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SUSTAINED OPERATIONS: RESEARCH RESULTS

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SUMMARY

This report summarizes the task performance, mood, and fatigue of 112 U. S. Marine Corps volunteers during a laboratory simulated sustained operation (SUSOP). These volunteers were observed in seven studies that were conducted over a period of seven years (1979-1985). The purpose of the studies was to obtain baseline information about the recuperative power of short periods of sleep (naps). During a SUSOP, naps between continuous work episodes (CWE) are used to maintain performance and relieve fatigue and sleepiness. However, there has been no comprehensive research program where physical workload, nap duration, and starting time variables in a SUSOP were systematically altered to evaluate the power of naps in maintaining effective performance and positive mood and in decreasing fatigue.

The Naval Health Research Center (NHRC) has conducted a research program subjecting volunteers to a simulated five day reconnaissance mission where these variables were manipulated. Cardiovascular fitness and response to prolonged physical work are measured. Task performance, mood, and fatigue were followed with the NHRC Performance Assessment Battery (NHRC-PAB). Polygraphic sleep recordings were obtained to assess the quantity and quality of sleep. The results of these studies demonstrated: (1) Starting Time of a mission has major effects on performance throughout the mission. Starting Time should be chosen so that a continuous work episode (CWE) will not end near the circadian trough in body temperature. (2) After the first 20 hours of continuous work, more than 3-4 hours of sleep is required to assure full recovery from fatigue. Allowing only 3-4 hours of sleep will result in up to a 30% degradation from baseline performance, mood deterioration, and increased fatigue during a second 20 hr CWE. (3) When subjects are required to do moderate physical work during these CWEs, performance, mood, and fatigue will be detrimentally affected to a greater extent than when no physical work is done. (4) Physical workloads of 30% of maximal aerobic power or greater will slow down response speed during a subsequent post physical work period. (5) The circadian phasing of nap time (the time-of-day when the nap is taken) is less important than the duration of the nap in determining the recuperative power of the nap. However, when awake time is extended beyond a period of 12 hrs, the circadian phasing becomes more important. Under these conditions, a short nap taken during the early hours

(0400-0700) will be followed by profound and persistent sleep inertia. The important factors in managing sleep include: (a) prior hours of wakefulness (which includes hours for rest, meals, personal hygiene as well as task completion), (b) time-on-the-job, (c) circadian phasing (time-of-day) of the nap, (d) duration of nap, and (e) physical workload experienced.

1. INTRODUCTION

Modern society requires 24 hr services. This is usually supplied by shifts, with 2-3 stationary or rotating crews working different periods of the day. However, some occupations require sustained work on an irregular or even a regular basis. Examples include fire fighters; police; health care providers; rail and air transportation workers; and nuclear, petrochemical, and steel workers. Some of the most dramatic examples are in military sustained operations (SUSOPS). Military planners recognize that, should SUSOPS be necessary, the weakest link will be human performance, not hardware (Defense Research Group, 1982, 1983; Department of the Army, 1983; Hegge, 1982).

Definitions for Continuous Operations (CONOPS) are continuous combat with opportunities for sleep, though these opportunities may be brief and scattered through the day and night. Sustained Operations (SUSOPS) are defined as continuous combat with no opportunity for sleep. Within any CONOPS there will likely be periods of SUSOPS; and during CONOPS, sleep for some personnel (e.g. those involved in command, control, communication and intelligence (C^3I)) will be more severely restricted than for others. Continuous Work Episodes (CWE) or Continuous Operations are goal-oriented continuous performances without rest or sleep. A SUSOP may include several CWEs.

This report summarizes the findings from a series of studies conducted at the Naval Health Research Center (NHRC) which examined the effects of continuous and repeated work episodes on psychological performance, mood, and fatigue when the time and duration of naps, exercise levels, and starting times of CWEs were manipulated. Some of the results have been published previously (Englund, Naitoh, Ryman, & Hodgdon, 1983; Englund, Ryman, Naitoh, & Hodgdon, 1985; Naitoh, 1981, 1982; Naitoh, Englund, & Ryman, 1982, 1983; Ryman, Naitoh, & Englund, 1984).

2. BACKGROUND

In previous studies, Marine Corps personnel were sufficiently recuperated by a nap taken after a CWE to enable them to continue working at tasks for an extended period of time. However, naps taken during early morning hours after a prolonged CWE produced profound and persistent performance decrements (sleep inertia) during the post nap period that might be hazardous to individuals as well as to a mission (Naitoh, 1981; Naitoh et al., 1982). These observations suggested an urgent need to develop Sleep Management and Sleep Logistics (Naitoh et al., 1983, 1986), especially for SUSOPS. Sleep Management has now been integrated into larger efforts on military performance management by Morgan and Associates (Morgan Management Systems, Inc., 1984a, 1984b).

The principles of sleep management assist all levels of military performance, from an individual soldier, to a platoon, to a larger battle unit, by evaluating the impact of sleep loss during any mission (Morgan Management Systems, Inc., 1984c; Naitoh et al., 1986). The field of sleep logistics is concerned with determining the operational merit of providing short sleep breaks at a particular time-of-day after so many hours of continuous work during a mission. Sleep logistics uses a cost/benefit analysis to balance the benefit of maintaining performance effectiveness after sleep against the lost man-hours during sleep.

Naitoh et al. (1983) and Englund et al. (1985) found that a 3 hr nap did not recuperate Marine Corps subjects from fatigue after they had been working continuously for 20 hours. Thus, performance during the second 20 hr CWE was not maintained at baseline level. Morgan and Coates (1974) studied the impact of different CWE starting times on performance. They obtained data from two five member crews who worked for 36 hrs continuously, starting at 0600, 1400, or 2200 (Figure 1). They found that performance was kept at nearly 100% of baseline level for 36 hrs when the CWE started at 1400. Crews that started at 0600 showed a decline in the level of performance, particularly around 0400-0800, when the circadian low in performance coincided with prolonged time-on-the-job. They also showed a gradual improvement in performance from 0800 to 1200. When the CWE started at 2200, performance showed precipitous deterioration starting at 2000 the second day, with the lowest level of performance between 0400-0800.

Military operations may start at any time of the day or night. A previous report on sleep management (Naitoh et al., 1983), did not discuss the effects of mission start up time. This paper reports the results from the most recent series of studies on mission startup time. These studies simulated field activities of Marine Corps personnel and emphasized the physical work component of Marine Corps missions. The performance maintenance powers of naps of various lengths taken at various times of day and the impact of starting a sustained, simulated Marine reconnaissance mission at around Noon (1300) or Midnight (0000) as opposed to Morning (0800) on performance, mood, and fatigue have been observed.

3. NHRC SUSOP STUDY

3.1 Rationale and Experimental Design

During the 1979-1985 period, the NHRC conducted a series of seven SUSOP studies involving a total of 112 U.S. Marine Corps volunteer subjects (Ss) in 13 groups. Tables 1 and 2 provide demographic and experimental information on the Ss. These experiments were conducted at the NHRC laboratories which house a sound-reduced, electrically-shielded sleep room and an air-conditioned exercise room. An average ambient temperature of 21°C and humidity of 50% were maintained for all studies.

Most SUSOP studies have been concerned with the direct effects of sleep loss during CVEs on performance, mood, and fatigue. These effects have been described in numerous studies (Alluisi and Chiles, 1967; Alluisi and Morgan, 1982; Angus, Heslegrave, & Myles, 1985; Copes, 1972; Haslam, 1981, 1982, 1985; Johnson & Naitoh, 1974; Morgan Management System, Inc., 1984a; Morgan & Coates, 1974; Morgan, Brown, & Alluisi, 1974; Naitoh, 1968, Naitoh et al. 1983; Opstad, Ekanger, Nummestad, & Raabe, 1978; Webb, 1985; Wilkinson, 1964; Williams, Lubin, & Goodnow, 1959). However, at NHRC the major concern has been Sleep Management, determining when and how long soldiers should sleep to maintain optimal performance levels.

The overall experimental design, including mission start-up time and nap variables, is presented in Table 3. The design consists of three factors: mission Start-up Time (0000, 0800, or 1300) x Nap Length (0 hr, 3 hr, 4 hr, or 8 hr) x Exercise (present or absent). A quasi-experimental approach (Campbell & Stanley, 1963; see also Dinges, Orne, & Orne, 1985) was adopted because of limitations in time and funds. These particular treatment combinations were chosen on the basis of their military relevance.

Comparisons between studies 1, 5, and 6 were done to show the influence of different mission Starting Times on performance, mood, fatigue, and physiological variables in both exercising and nonexercising Ss. A comparison of the nonexercising Ss in the studies 1, 2, 3, 4, and 7 was done to indicate the influence of Nap Length on task performance, moods, and fatigue. Comparison of exercising and nonexercising subjects in studies 1, 2, 3, and 4 allowed for the evaluation of the interaction of nap lengths of 0 hr, 3 hr, or 4 hr (8 hr sleep was not studied in exercising subjects) and exercise effects on performance, mood, and fatigue.

3.2 Data Collection Protocol

Figure 2 shows the data collection protocol used for all SUSOP studies at NHRC, with two exceptions. For Study 7 (see Table 3), the CWES (shaded areas of Figure 2) were shortened to accommodate 8 hrs of sleep between the first continuous work (CW1) and the second continuous work (CW2). For Studies 5 and 6, the Starting Time of the CWs were changed to 0000 and 1300 respectively.

Study 1

On Monday (Day 1), two Marines were given graded maximal exercise tests to determine maximal oxygen uptake and heart rate. During the remainder of Monday (Day 1), the Marines were familiarized with the study and trained in various study tasks. One member of each pair was randomly assigned as an exercising subject (S) and the other as a nonexercising S. During the first half hour of each hourly session (WA and A in Figure 2), the exercising S performed the alpha-numeric visual vigilance task while walking on a treadmill wearing full combat gear, including backpack and rifle. The nonexercising subject performed this task while seated in front of a CRT monitor in another room. During the 30 min WB or B sessions, both Marines worked at computer video stations, responding to instructions and prompts for psychological tasks, questionnaires, and physiological measurements.

Treadmill speed for each subject was adjusted to keep heart rate as near as possible to the rate previously determined to correlate with 30% of maximal aerobic power. The baseline experiment started at 0800 Tuesday (Day 2) and ended at 2115. The baseline work segment consisted of 12 one-hr blocks with meal-rest breaks of 30 to 45 mins every four hrs. The exercising S walked on the treadmill for a total of six hours.

The first continuous work period or workday (CW1) began Wednesday (Day 3) at 0800, ending at 0400 Thursday (Day 4), i.e., a 20 hr CWE. After CW1, each S was allowed a 3 hr nap, from 0400 to 0700 Thursday (Sleep 2 of Figure 2). After being awakened, the Ss were given breakfast and then at 0800 the second 20 hr episode of continuous work (CW2) began, ending at 0400 Friday (Day 5). After this the Ss were allowed to sleep until 1200.

Study 2

The basic data collection scheme was identical to Study 1, except that all Ss remained awake continuously from 0700 Wednesday to 0400 Friday, a 45 hr period.

As in Study 1, each member of a pair of the Ss was assigned randomly as either exercising or nonexercising. In Study 2, and in all subsequent studies, open circuit spirometer readings of expired air were monitored during the treadmill exercise and physical workload was adjusted to maintain oxygen consumption at the desired level (30% in Study 2, 40% in Studies 3 and 4).

Study 3

The data collection scheme was identical to Study 1, except that CW1 was started 30 min earlier (0330) and CW2 started 30 min later (0730) to accommodate a 4 hr period of sleep (Sleep 2 of Figure 1).

Treadmill speed was increased and an incline was added, bringing the starting physical workload to 40% of maximal oxygen consumption. The Ss were told that the purpose of walking on the treadmill was to determine the maximal physical workload they could maintain. They were instructed to keep up this work level for as long as they could, but to request an immediate reduction in workload if they were unable to maintain the pace.

Study 4

The data collection scheme was identical to Study 3, except that all Ss remained awake continuously from 0700 Wednesday (Day 3) to 0400 Friday (Day 5), a 45 hr period.

Study 5

The data collection protocol was the same as Study 1. However, the schedule was shifted in time to start CW sessions at midnight (0000) (see Table 4; Midnight group).

On Monday (Day 1), the Ss went to bed early at 2000, and were awakened at 0400 Tuesday (Day 2) after 8 hrs of sleep (Sleep 0 of Figure 2). In preparation for the midnight start of CW1, the Ss went to bed at 1500 on Tuesday and were awakened at 2300 of the same day. After a 1 hr preparatory period including breakfast, the Ss started CW1 at 0000 hour Wednesday (Day 3) and continued to work until 1900 Wednesday. Then, after a 1 hr preparatory period, the Ss had a 3 hr nap from 2000 to 2300 Wednesday. They were awakened at 2300 Wednesday and had a 1 hr preparatory period before they began the second 20 hr episode of continuous work (CW2) at 0000 Thursday (Day 4). The Ss were allowed to have a full 8 hr recovery sleep (2000 Thursday to 0400 Friday) after CW2. Friday (Day 5) was used for a final testing of maximal aerobic power and debriefing.

Elapsed time between one wake-up time to another is usually 24 hrs, representing one day. In Study 5, day length was altered. If we assume that the Ss were awaken at 0500 on Monday morning (Day 1), the length of their first day at NHRC was 23 hrs, and the length of the second day was shortened to 19 hrs. Thus, the Ss in Study 5 experienced a short day, or a phase advance of 5 hrs (analogous to flying from West to East across 5 time zones) before the start of CW1.

Study 6

The basic data collection scheme was identical to Study 1. However, the schedule was shifted to start both CW sessions at noon (1300) (see Table 4, Noon group).

After checking into the NHRC laboratory on Monday (Day 1), the Ss remained awake and worked on the tasks until 0400 of Tuesday (Day 2). Then, the Ss slept from 0400 to 1200 Tuesday. After a 1 hr preparatory period, the Ss began CW1 at 1300 Tuesday and continued to work until 0800 Wednesday (Day 3). This was followed by a 1 hr preparatory period and a 3 hr nap (0900 to 1200). After the nap and a 1 hr preparatory period, the Ss started CW2 which lasted from 1300 Wednesday to 0800 Thursday (Day 4). After CW2, the Ss had 8 hrs of recovery sleep (1100 to 1900 Thursday).

If we assume that the Ss were awakened at 0500 on Monday morning, the length of their first day at NHRC was 31 hrs. Thus, the Ss in Study 6 experienced a long day, or a phase delay of 7 hrs (analogous to flying from East to West across 7 time zones), the day before CW1.

Study 7

The purpose of Study 7 was to determine whether performance of tasks was altered by repetition without any sleep deprivation or exercise. Data collection was identical to Study 1, except that the CWEs were shortened to twelve 1 hr sessions allowing an 8 hr sleep between CW1 and CW2, and no exercise was involved.

3.3 Subjects:

Marine Corps volunteers were obtained for these studies from either Camp Pendleton or the Marine Corps Recruit Depot. All Ss were young physically fit males accustomed to sleep loss and strenuous physical work. Table 1 shows age, pay grade, height, and weight of these Ss. Pay grade represents the number of years a subject has been in the service as well as his level of experience and Marine Corps skills. The nature of the study and the risks involved were explained verbally and given in written form to all Ss prior to their consent to participate. All Ss had the right to withdraw from the study at any time. They were also withdrawn if the attending medical officer and experimenters found the Ss unable to continue (see Table 2 for the number of Ss who began (NBEGIN) and who completed each study (NEND)).

3.4 Mood and Physiological Variables

A computer program was used to administer the following questionnaires and to record the physiological measures. All questionnaire responses and physiological measures were stored on diskette with the time of day for the individual sessions, 1 through 16 or 17, of each day.

The School of Aerospace Medicine (SAM) Subjective Fatigue Checklist, (Pearson & Byars, 1956; Naitoh, 1981) consists of 10 items which were presented one at a time on the video screen, below the instructions on how to enter the response. The Ss had an opportunity to change their response before it was entered to a computer file. The next task was to complete the 29 item NHRC Mood Questionnaire (Moses, Lubin, Naitoh, and Johnson, 1974), which has been found to be sensitive to sleep loss and fatigue (Opstad et al., 1978; Angus et al., 1985).

Following these questionnaires, the Ss were asked to measure and enter oral temperature, systolic and diastolic blood pressure, and grip strengths of the left and right hands separately. Grip strength of each hand was measured with a Jamar hand dynamometer. Oral temperature was measured by an electronic digital thermometer. In the earlier phase of this study, blood pressure was measured with an automatic device which sensed Korotokoff sounds. In the later phases, blood pressure was measured by an experimenter using the auscultation method.

In studies 2, 3, 4, 5, and 6, Borg's Rating of Perceived Exertion (RPE) (Borg, 1978; Pandolf, 1983) was administered to the exercising Ss in the middle of every 30 min session of treadmill walk, 16-17 times per day.

Polygraphic sleep data were obtained from a surface electrode over C3 (and C4 as a spare electrode) of the International 10-20 System, and outer canthi of the left and right eyes, all referred to the linked mastoid lead.

Polygraphic sleep data were recorded on paper, and they were manually scored for sleep stage, based on the sleep scoring manual by Rechtschaffen and Kales (1968).

3.5 Descriptions of Tasks

The NHRC Performance Assessment Battery (NHRC PAB) was developed to evaluate a wide range of psychomotor and cognitive capabilities necessary for military personnel to accomplish assigned jobs. NHRC PAB consists of 12 psychological tests. Tasks were chosen on an empirical basis of sensitivity to sleep loss and fatigue (e.g., Wilkinson, 1964; Naitoh, 1968, 1981; Naitoh & Townsend, 1970; Williams, Lubin, & Goodnow, 1959).

Psychomotor tasks in the NHRC PAB: Three of these tasks correspond to Donder's model of reaction time types (see Grice, Nullmayor and Spiker, 1982): (1) simple reaction time (SRT; in the present study, Simple Reaction Time task; stimulus detection followed by response), (2) disjunctive reaction time (DRT; in the present study, alphanumeric visual vigilance task; stimulus detection followed by sensory discrimination and response), and (3) choice reaction time (CRT; in the present study, four choice serial reaction time task; correct choice or response selection added to DRT). The fourth task of tapping (Two Response Alternation Performance) primarily measured motor response speed and consistency without stimulus detection.

Cognitive tasks in the NHRC PAB: These include Baddeley's logical reasoning task, Williams auditory memory task, Educational Testing Service visual memory test, Gates-Peardon reading exercise, Miller Reading Efficiency test, and Air Defense Game. Details of these cognitive tests and of the effects of sleep loss on these tests were given in papers by Englund et al. (1983, 1985).

In this report, the results of the following tests are discussed:

(1) Two Response Alternation Performance (TRAP): The TRAP task is a six minute task designed by Humphreys which has been used in a gradual sleep reduction study by Friedmann, Globus, Huntley, Mullaney, Naitoh and Johnson (1977) and in a series of sleep deprivation studies reported by Naitoh (1982). The Ss alternately tapped two 1 inch response buttons with their eyes closed. They are instructed to tap as rapidly as they can while keeping a regular rhythm. If the interval between taps exceeded 2.5 sec (i.e., a lapse in attention) a buzzing noise was given to the Ss through a headphone.

A scoring program analyzed the diskette stored data, giving the number of button presses each minute and the total number of presses over 6 min for each

S. Means and standard deviations for the slowest 10% and fastest 10% intervals between taps for each session, and the number of attentional lapses were calculated and the results stored in disks.

(2) Visual Simple Reaction Time Task SRT: Simple reaction time has been used in previous sleep loss research (e.g., Herscovitch and Broughton, 1981). The simple reaction time (SRT) task, initially developed by Lisper and Kellberg (1972) for an auditory signal, was modified to use a visual signal. The Ss were told to press any key on the keyboard the moment they saw numbers appearing on the video monitor. The numbers represented time elapsed since the numeral zero appeared on the screen, increasing by one for every 10 msec elapsed time. The number stopped increasing when any key was pressed, or at 250 (i.e., 2.5 sec after the start) when a warning bell was sounded for an error of omission. The response time remained on the screen for 0.5 sec, providing feedback to the Ss. There were 60 randomly spaced trials. Intervals between trials varied randomly from 1 to 11 sec, the mean interval being 6 sec. The scoring program listed all reaction times and calculated the means and standard deviations of the 60 reaction times, the 6 fastest and 6 slowest. It also obtained the number of inter-response intervals which were less than 2.5 sec, and the number of inter-response intervals longer than 2.5 sec, i.e., lapses of attention. SRT was administered 16 or 17 times each workday.

(3) Alpha-numeric Visual Vigilance Task: In this task (Hord, 1982), a single, randomly selected alphabetical character or number was presented on the screen at random time intervals ranging from 6 to 14 sec, with a mean interval of 10 sec. The number or character remained on the screen for 10 msec. The Ss were instructed to press a hand held button with their thumb every time an A or 3 (the signal stimuli) appeared. An error of omission was declared when response to an A or a 3 was not made within 5 sec. This task lasted for 30 min, during which 20 signal stimuli were randomly mixed with 160 stimuli of nonsignal numbers and letters. As was previously noted, this visual vigilance task was given to the exercise S while he walked on a treadmill, and the other S performed the task while seated in front of a video terminal.

The scoring program for the visual vigilance task listed the number of responses per 30 min session, the number of correct responses (button presses following an A or a 3), errors of omission, and errors of commission. The means and standard deviations for the correct responses, the five slowest correct, and five fastest correct responses were also printed out, along with the percent-correct detection. In calculating a mean reaction time, errors of omission were arbitrarily regarded as reaction times of 5 sec. The Alphanumeric Visual Vigilance Task was administered 16 or 17 times each workday.

(4) Four-choice Serial Reaction Time Task (Four Choice Task): This task was described by Wilkinson and Houghton (1975) and has been used in previous sleep loss research (e.g., Glenville, Broughton, Wing, & Wilkinson 1978; Naitoh, 1981). A blinking "+" (plus sign) is presented in one of the four quadrants of a computer monitor screen. The Ss pressed one of four buttons on the terminal keyboard corresponding to these quadrants (upper left, upper right. lower left, and lower right). The blinking "+" remained in a quadrant until one of the buttons was pressed and then it randomly reappeared in another quadrant or stayed in the same position. If none of the four buttons were pressed in 2.5 sec, a bell sounded until a response was made. This task lasted 7 min. The Ss were instructed to respond as accurately and as quickly as possible.

The scoring program calculated the means and standard deviations for all correct responses, the fastest 10% and slowest 10% correct responses, and the incorrect responses. It counted the number of correct and incorrect responses and lapses and calculated the percent-correct responses. Four Choice was given 5 or 6 times in each workday (every 3 hours).

(5) Logical Reasoning Task: This task was devised by Baddeley (1968), recently evaluated by Carter, Kennedy, and Bittner (1981), and has been used extensively in sustained operations research (Haslam, 1981, 1982, 1983; Thorne, Genser, Sing and Hegge, 1983). The task consists of random presentation on a video screen of one of 16 sentences followed by a pair of letters (AB or BA). The Ss were told to type the numeral one if the sentence was a true description of the letter pair (i.e., "A follows B" BA) and the numeral two if the sentence incorrectly described the letter pair (i.e., "A is preceded by B" AB). After the S pressed a 1 or 2 key, the response was displayed next to the sentence letter pair. If a S changed his mind, he could delete the response and enter another. When the S thought that the response was correct, he entered the response into a computer file by depressing the ENTER key, at which time the next sentence-letter pair appeared. At the end of the 3 min task, the sentence-letter pairs given and the subject's responses to each pair were stored on the floppy disk.

The scoring program counted the number of sentence-letter pairs attempted, the number correct, and calculated the percent correct. The Logical Reasoning Test was given 16 or 17 times each workday.

(6) Williams Auditory Word Memory Test: This test, devised by Williams, Gieseking, and Lubin (1966), is a short term memory test involving the presentation of 36 tape recorded lists of 15 words each. Three lists were presented each time the task was performed. Each word was announced, spelled, and then repeated. The Ss were instructed to write the word as soon as they heard it. The next word followed immediately after the second presentation of the previous word. As soon as the S wrote down the last word, he was given a recall sheet for writing down all the words he could remember in any order. Two minutes were allowed for recall of each list. The number of correct words recalled was recorded and expressed as a percentage of the total. The Word Memory test was given four times each workday.

3.6 Statistical Analyses

Tables and Figures presenting statistical findings are provided in the Apendix. The exact probability of each F ratio has been given in the text to facilitate interpretation of observed differences, instead of calculating Bonferroni critical value for multiple F tests (Harris, 1976). Sometimes the exact probability is listed as $p = 0.0000$, indicating it was smaller than 0.00%. In the present study, the level of significance was set at 5% or less. Whenever necessary, a conservative test was used (Geisser & Greenhouse, 1958; Huynh & Feldt, 1976; Winer, 1971).

If more than one third of a subject's data in any task was lost due to equipment failures and/or scheduling problems, that subject's data were dropped from further statistical analyses. Therefore, there are small differences in the subject number among the tasks in each statistical analysis.

The reaction time of the slowest 10% responses of each session was used in this study, because Williams et al. (1966), Lisper & Kjellberg (1972), and our studies (Englund et al., 1985; Naitoh et al., 1982, 1983) have found this measure to be the most sensitive to sleep loss effects.

Statistical analyses were designed to evaluate the following two questions:

(1) What is the influence of a Starting Time (Morning, Noon or Midnight) and Exercise on performance and mood?

Four factor analysis of variance (ANOVA) was used. The factors were Exercise, Starting Time, Workday, and Session, where Workday and Session were repeated measure factors. Starting Time had three levels: Morning, Noon, and Midnight. Exercise had two levels: exercise and nonexercise conditions. The Workday had two levels: the first continuous workday (CW1) and the second continuous workday (CW2). In the statistical analyses, the Ss were regarded showing performance and mood unaffected by sleep loss and fatigue during the CW1 as it followed an 8 hr sleep. The factor of Session consisted of 4 to 17 repetitions per workday, depending on a task. In ANOVA, either the data from the first and last session of each workday, or the means of the first 4 and last 4 sessions of each workday were used. The data from the Ss in Studies 1, 5, and 6 were used for this evaluation (see Table 3). All Ss had a 3 hr nap after CW1 and before the start of CW2.

(2) What are the effects of a Nap Length (0 hr, 3 hrs, 4 hrs, or 8 hrs) on performances and mood of the exercising and nonexercising Ss?

(a) Three or four factor ANOVAs were used. The factors were Nap Length, Workday, Session, and sometimes Exercise. Again, Workday and Session were repeated measure factors. Data from the Ss in Studies 1, 2, 3, and 4 were used for evaluating the effect of a nap length on performance and mood of the exercising Ss, while data from Studies 1, 2, 3, 4, and 7 were used to evaluate effects of a nap length on the nonexercising Ss. All the Ss in this analysis had the same Starting Time (0800).

(b) Univariate ANOVA with repeated measures was used as an omnibus statistical evaluation (Dixon, 1983; Geisser & Greenhouse, 1958; Huynh & Feldt, 1976; Winer, 1971). Where an ANOVA showed significant group mean differences, Tukey Honest Significant Difference (HSD) was run to indicate which groups were significantly different.

(c) The performance and mood differences between the two workdays were calculated for each session by subtracting CW2 from CW1 scores. The differences in performance and mood were expected to be near zero for those who slept for 8 hrs before the start of CW2 (the Ss in the control group of Study 7), because an 8 hr sleep should have given full recovery from the fatigue of CW1. In contrast, those who had either no sleep or 3 hr sleep were expected to show large changes reflecting the degree of performance and mood degradation during CW2.

The CV1-CV2 differences should show when and if those who slept less than 8 hrs began to show greater degradation (i.e., larger differences) than those who slept for 8 hrs. BMDP One Way Analysis (Dixon, 1983) was used to compare the difference scores of the 8 hr sleep Ss with those of the other groups on the Simple Reaction Time test, Alpha-numeric Visual Vigilance test, SAM Subjective Fatigue Checklist, and NHRC Positive Mood Scale. Hotelling's T-squared test was also calculated for overall evaluation of all session differences; t-ratios for each of the 12 sessions were then calculated.

3.7 Graphical Analysis

Figure 1 and odd numbered figures 5-25 show local time on the abscissa. Since some groups started their workday in the Morning (0800), while the others started their workday at Noon (1300) or Midnight (0000), the figures show the data starting from different locations on the abscissa of the graphs. This graphic presentation corresponds to what Morgan and Coates plotted in their 1974 paper (Figure 1). These figures illustrate the influence of time-of-day over performance and mood.

Another important question in this study was how well Ss in the Morning, Noon, or Midnight group could perform the tasks when they had been on-the-job for various periods of time (e.g. 5, 10, or 15 hours) continuously. A second set of graphs (even numbered Figures 6-26) was prepared to ease comparisons of the performance and mood of the Ss in Morning, Noon, and Midnight groups on the basis of how long Ss were on-the-job, disregarding the time-of-day effect.

These two sets of graphs were prepared on performance scores for each task and mood scale values. Each graph showed data from 8 groups:

(1) NOON start time, 3 hrs NAP, no exercise control (CNT) group [Study 6];

(2) NOON, NAP, EXercise group [Study 6];

(3) MIDNIGHT start time, 3 hrs NAP, CNT group [Study 5];

(4) MIDNIGHT, NAP, EX group [Study 5];

(5) 8AM, start time, RESTing but no sleep allowed, CNT group [Study 2];

(6) 8AM, REST, EX group [Study 2];

(7) 8AM, NAP, CNT group [Study 1]; and

(8) 8AM, NAP, EX group [Study 1].

3.8 Analysis of Interaction

When an interaction term in ANOVA is significant, tneoretical interpretation of the results becomes complex, because each of the main factors need to be examined at each level of the interacting factor. A significant interaction means that the main factors may affect performance and mood, only in combination with particular levels of another main factor (Lubin, 1961; Kopell, pp. 182-185, 1973).

Special efforts were made to understand significant two factor interactions, although both of the main effects were not significant. The presence of a significant interaction with nonsignificant main effect means that the performance or mood results differed significantly between the factor groups over the repeated time intervals (days or sessions), but when the data were averaged across time (main effects) differences cancelled out. To interpret such significant interactions, separate ANOVAs were calculated for different levels of the interacting repeated measure. Also an interaction was examined in terms of the treatment functions and their preservation of ordinality (Lubin, 1961).

4. NHRC RESEARCH ON SUSOPS: RESULTS

4.1 Impact of Starting Time and Exercise on Performance and Mood (Studies 1, 5, and 6; Table 3)

Data from 56 Ss were available for the assessment of impact of Starting Time and Exercise on performance and mood (Table 2).

4.1.1 Simple Reaction Time Task (Studies 1, 5, and 6; see Table 3)

Table 5 presents the means and standard deviations. Figures 5 and 6 are graphs of the time-of-day and time-on-the-job results, respectively. An ANOVA on the data of the slowest 10% reaction times observed during the first and last 4 sessions of both workdays, CW1 and CW2 indicated that (1) exercising Ss were significantly slower than control Ss ($F(1/48) = 7.00$, $p = 0.0118$), and (2) the influence of Starting Time was not significant. However, a significant interaction, Session x Starting Time ($F(1/24) = 6.07$, $p = 0.0213$), was found. An occurrence of this significant interaction was anticipated because no performance differences were expected between the first 4 sessions of CW1 and of CW2, as all subjects in the Morning, Noon, and Midnight groups should have been equally refreshed upon termination of sleep or rest; only during the last sessions of CW1 and CW2 were the effects of Starting Time on the rate of fatigue buildup expected.

To better define this interaction, additional ANOVAs of Starting Time x Workday (3 x 2) design were calculated. An ANOVA using the averages of the first 4 sessions of CW1 and CW2 showed that Starting Time did not affect performance. However, a similar analysis using the last 4 sessions of the workdays, showed that Starting Time was a significant factor ($F(2/48) = 3.39$, $p = 0.0148$). Thus, the subjects in the Morning, 8AM, Noon, and Midnight groups all started the early sessions of CW2 sessions at a similar level. However, as Ss neared the end of CW2, the reaction time of Ss in the Noon exercising group slowed down significantly than those who were in the 8AM or Midnight exercising groups.

4.1.2 Four Choice Task (Studies 1, 5, and 6)

Both the slowest 10% reaction time and the percent correct measure were used to evaluate the performance of the Four Choice Task.

(A) 10% Slowest Responses Measure

Table 6 presents the means and standard deviations. Figures 7 and 8 are graphs of the time-of-day and time-on-the-job results. An ANOVA using only the first and last sessions of both workdays revealed that (1) Exercise slowed responses ($F(1/46) = 24.98$, $p = 0.0000$), and (2) Starting Time slowed responses ($F(2/46) = 5.26$, $p = 0.0087$), with the Noon group having the slowest responses.

(B) The percent correct

Table 7 presents the means and standard deviations. Figures 9 and 10 show the time-of-day and time-on-the-job graphs. An ANOVA using the first and last session of both workdays indicated that (1) the exercising Ss did worse than the nonexercising Ss ($F(1/46) = 4.82$, $p = 0.0333$), and (2) Starting Time influenced the percent correct ($F(2/46) = 4.68$, $p = 0.0141$), with the Noon group having the lowest percent correct.

4.1.3 Alpha-numeric Visual Vigilance Task (Studies 1, 5, and 6)

Table 8 presents the means and standard deviations of % correct measure. Figures 11 and 12 are graphs of the time-of-day and time-on-the-job results for percent correct scores. An ANOVA using the first 4 and last 4 sessions of each workday indicated that (1) there were no differences between the exercising and nonexercising Ss, and (2) Starting Time influenced the percent correct scores ($F(2/42) = 5.16$, $p = 0.0099$), with the Ss in the Morning group having the lowest percent correct during the last 4 sessions of CW2.

4.1.4 Logical Reasoning Task (Studies 1, 5, and 6)

Table 9 presents the means and standard deviations of the percent correct. Figures 13 and 14 are graphs of the time-of-day and time-on-the-job results, respectively. An ANOVA of an Exercise x Starting Time x Workday x Session design showed (1) Exercise did not influence the scores and (2) different Starting Times did not alter performance.

4.1.5 Word Memory Task (Studies 1, 5, and 6)

Table 10 shows the means and standard deviations of % correct recall. Figures 15 and 16 show the time-of-day and time-on-the-job graphs respectively. An ANOVA using the data from the first and last sessions of each workday showed (1) Exercise Ss did not differ significantly from Control Ss, and (2) Starting Time did not influence performance. However, there was a significant two way interaction of Session x Workday and a triple interaction of Starting Time x Sessions x Workday.

To understand the nature of these interaction terms, two additional ANOVAs of Starting Time x Workday design were run to evaluate the data from (1) the first session of CW1 and CW2, and (2) the last session of CW1 and CW2. An ANOVA of the data from the first session showed that none of the main effects were significant, but it found a significant interaction term of Starting Time x Workday ($F(2/49) = 3.86$, $p = 0.0277$). The Ss in the Morning group showed the lowest percent correct recall during CW2 in comparison with the Ss in the Noon and Midnight groups. The second ANOVA over the last session of CW1 and CW2 again showed that no main effects were significant, but Workday x Starting Time interacted significantly ($F(2/47) = 4.53$, < 0.0159). The Ss in the Midnight group had the best percent recall during CW2. Thus, Exercise had no effect and Starting Times influence was clear only during the second Workday.

4.1.6 NHRC Positive Scale/NHRC Negative Scale (Studies 1, 5, and 6)

Table 11 has the means and standard deviations of the positive scale values. Figures 17 and 18 are graphs of the time-of-day and time-on-the-job results, respectively. An ANOVA using the data from the first 4 and last 4 sessions of each workday showed that there were no differences between the Exercise and Control groups, nor between the Starting Time groups.

NHRC Negative Scale (Studies 1, 5, and 6; see Table 3)

Table 12 presents the means and standard deviations of the negative scale scores. Figures 19 and 20 are graphs of the time-of-day and time-on-the-job results. An ANOVA using data from the first 4 and last 4 sessions indicated that (1) Exercise did not influence mood score, and (2) Starting Time did not influence mood score. However, two interaction terms, Session x Starting Time and Workday x Session were significant. A Starting Time X Exercise ANOVA using the data from the first 4 sessions of CW1 and CW2 again showed no effects from (1) Starting Time or (2) Exercise. A similar ANOVA using the last 4 sessions of CW1 and CW2 (Figure 33) showed that Starting Time significantly influenced negative mood scores ($F(2/50) = 8.91$, $p = 0.0005$). The Ss in the Noon group had the greatest increase in negative scores in comparison with the other groups during the last sessions of CW2.

4.1.7 SAM Subjective Fatigue and Borg's RPE (Studies 1, 5, and 6)

Table 13 presents the means and standard deviations of scale values. Figures 21 and 22 are graphs for the time-of-day and time-on-the-job results, respectively. An ANOVA using the data from the last 4 sessions of CW1 and CW2 showed that (1) Exercise had no influence, and (2) Starting Time also did not affect the scores. However, there were two significant interactions, Starting Time x Sessions and Workday x Sessions. An ANOVA of an Exercise x Starting Time x Workday design using the data from the first 4 sessions of each day showed that only the Workday factor was significant ($F(1/50) = 20.55$, $p = 0.0000$). However, a similar ANOVA using the data from the last 4 sessions of each day showed that Starting Time influenced the scores ($F(2/50) = 5.14$, < 0.0094). The Ss in the Noon group showed the largest fatigue scores. The exercised Ss did not differ significantly from the nonexercising Ss in either ANOVA.

Rating of Perceived Exertion (Studies 1, 5, and 6)

Borg scale of Rating of Perceived Exertion (RPE) was given only to the exercising Ss (see Table 14 for the means and standard deviations). Figures 23 and 24 are graphs of the time-of-day and time-on-the-job results, respectively. An ANOVA using the data from the first and last four sessions of each workday showed that Starting Time did not influence RPE scores, but two interactions, Session x Stating Time and Starting Time x Workday were significant. However, a Starting Time x Workday ANOVA using the first four sessions of each workday and a similar ANOVA using data in the last four sessions of CV1 and CV2 both showed no effect of Starting Time on the RPE scores.

4.1.8 Task of Response Alternation Performance (Studies 1, 5, and 6)

Table 15 has the means and standard deviations of reaction time and errors of omission. Figures 25 and 26 are graphs of the time-of-day and time-on-the-job results, respectively. An ANOVA using the first and last sessions of each workday showed that Exercise and Starting Time had no a main effects on TRAP performance. However, a separate ANOVA using reaction time data from the sessions, 1, 4, 7, 10, 13, and 16 of each workday indicated that the Exercise Ss were significantly slower than the Control (nonexercising) Ss ($F(1/48) = 5.31$, $p = 0.0255$). Starting Time still showed no main effect on TRAP performance. Session significantly interacted with Starting Time, indicating that the influence of Starting time on TRAP performance depended on which sessions were being examined.

4.1.9 Summary

Simple Reaction Time, Four Choice, Alpha-numeric Visual Vigilance, NHRC Negative Scale, and SAM Fatigue were affected by the Starting Time of a continuous workday. The Ss in the Noon group showed the worst degradation of performance, mood, and fatigue in comparison with the Ss in the other 2 groups. However, Starting Time generally affected performance scores during a limited number of sessions (i.e., the last 4 sessions of each workday).

The Exercise Ss in the Noon group showed the largest degradation in performing Simple Reaction Time and Four Choice. They showed also the largest negative mood and fatigue scores as measured by NHRC Negative Scale and SAM Subjective Fatigue Checklist. The subjects in the Morning group showed the lowest percent correct on the Alphanumeric Visual Vigilance and Word Memory tests.

4.2 Impact of Nap Length and Exercise on Performance (Studies 1, 2, 3, and 4)

Data were available on 70 Ss for the study of impact of Nap Length (3 levels; 0, 3, or 4 hrs) and Exercise (30% and 40% of maximal oxygen consumption combined, compared with nonexercising Ss) on performance (Table 2).

4.2.1 Simple Reaction Time Task (Studies 1, 2, 3, and 4)

The 10% slowest response measure was used (see Table 16 for the means and standard deviations). An ANOVA using the data from the first four sessions and the last four sessions of each workday revealed that (1) Nap Length did not influence reaction time, but (2) Exercise did ($F(1/48) = 6.70$, $p = 0.0127$). The exercising Ss were slower than nonexercising Ss.

4.2.2 Four Choice Task (Studies 1, 2, 3, and 4)

Both the slowest 10% reaction time and percent correct measures were used to evaluate performance of the Four Choice Task.

(A) Analysis using 10% slowest response measure.

Table 17 presents the means and standard deviations of 10% slowest response measure. An ANOVA using data from the first and last session of CW1 and CW2 showed that (1) Exercise significantly influenced reaction time ($F(1/50) = 10.96$, $p = 0.0017$) (i.e., the exercising Ss were slower than the nonexercising Ss), and (2) Nap Length did not affect reaction time.

(B) Analysis using % correct measure.

Table 18 presents the means and standard deviations of percent correct measure. An ANOVA using data from the first and last session of CW1 and CW2 showed that (1) Exercise had no effect, and (2) Nap Length had no effect. However, 3 two-way interaction terms were significant: Sleep Length x Workday, Sleep Length x Session, and Workday x Session. An ANOVA of an Exercise x Sleep Length x Workday design using the data from the first session of CW1 and CW2 showed no main effects. However, a similar ANOVA using the data from the last session of each workday showed that (1) Nap Length significantly influenced performance, i.e., the Ss in 4 hr nap group showed the lowest percent correct ($F(2/50) = 4.65$, $p = 0.0141$), and (2) Exercise did not affect performance. Thus, exercise did not affect task performance at all and Nap Length affected performance only during the last session of CW2.

4.2.3 Alpha-numeric Visual Vigilance Task (Studies 1, 2, 3, and 4)

Table 19 presents the means and standard deviations of percent correct measure. An ANOVA using the data from the first 4 and last 4 sessions of each workday showed that (1) Sleep Length did not influence performance, and (2) Exercise did not affect task performance. None of the interaction terms were significant.

4.2.4 Logical Reasoning Task (Studies 1, 2, 3, and 4)

Table 20 presents the means and standard deviations of percent correct measure. An ANOVA using data from the first and last sessions of each workday showed that none of the main effects or interactions were significant.

4.2.5 Word Memory Task (Studies 1, 2, 3, and 4)

Table 21 presents the means and standard deviations of the percent correct recall measure. An ANOVA using the percent correct recall data from the first and last sessions showed that neither Nap Length or Exercise had an influence. However, 3 interactions were significant: Nap Length x Workday, Workday x Exercise, and Session x Workday. An ANOVA of an Exercise x Nap Length x Workday design was applied to data from the first session during CW1 and CW2. The results showed that none of the main effects and interactions were significant. However, a similar ANOVA using data from the last session of each workday showed that Nap Length interacted with Workday ($F(2/47) = 6.13$, $p = 0.0043$). These results showed that the influence of Nap length depended on workday and session within each workday. Exercise had no effect on short term word memory.

4.2.6 NHRC Positive Scale/NHRC Negative Scale (Studies 1, 2, 3, and 4)

Table 22 presents the means and standard deviations of the positive scale values. An ANOVA using the data from the first 4 and last 4 sessions of both CW1 and CW2 showed that neither Exercise nor Sleep Length had a significant influence. However, Nap Length interacted with Session. An ANOVA using the first four sessions of CW1 and CW2 showed that Nap Length and Exercise did not influence mood scores. A similar ANOVA using the data from the last session of each workday showed that the only significant effect was from Workday.

NHRC Negative Scale (Studies 1, 2, 3, and 4).

Table 23 has the means and standard deviations of the negative mood data from the first four and last four sessions which were used for ANOVA. The ANOVA showed no effect from Exercise or Nap Length. However, interactions of Nap Length x Session and Workday x Session were significant. An ANOVA of an Exercise x Nap Length x Workday design using the first 4 sessions of data from both workdays showed that only Workday influenced mood scores. The Ss during CW2 had greater negative scores than during CW1. A similar ANOVA using the data from the last 4 sessions of both CW1 and CW2 showed that (1) the influence of Exercise was not significant, but (2) Nap Length affected the scores ($F(2/52) = 3.91$, $p = 0.0262$).

4.2.7 SAM Subjective Fatigue Checklist (Studies 1, 2, 3, and 4)

Table 24 has the means and standard deviations for the SAM scale data from the first and last sessions of CW1 and CW2. An ANOVA of these sessions showed that the influence of Exercise and Nap Length was not significant. None of the interaction terms was significant.

4.2.8 Summary

No overall effects on performance, mood, or fatigue were observed during CW2 from varying nap length from 0 hr, to 3 hr, or 4 hr. The only differences between the nap groups were that the Ss in the 4 hr nap group (not the 0 hr nap group) had the lowest Four Choice Task and word memory scores during the last session of CW2. The exercising Ss showed more response slowing in SRT and Four Choice task than the nonexercising Ss, but other task performances and mood/fatigue scale values were similar with and without exercise.

4.3 Impact of Nap Length on Performance (Studies 1-4 and 7)

The influence of Nap Length on task performance, mood, and fatigue was evaluated using the data from the nonexercising control Ss in Studies 1, 2, 3, 4, and 7 (Table 3). All of the Ss in these studies started both workdays (CW1 and CW2) at 0800. Data on 43 Ss were available.

The one way procedure with Tukey's Honestly Significant Difference (HSD) (SPSS, 1983) was applied to the difference score obtained for each session by subtracting each subject's CW1 value from his CW2 value (d = CW2-CW1). A percent change score was defined as the difference score divided by CW1 value and multiplied by 100 (d/CW1 X 100). The means for CW1, CW2, and percent change are listed in Tables 25 and 26.

4.3.1 Simple Reaction Time Task (Studies 1-4 and 7)

Figure 26 shows a 4 point moving average graph of the percent change scores over 12 sessions of 4 groups: 0 hr, 3 hr, 4 hr and 8 hr sleep. The effect of Nap length on performance was significant ($F(3/33) = 6.67$, $p = 0.0012$). Tukey's HSD indicated that SRT reaction times of the Ss in the 0 hr nap group were slower than those of the Ss in the 3 hr or 8 hr nap groups.

4.3.2 Four Choice Task (Studies 1-4 and 7)

(A) Analysis using 10% slowest response measure.

Nap Length affected performance ($F(3/34) = 6.5891$, $p = 0.0012$). Tukey's HSD indicated that Four Choice performance of the 8 hr sleep Ss was significantly better than that of the 0 hr and 4 hr nap groups. However, Sheffe's test showed the 8 hr sleep Ss to be faster than the 0 hr sleep Ss only. This test suggested that performances of the 3 hr and 4 hr nap groups were located in the middle of the performance range between the 8 hr and 0 hr sleep groups, and were not significantly different from either of those groups.

(B) Analysis using Percent Correct measure.

Nap length significantly affected the % correct (F(3/34) = 4.04, p = 0.0146). Tukey's HSD and Sheffe's test both indicated that Four Choice performance of the 8 hr sleep group was better than that of the 4 hr sleep group.

4.3.3 Alpha-numeric Visual Vigilance Task (Studies 1-4 and 7)

Figure 27 shows the change scores of (CV2-CV1) observed in Ss of the 0 hr, 3 hrs, 4 hrs, and 8 hrs sleep groups at each session over the 12 sessions. The groups differed significantly (F(3/32) = 6.30, p = 0.0018). Tukey's HSD indicated that the 8 hr sleep group performed better than the 0 hr and 3 hr nap groups.

4.3.4 Logical Reasoning Task (Studies 1-4 and 7)

Nap Length did not affect performance.

4.3.5 Word Memory Task (Studies 1-4 and 7)

Nap Length did not effect short term memory performance.

4.3.6 NHRC Positive Scale (Studies 1-4 and 7)

Figure 28 shows a 4 point moving average graph of the percent change scores over 12 sessions of 4 groups: 0 hr, 3 hr, 4 hr and 8 hr sleep. The positive scale scores did not differ between these groups. NHRC Positive Scale differences between the 8 hr sleep and 3 hr nap group were evaluated first by Hotelling's T-squared test, and then by repeated t-tests for each of twelve sessions. Hotelling's T-squared was not significant, indicating that the 3 hr sleep Ss felt as positive as the 8 hr sleep Ss.

4.3.7. SAM Subjective Fatigue (Studies 1-4 and 7)

Figure 29 shows a 4 point moving average graph of the change scores over 12 sessions of 4 Nap Length groups. Nap Length did not affect fatigue ratings. Hotelling's T-squared test showed that SAM Subjective Fatigue Checklist ratings of the 8 hr sleep and 3 hr nap group did not differ.

5. DISCUSSION

A purpose of this series of studies was to produce a field manual for managing sleep and rest of workers on irregular work schedules (see Appendix). In our previous studies (Englund et al., 1983, 1985; Naitoh et al., 1982, 1983), we focused on optimal duration of recovery sleep and the best time for sleep. We found that soldiers need to sleep for at least 3 hrs per 24 hr period to maintain baseline performance. We recommended that, after a prolonged continuous work period, short naps during 0300-0700 should be avoided because they are followed by profound and lasting sleep inertia. However, naps at other time periods of the day were beneficial. Planners for combat scenarios could utilize our findings to maximize performance of available personnel and to extend human effectiveness beyond the usual range. In actual field operations, conditions may change unexpectedly, preventing personnel from complying with the preplanned work/rest schedules. In this situation, the field commander should do the sleep management analysis to adjust for the unexpected changes.

Results from our studies as well as studies by others (Dinges, et al., 1985; Dinges, Orne, Evans and Orne, 1981; Haslam, 1982; Rosa, Bonnet and Warm, 1983; Taub, 1982; Wilkinson, 1963) have suggested that any amount of sleep would always have some benefit on task performance and mood. However, we found that short recovery sleeps after a long period of continuous work sometimes produced performance decrements lasting for many hours. For example, a short 2 hr nap taken around 0400-0600, after a 45 hr CWE, did not refresh sleep-deprived subjects (Naitoh et al., 1981). Those who slept were worse off than those who remained awake. These aftereffects of 2 hr and 3 hr naps have been discussed fully in a report by Naitoh et al. (1983).

The present report added a critical chapter in sleep management by examining the influence of Starting Time on task performance, mood, and fatigue. Not all military missions begin at 0800. Morgan and Coates (1974) studied three starting times: 0600, 1400, and 2200. In their study one CW of 36 hr duration was examined. They stated that "distinctly different (performance) functions were obtained for the three start times," and that "clearly, minimum performance decrements were experienced by the group that began continuous work at 1400 hours (on the average). The largest decrement (approximately 34%) was experienced by the 2200 group that was working during the early morning hours at the end of their 36 hr period." (Morgan & Coates, 1974, p. 18).

The present report presents results from two other Starting Times, Noon (1300) and Midnight, using two 20 hr CWES separated by a 3 hr nap. The results showed that the Ss in the Noon group had the largest performance degradations, compared with the Morning and Midnight Ss, in the tasks of Simple Reaction

Time, Four Choice, and Alpha-numeric Visual Vigilance. The Noon Ss also showed larger negative mood scores and greater fatigue scores than the Ss in the Morning and Midnight groups. In contrast, the Morning group had the lowest number of percent correct results on the Word Memory task, while the Midnight group had the highest number.

Our observations differ from those of Morgan and Coates (1974). They found that the Ss who started an extended work period at 1400 showed a minimal performance deterioration compared with Ss in 0600 or 2200 start groups. The protocols of the two studies differ a great deal. The present study contained two 20 hr CWEs separated by a 3 or 4 hr nap, whereas Morgan and Coates' Ss remained awake and worked straight through for 36 hours. Also, the present study included exercising Ss. These factors may have contributed to the differing results.

From a circadian point of view (Aschoff, Giedke, Poppel and Wever, 1972; Morgan and Coates, 1974; Moses, Lubin, Naitoh and Johnson, 1978; Naitoh, 1982), the deterioration of performance and mood in the Ss in the Noon group of the present study makes sense. This group's work schedule was such that the end of the 20 hour CWE fell near the circadian trough. The Ss in the Noon group in our study had been on-the-job for 15 hrs when they entered the circadian trough zone of 0400-0700. The fact that Ss in Morgan and Coat's "midnight" group showed the largest performance decrement as they worked during the early morning at the end of a 36 hr period (1974) also suggests the importance of the interaction of time-on-the-job and time-of-day.

Another possible explanation of the deterioration among the Ss of the Noon group could be poor sleep before the start of CW1 and CW2 because they were forced to sleep at an unaccustomed time-of-day (0400-1200, Table 4). However, the results of sleep stage analysis showed that the Ss in the Noon group slept well (Table 27). The sleep efficiencies of the Morning, Noon, and Midnight groups did not differ significantly.

The most surprising finding of the present studies was the influence of Exercise on Simple Reaction Time and Four Choice (in terms of both percent Correct and 10% Slowest measures). Exercise resulted in slowed reaction times and in increased inaccuracy of response. Exercise may have contributed to increased feelings of fatigue and sleepiness during post-exercise periods when Ss were tested. An examination of data suggested that much of the response slowing was due to an increased number of lapses or errors of omission, i.e., failure to respond to command in a timely manner (Tables 5, 6, and 15).

It is important to sleep management to know the minimal hours of sleep per 24 hr period required to maintain an acceptable level of performance. Results from Haslam (1981) support a requirement of more than 3 hours of sleep per 24 hr period for recovery of all task performances. We found that a 4 hr nap was not sufficient to maintain the baseline level of performance, especially during the last few sessions of CW2. There were no clear differences in performance, mood, and fatigue between the Ss in the 3 hr and 4 hr nap groups. These results and a literature survey (see Naitoh, 1981) suggest that a nap period longer than 4 hrs is required to allow Ss to continue working at baseline level during a second 20 hr CWES.

It could be theorized that some of the behavioral changes are a reflection of changes in the circadian rhythm of body temperature. However, Aschoff, Fatranska, Gerecke, and Giedke (1974) reported that the sleep loss did not change circadian rhythm. Also Murray, Williams, and Lubin (1958) have noted that, although average body temperature decreased over the course of sleep deprivation, the circadian rhythm of body temperature remained intact. Figures 3 and 4 show intact oral temperature of 8 groups on the time-of-day and time-on-the-job graphs. Statistical analysis of the means and standard deviations (Table 28) showed that Starting Time, Exercise, and Workday did not influence oral temperature.

6. SUMMARY

Strictly speaking, the following conclusions apply only to the specific laboratory simulated SUSOP used at NHRC. However, to some degree, they should be applicable to Sleep Management in general.

1. The Starting Time of a mission can critically affect performance, mood, and fatigue. Starting Time should be chosen so that an end of CWE will not coincide with the circadian trough because of the deleterious effects of the interaction of time-on-the-job with time-of-day.

3. Soldiers who work for 20 hrs continuously and then sleep for 3-4 hrs may experience up to a 30% degradation in performance, poorer mood, and increased fatigue during a subsequent long CWE (Table 25). When soldiers are required to do moderate physical work during this second CWE, their performance, mood, and sense of fatigue are even worse (Table 26).

3. Soldiers given 3-4 hrs of nap between CWES can remain effective members of fighting teams. However, soldiers need to sleep more than 4 hrs/24 hr period to maintain performance at baseline level.

4. Physical workload of 30-40% maximal aerobic power slows down subsequent response speed, probably due to increased sleepiness and fatigue.

5. The circadian phasing of nap time (i.e., time-of-day when a nap is taken) is less important than the absolute duration of nap in determining the recuperative power. However, when soldiers have remained awake for an extended period of time, accumulating heavy sleep debt, a short nap should not be taken during early hours (0400-0700) because of profound sleep inertia.

6. The important factors in managing sleep are: (a) prior hours of wakefulness (which includes hours for rest, meals, personal hygiene, as well as for completing a job), (b) time-on-the-job, (c) circadian phasing (what time-of-day) of nap, (d) duration of nap, and (e) physical workload.

Sleep research findings have been summarized for operational force commanders in the "Sleep Management in Sustained Operations User's Guide" by P. Naitoh, C. E. Englund and D. H. Ryman, Report No. 86-22, Naval Health Research Center, San Diego, CA (1986).

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APPENDIX

Table 1: Mean Age, Pay Grade, Height, and Weight by Study-Experimental Condition

Study	1		2		3		4		5		6		7
Break: CW 1-2	3 Hr Nap		3 Hr Rest		4 Hr Nap		4 Hr Rest		3 Hr Nap		3 Hr Nap		8 Hr Sleep
Exercise	E30%	C	E30%	C	E40%	C	E40%	C	E30%	C	E30%	C	C
Age	20.6	20.5	21.1	22.3	22.2	21.2	21.3	22.8	22.4	21.7	20.2	20.1	23.6
Pay Grade*	3.10	3.18	3.44	3.50	3.50	3.25	2.75	2.25	3.11	3.44	3.00	2.86	2.75
Height cm	177.3	180.6	172.4	174.3	173.9	178.8	177.7	177.8	178.0	177.9	178.0	172.8	175.0
Weight Kg	71.8	80.4	76.8	76.6	77.9	76.6	70.1	75.3	80.4	75.0	76.6	68.2	76.6

*1 = Pvt
2 = PvtFC
3 = Cpl
4 = L/Cpl
5 = Sgt

Table 2. Seven Sustained Operations Studies

STUDY	E-C	N BEGIN	N END	% WORK	#SESS	CW1-CW2 BREAK TYPE	BREAK HRS	BREAK TIME	START TIME
1	E	11	11	30% HR	46	NAP	3	04-0700	0800
1	C	11	11	0%	46	NAP	3	04-0700	0800
2	E	12	8	30% VO2	46	REST	3	04-0700	0800
2	C	12	8	0%	46	REST	3	04-0700	0800
3	E	11	8	40%	44[A]	NAP	4	03-0700	0800
3	C	11	8	0%	44[A]	NAP	4	03-0700	0800
4	E	12	8	40 VO2	44[A]	REST	4	03-0700	0800
4	C	12	8	0%	44[A]	REST	4	03-0700	0800
5	E	13	9	30% VO2	45[B]	NAP	3	20-2300	2400
5	C	13	9	0%	45[B]	NAP	3	20-2300	2400
6	E	9	8	30 VO2	44[b,c]	NAP	3	09-1200	1300
6	C	9	8	0%	44[b,c]	NAP	3	09-1200	1300
7	C	10	8	0%	36	SLEEP	8	23-0700	0800

a The 17th session of each CW was not included in the study design because of the 1-hr increase in break time (nap or rest) between CW1 and CW2, and because of the increased exercise level causing delay (i.e., blisters on feet of exercising subjects).
b The 17th session on CW2 was given over to a second Max Stress test in order to measure the physical reserves of the subjects.
c The 17th session of CW1 was omitted because this study proved to be very difficult for the subjects to keep on schedule.
E = Exercise; C = No Exercise, Control; NBEGIN = Number of subjects at the beginning of study; NEND = Number of subjects who completed the study; % WORK = Workload re % Max O2; #SESS = Number of sessions.

Table 3: Experimental Design stressing Mission Startup Time and Nap

			MISSION STARTUP TIME		
		EXERCISE (E)* CONTROL (C)	08 AM	NOON	MIDNIGHT
Length of Nap	0 hr	E (30%) E (40%) C C	STUDY 2 STUDY 4 STUDY 2 STUDY 4	XX	X
	3 hrs	E (30%) C	STUDY 1 STUDY 1	STUDY 6 STUDY 6	STUDY 5 STUDY 5
	4 hrs	E (40%) C	STUDY 3 STUDY 3	XX	XX
	8 hrs	C	STUDY 7	XX	XX

* = Physical workload set to be at % MAX O_2
XX = No study was conducted in this cell.

Table 4: Experimental Protocols

	Orien-tation	Adaptation Sleep	Baseline Work	Baseline Sleep	CW-1	Nap	CW-2	Recovery
Morning	(08-22) •	(23-07) •	(08-22) •	(23-07) •	(08-03) •	(04-07) •	(08-03) •	(04-12)
Noon	(08-12) •	------> •	(13-03) •	(04-12) •	(13-08) •	(09-12) •	(13-08) •	(11-19)
Midnight	(08-19) •	(20-04) •	(05-14) •	(15-23) •	(00-19) •	(20-23) •	(00-19) •	(20-04)

• Time needed to go from one phase to the next phase

Table 5: Simple Reaction Time (msec)

10% Slowest RT and Errors of Omission

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=8				N=8
Mean (10% Slow)	772	817	1036	1136	664	1545	1038	1521	438	685	832	1071
SD	644	417	674	589	356	695	617	848	294	673	596	765
Mean (# Error)	0.70	0.37	1.67	0.64	0.16	4.74	0.81	5.15	0.04	1.44	1.00	4.69
SD	1.96	0.45	2.52	1.35	0.35	5.07	1.31	4.44	0.12	4.07	1.76	11.01
No Exercise				N=11				N=8				N=8
Mean (10% Slow)	594	671	702	817	465	761	663	947	471	574	551	801
SD	215	221	233	340	80	596	352	[illegible]	174	262	365	456
Mean (# Error)	0.05	0.15	0.09	0.17	0.03	0.50	0.06	0.74	0.07	0.08	0.13	0.41
SD	0.10	0.22	0.13	0.23	0.09	1.41	0.18	1.14	0.14	0.11	0.35	0.68

SA = Sessions 1-4; SB = Sessions 13-16.

Table 6: Four Choice Task (msec)

10% Slowest RT and Errors of Omission

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=10				N=7				N=9
Mean (10% Slow)	1453	1487	1540	1568	1571	2049	1704	2224	1301	1417	1502	1766
SD	274	450	404	483	423	505	513	499	127	422	206	496
Mean (# Error)	3.1	8.8	7.0	2.7	3.0	16.4	3.4	12.0	0.4	3.7	2.6	4.3
SD	3.0	[illegible]	14.6	2.6	3.0	15.0	4.1	12.0	0.5	9.2	2.6	4.6
No Exercise				N=10				N=7				N=9
Mean (10% Slow)	1269	1255	1245	1247	1211	1544	1203	1500	1232	1219	1246	1298
SD	185	262	238	282	257	441	265	525	144	124	128	182
Mean (# Error)	1.0	2.0	0.9	1.2	0.7	4.9	1.1	1.4	1.1	0.7	0.6	0.7
SD	1.6	3.5	1.3	2.0	1.5	9.4	1.3	3.0	1.6	1.0	0.7	0.9

SA = Session 2; SB = Session 14.

Table 7: Four Choice Task (Percent Correct)

% Correct

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=10				N=7				N=9
Mean	81.9	82.6	85.3	77.8	76.7	58.4	78.2	48.2	93.5	87.7	90.7	75.4
SD	20.4	20.3	19.8	26.6	26.0	17.9	21.6	24.9	5.4	18.6	12.3	28.1
No Exercise				N=10				N=7				N=9
Mean	89.6	91.9	89.1	90.1	91.8	80.2	92.1	62.3	86.6	88.4	89.2	87.0
SD	10.5	7.6	19.7	10.6	3.9	25.2	8.8	33.4	15.0	7.9	16.7	9.6

SA = Session 2; SB = Session 14.

Table 8: Alpha-Numeric Visual Vigilance Task

% Correct

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise												
Mean	78.3	78.7	77.1	68.6	89.8	77.8	85.9	76.7	91.8	92.4	88.2	88.9
SD	21.6	16.7	21.0	25.9	8.0	20.2	13.0	22.9	7.9	5.6	16.1	14.9
No Exercise												
Mean	82.0	75.1	61.0	65.7	92.6	70.6	94.7	78.0	90.1	91.5	92.6	85.5
SD	13.9	20.4	29.5	28.8	6.9	18.7	27.0	12.4	5.3	6.8	8.2	15.0

SA = Sessions 1-4; SB = Sessions 13-17 (CW1) and 13-16 (CW2).

Table 9: Baddeley's Logical Reasoning Task

% Correct

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA.	SB	SA	SB	SA	SB
Exercise				N=7				N=5				N=7
Mean	91.4	87.6	92.0	89.9	67.8	71.8	85.4	75.0	87.3	89.7	92.9	93.1
SD	3.1	11.2	4.9	8.3	12.8	26.8	19.1	17.5	15.7	12.0	9.5	8.6
No Exercise				N=7				N=5				N=7
Mean	86.3	81.6	88.4	84.7	93.0	87.7	92.3	92.0	74.7	83.3	88.3	85.3
SD	13.5	9.9	9.5	11.0	4.6	9.5	4.0	7.5	16.0	14.2	7.8	9.9

SA = Session 1; SB = Session 16.

Table 10: Williams' Word Memory Test

% Correct Recall

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=9				N=6				N=9
Mean	56.4	49.7	45.8	63.0	65.5	53.3	56.5	53.3	54.7	53.1	57.1	53.9
SD	11.5	11.2	20.9	11.9	10.8	16.9	22.8	18.8	13.6	18.8	21.1	19.8
No Exercise				N=7				N=5				N=7
Mean	62.8	46.0	57.0	57.0	56.5	50.8	52.5	59.5	53.8	70.7	71.8	63.6
SD	18.6	17.1	25.0	14.2	19.8	18.1	23.7	19.8	22.9	22.3	16.6	14.7

SA = Session 1; SB = Session 17 (CW1) o3 13 (CW2).

Table 11: NHRC Mood Scale (Positive)

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=8				N=9
Mean	42.7	31.1	32.5	28.8	36.1	20.4	23.2	19.1	39.8	27.1	28.0	19.5
SD	13.3	8.8	12.0	13.3	14.0	13.0	14.0	11.5	11.8	11.5	14.2	8.4
No Exercise				N=11				N=8				N=9
Mean	32.1	26.1	22.0	23.1	35.5	23.5	29.9	19.2	41.1	34.5	33.1	25.5
SD	10.6	12.2	10.1	11.8	12.3	16.4	14.4	16.0	15.4	16.6	17.5	19.[illegible]

SA = Sessions 1-4; SB = Sessions 13-17.

Table 12: NHRC Mood Scale (Negative)

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=8				N=9
Mean	3.1	6.0	6.1	7.2	3.2	12.7	4.9	12.0	2.5	6.4	7.6	6.7
SD	3.8	3.9	5.0	5.7	4.6	7.0	5.4	6.4	3.5	5.3	8.1	4.4
No Exercise				N=11				N=8				N=9
Mean	1.5	4.1	5.7	5.9	4.0	10.0	5.1	10.3	2.0	4.4	4.3	4.6
SD	1.7	3.4	4.2	4.9	4.0	5.5	4.9	5.3	1.2	3.7	3.9	4.0

SA = Sessions 1-4; SB = Sessions 13-17.

Table 13: Subjective Fatigue Checklist (School of Aerospace Medicine)

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=8				N=9
Mean	4.9	9.6	8.7	8.5	6.5	12.6	9.0	13.8	6.6	10.6	9.5	11.7
SD	3.9	4.3	4.0	5.7	3.5	5.8	4.3	3.3	2.1	4.4	3.2	5.9
No Exercise				N=11				N=8				N=9
Mean	5.8	7.5	8.8	9.9	7.4	12.4	8.4	13.8	6.6	7.4	8.0	8.9
SD	3.0	4.3	3.7	4.3	2.9	3.6	4.5	3.3	2.4	3.7	4.3	4.9

SA = Sessions 1-4; SB = Sessions 13-17.

Table 14: Borg's Rating of Perceived Exertion

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=8				N=7				N=8
Mean	8.3	10.8	10.6	11.9	7.9	12.6	10.0	12.8	8.8	11.1	10.4	11.6
SD	1.6	1.6	2.2	2.1	1.3	3.1	2.1	2.6	2.4	2.4	4.0	3.0

SA = Session 1-4; SB = Session 13-16.

Table 15: Two Response Alternation Performance (TRAP)

10% Slow (msec) and Error of Ommission

	8AM				NOON				MIDNIGHT			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=7				N=8
Mean	742	777	914	854	621	939	804	831	580	854	790	877
SD	324	330	332	458	150	375	182	343	209	380	335	396
Mean (# Errors)	2.0	6.6	4.6	10.2	10.0	26.1	11.8	23.3	6.4	6.9	8.9	11.3
SD	4.2	14.7	6.4	20.6	18.7	29.8	23.9	33.0	17.2	12.6	13.6	17.9
No Exercise				N=11				N=8				N=9
Mean (10% Slow)	591	746	788	616	813	785	652	665	694	775	515	715
SD	1.0	15.0	1.3	1.3	18.1	26.0	0.8	34.6	8.7	13.6	1.7	12.2

SA = Session 1; SB = Session 16.

Table 16: Simple Reaction Time Task

10% Slow (msec)

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	563	786	1308	1221	772	817	1036	1136	496	847	960	1591
SD	581	436	846	499	644	417	674	589	190	407	454	551
No Exercise				N=13				N=11				N=5
Mean	474	655	766	912	594	671	702	818	388	560	544	902
SD	222	335	479	468	215	221	233	340	60	230	245	556

SA = Sessions 1-4; SB = Sessions 13-17.

Table 17: Four Choice Serial Reaction Time Task

10% Slow

Sleep Duration	0 HRS				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=10				N=5
Mean	1350	1673	1945	1649	1453	1487	1540	1568	1284	1526	1496	1572
SD	245	376	478	580	274	450	404	483	185	262	238	282
No Exercise				N=13				N=10				N=5
Mean	1230	1289	1429	1266	1269	1255	1245	1247	1304	1364	1294	1292
SD	120	181	259	437	185	262	238	282	204	291	172	912

SA = Session 2; SB = Session 14.

Table 18: Four Choice Serial Reaction Time Task

% Correct

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=10				N=5
Mean	93.0	83.2	75.9	68.6	81.9	82.6	85.3	77.8	83.6	87.2	85.5	41.0
SD	5.9	26.5	22.6	27.2	20.4	20.3	19.8	26.6	24.5	16.6	21.1	36.2
No Exercise				N=13				N=10				N=5
Mean	94.3	93.7	89.1	81.3	89.6	91.9	89.1	90.1	82.9	80.3	86.4	47.8
SD	4.5	6.8	10.1	29.0	10.6	7.6	19.7	10.6	14.2	14.2	16.9	43.4

SA = Session 2; SB = Session 14.

Table 19: Alpha-Numeric Visual Vigilance Task

% Correct

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	83.2	80.3	77.1	71.3	78.3	78.7	77.1	68.6	94.7	89.1	83.5	86.3
SD	17.8	19.4	26.0	25.0	21.6	16.7	21.0	25.9	6.4	12.9	18.6	17.4
No Exercise				N=13				N=11				N=5
Mean	77.7	66.5	47.9	55.4	82.0	75.1	61.0	65.7	85.1	90.1	88.7	86.4
SD	19.9	21.5	23.6	26.9	13.9	20.4	29.5	28.8	13.8	8.2	16.8	11.6

SA = Sessions 1-4; SB = Sessions 13-17 (CW1) or 13-16 (CW2).

Table 20: Logical Reasoning Task

% Correct

	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=7				N=7				N=3
Mean	86.9	85.7	90.4	88.0	91.9	87.6	92.0	89.9	97.3	86.0	97.0	96.7
SD	14.2	11.8	8.5	12.8	3.1	11.2	4.9	8.3	2.3	10.8	3.0	4.2
No Exercise				N=8				N=7				N=4
Mean	91.0	89.5	89.0	88.3	86.3	81.6	4	84.7	88.3	92.5	88.3	95.0
SD	13.2	13.4	15.0	13.6	13.5	9.9	9.5	11.0	11.9	11.7	14.5	14.1

SA = Session 1; SB = Session 16.

Table 21: Williams' Word Memory Task

% Recall

	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=11				N=9				N=3
Mean	54.2	56.6	52.5	55.2	56.4	49.7	45.9	53.0	78.0	53.3	33.0	39.7
SD	14.0	14.4	9.8	16.0	11.5	11.2	20.9	11.9	10.1	26.5	0.0*	11.6
No Exercise				N=11				N=9				N=3
Mean	60.7	47.5	50.5	45.9	62.8	46.0	57.0	57.0	60.0	40.0	51.0	37.7
SD	14.8	12.1	12.3	15.2	18.6	17.1	25.0	14.2	20.0	7.0	10.1	4.0

SA = Session 1; SB = Session 17 (CW1) or 13 (CW2).

* All three Ss had the same % Correct Recall.

Table 22: NHRC Mood Scale (Positive)

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	37.5	27.8	27.9	18.2	42.7	31.1	32.5	28.8	38.0	24.5	22.4	15.4
SD	10.4	13.2	11.7	11.7	13.3	8.8	12.0	13.3	8.8	14.0	14.7	16.1
No Exercise				N=13				N=11				N=5
Mean	40.9	32.0	26.3	26.1	32.1	26.1	22.0	23.1	44.6	30.8	36.3	29.4
SD	9.2	15.0	11.8	10.8	10.6	12.3	10.1	11.8	10.6	16.4	20.4	20.9

SA = Sessions 1-4; SB = Sessions 13-17.

Table 23: NHRC Mood Scale (Negative)

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	2.2	6.3	5.9	9.1	3.1	6.0	6.1	7.2	2.1	11.0	11.0	12.7
SD	3.6	5.6	4.8	5.9	3.8	3.9	5.0	5.7	2.1	9.4	7.3	7.2
No Exercise				N=13				N=11				N=5
Mean	4.5	8.3	10.6	11.0	1.5	4.1	5.7	5.9	4.1	10.7	9.0	12.3
SD	5.6	7.4	6.6	6.5	1.7	3.4	4.2	4.9	4.2	7.5	8.8	7.5

SA = Sessions 1-4; SB = Sessions 13-17.

Table 24: Subjective Fatigue Checklist (School of Aerospace Medicine)

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	4.2	10.5	9.5	12.0	4.9	9.6	8.7	8.5	6.8	13.8	13.1	15.4
SD	3.7	5.8	5.4	5.0	3.9	4.3	4.0	5.7	2.4	6.6	4.6	5.1
No Exercise				N=13				N=11				N=5
Mean	5.5	9.7	10.4	10.7	5.8	7.5	8.8	9.9	7.1	10.2	9.0	12.7
SD	4.2	5.4	5.1	4.3	3.0	4.3	3.7	4.3	2.0	3.0	5.0	2.6

SA = Sessions 1-4; SB = Sessions 13-17.

Table 25: Sleep Length and Recovery: Summary of Results

Studies 1, 2, 3, 4, and 7
Control Ss

Tasks	Sleep/Hrs	CW1 Mean	CW2 Mean	% Change*	Comments on Direction of Change
SRT (10% Slow; Msec)	8	509	524	+ 3.9	No change in CW2
	4	457	596	+30.4	Slower RT in CW2
	3	602	744	+23.6	Slower RT in CW2
	0	509	774	+52.1	Much slower RT CW2
Four Choice (10% Slow; Msec)	8	1211	1150	- 5.0	Faster RT in CW2
	4	1320	1490	+12.9	Much slower RT CW2
	3	1240	1260	+ 1.6	No change in CW2
	0	1260	1371	+ 8.8	Slower RT in CW2
Logical Reasoning (% Correct)	8	91.6	93.2	+ 1.7	No change in CW2
	4	90.1	88.2	- 2.1	No change in CW2
	3	82.0	81.0	- 1.2	No change in CW2
	0	88.2	84.3	- 5.5	Low score in CW2
Alpha-Numeric (% Correcr)	8	87.6	89.5	+ 2.3	No change in CW2
	4	85.5	80.9	- 5.4	Low score in CW2
	3	78.3	64.9	-17.1	Lower score in CW2
	0	74.6	53.6	-28.2	Much lower score CW2
Word Memory (% Correct Recall)	8	34.2	35.1	+ 1.8	No change in CW2
	4	48.3	40.5	-16.1	Low score in CW2
	3	56.7	52.0	- 8.3	Low score in CW2
	0	58.6	45.5	-22.4	Much lower score CW2
NHRC Positive	8	35.7	33.3	- 6.7	Less positive in CW2
	4	38.9	34.8	-10.5	Less positive in CW2
	3	29.0	23.1	-20.3	Much less positive CW2
	0	36.9	28.5	-22.8	Much less positive CW2
SAM Fatigue	8	10.8	10.6	- 1.7	No change in CW2
	4	8.7	11.3	+29.9	More fatigue in CW2
	3	6.6	9.4	+42.4	Much more fatigue CW2
	0	7.6	10.4	+36.8	Much more fatigue CW2

* % Change = (CW1 - CW2)/CW1 x 100.
Any 5% or less change was arbitrarily commented as "No change."

Table 26: Sleep Length and Recovery: Summary of Results

Studies 1, 2, 3, 4, and 7
Control Ss

Tasks	Sleep/Hrs (Submax O2 Workload in %)	CW1 Mean	CW2 Mean	% Change*	Comments on Direction of Change
SRT (10% Slow; Msec)	4(40%)	557	1077	+93.4	Much slower RT in CW2
	3(30%)	784	1071	+36.6	Slower RT in CW2
	0(30%)	571	1261	+120.8	Much slower RT in CW2
Four Choice (10% Slow; Msec)	4(40%)	1470	1490	+12.9	Much slower RT in CW2
	3(30%)	1480	1570	+ 6.1	Slower RT in CW2
	0(30%)	1476	1867	+26.5	Much slower RT in CW2
Logical Reasoning (% Correct)	4(40%)	93.9	89.8	- 4.4	No change in CW2
	3(30%)	83.6	83.0	- 0.7	No change in CW2
	0(30%)	88.1	82.4	- 6.5	No change in CW2
Alpha-Numeric (% Correcr)	4(40%)	89.5	84.3	- 5.8	Low score in CW2
	3(30%)	79.2	71.3	-10.0	Lower score in CW2
	0(30%)	82.5	73.8	-10.5	Lower score in CW2
Word Memory (% Recall)	4(40%)	56.9	41.5	-27.1	Much lower score CW2
	3(30%)	52.9	53.9	+ 3.0	No change in score CW2
	0(30%)	63.2	49.7	-21.3	Much lower score CW2
NHRC Positive	4(40%)	30.5	21.3	-30.2	Much less positive CW2
	3(30%)	37.3	32.1	-13.9	Less positive in CW2
	0(30%)	34.0	24.9	-26.8	Much less positive CW2
SAM Fatigue	4(40%)	11.3	13.9	+23.0	Much more fatigue CW2
	3(30%)	7.1	8.8	+23.9	Much more fatigue CW2
	0(30%)	7.7	10.8	+40.3	Much more fatigue CW2

* % Change = (CW1 - CW2)/CW1 x 100.
Any 5% or less change was arbitrarily commented as "No change."

Table 27: Sleep Characteristics of Subjects in Studies 1, 6, and 5 [Mean (Standard Deviation)]

Sleep Measures	Study	Baseline Sleep		3 hr Nap		Recovery Sleep	
		C-Group	E-Group	C-Group	E-Group	C-Group	E-Group
Latency to Stage 2 in minutes	#1	14.9(8.8)	16.9(14.1)	9.0(5.9)	8.8(7.1)	7.8(4.2)	9.4(8.5)
	#6	13.1(6.5)	6.9(3.3)	9.9(7.5)	4.6(2.9)	5.9(1.7)	4.0(2.5)
	#5	13.7(6.5)	11.2(7.5)	28.6(30.5)	12.9(7.1)	17.4(10.0)	10.0(8.4)
Latency to Stage REM in Minutes	#1	83.7(33.3)	76.4(26.5)	36.3(29.2)	45.7(28.3)	43.6(29.2)	63.6(33.7)
	#6	38.0(33.3)	104.1(75.2)	46.0(24.8)	101.7(58.1)	96.9(34.7)	87.0(35.8)
	#5	43.9(15.2)	50.1(37.1)	52.6(16.3)	59.9(11.5)	85.3(31.7)	91.2(26.3)
Duration of REM in Minutes	#1	113.8(22.6)	99.9(31.3)	36.2(17.8)	34.5(11.2)	97.3(16.5)	77.3(21.0)
	#6	99.9(41.4)	95.3(23.2)	25.6(9.1)	15.0(11.4)	73.9(26.9)	66.9(30.6)
	#5	63.5(20.9)	85.2(32.6)	16.8(9.5)	21.0(6.3)	82.6(24.2)	101.3(16.9)
% Slow Wave Sleep	#1	22.5(5.9)	21.4(6.4)	45.3(10.3)	39.9(12.2)	27.6(7.8)	27.3(9.5)
	#6	14.0(4.8)	25.6(2.9)	33.1(10.5)	53.1(6.0)	20.5(5.8)	19.6(5.3)
	#5	11.0(4.4)	11.6(8.3)	33.4(9.3)	35.6(7.1)	18.3(6.7)	19.6(5.3)
Sleep Efficiency	#1	95.2(2.4)	96.4(1.8)	96.6(1.8)	96.7(2.1)	95.8(3.4)	96.0(5.4)
	#6	96.6(2.7	97.3(1.3)	95.2(3.1)	97.8(0.9)	97.0(2.2)	98.1(0.5)
	#5	88.6(10.7)	91.7(6.3)	88.1(11.1)	94.1(2.8)	96.0(1.9)	95.6(4.0)

Time for:	Baseline Sleep	Nap	Recovery Sleep
Study #1(8AM Group) :	2300-0700	0400-0700	0400-1200
Study #6(Noon Group):	0400-1200	0900-1200	1100-1900
Study #5(Midnight) :	1500-2300	2000-2300	2000-0400

Table 28: Oral Temperature

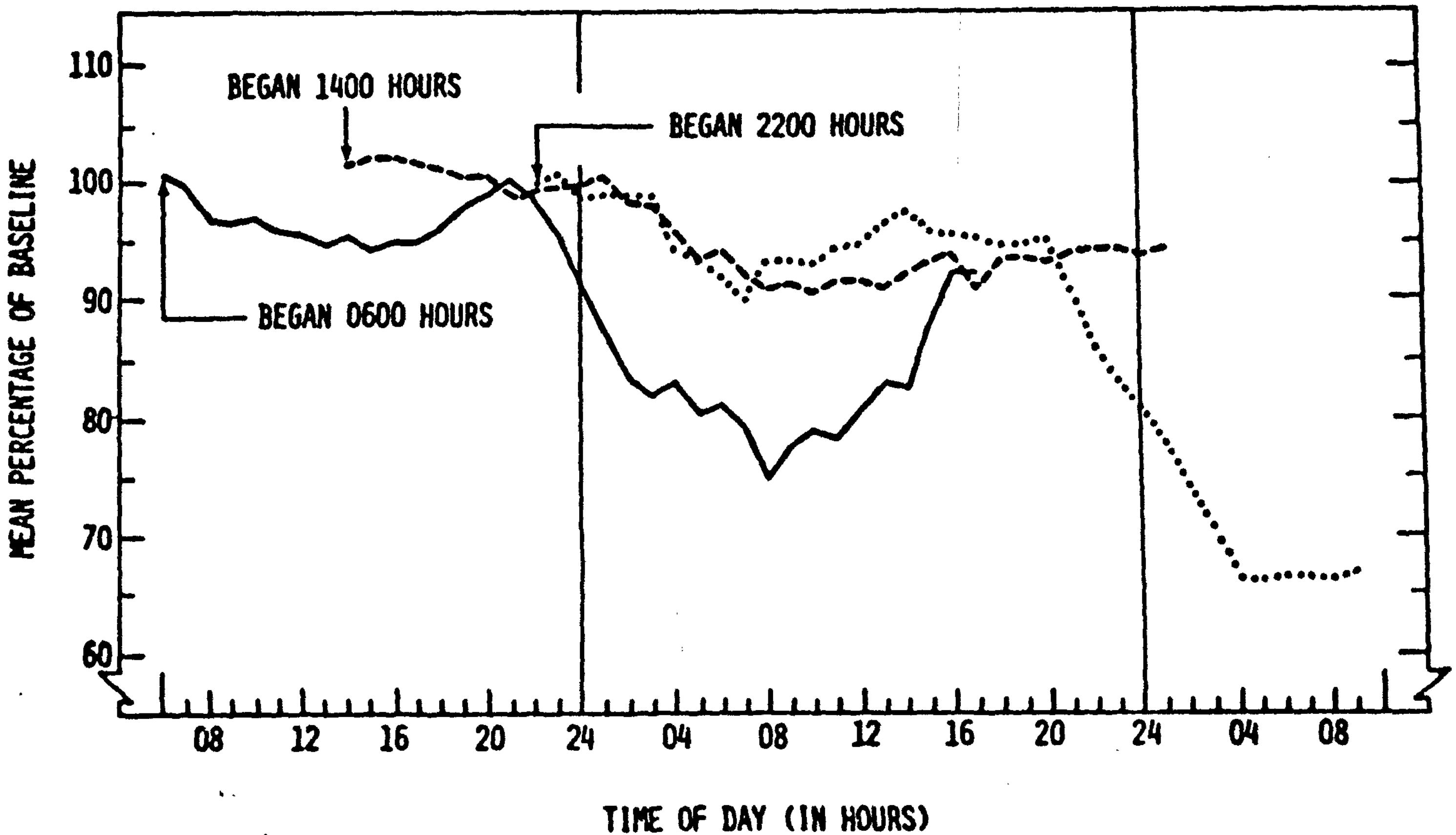
Centigrade

Sleep Duration	0 HR				3 HRS				4 HRS			
	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2	CW1	CW1	CW2	CW2
	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB	SA	SB
Exercise				N=13				N=11				N=5
Mean	36.40	36.32	36.33	36.29	36.29	36.36	36.07	36.33	36.32	36.53	36.37	36.34
SD	0.39	0.29	0.39	0.28	0.42	0.30	0.45	0.33	0.24	0.37	0.18	0.15
No Exercise				N=13				N=11				N=5
Mean	36.51	36.32	36.25	36.17	36.43	36.39	36.10	36.47	36.69	36.30	36.49	36.51
SD	0.33	0.20	0.32	0.37	0.35	0.29	0.41	0.33	0.30	0.40	0.36	0.40

SA = Sessions 1-4; SB = Sessions 13-17.

10. FIGURES 1 - 29

Synthetic Performance Scores and Mission Startup Time



Taken from Morgan and Coates (1974).
Used with permission of B. B. Morgan.

Figure 1

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
EXPT'L PHASE	Training		Baseline		CW1		CW2		Recovery	
TIME	WA	WB	WA	WB	WA	WB	WA	WB	WA	WB
00 - 01							15A	15B	15A	15B
01 - 02							16A	16B	16A	16B
02 - 03							17A	17B	17A	17B
03 - 04			SLEEP 0		SLEEP 1					
04 - 05										
05 - 06							SLEEP 2		SLEEP 3	
06 - 07										
07 - 08			----- BREAKFAST* -----							
08 - 09			1A	1B	1A	1B	1A	1B		
09 - 10			2A	2B	2A	2B	2A	2B		
10 - 11			3A	3B	3A	3B	3A	3B		
11 - 12			4A	4B	4A	4B	4A	4B		
12 - 13			----- LUNCH ----- 5A		5A		5A		LUNCH	
13 - 14			6A	5B	6A	5B	6A	5B		
14 - 15			7A	6B	7A	6B	7A	6B		
15 - 16			8A	7B	8A	7B	8A	7B		
16 - 17			----- SUPPER -----	8B		8B		8B		
17 - 18			9A	9B	9A	9B	9A	9B		
18 - 19			10A	10B	10A	10B	10A	10B		
19 - 20			11A	11B	11A	11B	11A	11B		
20 - 21			12A	12B	12A	12B	12A	12B		
21 - 22			----- SNACK** -----							
22 - 23					13A, 14A	13B	13A, 14A	13B		
23 - 24	SLEEP 0		SLEEP 1		15A	14B	15A	14B		

CW = Continuous Work
*Includes time for attachment of ECG electrodes and rifle assembly task.
**Includes time for rifle assembly task.

Figure 2

ORAL TEMPERATURE

CENTIGRADE

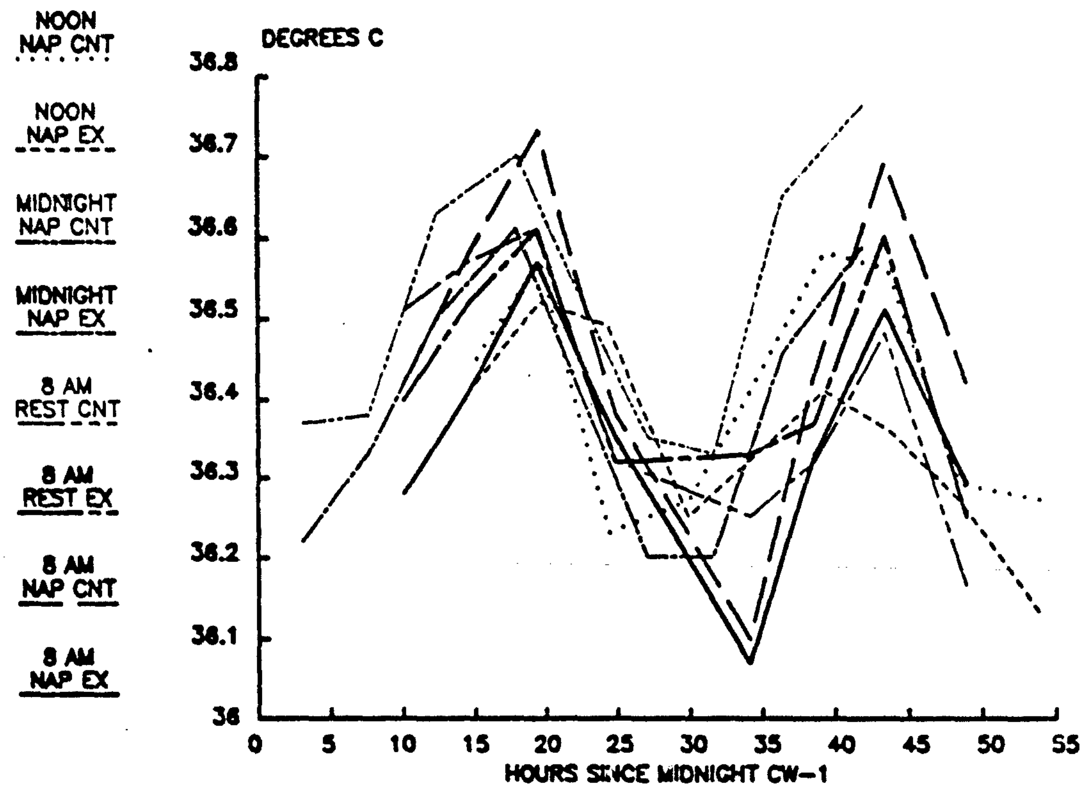


Figure 3

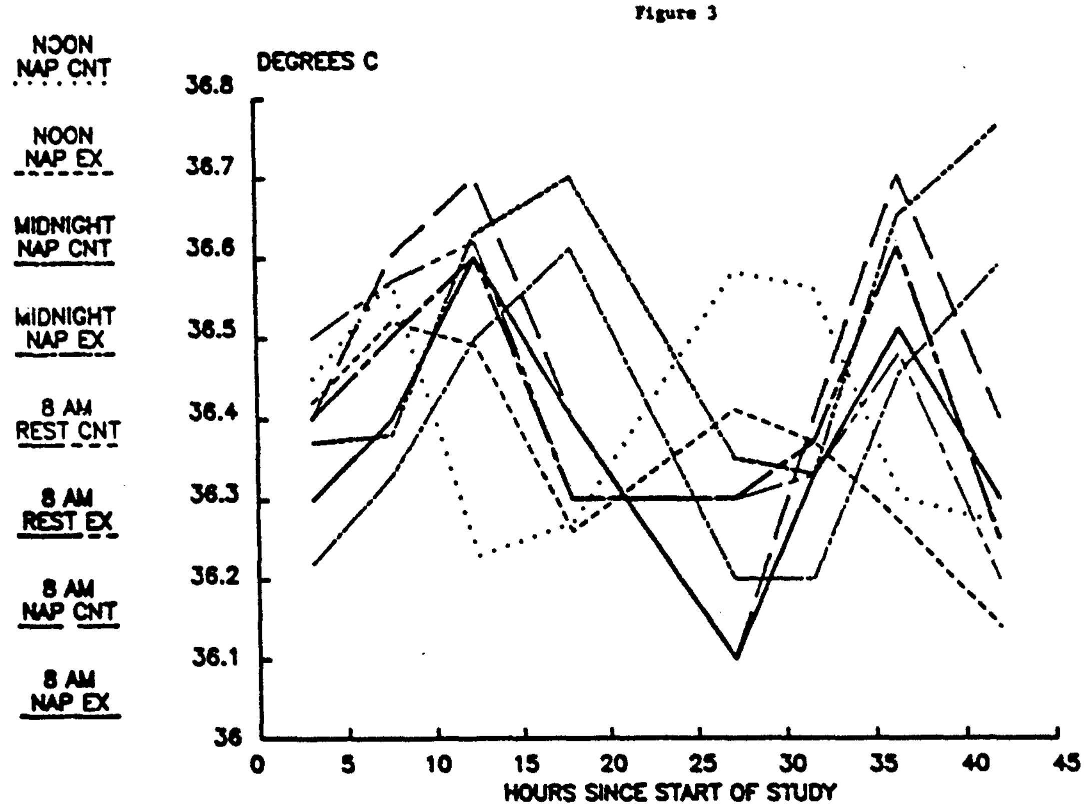


Figure 4

SIMPLE REACTION TIME
MEAN OF THE SLOWEST 10% RESPONSES

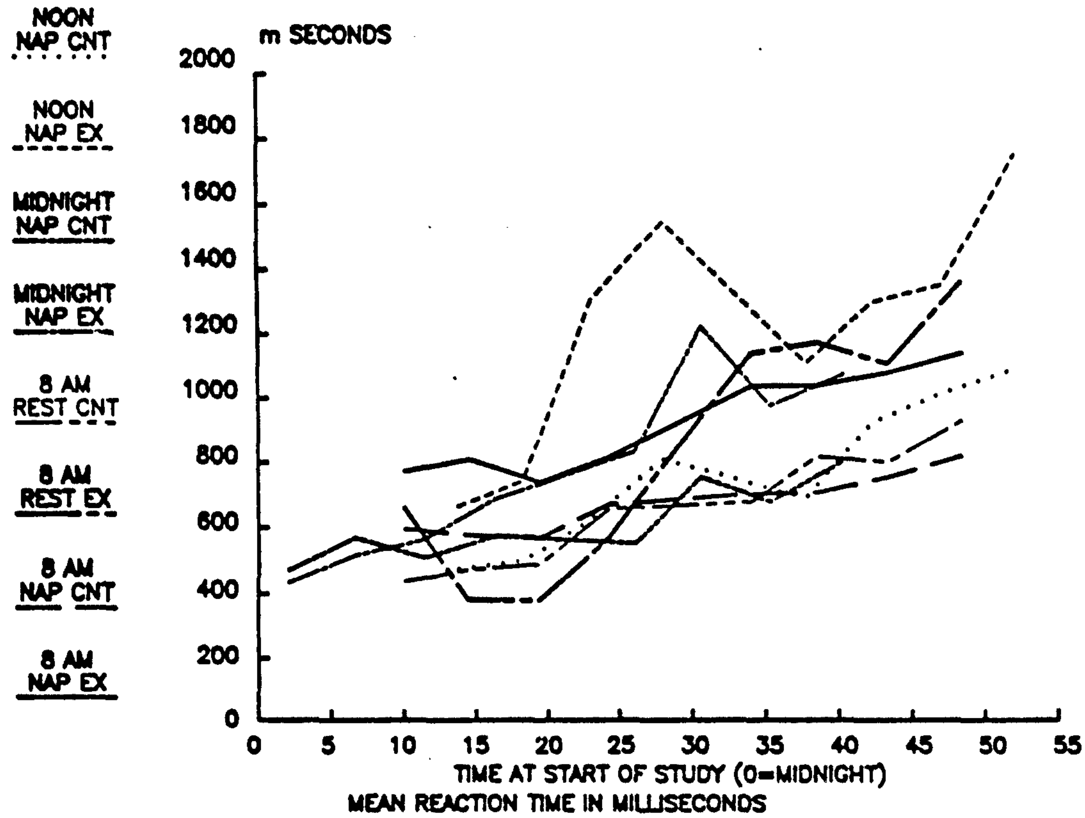


Figure 5

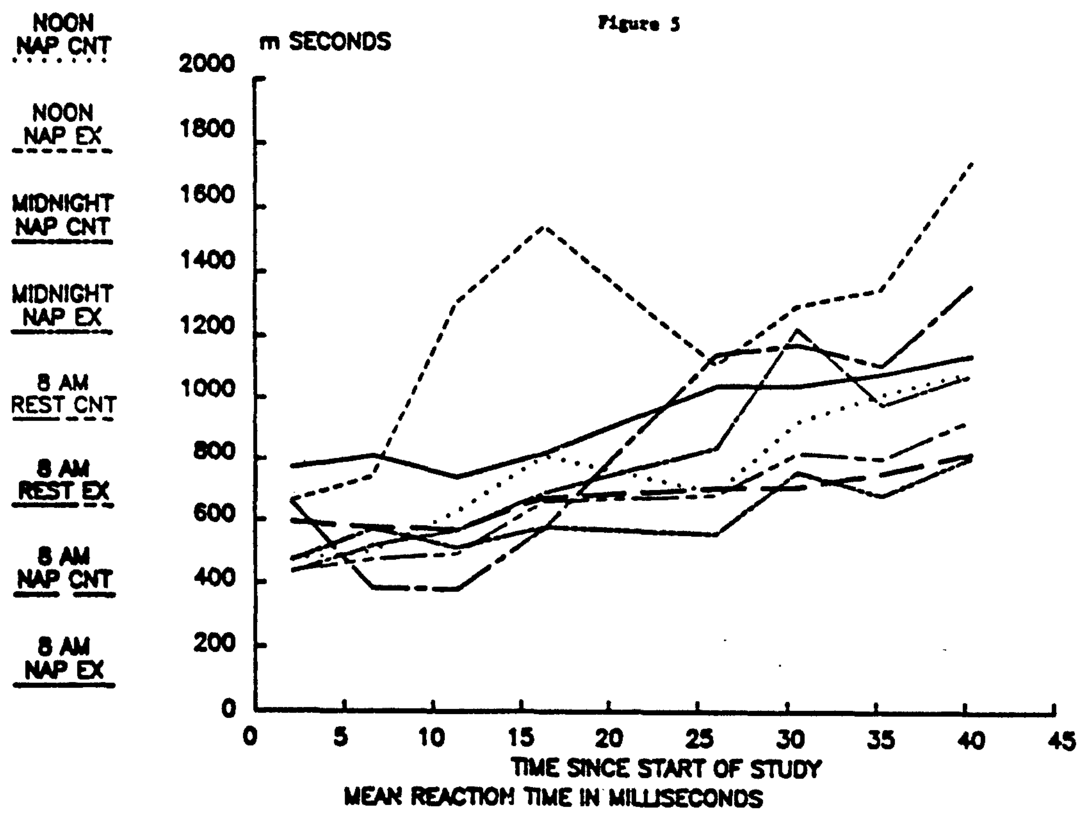
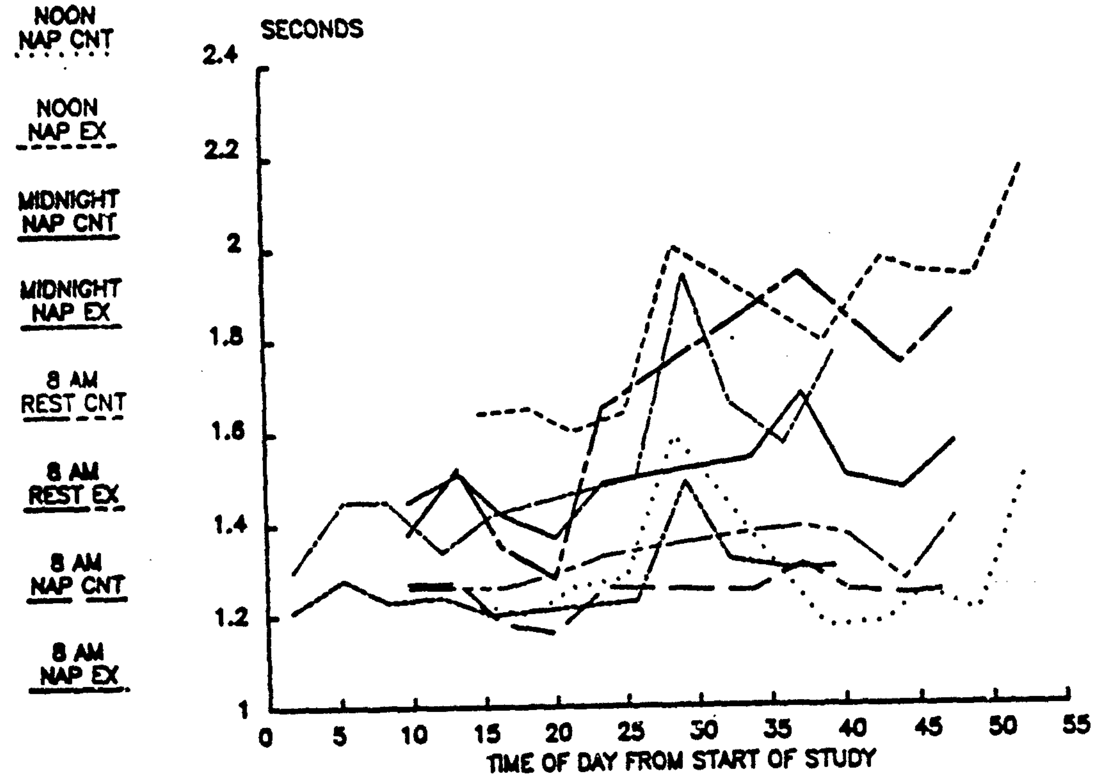


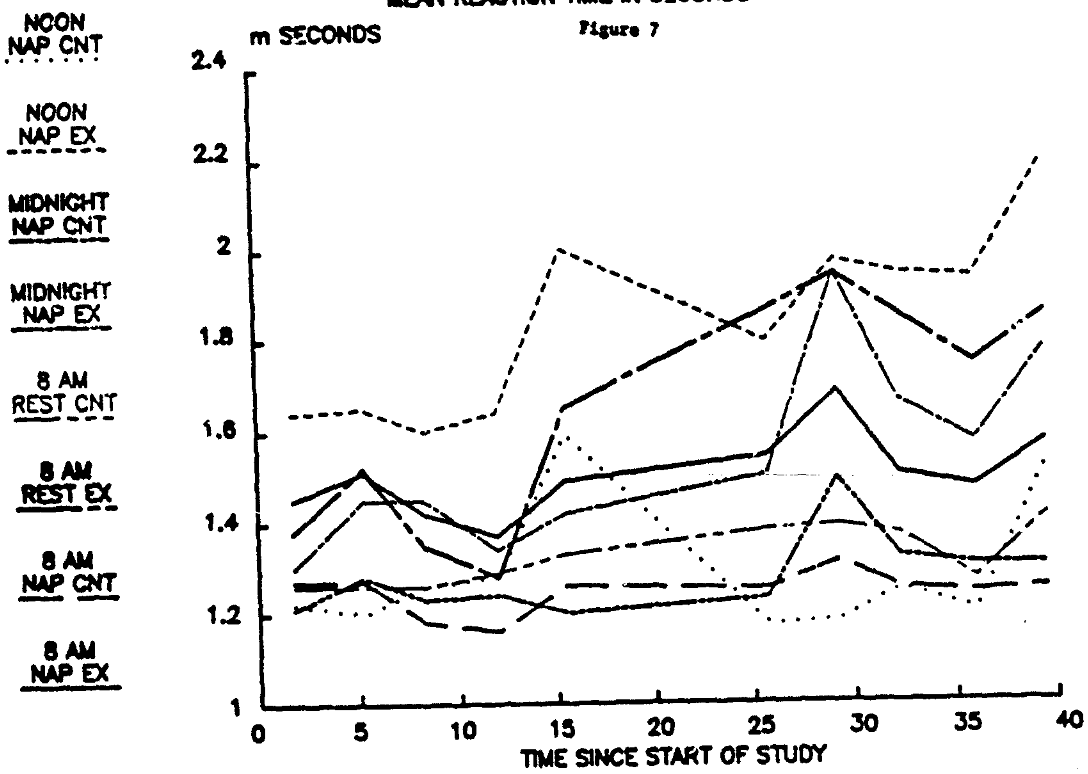
Figure 6

FOUR CHOICE REACTION TASK
MEAN OF THE SLOWEST 10% OF RESPONSES



MEAN REACTION TIME IN SECONDS

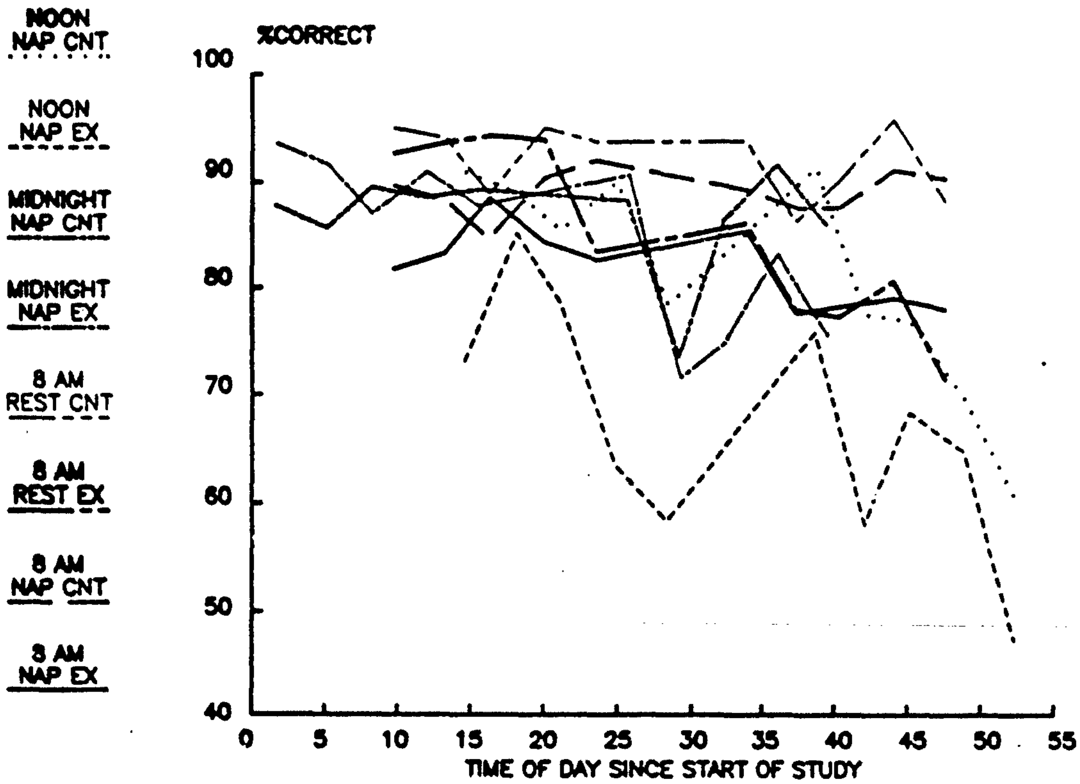
Figure 7



MEAN REACTION TIME IN MILLISECONDS

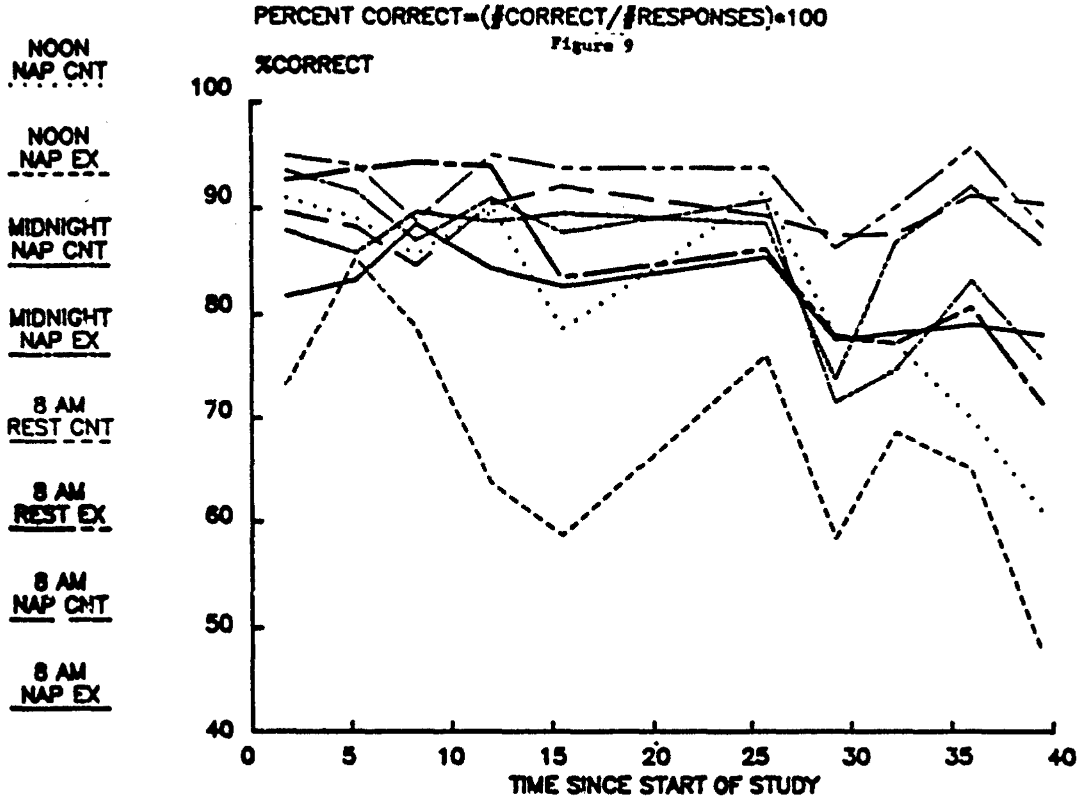
Figure 8

FOUR CHOICE REACTION TASK
MEAN PERCENT CORRECT



PERCENT CORRECT=(#CORRECT/#RESPONSES)*100

Figure 9



PERCENT CORRECT=#CORRECT/#RESPONSES

Figure 10

ALPHA-NUMERIC VISUAL VIGILANCE
PERCENT CORRECT RESPONSES

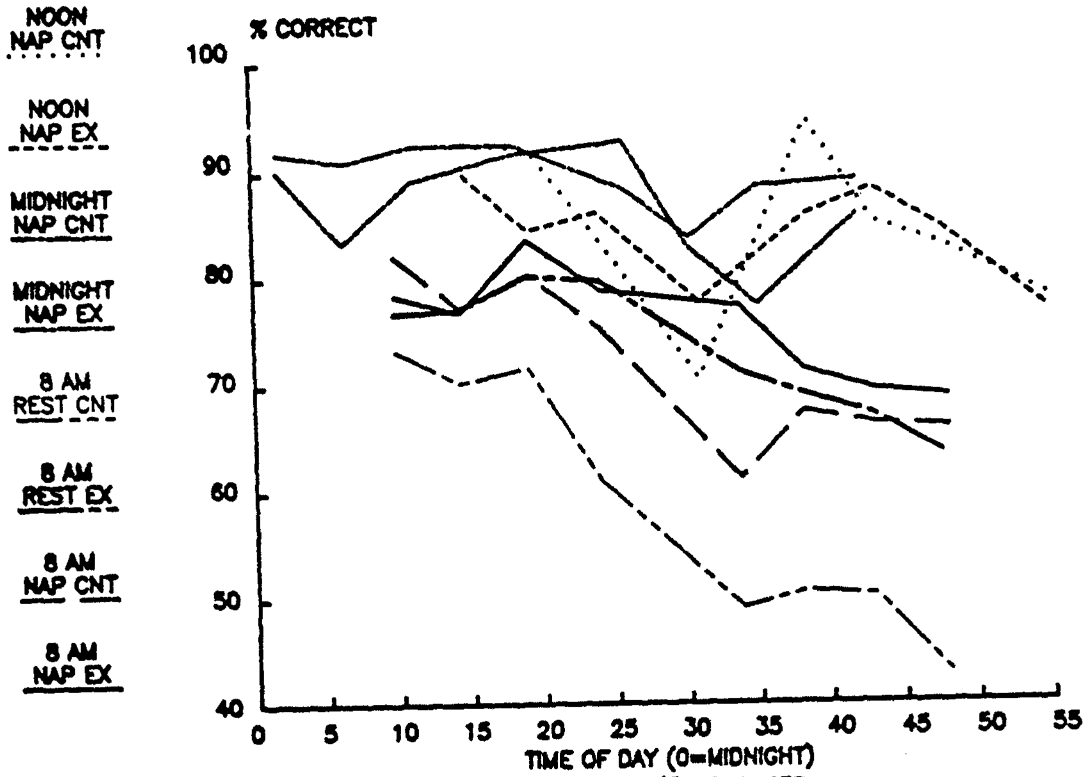


Figure 11

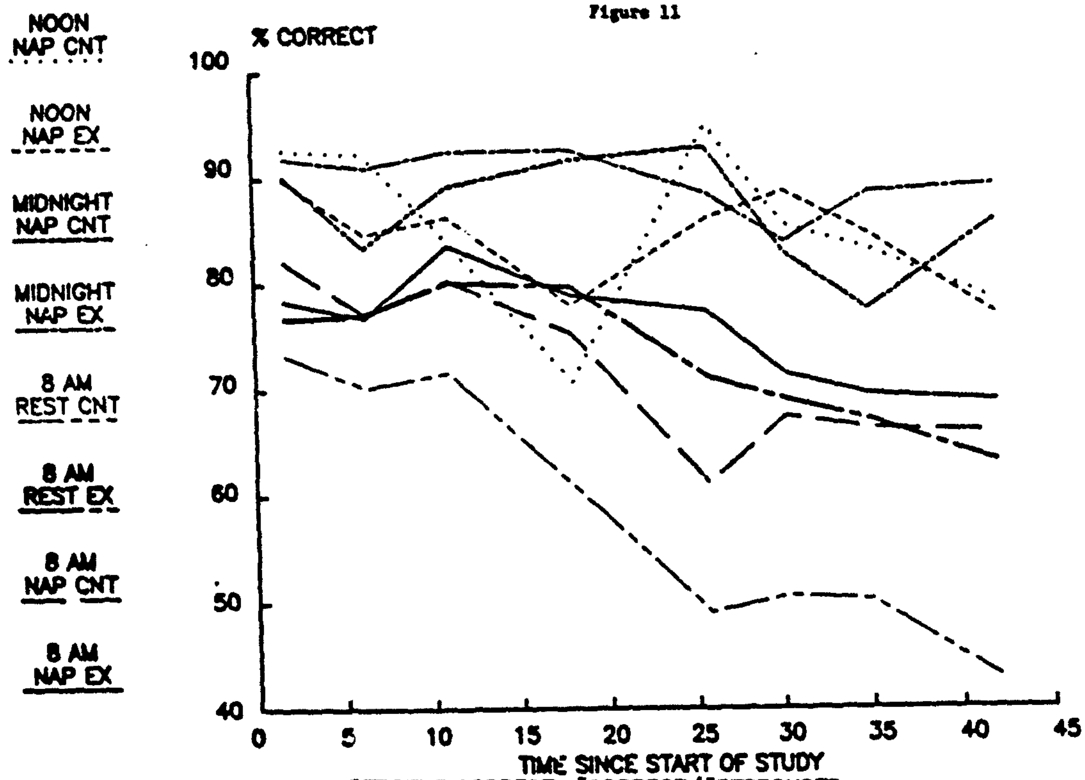
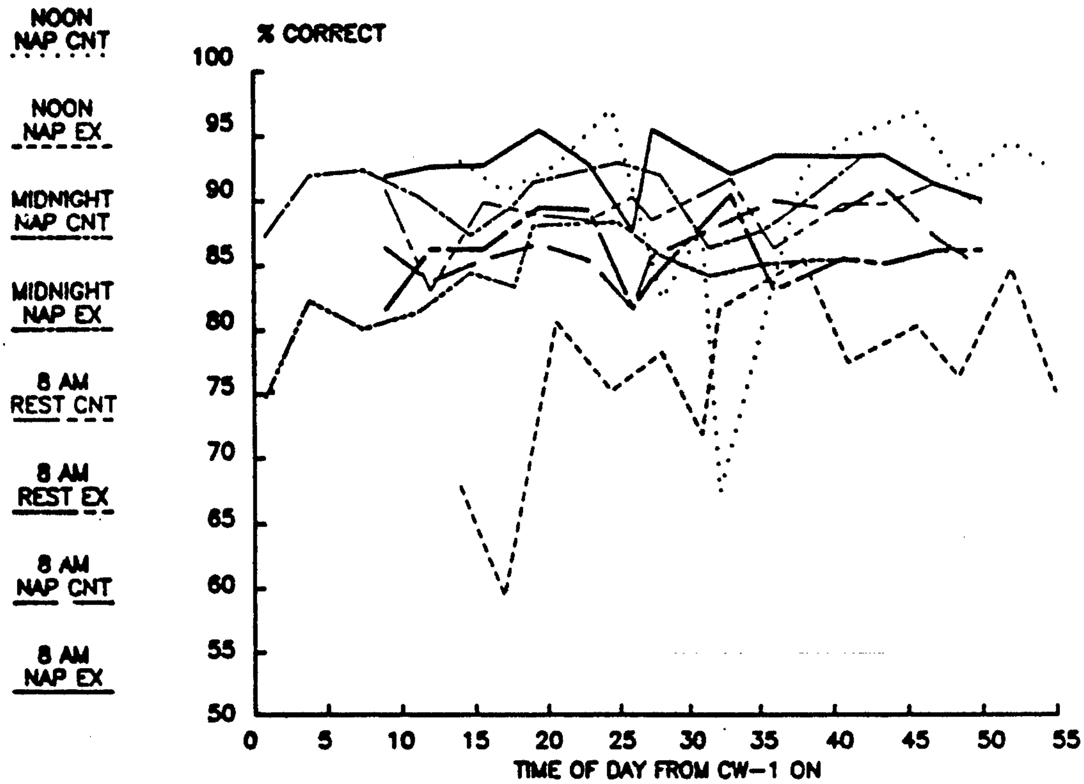


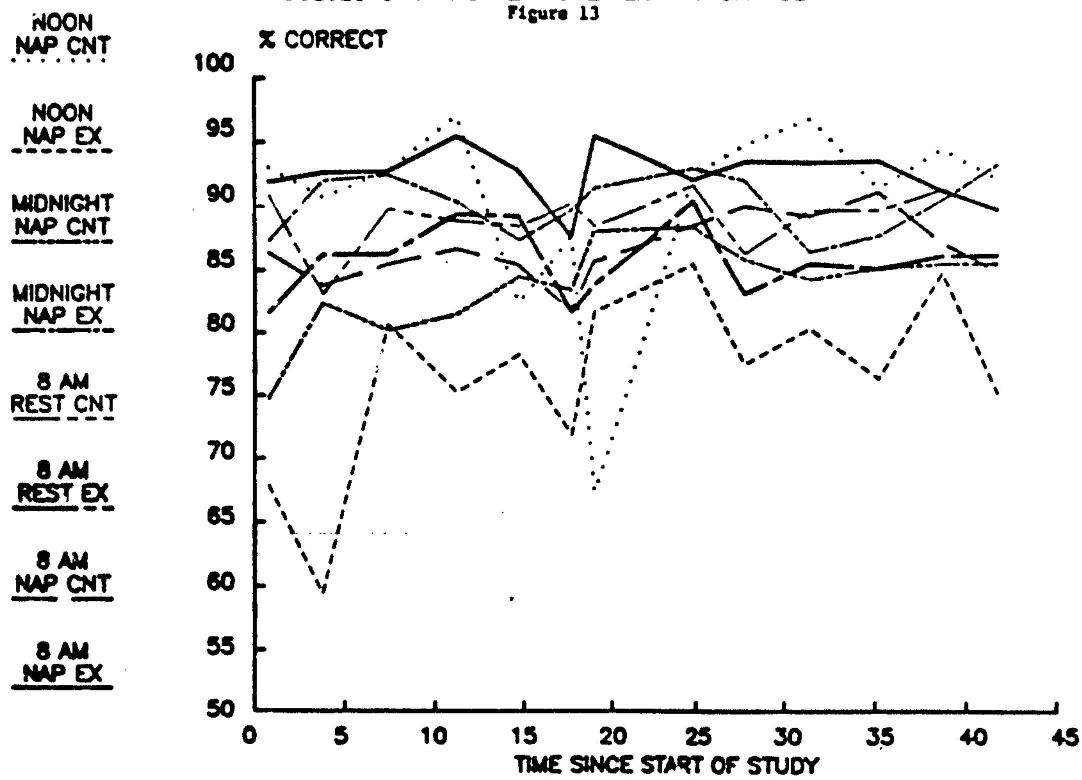
Figure 12

LOGICAL REASONING TASK
PERCENT CORRECT



SUBJECTS HAVING MEAN GREATER THAN CHANCE

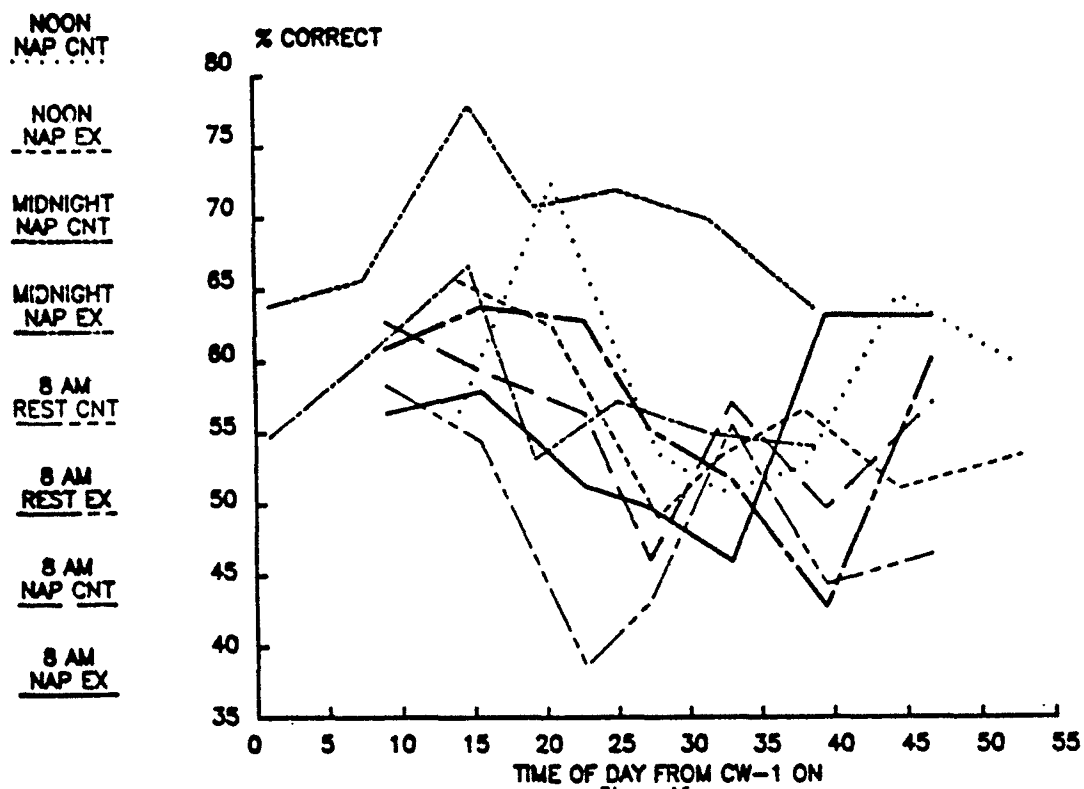
Figure 13



SUBJECTS HAVING MEAN GREATER THAN CHANCE

Figure 14

WORD MEMORY
PERCENT CORRECT RECALL



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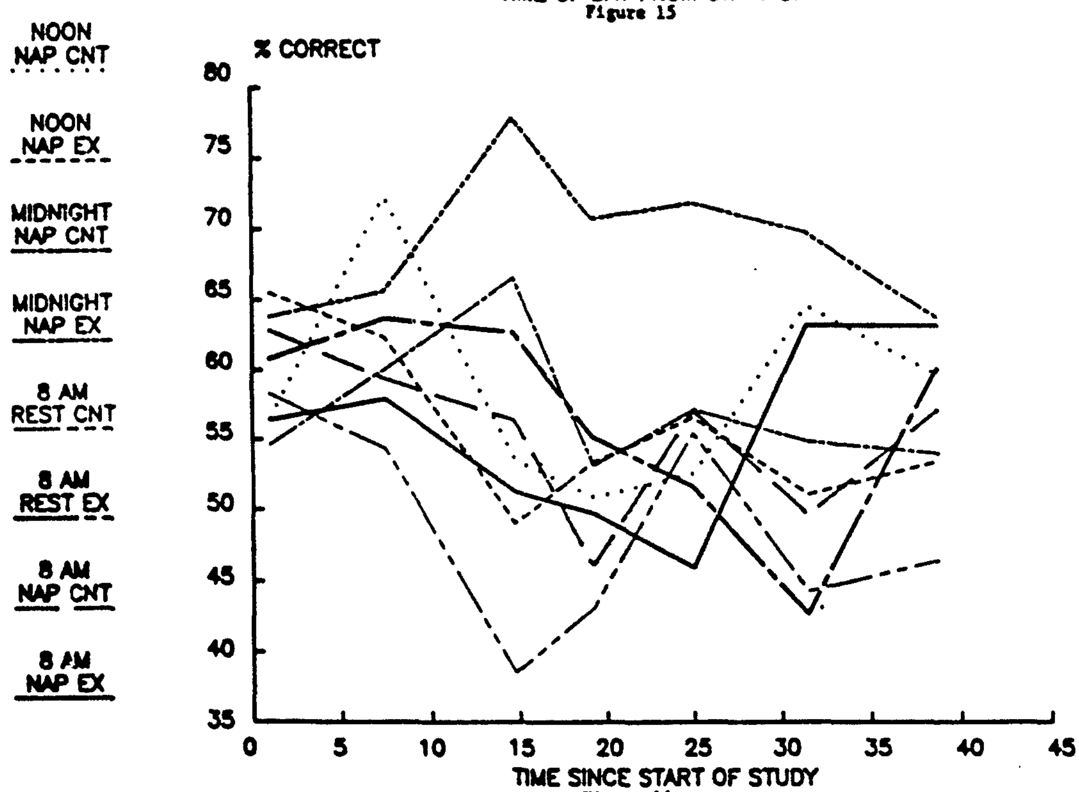


Figure 16

NHRC POSITIVE MOOD SCALE

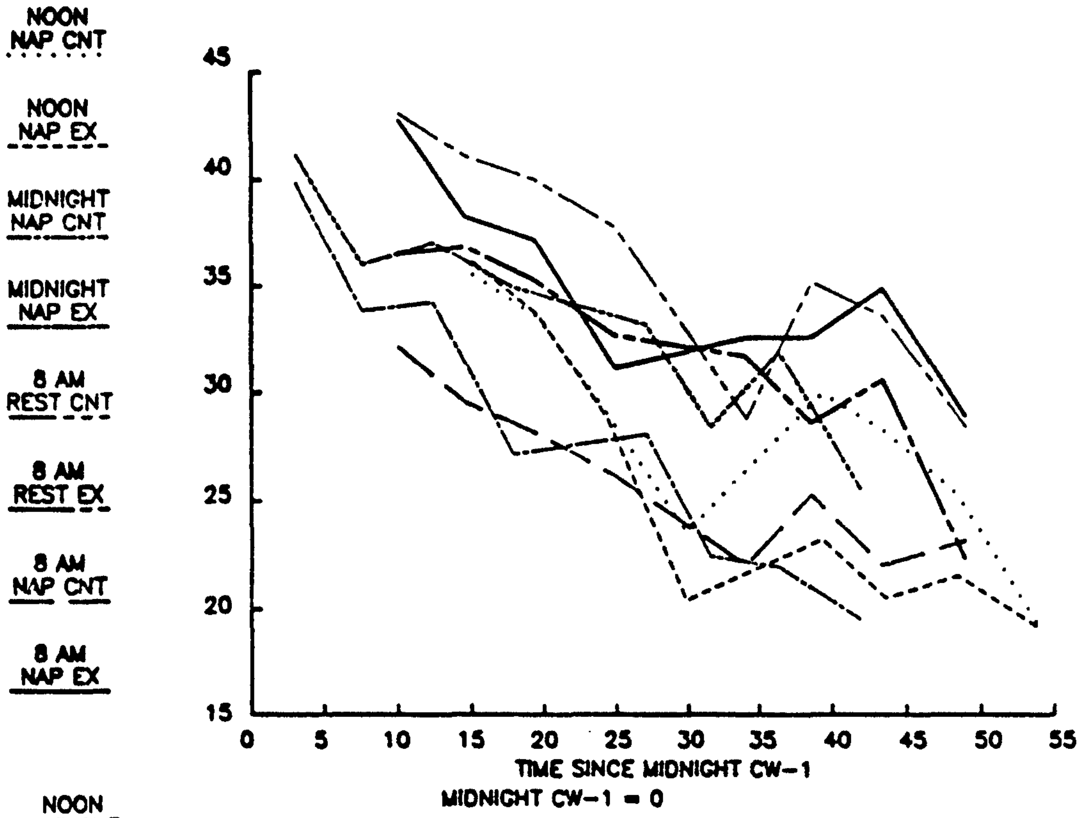


Figure 17

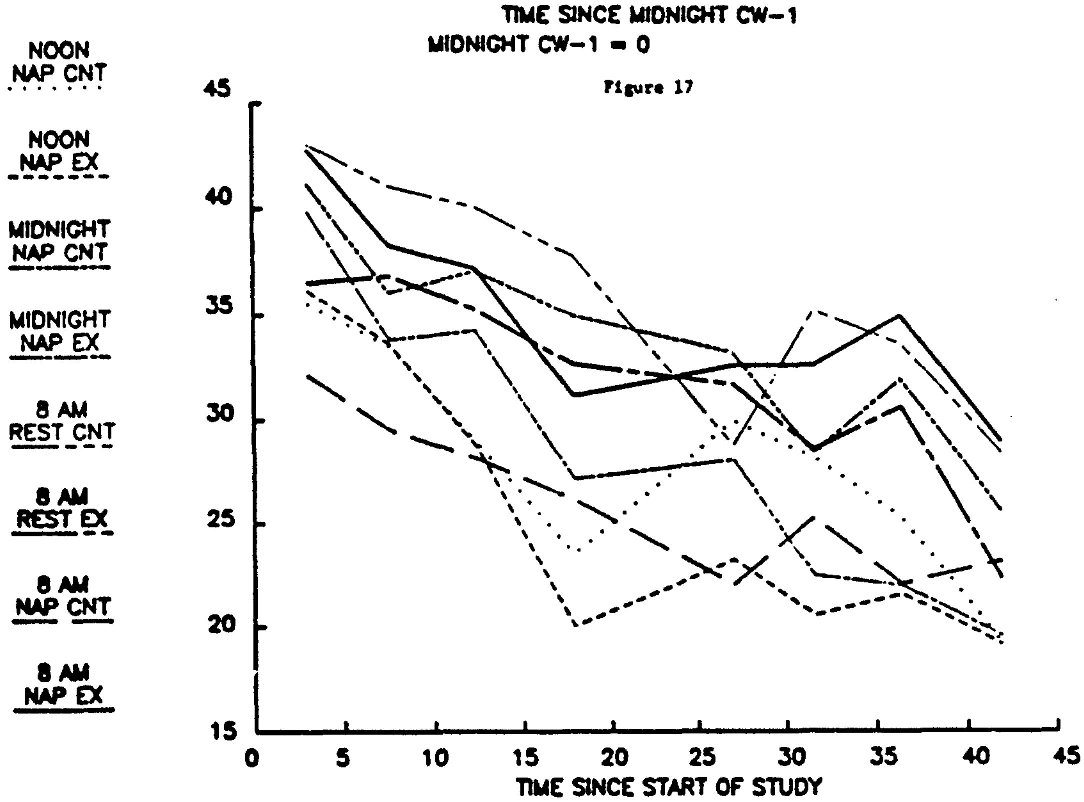


Figure 18

NHRC NEGATIVE MOOD SCALE

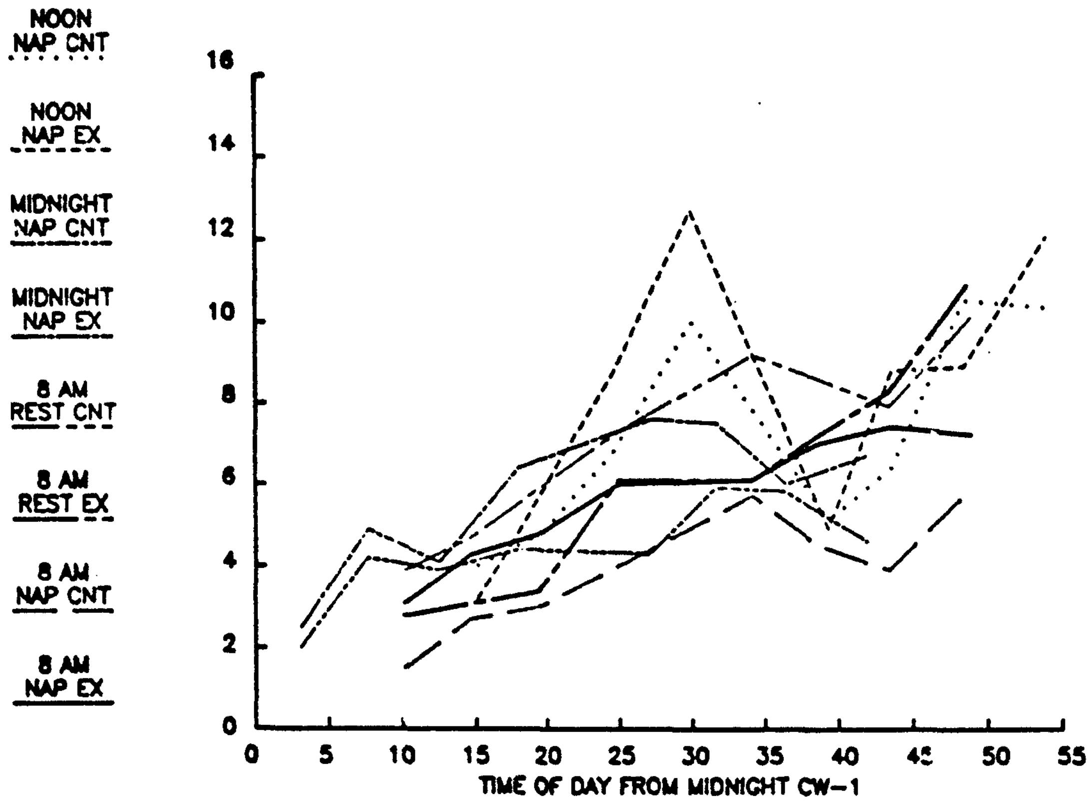


Figure 19

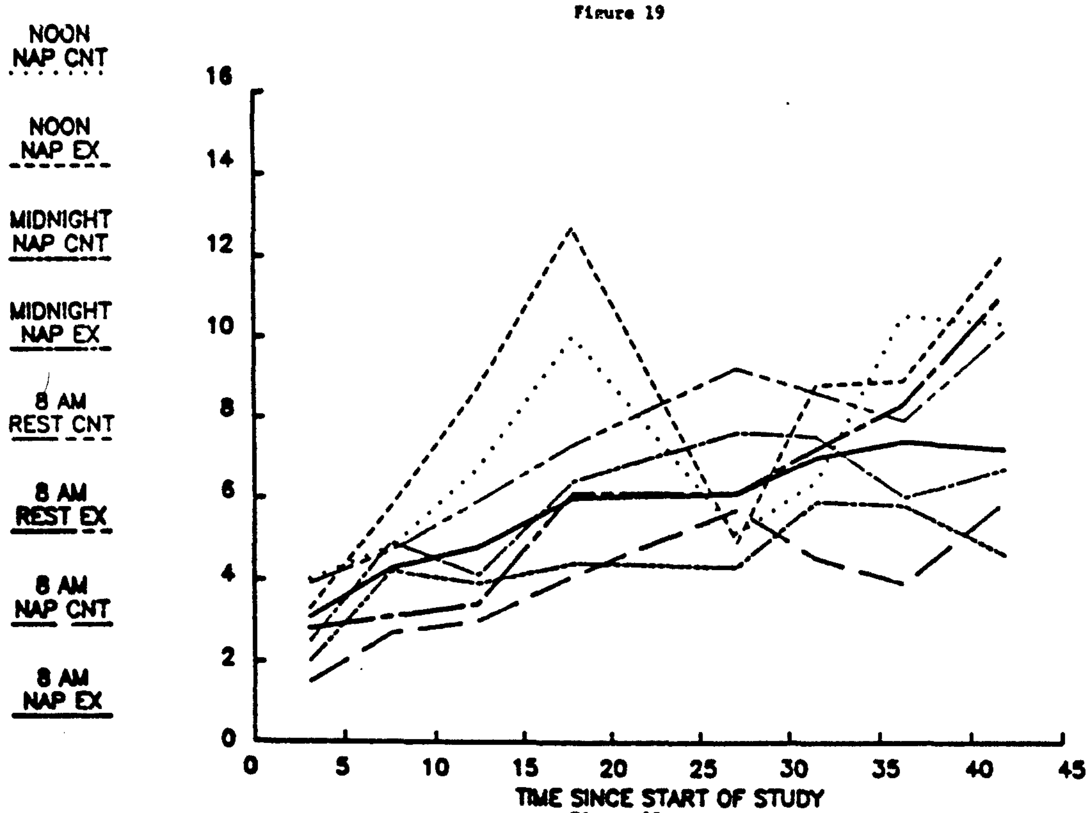
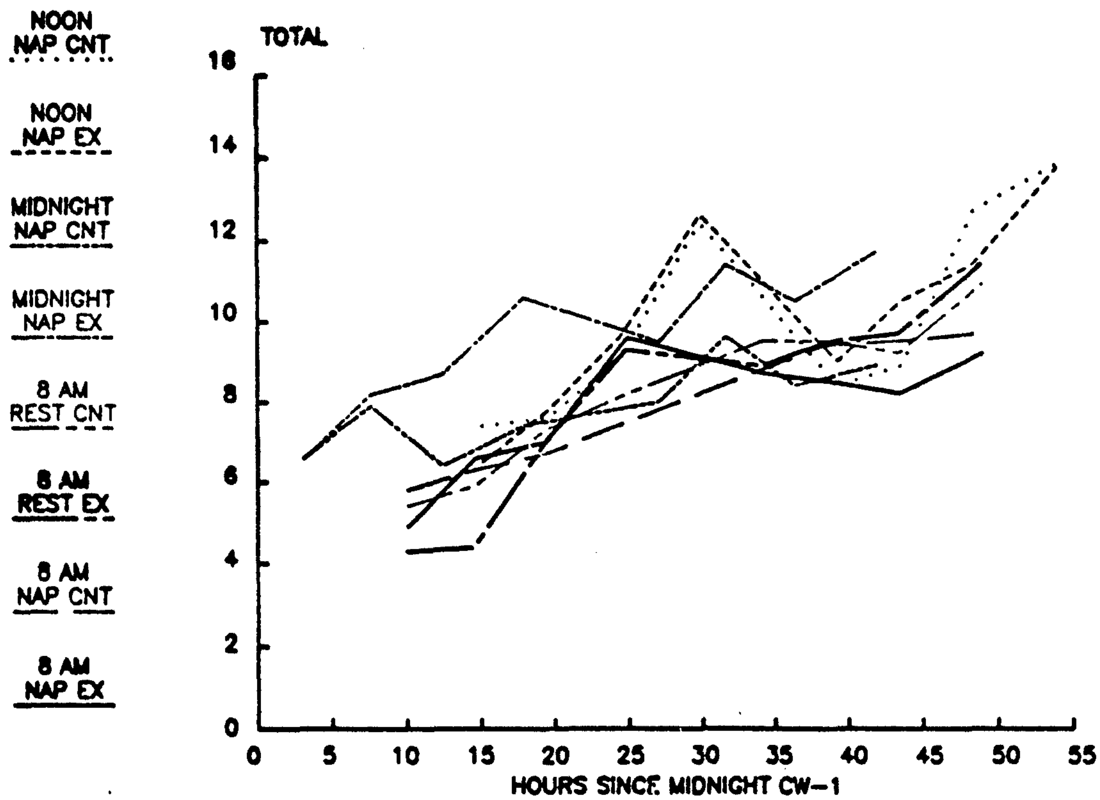


Figure 20

SAM FATIGUE CHECKLIST



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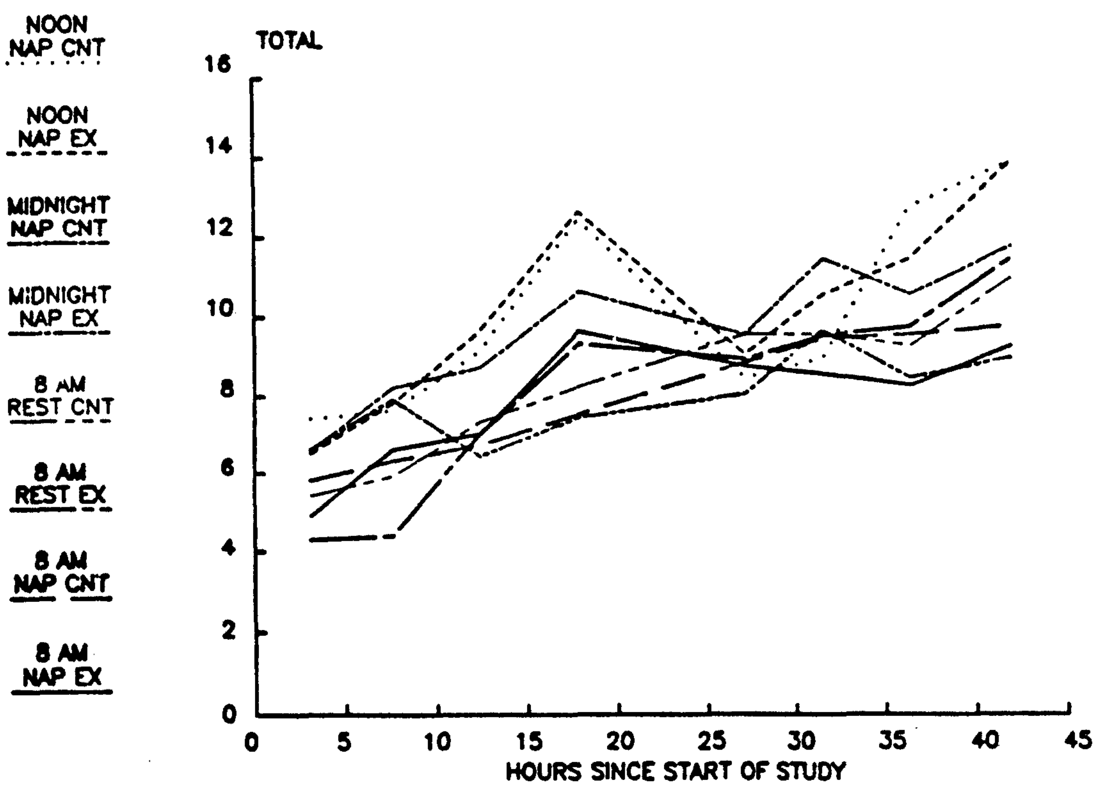
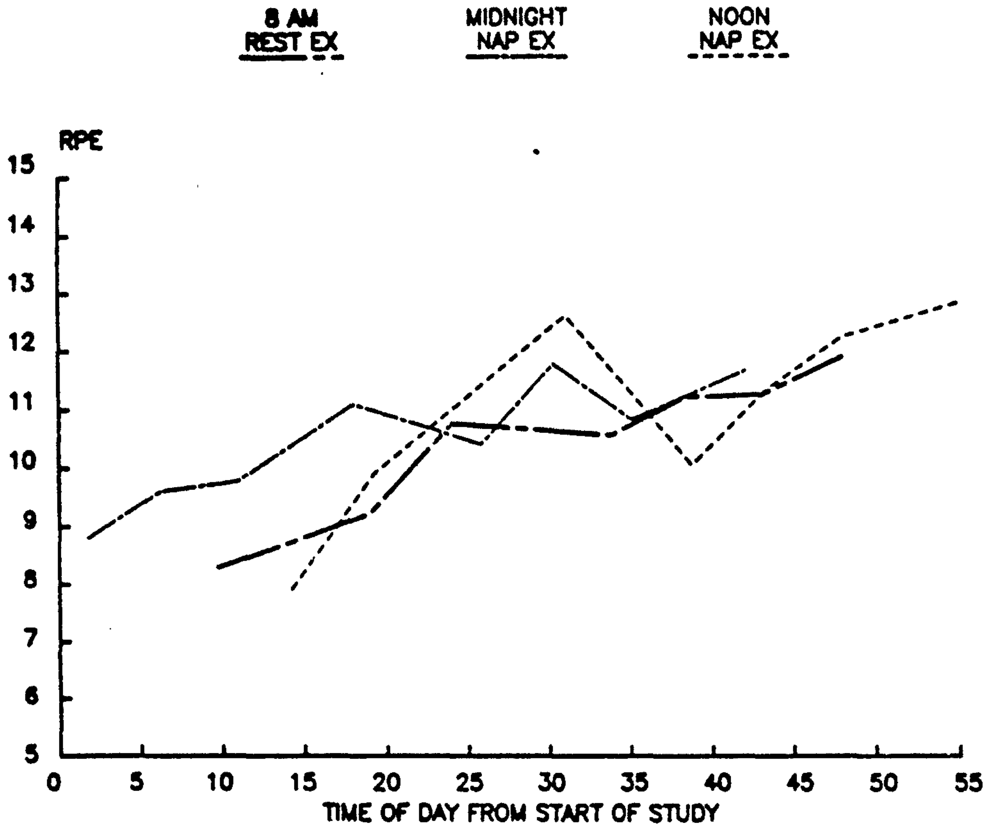


Figure 22

BORG WORKLOAD SCALE (RPE)

MEAN RATED PERCEIVED EXERTION



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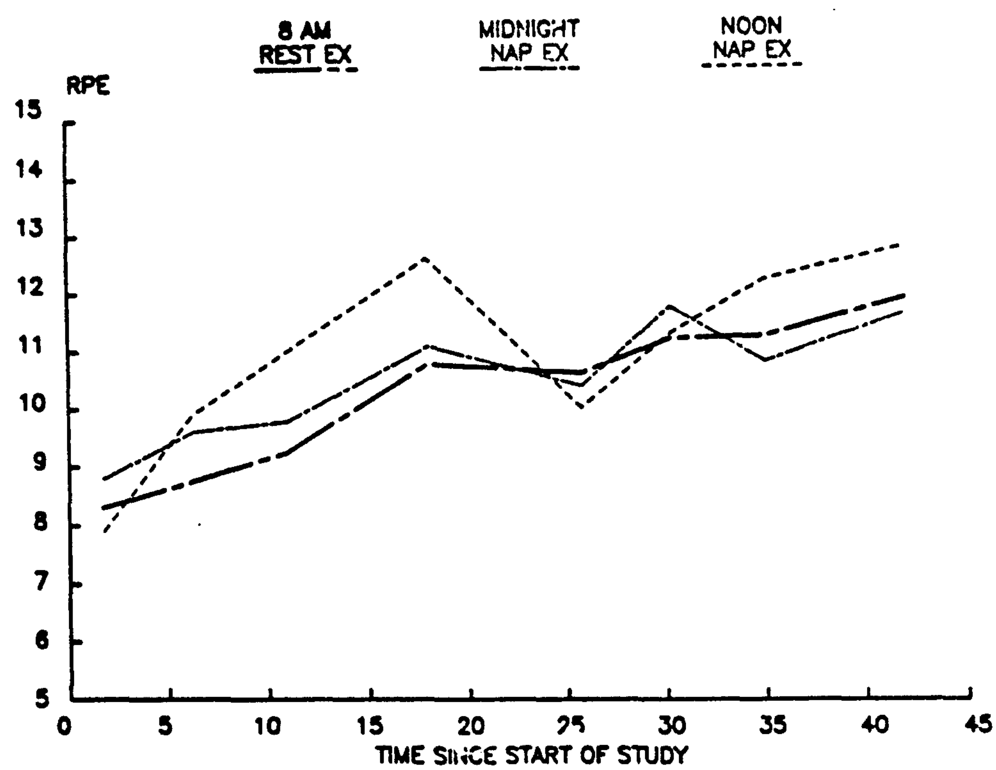
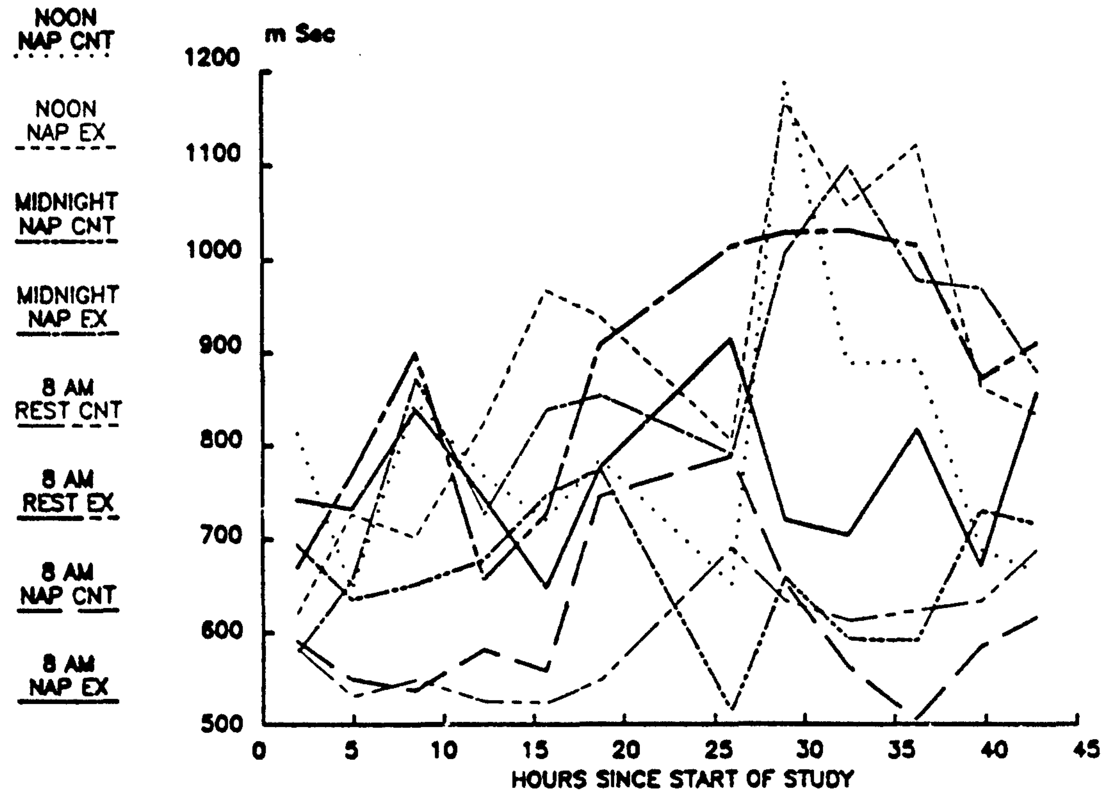


Figure 24

TRAP MEAN REACTION TIME
FOR THE SLOWEST 10% RESPONSES



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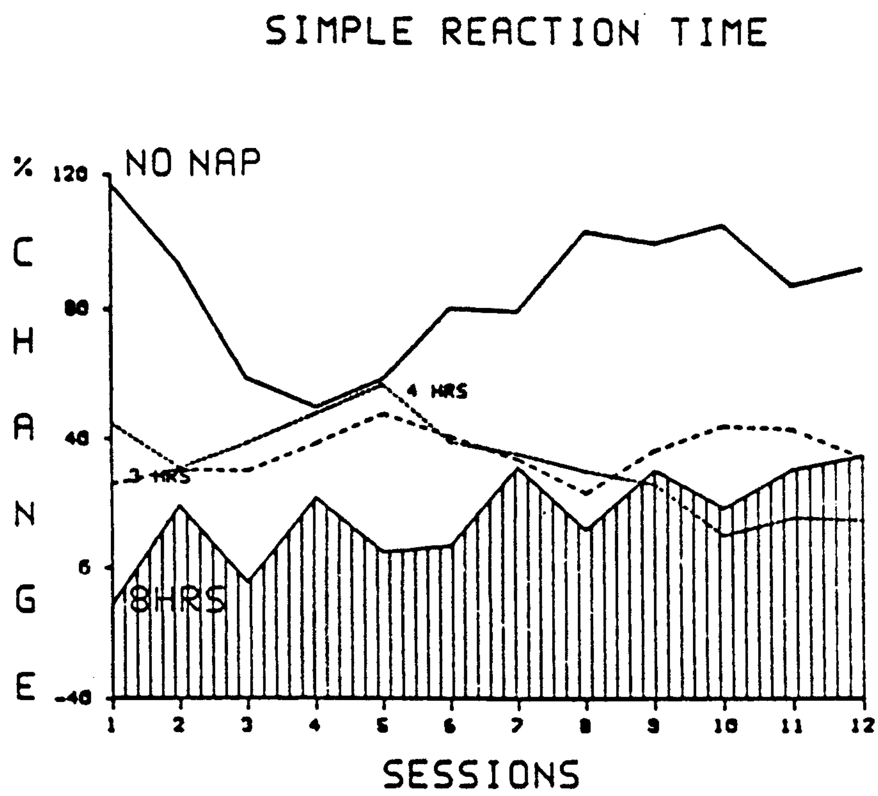

Figure 26

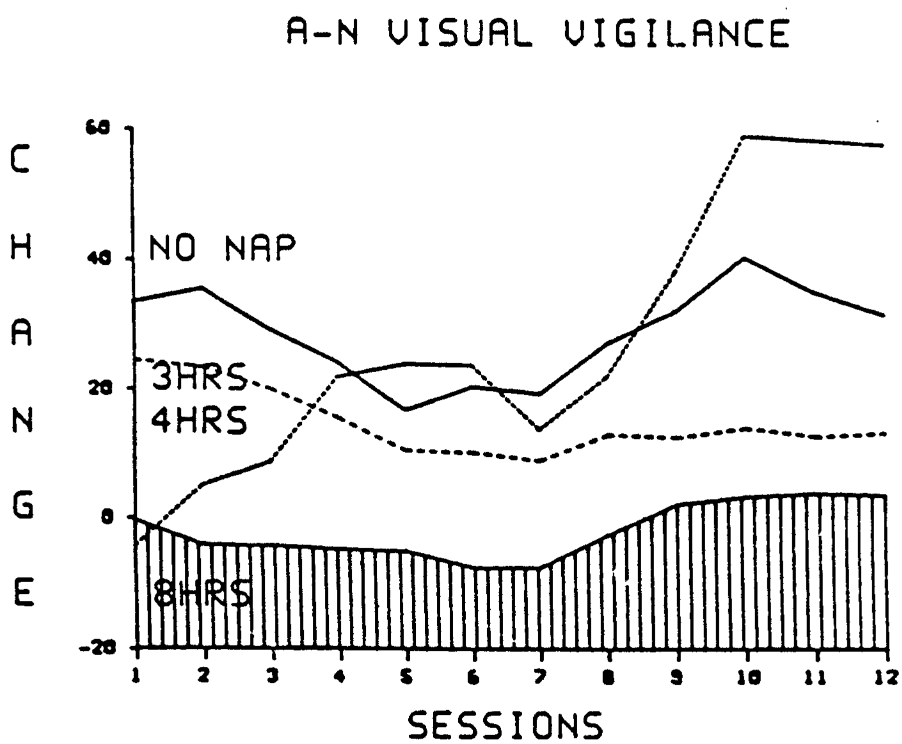

Figure 27

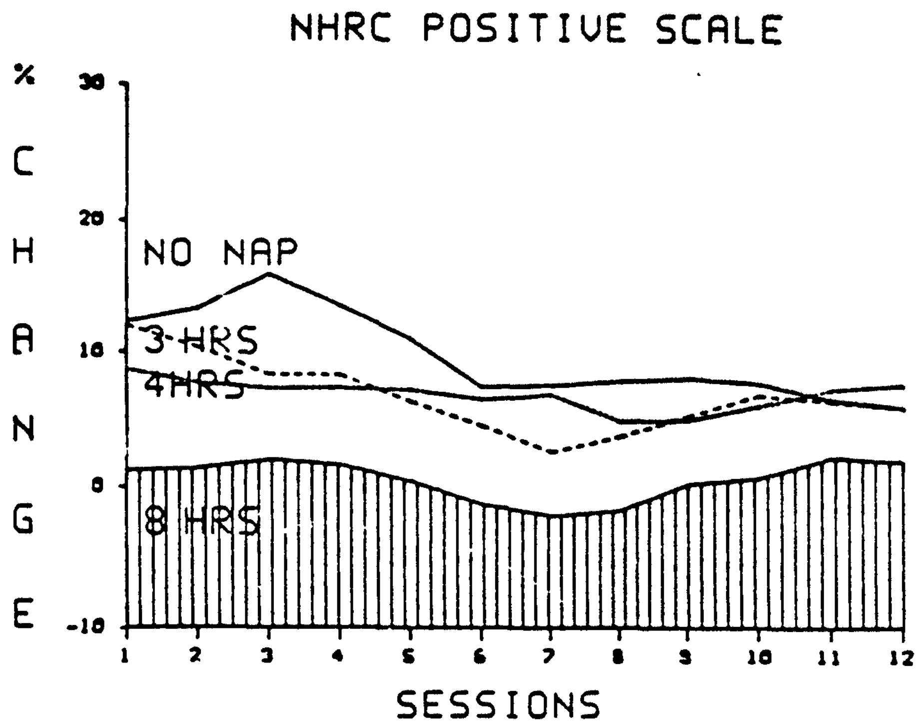

Figure 28

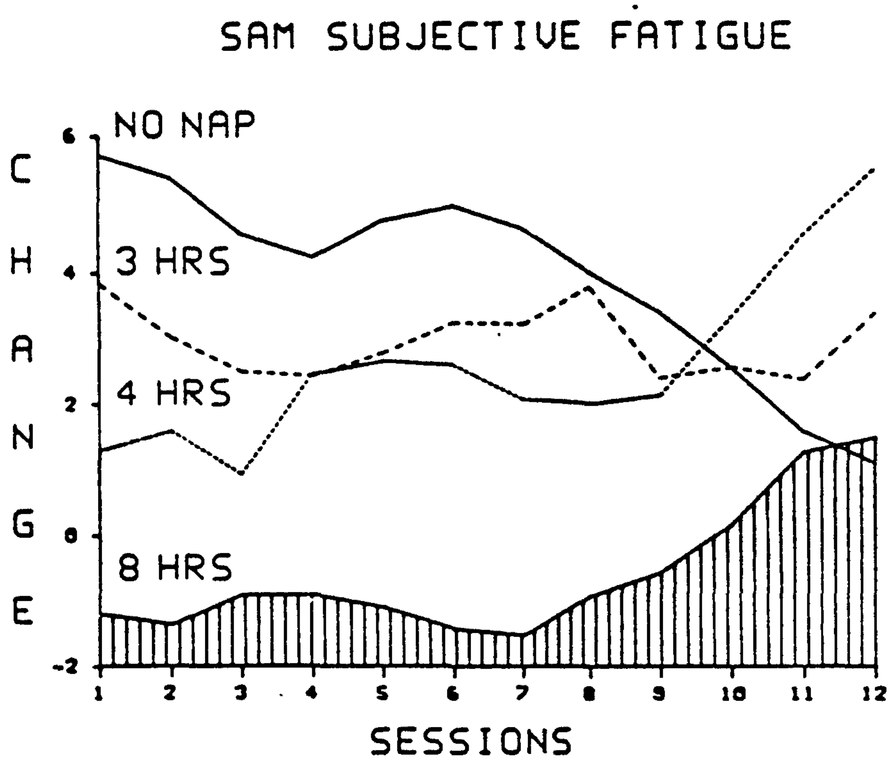

Figure 29

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The effects of a laboratory simulated reconnaissance operation on behavioral and physiological performance were assessed in seven separate sustained operations (SUSOP) studies involving a total of 112 U.S. Marine Corps volunteers. The scenario of this week-long SUSOP involved two 20-hr continuous work episodes with a break period of 3 to 4 hours of sleep or rest. One half of the volunteer subjects experienced 30-40% VO2Max physical work load by walking on a motor-driven treadmill. All subjects performed psychological cognitive tasks. The immediate goal of these seven studies was to obtain an estimate of the performance recuperative power of a nap of 3 to 4 hours duration. Their long-term goal was to define the limits of human endurance in a SUSOP conducted under hostile environments. The results suggested that (1) starting time of a mission should be chosen to avoid extending a continuous work period into early morning hours of circadian trough, (2) a 3-4 hour nap is not long enough to allow recovery from fatigue of a 20-hour continuous work episode to maintain baseline level of performance during successive continuous work episodes, (3) a physical workload of 30% or greater VO2Max will slow down reaction time post physical work period, and (4) (over)

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19. ABSTRACT (continued)
time-of-nap is not as important as the duration of the nap. Management of sleep (nap) is recommended in redefining the limits of human endurance in any SUSOP.

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