps appeared to have achieved a partial recuperation by lessening the SWS rebound during the first recovery sleep.

This study has shown that the recuperative power of naps can be determined by knowing the prior hours of wakefulness, time-of-day the nap will be taken, and the duration of each nap. The importance of circadian cycles in the recuperative power of naps was indicated in this study, but further studies are necessary before it can be firmly established.

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