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COGNITIVE PERFORMANCE DURING SUCCESSIVE SUSTAINED PHYSICAL WORK EPISODES

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SUMMARY

In modern life some occupations require continuous work (CW) for sustained periods. Military operations can last over 24 h, and, the logistics for the lengths and timing of naps or rest periods to minimize performance loss due to physical effort or sleep loss is not fully known. The present study analyzed various cognitive performance measures to determine if and when certain abilities degrade with CW and exercise of 45 h with only a 3-h nap midway. Twenty-two Marine reconnaissance personnel were studied over two CW days. Eleven of these (exercise group) walked on a treadmill with pack (20 Kg) at 30% of maximal oxygen uptake (VO_2 max) for the first half h of 17 one h sessions each CW while the others (controls) worked at a video terminal. They both performed an alphanumeric task during this half h to determine their long term visual vigilance. This task consisted of randomly appearing letters or numbers in which the subject responds to only the A's and 3's. During the other half h of every session other sets of tasks were given including: a four choice discrimination task, word memory, reading comprehension and speed reading tasks, and a logical reasoning test of complex information processing. At other periods before, during, and after the CW days, map, shape and building location memory, and a task of radar missile simulation were given.

An analysis of variance with repeated measures was used to partial out the effects of groups, (exercise-control), CW days, and the session of administration on these various measures. Particular attention was given to the interactions of the groups, days, and sessions effects to indicate on which day or at what time (if any) each cognitive measure changed, and to show when exercise or sleep loss or time-of-day effects occurred.

The results indicated that the exercise of treadmill walking did not accentuate sleep loss effects on the cognitive measures studied. Sleep loss (day differences) was significant for the visual vigilance task (CW1 = 80.9%, correct; CW2 = 70.6%). Choice reaction and logical reasoning primarily showed time-of-day differences with early morning performance worse. Sleep loss effects during the first day were observed in the word memory task, again with early morning recall worst. There was continued low, word memory performance in the morning of the second day indicating no recovery following the nap. Visual vigilance appeared to degrade earlier in the second day for the controls than for the experimental subjects who were exercising during this task. Two reading comprehension measures showed complex differences over the days or between groups over sessions, with lower reading performance in the evening (1800).

These findings indicate that exercise at 30% of VO_2 max does not compound sleep loss effects in cognitive performance. Indeed physical activity during video terminal monitoring

may delay any sleep loss decrement. Variability of many cognitive abilities throughout the day appeared to show a greater effect than the sleep loss and exercise effects over two days.

INTRODUCTION

Modern high technological society requires full time round-the-clock services. The usual response to this requirement has taken the form of various shift systems, staffed typically by 2-3 stationary or rotated crews ("shifts"). However, some occupations require extended periods of continuous work (CW) on a regular or periodic 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 of CW are in military engagements, witnessed within the last few years. Military planners recognize that should engagements be necessary, the weakest link will be human and not hardware (Radomski and Defayolle, 1981; see Defense Research Group (DRG) Proceedings, 1983).

The major endogenous factors delimiting optimum, extended human performance have been identified as health, physical fitness and fatigue, training/skill level, information processing ability and biological rhythms. External factors are workload, work-rest cycles, and environmental hazards (Englund, Naitoh, Ryman and Hodgdon, 1983; Englund, 1979; DRG Proceedings, 1983). Resolution of problems arising from the influence of these factors is the subject of intense investigation. Intervention methods for performance enhancement range from pharmacological (external input, see Spinweber and Johnson, 1983) to sleep management (Internal Control, see Naitoh, Englund and Ryman, 1983). Discovery of the requirements to support sustained quality mental and physical performance is the major objective of most CW studies which involve critical industrial or military applications. The relationships between physical work, sleep loss, and mental efficiency are not fully understood and require study.

The present study, which is one of a series, concerned mental effectiveness during repeated CW work periods. Successive sustained operations are those in which partial or complete rest/recovering periods separate two or more intensive extended work phases. Specifically, we have been studying the effects of continuous and repeated work episodes on cognitive performance by manipulating the time and length of naps, the exercise levels, and shifting time schedules. The prime purpose has been to determine effectiveness of cognitive performance over lengthy CW episodes.

METHODS

Subjects

Volunteer Marine reconnaissance personnel were obtained from Camp Pendleton, CA and studied in pairs, over a five day period. All subjects were young physically fit males (mean age 20.5 $\pm$ 1.7 years, 18-24, mean VO_2 max = 53.5 $\pm$ 5.9), and had experienced some sleep deprivation (mean h awake 46.9 $\pm$ 22.2) previously. Each of these subjects was in either a first or second enlistment, most had completed high school and had a mean Nelson-Denny Reading Test (Brown, 1966) grade level of 11.2 (SD = 2.4). The nature of the study and risks involved were explained verbally and given in written form to each subject prior to their voluntary consent to participate. All the subjects had the right to withdraw from the study. They could also be withdrawn if the attending medical officer and experimeters found them unable to continue.

Materials

The study was conducted at the Physical Fitness and Ergonomics Laboratories of the Naval Health Research Center, San Diego (NHRC). Within the Ergonomics Lab is a sound-reduced, electronically shielded sleep room and an air-conditioned exercise room. Equipment used included a DEC MINC 11 computer with VT 105 and VT 100 video terminals, a Tektronix 4051 computer and a Quinton clinical research treadmill, model 18-60. Other equipment included a polygraph, FM instrumentation tape recorder, four electronic filters and four differential amplifiers.

Measurements

Physical work was a major independent variable presented in two levels: moderate physical workload vs. no physical workload, selected to test for effects on cognitive performance. Additionally, a 3-h nap was given midway (0400-0700) between sustained episodes to determine the restorative effects of the nap at that particular time of day. Oral temperatures, blood pressures, grip strengths, heart rates and sleep polygraphs were systematically measured on all subjects. The results on these measurements are presented elsewhere (Englund, et al., 1983; Naitoh, Englund, and Ryman 1982). A full description of the computerized Performance Assessment Battery (PAB) utilized in the SUSOPS series of studies at the NHRC has been provided in Ryman, Naitoh, and Englund, 1983; see also Naitoh, et al., 1982, and Naitoh, 1981. The other independent variables in this study were sustained work and sleep loss. The sustained work episodes consisted of 17 sets of two half h segments each day: with visual vigilance with physical work given the first half h, and computer generated tasks and other performance measures the second half h. The protocol (Fig. 1) and treatment sequences are detailed in the procedures section below. The dependent measures and focus of this paper are described next.

Description of Tasks

Air Defense Game. This task, representing significant features of a Navy tactical problem, was developed at the Navy Personnel Research and Development Center, San Diego. Details of the computer simulation and game scenario may be found in Greitzer, Hershman and Kelly (1981). This task was given on a Tektronix 4051 microcomputer. The computer's graphic CRT simulates a radar screen. The player of the game defends his ship by launching missiles at approaching air targets. The game's complexity can be predetermined by the three speeds of incoming missiles and the tempo of operation (number and frequency of incoming missiles) from a relatively low information processing load to demanding. Since the ship's detection range exceeds its weapon range a player must decide when to launch a missile on the basis of target speed. There is an optimal range to destroy targets (the range of the defensive missiles). The goal of the game is to effectively destroy all incoming targets during each operation at the maximum range. Feedback is given to the player on target identity, successful launches, errors, target destruction, or a missile hit on the ship. The average range of intercept was the performance measure selected for analysis. The game was found to be highly motivating and requires sustained attention and timely decisions by the subject. Each administration in this study lasted 30 mins, during which time subjects performed five, 5-min operations, with 1-min breaks in between. The task was given five times on Monday for training purposes. The four administrations analyzed were on Tuesday at 2200, Thursday at 0300, and Friday at 0300 and 1230.

Logical Reasoning Task. This task was devised by Baddeley (1968), recently evaluated by Carter, Kennedy and Bittner (1981), and has been used extensively in research (e.g., Haslam, 1982). The task consists of the random presentation on the computer screen of one of 16 possible sentences (such as "A follows B") followed by a pair of letters (either "BA" or "AB"). Subjects were instructed to enter a "1" on the terminal keyboard if the sentence was a true description of the letter pair or a "2" if false (i.e., for the above example, "BA" is a true description of the grammatical relationship in the sentence "A follows B"; hence enter "1" on the keyboard). The subjects were urged to work accurately on as many sentences as possible in 3 mins. Percent correct responses are reported in this paper. Subjects took this task seven times per CW episode. Two analyses were done: 1) subjects with more than 60% correct at each episode (one 24 h period) were analyzed (N=14), and 2) the total sample (N=22).

Alpha-Numeric Visual Vigilance Task. This task was developed at the NHRC. In this task, single random alphabetical characters or numbers are presented on the screen at random time intervals ranging from 6 to 14 sec, with a mean interval of 10 sec. These numbers or characters remain on the screen for 10 msec. Subjects were instructed to press a hand-held button with their thumb every time an A or a 3, the signal stimuli, appeared. An error of omission was declared when response to an A or a 3 was not made within 5.0 sec. This task lasted for 30 mins during which 20 signal stimuli were randomly mixed with the other 160 numbers and letters presented. A measure of percent correct responses was used. This task was given the first half h of each one h session during both CW1 and CW2, thus subjects completed this task 17 times per CW episode. Analysis was done on the means of four time periods: morning (0900-1200), afternoon (1230-1630), evening (1715-2145) and late evening (2215-0215).

Williams Auditory Word Memory Test. This short-term memory task involves 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 subject was instructed to write down the word as soon as he first heard it. The next word followed immediately after the second presentation of the previous word. As soon as the subject wrote down the last word he was given a recall sheet for writing down all remembered words in any order. Two mins were allowed for each recall for each list (Williams, Gieseking, and Lubin, 1966). Correct words recalled were calculated and expressed as percents. This test was given four times during each CW episode.

Educational Testing Service (ETS) Visual Memory Test. Factor-referenced cognitive tests were developed in 1976 by Harman and his team under an Office of Naval Research (ONR) contract. A kit of 72 factor-referenced cognitive tests for 23 factors (mental aptitudes) is available from Educational Testing Service (Ekstrom, French, Harman, and Dermen, 1976). One factor of visual memory was selected to augment the William's auditory memory test. The visual memory factor has three tests and represents the "ability to remember the configuration, location and orientation of figural material (Ekstrom, et al., 1976, p 109)." The three tests examine the iconic sensory memory system (Atkinson and Shiffrin, 1971; 1977; Sperling, 1960). They are 1) Shape Memory: The subject is asked to identify those irregular forms which were previously seen in the same orientation on a study page. There are 16 items. The subject is given 4 mins for memorizing and 4 mins for testing recall; 2) Building Memory: The subject is asked to indicate the location of a number of buildings seen on a previously studied map. There are 12 items. Again 4 mins for memorizing and 4 mins for testing, and 3) Map Memory: The subject is asked to identify sections of a map which were previously presented on a study page. Three mins are given for memorizing and 3 mins answering the 12 items. Each test is preceded by a short example section. The tests are suitable for grades 6-16. They appear militarily relevant, particularly for reconnaissance troops (the subjects used in the present study). Subjects took the two different forms of this task, once at 2200 Tuesday (baseline data) and the other at 0230 Friday.

Four-Choice Serial Reaction Time Task (Four-Choice). The "Four-Choice" task was developed by Wilkinson and Houghton (1975) and used in previous sleep loss research (e.g., Glenville, Broughton, Wing and Wilkinson, 1978). In this task, subjects observed a blinking "+" (plus sign) in one of four quadrants of a computer monitor screen. Subjects were to press one of the four buttons on the terminal keyboard corresponding to the quadrants on the screen, i.e., upper left, upper right, lower left, and lower right. The blinking "+" remained in a quadrant until one of the four buttons was pressed, then it randomly reappeared in another quadrant or stayed in the same one. If none of the four buttons was pressed in 2.5 sec, a bell sounded at 0.1 sec intervals until a response was made. This task lasted for six mins. Subjects were instructed to respond as accurately and quickly as possible. Percent correct responses was used to assess performance. The Four-Choice was given six times per CW episode.

Gates-Peardon Reading Exercises - Advanced. The Gates-Peardon Reading Exercises (1963) consists of three short reading exercises, each followed by questions requiring reader response. The Advanced booklets were set for average sixth graders to the less-abled ninth grader. Responses to the questions require the reader to utilize a range of reading skills while answering questions on three important types of reading: comprehending the main idea of a selection (Section About), reading to note and recall details (Remembering Details), and reading to understand precise directions (Following Directions). The selection of exercises are well within the reading abilities of our Marine subjects, therefore avoiding reading level as an extraneous variable. The three types of reading skills examined (comprehension, remembering details and following directions) are important to military communications. Previous studies have shown that comprehension and attention to details are degraded by sleep deprivation (Banderet, Stokes, Francesconi, Kowal and Naitoh, 1981; Johnson and Naitoh, 1974). This reading task emphasized accuracy of responding rather than speed, which was emphasized in the other reading task (see Miller Reading Efficiency Test). Subjects could refer to the reading passage while responding to questions. Subjects performed a Gates exercise six times per CW episode.

Miller Reading Efficiency Test. The test consists of five comparable standardized forms of a reading test designed to measure reading rate, comprehension, and efficiency. Each test is 5,000 words in length with lines numbered for easy determination of reading rate. An answer sheet of 50 items is available with content organized so that the subject is only tested on material read. Time allowed to read was two mins. Test forms cover basic information such as history, geography, culture, government, and people of some countries not usually encountered in school curriculum. All five forms were developed at comparable readability as measured by the Flesch Formula (Miller, 1970). In our study subjects read for two mins then completed the test items pertaining to material read. For their next reading they continued where they finished during the last reading session. Number of lines completed was noted after each two min reading session. This task was given six times per CW episode. It has been used in previous circadian rhythm and cognitive performance research (Englund, 1979).

Procedure

For this study and others in the SUSOPS series, subjects were required to live, two-at-a-time, in the laboratory for five days, Monday through Friday. Fig. 1 depicts the data collection protocol. Average ambient temperature (21.1°C) and humidity (50%) were maintained witn air conditioning.

On Monday, subjects were given a graded maximum exercise test developed at the NHRC Physical Fitness Laboratory to assess VO_2 max with simultaneous measurement of heart rate. During the remainder of Monday, subjects were familiarized with the study and trained in the various tasks. One member of each pair of subjects was randomly assigned as the experimental subject. The other was treated as the control. Both subjects performed the same tasks at the same time throughout the experiment. The first half h of each hourly session the experimental "exercise" subject performed the Alpha-Numeric Visual Vigilance Task while wearing full combat gear, carrying a pack and rifle. and walking on a treadmill. Gear worn or carried (boots, rifle, and field pack) by the experimental subjects weighed 27 Kgs. Control "no exercise" subject sat in a chair in front of a video monitor screen performing the same Alpha-Numeric Visual Vigilance Task.

The experiment started at 0800 Tuesday (see Fig. 1). The first work segment, or baseline, consisted of 12 one-h blocks, ending at 2115. Experimental subjects walked on the treadmill for a total of six h during this first day. Treadmill speed was determined by heart rate. The experimental subject's exercise heart rate was kept as near as possible to the rate determined from his individual exercise test to correspond to an energy expenditure equal to 30% of his VO_2 max.

The first CW period (CW1) began Wednesday at 0800, ending at 0400 Thursday (20-h CW). After the end of CW1, each subject was allowed a 3-h nap, from 0400 to 0700 Thursday (Sleep 2 of Fig. 1). Awakened from napping, subjects were given breakfast, and then at 0800 the second CW episode, CW2, of 2-h duration began, ending at 0400 Friday. After the end of CW2, subjects were allowed to sleep until 1200 on Friday.

In Fig. 1, the "sessions" with "A" represent the 30-min period when the experimental subject walked on the treadmill, the control subject sat in front of a video monitor. Both subjects also performed the Alpha-Numeric Visual Vigilance Task at this time. The sessions with "B" are the 30-min periods when all subjects worked at other tasks.

ANALYSIS

Three-way analysis of variance (ANOVA, groups x days x sessions) for repeated measures was performed on each cognitive performance measure (BMDP, 2V, Dixon, 1983). When an F-ratio involving the comparisons of more than two means was significant, Tukey's HSD (Honestly Significant Differences) was computed to indicate which means differed from each other (see Winer, 1971, p. 198). The analysis was performed to answer the following questions: (1) Did the physical workload effect performance? (significant group difference); (2) Did sleep loss effect performance? (significant between-day difference); (3) Did performance change as a function of time-of-day? (significant session (each 1-h of the 24-h day) differences); (4) What, if any, were the combined effects (interactions) between sleep loss, physical workload and time-of-day variations?; and (5) Was the 3-h nap (0400-0700) effective for restoring performance?

Since the Alpha-Numeric Visual Vigilance Task was given 17 times on each of the CW days, the combined means of the morning (0800-1200), afternoon (1230-1630), evening (1715-2115) and late night (2145-0245) sessions were used in order to keep the number of repetitions less than the number of subjects. Two-way ANOVA (groups x days) was computed for the Educational Testing Service Visual Memory Test. This test was given only two times since only two forms are available. Two-way ANOVA (groups x days) was also computed for the Air Defense Game. There were four administrations of this test on different days.

When a subject was missing more than 25% of his data for a variable, he was dropped from the analysis. For subjects with less than 25% missing data a subject's grand mean was substituted for those sessions without data. Missing data occurred because the task (session performance) was dropped due to time constraints or because of computer hardware or software problems.

The Logical Reasoning Task, the most challenging cognitive task in our battery, was subject to guessing (chance equal to 50% correct). We performed two analyses; one with subjects who had no sessions with guessing (N=14) and one with all subjects (N=22). No change in significance of the results was found (see Table 1).

The baseline day was not analyzed, but was treated both as a training day and a day where most of any "learning curve" effects would have occurred; the CW days also involved five extra sessions (2145-0315) of the tasks which the baseline day did not have. It should be emphasized that CW1 was post 8-h sleep, whereas CW2 occurred after a 3-h nap (0400-0700). Student t-tests of the between-episode (CW1/CW2) measures were used to examine the immediate effect of the 3-h early morning nap (0400-0700) upon performance.

Both the exercise, heart rate at 30% VO_2 max, and the sleep loss (5 h in 21 h wakefulness) used in this study were of such moderate levels that neither of them should have had a predominant effect during the first day. The cumulative effects on performance, if any, from exercise and sleep loss should appear during the second day. Therefore the interaction terms, particularly groups x days, were of special interest. The interference of any circadian rhythm effects in performance by these exercise and sleep loss levels would also be apparent from significant interaction of sessions with either group or day or both (group x day x session). If the exercise group performed worse during the second CW day, especially during the later sessions, the cumulative fatigue due to physical workload would be indicated. If the controls were worse the second day the beneficial effect of moderate exercise in counteracting sleep loss would be shown.

Recognizing the possible violations of the compound symmetry assumptions (pattern of constance variances in covariance matrix) in repeated measures designs we have included the probabilities from the conservative GeisserGreenhouse (pGG) adjustments of the degrees of freedom (1958) along with the regular probabilities (pReg) as lower and upper bounds of significance in the tables. The probabilities from the Huynh-Feldt method (1976) were used in determining the significant findings for those repeated measures effects in the text and tables ($pHF \leq .05$) because it reflects the covariance found in the repeated measures. This also avoids the Type II errors more likely in the Geisser-Greenhouse method and the Type I errors found in using the probabilities from the regular df.

RESULTS

Group Differences (Exercise Effects)

The ETS "Building Memory" test was one of two cognitive performance measures indicating significant group differences (F=7.11, df=1,20, P=.015). The control group located 10% more objects than the exercise group during both test administrations (Table 1). The Gates reading section called "Remembering Details," showed a trend toward a significant group difference (F=4.24, df=1,20, p=.053), with the control group averaging 7.11 out of eight questions correct, whereas the exercise group averaged 6.33 questions correct over the two CW days (Table 2 for main effects).

Analysis of the Alpha-Numeric Visual Vigilance (percent correct detections) Task indicated a significant interaction involving groups (groups x day x session) F=3.41, pHF*=.036). Table 3 (also Fig. 2) shows the significant difference in the linear trend of each group over the two days (F=4.96, df=1,20, p=.04). The exercise group improved in performance (75.8% to 86.4%) during CW1, whereas the control group's performance was essentially the same across the first day. During CW2 the exercise group showed the same slight improvement during the first half of the day as in CW1, declining significantly in percent correct detections only during the second half of CW2. The control group indicated significantly lower performance during CW2 (80% CW1, 68% CW2).

There was also a significant groups x day x session interaction for the Gates "Section About" measure (F=3.67, pHF=.004), (see Table 3, and Fig. 3). The control group's performance fluctuated significantly over certain sessions of CW2 as compared to CW1.

<u>Day Differences</u> (Sleep Deprivation Effects)

Performance on the Alpha-Numeric Visual Vigilance Task indicated a significant day difference (F=10.0, df=1,19, p=.005). The mean percent correct detections was 80.9% during CW1, but only 70.6% during CW2, indicating a significantly lower performance on this task on the second CW day. Additionally, performance on the ETS "Shape Memory" test showed 10% less correct responses (F=10.18, df=1,20, p=.005) for both groups on the second test night (0300 Friday). In contrast subjects showed slight though nonsignificant (pHF=.07) improvement over the experiment on the Air Defense Game.

<u>Session Differences</u> (Time-of-Day Effects)

Performance on both the Four-Choice (F=3.65, pHF=.012) and the Logical Reasoning (F=3.77, N=14, pHF=.012) percent correct measures (Table 2, Fig. 4) showed significant session differences. Performance on the Four-Choice task was significantly lower (79.5%) during the last session (17th, 0230 h), as compared to all other administrations (85.2-87.7%). The Logical Reasoning Task showed a significant evening peak (10th session, 1900 h) as compared to those sessions between 2240 and 0215. Morning (1000 h) and afternoon (1530 h) performance on this task was not significantly different from any other session.

There was a significant day x session interaction (F=3.90, pHF=.013) found for Word Memory percent recall with a significant difference in linear trend across sessions on the two days (F=8.85, p=.008) (Table 3, Fig. 5). There was a significant linear decrease in percent recall during CW1 (1000-0245). Performance during CW2 followed a more quadratic profile with lowest recall during session 1 (1000 h) and higher recall during the middle of the day and evening with a slight drop again by 0245 (session 17). Memory for words was worse the last session of CW1 and the first session of CW2 as compared to all other administrations.

The performance profile for the "Section About" section of the Gates Reading Test had significantly differing session means (F=4.43, df=5,100, pHF=.001). Analysis of performance for the "Following Directions" section of the Gates showed significant session differences (F=3.76, pHF=.004). Both these areas of reading indicated that subjects performed worse at session 9 (1800 h). Peak performance occurred at different times for these two tasks (Section About 2400 h; Following Direction 1400 h). There was also a significant interaction for FD (days x sessions, F=3.23, pHF=.013; Fig. 6). A significant linear decline appeared during CW2 whereas CW1 showed the higher order trends (differences in linear trends [F=6.72, df=1,20, p=.02]).

Nap Inertia Effects

We computed performance differences (student t-test) for several tasks just before and after the 3-h nap. The time difference between the last time during CW1 that a subject performed a particular cognitive task and the first time performing the same task in CW2 ranged from 6 to 8 h. Out of the computations for all tasks no significant differences were found. Additionally, T-tests comparing the combined morning sessions of each CW day were computed. The findings indicated no immediate recovery with nap following 21 h wakefulness.

Non-Significant Measure

There were no significant group, day or session main effect differences or interactions found for performance on the Miller's RET.

DISCUSSION

In the design of this study an attempt was made to cover a wide range of cognitive abilities. The results indicate that the various tasks were differentially affected by sleep loss, physical work, and time-of-day. The results also indicated that taking a 3 h nap between successive 21 h sustained operations appeared to have no immediate effect upon performance of cognitive tasks (at least during the first session of CW2). This same conclusion was reached previously for psychomotor but not necessarily for strength measures (Englund, et al., 1983).

The effects of sustained exercise were tested by determining the difference between the two groups (exercise and non-exercise). Two of the eight tasks measured indicated a possible work effect. The non-exercise group clearly showed a 10% advantage when required to locate buildings previously seen on a map. This advantage however was shown during both administrations of this test when the analysis was performed for percent correct responses. No exercise effect (or group difference) was found for total number correct responses rather than percent. In this case the non-exercise group completed fewer questions (left more blank) but had the same number correct as the controls. Since there were only two forms of the test, any effect of physical work would have to have also appeared during the second administration (CW2). It did not. We conclude therefore that no real effect was produced by the physical work upon map memory (iconic memory used to store visual impressions).

Throughout the experiment the non-exercise group was able to remember the details of a recently read passage slightly better than the exercise group. A related finding was reported during two 38 h successive SUSOPS (in lab setting) separated by a 34 h rest period (Bandaret, Stokes, Francesconi, Kowal, and Naitoh, 1981, p. 14). Subjects in a Fire Direction Center simulation began to ignore or miss important spoken message details during the second episode resulting in endangering friendly troops.

Going without sleep affected the performance on some tasks by all subjects. Their ability to correctly detect specific targets in the Alpha-Numeric Visual Vigilance Task decreased by 10% on second CW day. They also decreased by the same percentage their ability to correctly identify objects of different shapes (ETS shape memory). Exercise may have delayed the decrement in alpha numeric target detection for as much as 8 h into the second CW day. This finding indicates that sustained sedentary CRT monitoring may suffer by as much as 12% after just one day without some physical exercise between tasks. Thus moderate exercise while attending to a CRT may extend target detection performance levels 8 h, and, limit the performance decrement when it occurs (in this case 6%).

A sleep deprivation effect was found for another component of the map memory test (ETS). Memory for irregular shapes had decreased 10% by CW2. Whereas exercise (at 30% VO_2 max) had no effect upon iconic memory, apparently sleep loss did. This may be an addition to the memory and sleep loss data. Williams, et al., (1966) had found that learning while sleep deprived was less efficient when the new material was recalled after a night of rest than learning under normal conditions. However, learning on one day and recalling the next was not effected by intervening sleep loss when compared to non-sleep loss conditions. In our study subjects were required to recognize material immediately after learning, and, under the same conditions. Further support for the effects of sleep loss on memory was found in the declines in word memory performance during CW1 and at the early part of CW2. This affect was confounded by time-of-day and nap inertia effects. The 3-h nap may have enhanced word memory performance later in the second day (CW2) though improvement was not seen immediately after the nap, perhaps because of nap inertia.

There were no significant two-way interactions for groups x days for any of the measures used in this study. This indicates that the repeated moderate exercise combined with the sleep loss did not have a direct impact on the cognitive functions measured in this study. Most other research has not found performance decrements from exercise with sleep loss. Webb and Agnew (1973) found no detrimental effects for exercise (bicycle ergometer for 15 mins every 2 h) in two nights of sleep loss (5.5 h sleep each night), but an improvement in simple addition with exercise was found. They did find that sleep loss decreased performance in memory, complex addition, and auditory vigilance. Angus, Heselgrave, and Myles (in press) using a similar exercise protocol as the present study (treadmill walking at 25-30% of maximal aerobic capacity) over a longer period of time (64 h) found sleep loss, not exercise, to be associated with decreased performance in auditory vigilance, Four-Choice, and logical reasoning. Lubin, Hord, Tracy, and Johnson (1976) compared the performance of exercise (bicycle ergometer 5 miles an h - 50% increase over resting heart rate for one of every 4 h) with no sleep over 40 h, and sleep and bed rest groups. They found decreased performance in word memory and simple addition for the exercise group. The sleep and bed rest groups in that study had more rest, indicating that intermittent exercise with no nap or rest over 40 h produced some decreases in cognitive functioning.

Performance on the Air Defense Game (the task considered the most interesting by our subjects) may have improved slightly over the course of the two CW days. This showing could indicate that performance on interesting/exciting tasks can continue to show learning trends up to two days in spite of numerous previous practice trials, and moderate sleep loss. In a previous report (Englund, et al., 1983) a similar improvement in a rifle assembly task was noted wherein subjects competed for best times. Thus competition and interest, each motivating factors, influenced both psychomotor and cognitive task performance during SUSOPS.

No decrements were found in the 2 min Miller Reading Efficiency Task in this study. The RET performance time although set as a message reading task, may have been too limited to show effects. Short duration or interesting and motivating tasks requiring a brief energy burst often show no performance changes over time (Wilkinson, 1964; Alluisi and Chiles, 1967). Recently Haslam (1983) similarly reported that increased willingness to perform overcame performance decrements due to sleep deprivation. The RET passages are highly interesting to subjects.

Time-of-day was again implicated in SUSOPS performance change (Englund, et al., 1983; Englund, 1979) although sleep loss and exercise in some cases contributed to the effect. The ability to make rapid choices decreased by 7% in the early morning h. A similar finding was reported in a field study by Angus, Pearce and Olsen (1981). A similar but larger drop was noted in the ability to think logically, after peak performance in the evening h. Since no interactions were found these changes were probably due to circadian effects. Alluisi and Chiles (1967) reported that the addition of simultaneously performed tasks produced sufficient stress on subjects to accentuate reduced performance rhythm. Information and motivation were shown in that study to overcome or modify that same rhythm.

Reading a message and 1) determining what it means and then 2) following the directions each presented significant time-of-day profiles. However both of these components of reading were also influenced by other than time-of-day factors. Exercise, sleep loss and time-of-day combined to decrease the ability to extract the central meaning from a message at the end of the second day. Sleep loss interacted most with time-of-day to flatten the rhythm effect for following directions on the second CW day. Previously Englund (1979) had found that reading comprehension, speed, and efficiency indicated different time-of-day profiles. Interaction effects of sleep loss or physical work were not measured in that study.

The performance similarities before and after napping may be accounted for by both after nap sleep inertia (Naitoh and Townsend, 1970) and circadian influences (Folkard and Monk, 1980) combined with fatigue. Sleep inertia can last for 1-2 h or more (Taub, 1979; Wilkinson and Stretton, 1971). The circadian low in oral temperature and task performance has been found previously during the early morning h (Englund, et al., 1983; Englund, 1979), the time when the 3-h nap was given. Whatever value the 3-h nap may have had it was not enough to overcome the effects of sleep inertia and circadian influences. The combined effects of nap inertia, time-of-day and length of previous work schedule are suggested as the basis for lack of improvement in performance after nap.

The results from this study indicate that moderate exercise does not add to sleep loss to further decrease cognitive performance. Variability at different times of the day, however, appeared to have a greater impact on cognitive abilities than the sleep loss or exercise levels in this study.

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TABLE 1 - Means and SDs for ETS Sections and Air Defense Game Average Range

ETS		Group Exercise	Control	Day - Time of Administration: Pre Baseline 2100	End CW-2 0300
Shape Memory	M	81.5	82.0	87.0	76.5
	SD	11.3	11.1	8.9	12.6
				F = 10.2 p = .005	
Map Memory	M	76.2	73.3	73.3	76.2
	SD	17.8	16.3	18.2	15.5
Building Memory	M	93.4	85.1	87.7	90.9
	SD	8.1	12.1	10.5	10.8

F Group = 7.11 p = .015

Air Defense Game		Group Exercise	Control	Day - Time of Administration: Pre Baseline 2030	End CW-1 0300	End CW-2 0300	Recovery 1200
Average Range at Intercept	M	17.0	17.0	16.7	16.8	17.2	17.3
	SD	1.2	1.2	1.1	1.4	1.2	1.0

F Admin = 3.08, df=3; p reg=.04; p GG=.12; p HF=.07 (ns)

p reg = probability with regular df

p GG = probability with Geiser-Greenhouse adjusted df

p HF = probability with Huynh-Feldt adjusted df

TABLE 2 - Means and (SDs) by Groups, Days, and Sessions for Cognitive Measures (Main Effects)

Measure	Group: Exercise	Group: Control	Day: CW1[a]	Day: CW2[b]	Morning: *8:	Morning: 10:	Afternoon: 12:	Afternoon: 14:	Evening: 16:	Evening: 18:	Late Evening: 20:	Late Evening: 22:	Early A.M.: 0:	Early A.M.: 2:	Early A.M.: 4:
Alpha Numeric Visual Vigilance % Correct Detections	77.4 (22.3)	74.2 (25.6)	80.9[H] (17.7)	70.6[L] (17.7)		74.4 (22.4)		77.0 (24.3)			75.2 (23.6)		76.4 (26.1)		
Four Choice % Correct	82.3 (22.1)	88.5 (15.0)	86.7 (18.2)	84.1 (20.5)		37.7[H] (17.3)	85.2[H] (20.3)		85.8[H] (16.8)		86.7[H] (17.6)		87.6[H] (18.9)		79.5[L] (23.5)
Word Memory % Recall	55.2 (14.0)	56.8 (18.2)	55.5 (15.1)	56.5 (17.6)	54.7 (19.2)			58.8 (16.7)			58.0 (12.9)				52.5 (15.2)
Gates Reading Remembering Details # Correct	6.33 (1.74)	7.11 (1.02)	6.84 (1.41)	6.60 (1.60)		6.52 (1.39)		6.89 (1.79)		6.45 (1.41)		6.93 (1.15)	6.59 (1.66)		6.82 (1.45)
Section About # Correct	1.42 (.75)	1.55 (.65)	1.57 (.67)	1.41 (.73)		1.61 (.60)		1.32 (.74)		1.27[L] (.70)		1.57 (.69)	1.70[H] (.54)		1.45 (.78)
Following Directions % Correct	68.8 (27.9)	76.8 (20.8)	74.4 (22.3)	71.3 (26.5)		70.7 (21.6)		80.7[H] (21.9)		64.3[L] (30.5)		73.4 (24.6)	74.1 (22.4)		73.6 (22.8)
Millers Reading # Lines Read	34.6 (10.3)	32.5 (10.9)	34.0 (10.4)	33.1 (10.9)		34.7 (10.8)	32.3 (9.6)		34.4 (9.7)		33.6 (10.7)	32.9 (11.7)			33.3 (10.7)
Comprehension	73.0 (29.6)	71.4 (28.9)	73.0 (29.6)	71.4 (28.6)		74.2 (24.0)	77.5 (22.2)		70.9 (30.9)		70.8 (30.5)	70.4 (32.5)			68.2 (28.0)
Logical Reasoning % Correct (N=22)	76.4 (18.8)	85.3 (14.0)	81.4 (16.6)	80.4 (17.2)	80.2 (17.7)		82.9 (15.1)	84.0[H] (17.2)		80.4 (15.6)			78.2[L] (17.9)		79.2[L] (18.0)
% Correct (N=14)	89.7 (9.9)	90.7 (10.3)	91.0 (9.1)	89.9 (10.7)	91.5 (8.2)		91.8 (7.9)	93.8[H] (8.5)		87.9[L] (11.4)			87.0[L] (10.5)		88.9[L] (11.0)

[a] CW-1 was the first continuous workday, which occurred after an 8-hr sleep.
[b] CW-2 was the second continuous workday, which occurred after a 3-hr nap (0400-0700).
[H] Significantly higher mean(s) than those marked L, by Tukey's HSD test.
[L] Significantly lower mean(s) than those marked H, by Tukey's HSD test.
* mid-point time of task administration.

TABLE 3 - Means and SDs for Variables with Significant Interactions

Alpha Numeric Visual Vigilance Task
Groups x Days x Sessions F=3.41, df=3,57, p reg=.023, p GG=.084, p HF=.036

Group	Sessions / Time[c]	CW-1[a] 1-4 / 1000	CW-1[a] 5-8 / 1415	CW-1[a] 9-12 / 1930	CW-1[a] 13-17 / 0045	CW-2[b] 1-4 / 1000	CW-2[b] 5-8 / 1515	CW-2[b] 9-12 / 1930	CW-2[b] 13-17 / 0045
Exercise	Mean	75.8	79.6	82.9	86.4	75.0	78.6	69.9*	71.2*
	SD	14.9	25.3	16.9	13.5	21.1	21.2	24.6	28.2
Control	Mean	80.1	82.9	80.7	79.1	66.8*	67.6*	67.5*	69.1
	SD	6.8	13.7	14.7	19.4	29.1	29.2	29.0	31.8

Word Memory (Percent Correct Recall)
Days x Sessions F=4.48, df=3,60, p reg=.007, p GG=.047, p HF=.007

Session / Time[c]	CW-1[a] 1 / 0855	CW-1[a] 7 / 1525	CW-1[a] 13 / 2240	CW-1[a] 17 / 0255	CW-2[b] 1 / 0855	CW-2[b] 7 / 1525	CW-2[b] 13 / 2240	CW-2[b] 17 / 0255
Mean	60.0	58.3	55.8	49.1†	48.4*	59.2	60.5	58.1
SD	14.9	15.0	12.0	16.4	22.2	18.0	13.5	12.7

Gates Reading "Section About" Section
Groups x Days x Sessions F=3.67, df=5,100, p reg=.004, p GG=.070, p HF=.004

	Session / Time[c]	3 / 1050	6 / 1520	9 / 1810	12 / 2110	15 / 0045	17 / 0300
Exercise:							
CW-1[a]	M(SD)	1.9(.3)	1.5(.8)	1.1(.5)	1.5(.7)	1.5(.5)	1.4(.5)
CW-2[b]	M(SD)	1.4(.7)	1.3(.8)	1.3(.8)	1.4(.7)	1.7(.5)	1.2(.9)
Control:							
CW-1[a]	M(SD)	1.7(.5)	1.2(.6)	1.6 (.7)	2.0 (.0)	2.0 (.0)	1.4(.5)
CW-2[b]	M(SD)	1.5(.5)	1.4(.7)	1.1*(.7)	1.4*(.7)	1.5*(.5)	1.9(.3)

Gates Reading "Following Directions" Section
Days x Sessions F=3.23, df=5,100, p reg=.009, p GG=.087, p HF=.013

	Session / Time[c]	3 / 1050	6 / 1520	9 / 1810	12 / 2110	15 / 0045	17 / 0300
CW-1[a]	M(SD)	73.4(18.1)	82.3(15.2)	56.9†(28.6)	75.3(21.3)	80.8(21.7)	77.4(21.1)
CW-2[b]	M(SD)	68.1(23.8)	79.3(25.3)	71.5 (32.0)	71.5(26.7)	67.3*(23.0)	69.8(24.2)

a = CW-1 is the first continuous workday which followed an 8-h sleep
b = CW-2 is the second continuous workday which followed a 3-h nap (0400-0700)
c = Midpoint time of administration of task
* = Session Mean significantly (p<.01) lower CW-2 than same session CW-1 (Tukey's HSD)
† = Session Mean significantly (p<.01) higher CW-2 than same session CW-1 (Tukey's HSD)
p reg = regular df; p GG = Geiser-Greenhouse adjusted df; p HF = Huynh Feldt adjusted df

	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			SLEEP Ø		SLEEP 1		15A	15B	15A	15B
01 - 02							16A	16B	16A	16B
02 - 03							17A	17B	17A	17B
03 - 04									ETS Task	
04 - 05							SLEEP 2		SLEEP 3	
05 - 06										
06 - 07	TRAVEL									
07 - 08			BREAKFAST*							
08 - 09	Forms		1A	1B	1A	1B	1A	1B		
09 - 10	Max VO_2 Testing		2A	2B	2A	2B	2A	2B		
10 - 11			3A	3B	3A	3B	3A	3B		
11 - 12	LUNCH**		4A	4B	4A	4B	4A	4B		
12 - 13	Computer Task Trn		LUNCH / 5A		5A		5A		LUNCH	
13 - 14			6A	5B	6A	5B	6A	5B		
14 - 15	ADG Training†		7A	6B	7A	6B	7A	6B		
15 - 16			8A	7B	8A	7B	8A	7B		
16 - 17	DINNER		SUPPER	8B		8B		8B		
17 - 18	Computer Task Trn		9A	9B	9A	9B	9A	9B		
18 - 19			10A	10B	10A	10B	10A	10B		
19 - 20	N-D Read.††		11A	11B	11A	11B	11A	11B		
20 - 21	ADG Training†		12A	12B	12A	12B	12A	12B		
21 - 22			SNACK**		13A		13A			
22 - 23	Word Mem.		ETS Task EEG Hookup		14A	13B	14A	13B		
23 - 24	SLEEP Ø		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.

† Air Defense Game

†† Nelson Denny Reading Test

Figure 1 - Protocol for Sustained Operations Experiment

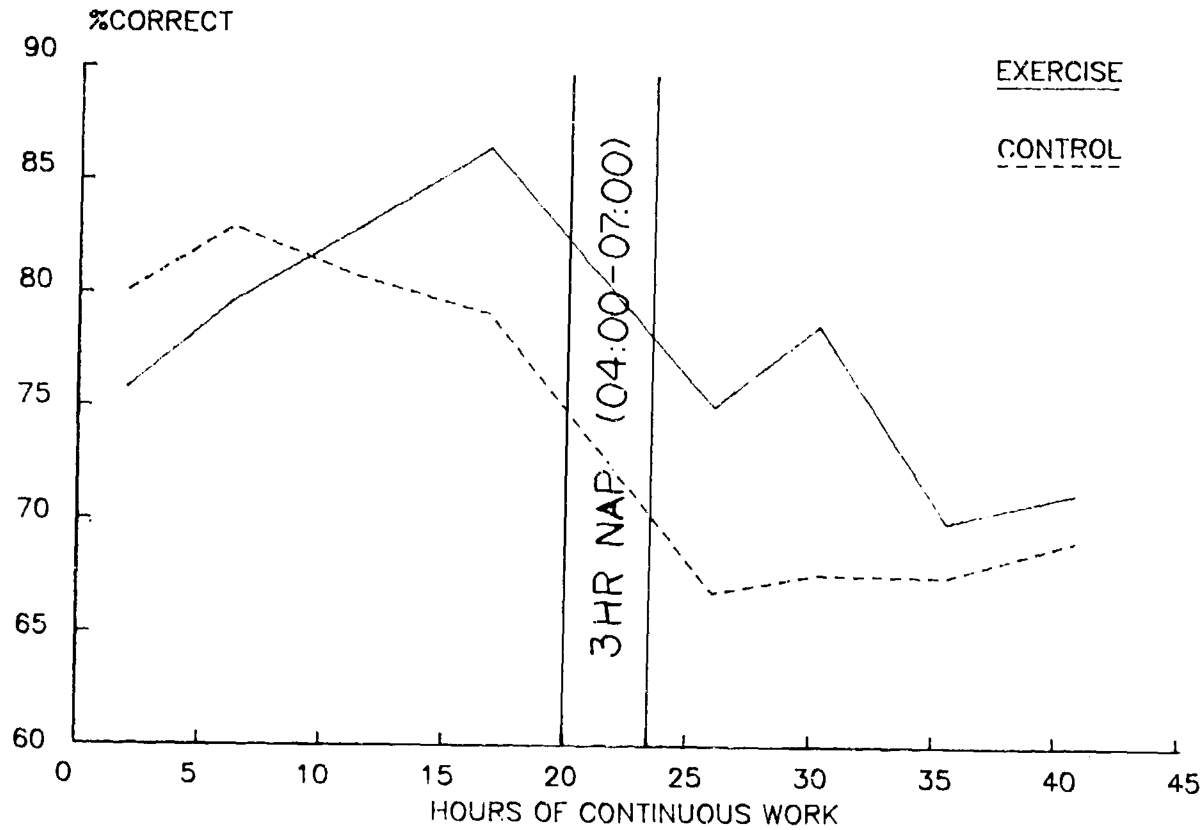

Figure 2 - Alpha Numeric Visual Vigilance Task, Group Means Over Two Continuous Workdays

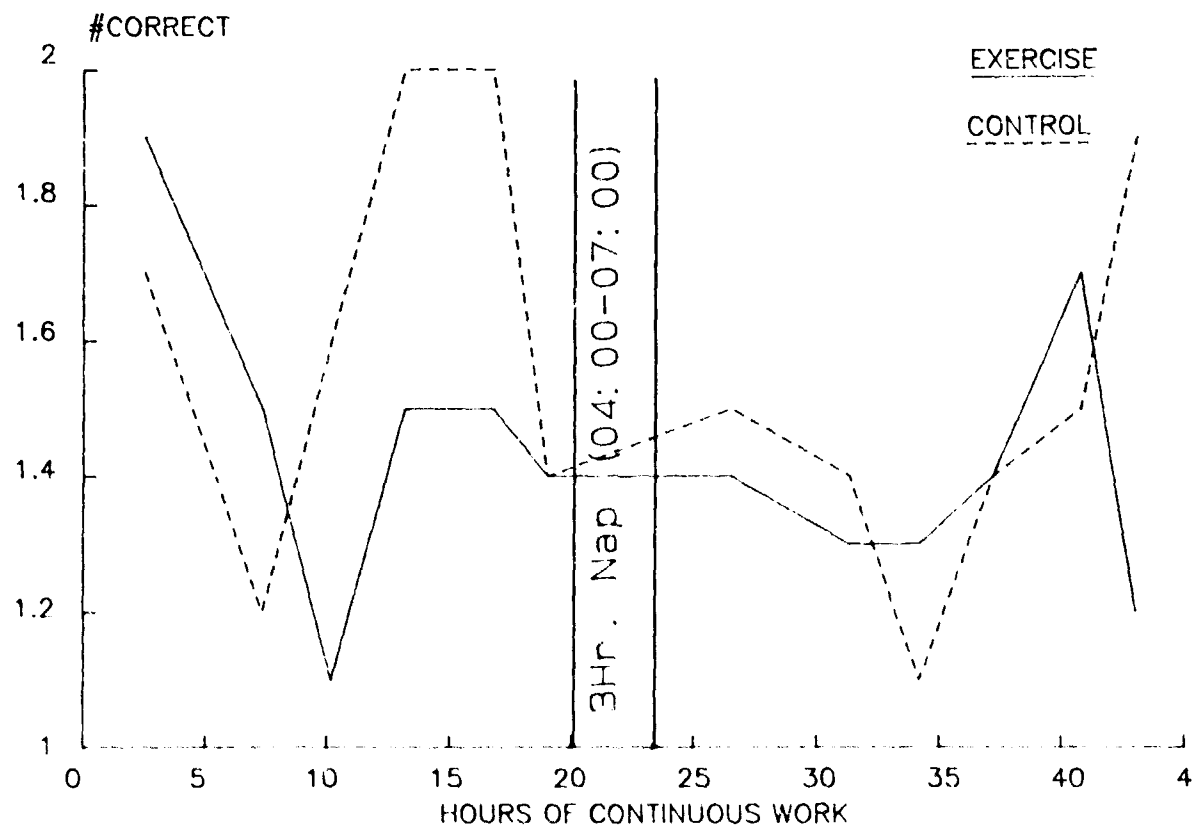

Figure 3 - Gates Reading 'Section About' #Correct, Group Means Over Two Continuous Workdays

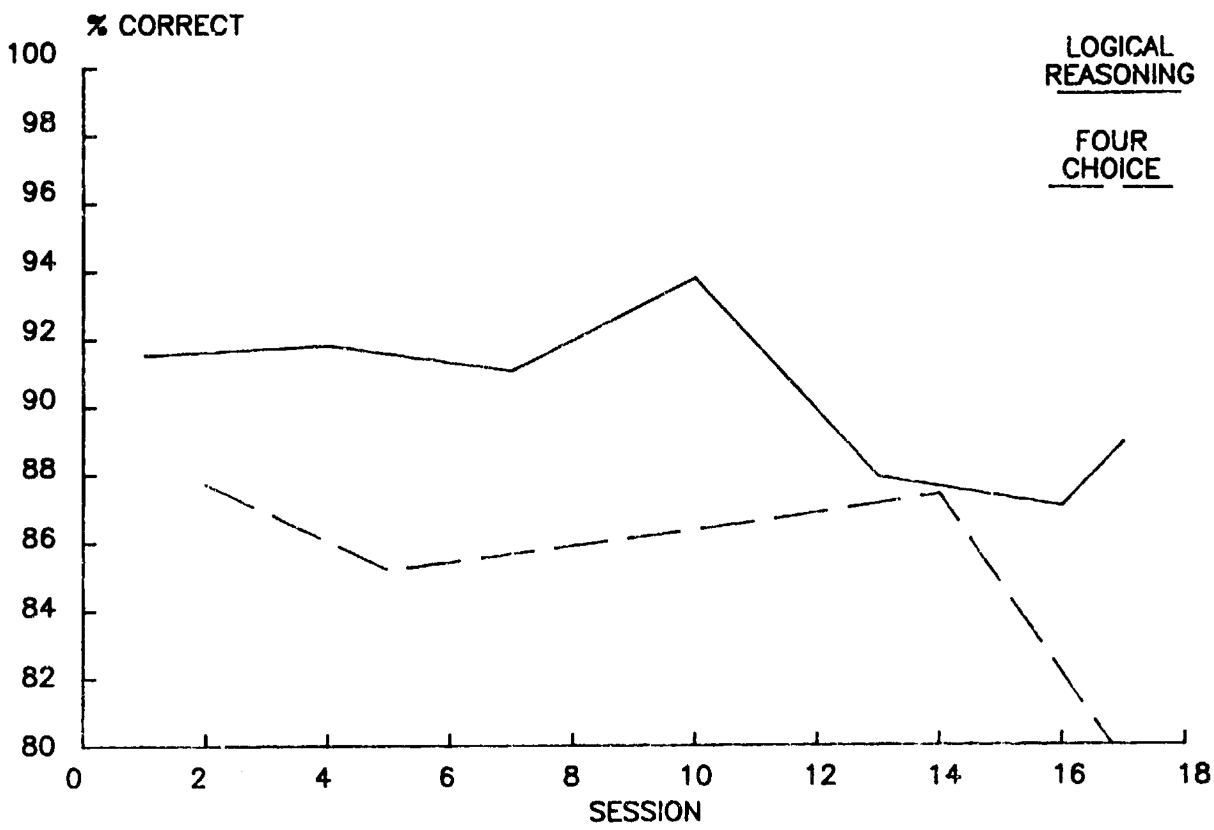

Figure 4 - Logical Reasoning and Four Choice % Correct Over Sessions

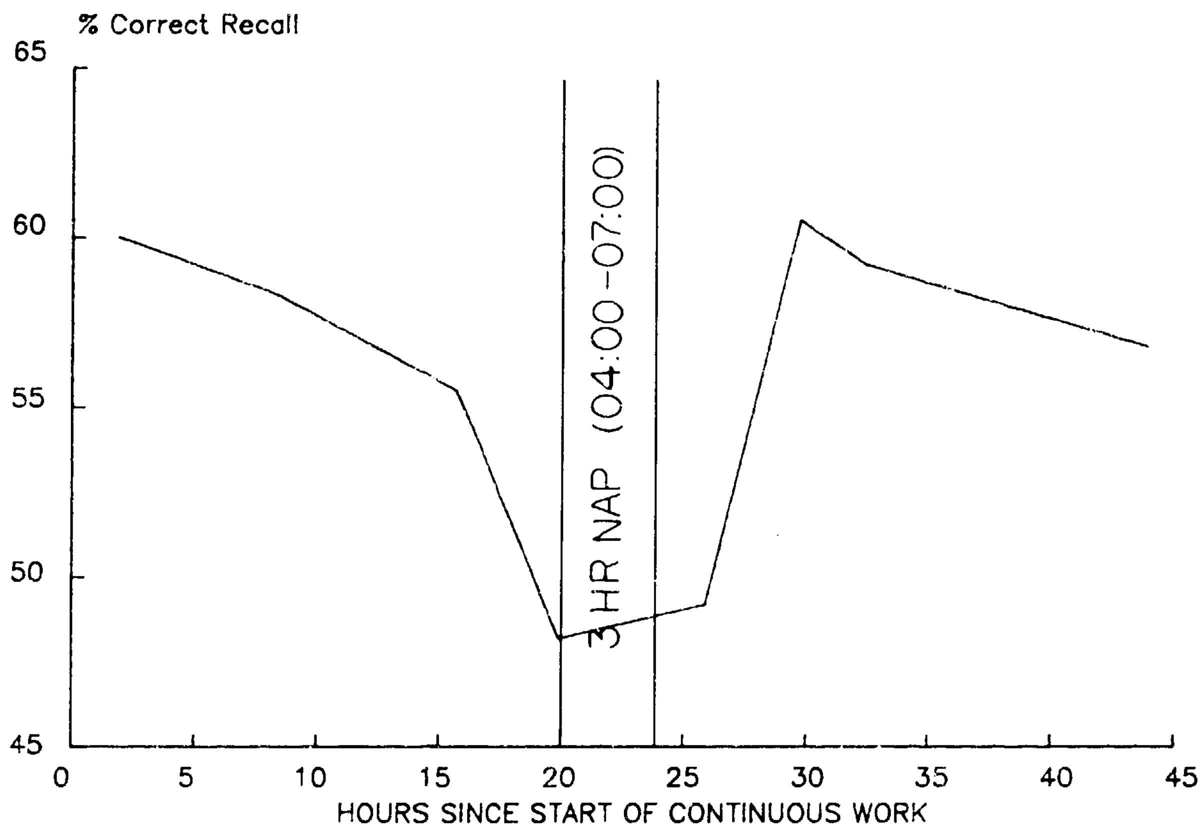

Figure 5 - Word Memory % Recall, Session Means Over Two Days

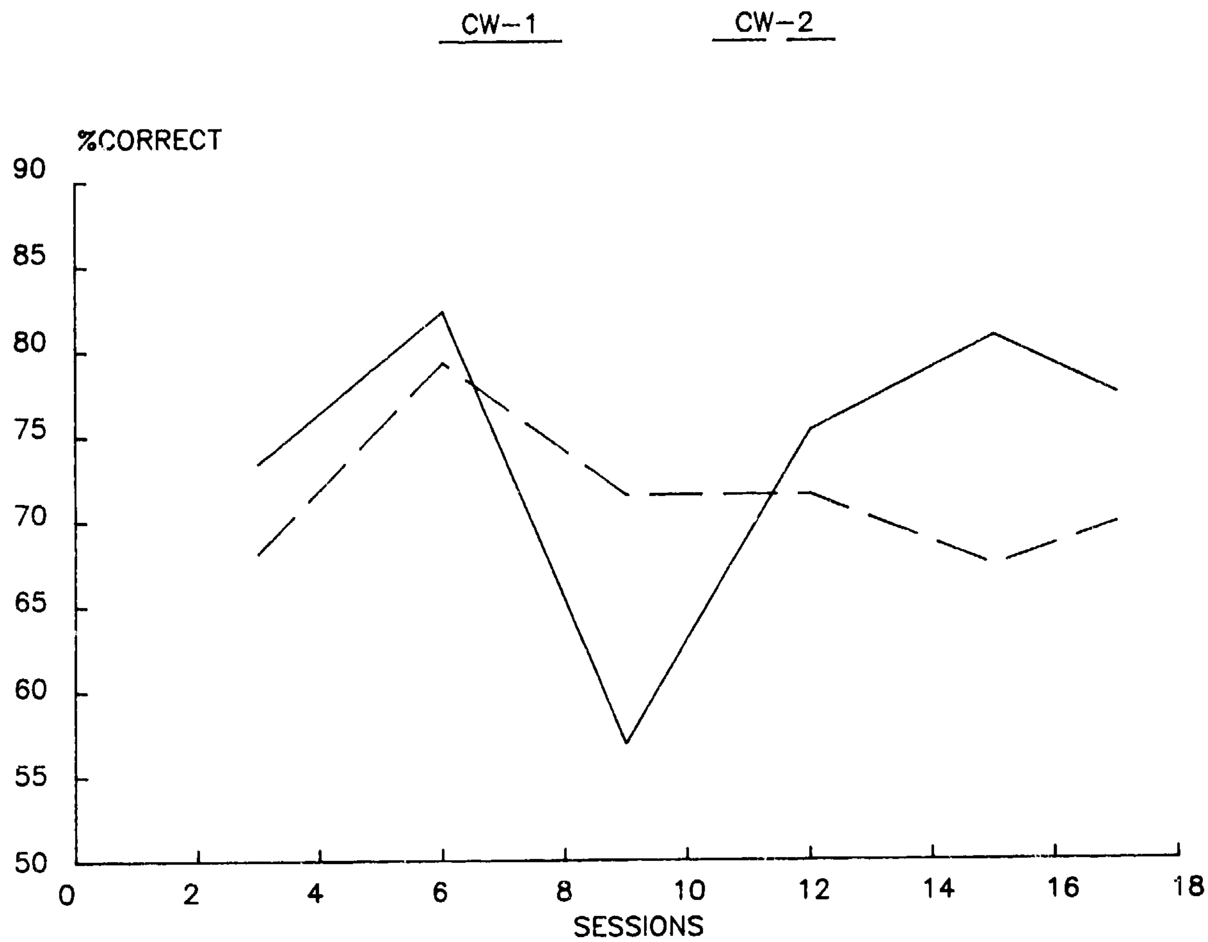

Figure 6 - Gate's Reading Following Directions, Days by Sessions % Correct

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REPORT DOCUMENTATION PAGE

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Circadian Rhythm	Cognitive Performance	Multivariate Design
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Fatigue	Sleep	
Physical Work	Military Tasks	

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

During times of emergency, e.g., military operations, humans must often work continuously for long hours at physically demanding tasks while remaining mentally alert. In this repeated measures study, eleven pairs (one experimental and one control) of Marines (N=22) experienced one 12-hour baseline and two 20-hour continuous work episodes (CWE). The 20-hour CWEs were separated by five hours which included a 3-hour nap from 0400-0700. Each hour of CWE was split into two half-hour sessions. During the first half-hour

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) subjects performed alpha-numeric (A-N) visual vigilance tasks. The experimental member of each pair spent this first 30 minutes also walking on a treadmill in full combat gear (25 kg) at approximately 30 percent max VO_2 heart rate for a total distance of approximately 114 km. The controls performed the A-N task sitting quietly at a video terminal. During the second half-hour, all subjects performed selected combinations of computer generated tasks.

The results indicated that the exercise of treadmill walking did not accentuate sleep loss effects on the cognitive measures studied. Sleep loss (day differences) was significant for the visual vigilance task (CW1 = 80.9%, correct CW2 = 70.6%). Choice reaction and logical reasoning primarily showed time-of-day difference with early morning performance worse. Sleep loss effects during the first day were observed in the word memory task, again with early morning recall worst. There was continued low word memory performance in the morning of the second day indicating no recovery following nap. Visual vigilance appeared to degrade earlier in the second day for the controls than for the experimental who were exercising during this task. Two reading comprehension measures showed complex differences over the days or between groups over sessions, with lower reading performance in the evening (1800).

These findings indicate that exercise at 30% of VO_2 max does not compound sleep loss effects in cognitive performance. Indeed physical activity during video terminal monitoring may delay any sleep loss decrement. Variability of many cognitive abilities throughout the day appears to show a greater effect than the sleep loss and exercise effects over two days.