NUREG/CR-6046

Alertness, Performance and Off-Duty Sleep on 8-Hour and 12-Hour Night Shifts in a Simulated Continuous Operations Control Room Setting

Manuscript Completed: March 1995
Date Published: April 1995

Prepared by
T. L. Baker

Institute for Circadian Physiology
677 Beacon Street
Boston, MA 02192

Prepared for
Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code L2630

DISCLAIMER

DISCLAIMER

Abstract

A growing number of nuclear power plants in the United States have adopted routine 12-hr shift schedules. Because of the potential impact that extended work shifts could have on safe and efficient power plant operation , the U.S. Nuclear Regulatory Commission funded research on 8-hr and 12-hr shifts at the Human Alertness Research Center (HARC) in Boston, Massachusetts. This report describes the research undertaken: a study of simulated 8-hr and 12-hr work shifts that compares alertness, speed, and accuracy at responding to simulator alarms, and relative cognitive performance, self-rated mood and vigor, and sleep-wake patterns of 8-hr versus 12-hr shift workers.

Twenty male subjects between the ages of 20 and 45 were randomly assigned to either an 8-hr or 12-hr shift protocol. The two shifts were designed as follows: (1) six 8-hr evening shifts (1500-2300), three days off, then six 8-hr night shifts (2300-0700), or (2) four 12-hr night shifts (1900-0700), three days off, then four additional 12-hr night shifts (1900-0700). Each subject slept in the laboratory for two nights of habituation immediately before the simulated work shift in either protocol. Subjects worked in teams of two, alternating the duties of monitoring a process control simulator (Foxboro Corp.), taking computer-based cognitive performance tests, completing self-assessment questionnaires, or taking tests to measure sleepiness-alertness. The simulator operation task required vigilance over system variables, response to auditory and silent alarm signals, and record keeping. Delays in recognizing and responding to alarms were computed and recorded throughout the work shift for later analysis of work task efficiency.

At hourly intervals during the work shift, each subject left the simulator monitoring task to complete a 15-minute Performance Assessment Battery developed at the Walter Reed Army Research Institute. This battery included subtests for logical reasoning, reaction time, numerical column addition, serial addition-subtraction, visualizing an object in 3-dimensions, and time estimation. Each subject also completed an hourly subjective rating scale called the Global Vigor and Affect scale.

Throughout the simulated work shift, alertness was monitored by recording electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG) data. At 2-hour intervals, each subject's sleepiness-alertness level was further assessed via standardized nap tests.

On simulated work days, during off shift hours, subjects resided in one of two attached and self-contained two-bedroom residential apartments with kitchen and bathroom facilities located next to the simulated control room. Subjects were restricted to bed for an 8-hr sleep period in total darkness, beginning approximately 1 hour after the end of each work shift. EEG, EMG, and EOG continued to be recorded during this sleep period to measure sleep-waking stage. Subjects did leave the HARC facility during days off between blocks of scheduled work shifts, but kept detailed logs of sleep-wake activities. Caffeine, alcohol, and psychoactive drugs were disallowed throughout the study, because of their potential impact on sleep, alertness, and performance.

No statistically significant differences in simulator performance were found between subjects on 12-hr and 8-hr night shifts. In addition, there was no significant difference between the two protocols in the length or quality of daytime sleep, or in physiological or subjective sleepiness-alertness on shift. With the exception of one subtest, subjects on 12-hr shift completed computer performance tests slower but with better accuracy than those on 8-hr shifts. Several measures showed better alertness, mood, and off-duty sleep on evening shifts than on night shifts.

Contents

List of Figures

Methods Section

Results Section

Simulator Operation

Cognitive Performance Tests

Results Section

Self-Rating Scales for Global Affect (GA) and Global Vigor (GV)

Sleep Measurements: Summaries of Significant Results

Multiple Sleep Latency Test

Stanford Sleepiness Scale

List of Tables

Executive Summary

The objective of this laboratory simulation study of shiftwork was to determine whether 12-hr work shifts used by operating personnel in nuclear power plants would lead to diminished mental performance, increased sleepiness and fatigue while on duty, negative mood changes, or disrupted off-shift sleep, as compared with more traditional 8-hr shifts.

The study focused on night shift work, when alertness and performance problems are most apparent. Twenty male volunteers worked for two weeks on 12-hr night shifts, or for one week on 8-hr evening shifts followed by a week of 8-hr night shifts. Their chief activity during the simulated work shift was operation of a simulator that was programmed to mimic plant systems. The speed and accuracy of their response to auditory and silent alarms was recorded throughout the work shift. They also took hourly standardized cognitive performance tests on a personal computer and completed hourly ratings of mood (affect) and energy level (vigor). Every two hours they took a standard test that measures physiological alertness and tendency to fall asleep. Physiological variables, including the electroencephalogram (EEG), were recorded throughout the work shift and during sleep that occurred in a required bed rest period of 8 hours immediately following each work shift.

The key findings of this study are as follows:

Comparison of 8-hr and 12-hr Night Shifts

- There were no differences in the operation of the simulator or the speed of responding to alarms related to working 8-hr or 12-hr shifts.
- There were no differences between 8-hr and 12-hr shifts on various self-rating scales of sleepiness, alertness, weariness, or effort during the simulated work shift.
- There were no differences between 8-hr and 12-hr shifts on three of four mood scales, including those for sad, calm, and tense. Only happiness was rated higher by subjects on 8-hr shifts, as compared to those on 12-hr shifts.
- There were no differences between 8-hr and 12-hr shifts in the Multiple Sleep Latency Test (MSLT), a measure of physiological tendency to fall asleep during duty hours.
- There were no differences between 8-hr and 12-hr shifts in the length of off-shift sleep, the proportion of various sleep stages, the sequence of sleep stages, or the time it took to fall asleep.
- Subjects who worked simulated 8-hr shifts completed the tasks on the computer-based cognitive performance test more quickly than those on 12-hr shifts.
- Subjects who worked simulated 12-hr shifts completed the tasks on the computer-based cognitive performance test with greater accuracy than those on 8-hr shifts.

Comparison of Evening and Night Shifts

- Sleep following evening shifts was significantly better than sleep following night shifts. When working evening shifts, sleep occurred during normal night time hours. In comparison with daytime sleep after night shifts, night sleep was characterized by more total sleep time, less mid-sleep wakefulness, less waking time at the end of the sleep, and less movement during sleep. Those working evening shifts took longer to fall asleep at night, but slept longer and more deeply. They did not experience the problems associated with day sleep following 8-hr or 12-hr night shifts: light stages of sleep, frequent brief awakenings, early awakening, and difficulty returning to sleep.

• Cognitive performance was not significantly better on evening shifts, compared with night shifts.

• Subjects working 8-hr evening shifts rated themselves more favorably on the mood scales, including lower sadness and overall improved affect.

• Subjects working 8-hr evening shifts rated themselves as significantly more alert and less sleepy.

• Efficiency of simulator operation was not found to be significantly different on evening shifts versus night shifts.

Effects of Time of Day: Alertness and Performance Problems Associated with 8-hr and 12-hr Night Shifts

• Physiological sleepiness (measured by a standard test called the MSLT) decreased over the evening shift hours, reaching a minimum (maximal alertness) by about 1900. During night shift hours, sleepiness increased dramatically, reaching a maximum (lowest alertness) between 0500 and 0700.

• Self-ratings of sleepiness and alertness showed hourly changes identical to those seen in the physiological tests, with alertness decreasing and sleepiness increasing steadily after midnight on both 8-hr and 12-hr shifts.

• Self-ratings of effort and weariness increased progressively after midnight on all night shifts.

• Self-ratings of mood declined steadily over both 8-hr and 12-hr night shifts, as sadness and tenseness increased, while happiness and calm decreased, after midnight.

• Average response time to one silent alarm generated by the simulator increased as a function of hour of shift on the night shift.

• Percent of correct responses on several cognitive performance tasks showed a decreasing trend across hours of the 8-hr night shifts for only. Response latency on the same remained stable for the duration of the work shifts.

• Both accuracy and speed of response on the cognitive performance tests remained stable across hours of shift for subjects working 12-hr night shifts. There were no indications of decrement in performance related to shift length, fatigue, or circadian rhythms.

Effects of Day of Shift

• Alertness increased across shifts for both 8-hr and 12-hr night shifts. This was demonstrated both by improvement in physiological tests of sleep tendency and by subjective ratings of sleepiness and alertness.

• The length and quality of sleep improved across successive daytime sleep periods for both 8-hr and 12-hr night shifts.

• Cognitive performance improved across days of shift for both evening and night shifts. This included an increase in accuracy and a reduction in response latency. Progressive improvement across days of shift is probably due to continued effects of learning.

Effect of Consecutive Weeks of Night Shift

• Subjects who worked 12-hr shifts showed significantly improved alertness, sleep, and cognitive performance on their second of two consecutive weeks of night shifts.

• Subjects who worked six 8-hr evening shifts before beginning 8-hr night shifts showed no consistent improvements in night shift alertness, accuracy on cognitive performance tests, mood, or length and quality of off-shift sleep. Only response latency changed, becoming progressively faster with each shift worked.

In summary, the major findings of the study are that neither mental performance nor objectively measured alertness were significantly impaired on 12-hr night shifts as compared with 8-hr night shifts. Subjective alertness and mood were, for the most part, not negatively affected by the extended work shifts.

Both 12-hr and 8-hr night shifts showed a strong night-of-shift effect, suggesting adaptation to night shifts after working three or more consecutive nights. By both subject report and review of the data, the first two night shifts were the most difficult to work. Subjective mood and alertness ratings, as well as speed on cognitve performance tasks, improved over successive night shifts.

The most robust, though least surprising, finding from the study is that it is much easier to work evening shifts than night shifts. Subjects working 8-hr evening shifts were more alert and scored better on mood scales than in any of the night shift conditions.

The most novel and potentially the most important finding of the study is that there is a distinct advantage to working consecutive blocks of night shifts. Both alertness (subjectively and objectively measured) and off-shift sleep were significantly improved during the second week of two consecutive weeks of 12-hr night shifts.

Although only the 12-hr shift protocol called for consecutive weeks of night shifts, the same principle would presumably apply for 8-hr night shifts. By comparison, working a week of 8-hr evening shifts did not appear to significantly improve alertness or sleep during a subsequent week of 8-hr night shifts, primarily because subjects were less likely to maintain adaptive sleep strategies during their days off between shifts.

Many technical terms are used in this report. They are described either in the text immediately following their first use or in the glossary of terms at the end of the report. These technical terms are indicated in italics the first time they appear in the body of the text.

Acknowledgments

Many people contributed their time and talents to make this project possible, but none gave more of themselves for a longer period of time than Ms. Dolores Morisseau, Human Factors Analyst at the Office of Nuclear Regulatory Research (RES) and project manager from the initial phases of this project through the final preparation of the manuscript. Dolores made significant contributions at each step in this long and arduous process. She visited the research laboratory, met with the project team, and spent countless telephone hours discussing the experiment, data analysis, and the preparation of many reports. Her editorial skills greatly improved this manuscript, and she has proven to be a superbly capable spokesperson, giving presentations of this research to both scientific and industry audiences in the U.S. and abroad. Without her continued support and encouragement, this project quite simply would not have been completed. I thank her for her patience, friendship, and for her genuine concern for the welfare of persons whose professions require them to work shiftwork and night work.

I owe special thanks to Dr. Brad Davis for undertaking the tremendous challenge of statistical analysis for this complex and irregular experimental design. Brad was extremely helpful during the data analysis and manuscript preparation phases, and contributed many of the fine graphics seen in this report. Dr. Scott Campbell, assistant professor of psychiatry at Cornell University School of Medicine, was co-principal investigator with Dr. Martin Moore-Ede, director of the Institute for Circadian Physiology, during the pilot phase of this study. Scott spent nearly six months preparing the Continuous Operations Simulation Facility at the Human Alertness Research Center and recruiting and training a skilled staff of research technicians. Dr. Moore-Ede, who first interested the NRC in this project, worked closely with Dr. J. J. Persensky, Chief, Human Factors Section, RES, to create the simulated shiftwork schedule and to formulate the experimental design.

No laboratory research project of this scope and level of complexity can be completed without the efforts of talented and dedicated technical personnel. An integral role was played by Ms. Ming Chan and Mr. Mark Pfohl, directly supervising a large staff of technicians, including Dr. Buktiar Shah, Waheed Younis, Saunders Hsu and more than a dozen other graduate and undergraduate students from Massachusetts Institute of Technology and Boston University. The technicians applied electrodes, operated physiological recording equipment, and looked after our shiftworkers 24 hours per day. For this study they scored over a quarter million pages of sleep EEG record, managed large data bases, assisted in data analysis, ordered supplies, and attended to the subjects' daily needs and concerns. Our technicians were themselves shiftworkers, whose highly irregular work and sleep schedules would have been the subject of a very interesting research study.

Thanks are also due to the twenty men, shiftworkers past and present, who gave two weeks of their time to work through the night shift performing simulated operations tasks, while we continuously tested and questioned them, scrutinized them via one-way mirrors and video cameras, and recorded the electrical potentials produced by their brain, eyes, and muscles. In the final analysis, only the diligence and patience of these research subjects made all of our efforts fruitful. We are grateful to the Boston Edison Company for its support of this research. Special thanks are also in order for the Foxboro Corporation for providing the full function process control simulator that occupied the subjects during their realistic night shift simulations. Dr. Ernoe Csaky, Vice President for Research and Development, helped to make the realistic work scenario possible through donation of the simulator to the research study, while Charlie Desault contributed many hours to assist in the programming of processes simulating power plant activities and maintaining reliable functioning.

Finally, I wish to thank those whose editing skills have made much of this potentially dry technical material more enjoyable to read. Our talented editors were my wife Mary Jane Baker, Ming Chan, Dr. Brad Davis, Dolores Morisseau, and Dr. J. J. Persensky. Thanks to Dr. Gary Hughes of Callaway Nuclear Station and Dr. Joe Yasutake of Electric Power Research Institute for serving as our nuclear industry reviewers.

INTRODUCTION

This laboratory shiftwork simulation study was designed to address some of the critical unanswered questions about the most common shiftwork schedules used by operating personnel in the nuclear power industry, with emphasis placed on studying the difficulties associated with night work. Self-rated mood and energy levels, cognitive performance, and both subjective and objective alertness were continuously assessed at regular intervals throughout simulated 8-hr and 12-hr evening and night work shifts. Quality and quantity of sleep during off-shift hours were also examined.

Experiments were conducted in a simulated control room equipped with a process control simulator, mock wall-mounted control panels, and adjoining residential apartments. The findings of this study provide important data on the physiological and behavioral consequences of shiftwork, night work, and extended work shifts.

12-Hr Schedules in the Nuclear Power Industry: A Brief History

Within a period of nine years, more than 30 nuclear power plants have instituted operator work schedules that include regular 12-hr duty shifts. In addition, plants that continue to use 8-hr shifts for regular duty routinely schedule 12-hr work shifts during plant outages, or to cover vacant positions when operators are absent due to sickness or holidays. If the present industry shift scheduling trends continue, nuclear power plants using regular 12-hr schedules for operations personnel will soon outnumber plants with traditional 8-hr schedules. *Compressed work week schedules*, which include both 12-hr and 10-hr shifts, are also growing in popularity in other nuclear industry departments (e.g., maintenance, chemistry, radiation protection).

The 12-hr schedule is the most common type of compressed work week schedule found among continuous operation industries (those requiring 24-hr per day staffing). These schedules are so named because an equivalent number of work hours per year are compressed into fewer working days. For example, if a nuclear power plant has relief and training weeks in the schedule (a 6-crew system), the number of days worked per year typically decreases from 260 to 199 (8-hr versus 12-hr schedule), while average hours per week (40) and hours per year (2080) remain unchanged. In this example, the number of weekends free in each year increases from 26 to 35, while the number of night shifts worked per year remains the same. The only way to reduce the number of night shifts worked per year on either 12-hr or 8-hr shift systems is to add extra crews to increase the number of weeks when predominantly day shifts are worked (e.g. training, relief, or special projects).

Where 12-hr shift schedules are in use, all nuclear plants but one use *rotating shift schedules*, in which operators regularly alternate between day and night shifts. With few exceptions, *rapid shift rotation* is used, which means that employees change between day shifts and night shifts at least weekly during the duty cycle. Again, only when training or relief weeks are added to the schedule do operators have an opportunity to work during the daytime hours for two or more consecutive weeks. By doubling the shift cycle to 10-12 weeks, it is possible to consolidate night shift work into a 3.5 week period, so that there are 6.5 to 8.5 consecutive weeks of day shifts. This *slow shift rotation* is used at three nuclear power plants that have 12-hr shifts. Only one nuclear plant uses *fixed shifts*, rather than rotating shifts. In this schedule, two crews of operators always work 12-hr night shifts (except during training or relief assignments), while two other crews always work day shifts.

The majority of nuclear plants use schedules that combine three and four consecutive 12-hr shifts in order to create long breaks elsewhere in the schedule. A less common variety of the nuclear industry 12-hr schedule alternates two and three consecutive shifts, which results in every other weekend off during the duty cycle. These two varieties of work patterns used for 12-hr shifts, known commonly as the *3-4 schedules* and *2-3-2 schedules*, respectively, are identical in terms of days worked per year and free weekends. They differ only in the length and distribution of breaks (days off work) and in the greatest number of consecutive days worked (three vs. four).

The shift schedule pattern has important implications for adjusting to night work. On 12-hr schedules using the 3-4 pattern, operators must readjust to night work exactly twice as often as on 8-hr shifts. On 2-3-2 schedules, as most commonly practiced, the number of blocks of night shifts, and hence the number of times the shiftworker must adjust to night shifts each year, is three times the number on 8-hr shifts. The potential advantage is that there is less cumulative fatigue on 12-hr schedules because operators never work more than four consecutive days or nights before a break.

In almost all cases, the impetus for considering 12-hr shifts has come from the operators themselves. Information about the 12-hr shifts, and news about their popularity among operators and other employees, has spread rapidly through the industry. EPRI report NP-6748 (1990) provides one of the most comprehensive surveys of control room operator experience with 12-hr shifts in the nuclear power industry. High approval ratings have been recorded after one year trial periods and in yearly work schedule evaluations in many plants; often more than 90% of employees favor continuation of the compressed work week.

Most nuclear plant operators who have worked both 8-hr and 12-hr schedules feel that the quality of personal and family life is improved by the compressed work week. They prefer having more days off, more weekends off, fewer consecutive days of work (reducing the number of consecutive evening and night shifts is particularly popular), and more consecutive days of break. The majority feel that these advantages justify the longer duty hours on working days.

Compressed work weeks have also gained favor because many managers believe that the schedules improve operating efficiency. Turnovers between shift operating crews are reduced from three per day to two per day, and most of these shift turnovers occur between crews that have communicated plant status to one another only 12 hours earlier. The probability of faulty information transfer at shift turnover is theoretically reduced by one third. Productivity often increases because of improved coordination between operations and maintenance groups and reduced unproductive time associated with shift turnovers.

Major practical difficulties with 12-hr shifts are associated with complex implementation issues (e.g. necessary amendments to existing labor contracts, employee benefits policies, and compensation formulae), limited options for relief coverage when there are unexpected absences (*shift splitting* and *double shifts* are no longer viable solutions), and less opportunity for communication between shiftworkers and management (day shift workers and on-shift operating personnel may work overlapping day shift hours as few as five times per month.). Most of these problems can be satisfactorily managed through procedural and policy changes.

Research on 12-Hr Work Shifts

Research in the area of operator fatigue, alertness, and performance has not kept pace with the rapid change-over to 12-hr shifts in the nuclear power industry. Concerns are often raised that 12-hr work shifts compromise the alertness, physical stamina, or mental performance of shift operating personnel to the point of reducing efficiency or safety. However, there is very little empirical evidence that directly addresses the suitability of 12-hr duty schedules for control room operators in nuclear power plants. Field research studies have been few in number, and their findings have been inconclusive or contradictory.

In attempting to answer important questions about the advisability of 12-hr shifts, subjective ratings by operators must be interpreted cautiously. Operator work schedule preferences may be more strongly influenced by personal lifestyle choices and family-social priorities than by productivity and safety issues.

The most comprehensive research on 12-hr shifts to date, sponsored by the National Institute of Occupational Safety and Health, emphasizes concerns about the use of compressed work week schedules (Rosa et al., 1985, 1988, 1989). The findings from both laboratory and field studies, primarily based on the use of self-rating scales and cognitive and reaction time tests performed on portable computers, are as follows: (1) performance of cognitive tasks was impaired on 12-hr shifts. Impaired cognitive performance included faster and less accurate *grammatical reasoning* (equivalent to the *logical reasoning* task used in the present study; see Appendix) and slower and less accurate mathematical addition ability; (2) subjective fatigue and drowsiness increased across consecutively worked 12-hr shifts; (3) the rate of improvement in cognitive performance across days of shift was slower for subjects on 12-hr shifts, as compared to 8-hr shifts; (4) data entry errors increased across 12-hr work days on a job simulation task; (5) manual coordination was reduced; (6) self-estimates indicated a reduction in off-shift sleep time.

Other laboratory (Colquhoun et al., 1968, 1969) and field (Volle et al., 1979; Daniel and Potasova, 1989) studies of 12-hr shifts have focused primarily on the finding that subjectively-rated fatigue increased as a function of work shift duration. The studies also demonstrated various performance decrements, most of which involve increased response time on tests of either cognitive performance or simple reaction time.

In apparent contradiction to the conclusions reached from computerized performance test results, many measures of operating efficiency and the performance of actual work duties at the Fast Flux Test Facility (a nuclear reactor in Richland, Washington) showed improvement as a result of the change from an 8-hr to a 12-hr schedule (Lewis et al., 1986; Rosa et al., 1989). Furthermore, operators rated stress as significantly reduced on their new schedule.

Seemingly contradictory findings are also reported in studies of hospital nurses who changed from 8-hr to 12-hr shifts (Mills et al., 1983). In this hospital pilot program, the compressed work week had many positive outcomes (high employee acceptance, reduced staff turnover, improved communications, and improved subjective ratings of the quality of clinical care). On the other hand, subjective reports of physical fatigue and drowsiness increased when nurses were queried during the final hour of the 12-hr work shift. A similar study of hospital nurses in Japan reported decreased performance on a vigilance task when they moved from 8-hr to 12-hr work shifts at night (Kogi et al., 1975).

Positive results were reported by police officers changing from an 8-hr to a 12-hr work schedule (Peacock et al., 1983). Subjectively reported benefits included greater personal satisfaction with the 12-hr work schedules, improved off-duty sleep duration and sleep quality, and increased subjective alertness. Objectively measured improvements included improved physical fitness scores and lower blood pressure. These findings, and the "atmosphere of overwhelming support for the new system" led to permanent adoption of the compressed work week in this instance.

When work tasks involve continuous physical or mental activity, performance and vigilance may be impaired on 12-hr work shifts. This is particularly true when work activities are externally paced, do not involve task variation, and provide little or no opportunity for rest. Work activities such as radar screen monitoring, truck driving, and flight simulator operation may fall into the category of tasks that cannot be optimally performed for 12 continuous hours (McKenzie and Elliot, 1965; Colquhoun et al., 1969; Higgins et al., 1975; Riemersma et al., 1976; Mackie and Miller, 1978).

Reports from electrical utilities on actual experience with 12-hr shifts have been extremely favorable (Ontario Hydro Technical and Training Services Division, 1985; Lewis et al., 1986; American Power Dispatchers Training and Education Committee, 1987; Smiley and Moray, 1989; EPRI NP-6748, 1990), as are reports from chemical and petroleum industries (St. John, 1978; Butterfield, 1979; Northrup et al., 1979; Moller, 1979; Wynn, 1979). Compressed work week schedules are now used widely, grow steadily in popularity, and are typically well-received by both management and employees. Compressed work week schedules generally receive favorable ratings in relation to plant operating efficiency, employee morale, job satisfaction, and quality of time off.

The increasing popularity of 12-hr shifts over nine years of nuclear industry experience must be weighed against research reports that caution against 12-hr work shifts. These reports have based their conclusions primarily on data from computer-based performance tests and employee self-ratings of alertness. It is important to keep in mind that research to date on 12-hr shifts, both in the laboratory and in the field, is limited in scope and suffers from a number of shortcomings. For example:

- Many of the research studies have addressed only daytime hours of work, yet night shifts are probably more susceptible to operator errors attributable to impaired alertness. Research on human circadian rhythms has shown that performance and alertness typically reach their 24-hour *circadian nadir* (low point) toward the end of the night shift (0300-0600). Research also shows that profound sleep disturbances are associated with night work and rotational shiftwork.

- It is extremely difficult to accurately measure alertness and performance in shiftwork field studies. For example, it is much harder in the field than in the laboratory to assure equivalent training on the performance tests, or to establish regular testing times without disrupting operating responsibilities. It is equally difficult to achieve uniform employee cooperation and motivation, which are key determinants of performance.

- Improved accuracy and speed on cognitive performance tests do not necessarily predict improved ability to perform actual job tasks. Control room operation tasks often involve complex decision-making processes and integration of multiple sources of information. Most standard laboratory performance tests are repeated brief trials measuring short-term memory or simple reaction time.

• Research studies often de-emphasize or completely overlook key factors influencing human performance and alertness, simply because they are too difficult to quantify and control. Important determinants of performance during working hours include motivation, level of stress and distraction, job satisfaction, novelty and variability of work tasks, caffeine intake, dietary habits and timing of meals. The design of the workplace is also critical because ambient temperature and illumination can dramatically alter alertness and cognitive performance. Off-shift factors such as exercise, commute time, social activities, sleep patterns, alcohol consumption, or exposure to environmental illumination may be equally important, and these are even more difficult to measure or control.

In designing this experiment, several assumptions about work shift scheduling were drawn from prior research and industry experience, and an effort was made to incorporate them into the design of the study. These are:

• Operators working rotating shift schedules that include night shifts are more susceptible to decrements in performance and alertness due to sleep loss. The effects of sleep loss compound over successive night shifts.

• Operators who work extended hours beyond the traditional 8-hr duty shift (i.e. 12-hr or 16-hr shifts) may show decrements in performance and alertness due to fatigue. Fatigue effects may compound over successive work days.

• Humans typically reach their circadian nadir of both alertness and cognitive performance during the early morning hours (0300-0600). Therefore, operators working the night shift are likely to make more errors at this time.

• Fatigue associated with extended hours of work may be exaggerated by the effects of circadian rhythms on alertness and performance. Since most 12-hr night shifts begin four hours earlier than 8-hr night shifts (1900 versus 2300), operators may have more cumulative fatigue when they reach their 0300-0700 circadian nadir. Therefore, fatigue and circadian effects may be compounded on 12-hr night shifts, or on 16-hr double shifts (1500-0700).

• Problems adjusting to night shifts are most evident on the first and second night shifts due to sleep loss and poor circadian readjustment.

• Working two or more consecutive sequences of night shifts (slow rotation pattern) may be better for alertness and performance than alternating day and night shifts on a weekly basis (fast rotation pattern). This rotation pattern may help operators to remain adjusted to night shifts.

METHODS

Subject Selection

Adult male volunteers aged 20-45 years were recruited for this experiment by placing advertisements in local newspapers and university placement services and by contacting managers at electric generating stations of local utility companies. Candidates who met exclusion criteria for normal sleep patterns, as determined by interview and sleep habits history, were considered for the study. *Exclusion criteria* included history of epilepsy, nervous system trauma, fainting spells, abnormally short or long sleep, drug abuse, long term use of psychotropic medications, and psychiatric illness. All subjects selected were in good health and were taking no medications at the time of the study.

Current employment in a shiftwork profession was not a selection criterion. However, all but two subjects who completed the study had prior or current experience working rotating shifts or night shifts, including power plant operation. Five subjects who had no prior shiftwork experience withdrew from the study, citing various hardships or symptoms associated with the demanding work/sleep schedule.

Experimental Protocols

Subjects were assigned randomly to an 8-hr shift protocol (Fig. 1), or to a 12-hr shift protocol (Fig. 2), while ensuring that age distribution was balanced (8-hr shifts, mean age = 32.5 years; 12-hr shifts, mean age = 31.8 years). 8-hr and 12-hr experiments were alternated throughout the year to control for possible effects of ambient light, day length, temperature and other seasonal variables. Both experimental protocols involved 96 hours of shiftwork simulation, scheduled as either twelve 8-hr shifts [six consecutive 1500 - 2300 evening shifts (designated as the 8E shift condition), four days off (2300 day 1 to 2300 day 5), then six consecutive 2300 - 0700 night shifts (designated as 8N)] or as eight 12-hr shifts [four consecutive 1900 - 0700 night shifts (designated as 12N1), 3.5 days off (0700 day 1 to 1900 day 4), then four consecutive 1900 - 0700 shifts (designated as 12N2)]. The first 8 hours of each period of time off were spent in the laboratory for recording sleep.

Subject Preparation and Training

When selected for the study, volunteers were instructed to reduce caffeine consumption gradually during the two weeks prior to the research study. This procedure was followed in order to control for the possible effects of *stimulants* and *depressants*. Caffeine, alcoholic beverages, and medications were disallowed at all times during the study, including during simulated work shifts, off-duty hours, and break days between work shifts.

Before beginning the simulated work shifts, all subjects were expected to spend two days in the laboratory for training in computer-based performance tasks, operation of a simulator, experimental protocol, general laboratory procedures, and techniques for completing self-assessment questionnaires. Training in computerized performance testing continued until subjects had completed a minimum of 10 practice sessions; more were required if subjects had not reached targeted competence levels. Practice on the simulator console continued until the research technicians supervising the training determined that the subjects were competent in alarm response procedures, control panel operation, and log record keeping.

Experiment Design and Statistical Analysis

The statistical design is quasi-experimental (Campbell and Stanley, 1963; Li, 1964) with

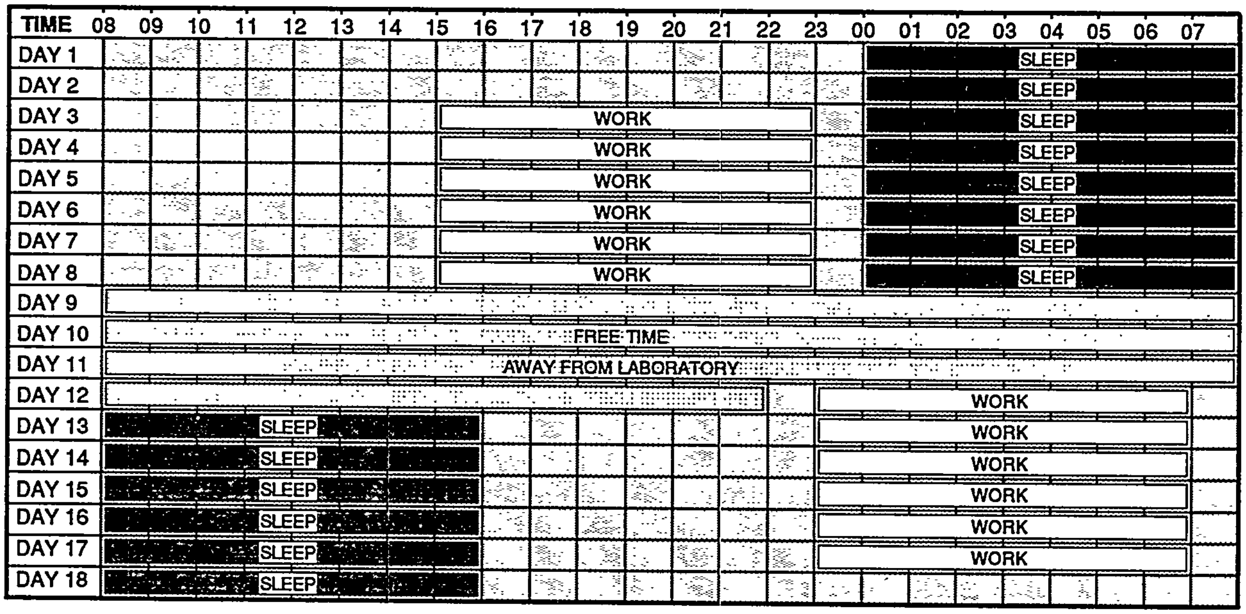

Figure 1 This figure shows the 18-day schedule for the study of simulated 8-hr evening and night shifts. Subjects came to the laboratory on two days before the simulated shift work study began. On these days they spent two adaptation nights sleeping in the laboratory bedrooms to become accustomed to the scalp electrodes and to the experimental surroundings. Before and after each adaptation sleep period they received supplemental training in the cognitive performance tests, subjective rating scales, and operation of the Foxboro simulator. Subjects then worked six consecutive 8-hr evening shifts (1500-2300), followed by six consecutive 8-hr night shifts (2300-0700) after a 4-day (96 hour) break away from the laboratory. Time in bed was fixed at 8 hours beginning within 1 hour following each work shift.

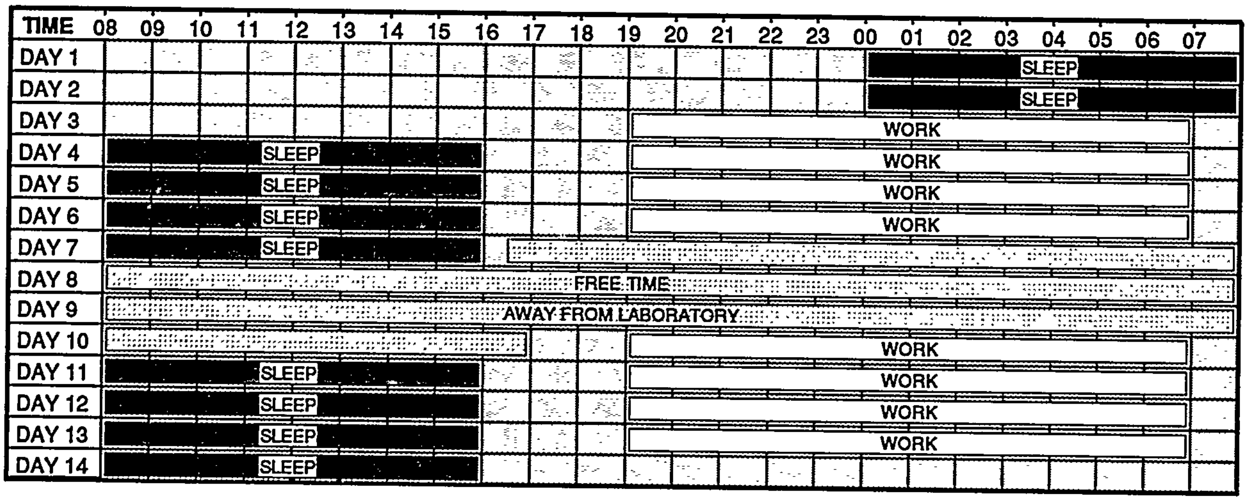

Figure 2 This figure shows the 14-day schedule for the study of simulated 12-hr night shifts. Subjects came to the laboratory on two days before the simulated shift work study began. On these days they spent two adaptation nights sleeping in the laboratory bedrooms to become accustomed to the scalp electrodes and to the experimental surroundings. Before and after each adaptation sleep period they received supplemental training in the cognitive performance tests, subjective rating scales, and operation of the Foxboro simulator. Subjects then worked four consecutive 12-hr night shifts (1900-0700), followed by an additional four consecutive 12-hr night shifts (1900-0700) after a 3.5-day (84 hour) break away from the laboratory. Time in bed was fixed at 8 hours beginning within 1 hour following each work shift.

four experimental conditions: (a) ***shift duration*** (8-hr versus 12-hr shifts); (b) ***shift condition*** [The four shift conditions are: (8E) 8-hr evening shifts, (8N) 8-hr night shifts, (12N1) 12-hr night shifts, first of two consecutive weeks, (12N2) second week of 12-hr night shifts]; (c) ***day of shift*** (six consecutive days for 8E and 8N, four consecutive days for 12N1 and 12N2); and (d) ***hour of shift*** (hourly tests were 1500-2300 for 8E, 2300-0700 for 8N, 1900-0700 for 12N1 and 12N2).

Two separate statistical strategies were used. ***Analysis of All Data*** included all shift conditions, all days of shift, and all hours of shift. This analysis included both evening and night shifts, each treated as a separate shift condition. ***Comparable Time Analysis*** included only the days and hours that were common to the 8-hr shift and 12-hr night shift protocols. The overlapping times and days of shift occurred on night shifts 1-4 from 2300-0700. Thus, the analysis included only the final 8 hours of the 12-hr night shifts, and all of the first four 8-hr night shifts. The rationale for performing the comparable time analysis is to directly compare circadian and fatigue effects on 8-hr and 12-hr night shifts.

Since the experimental design of this study is somewhat irregular, a custom analysis of variance program was written and tested against known data (Li, 1964). Where there was a significant effect for an experimental condition, a modified Least Significant Difference was calculated and used to identify the significant difference(s). High variability between subjects created problems for the statistical analyses of many measured variables. An alpha level of .05 was chosen, which is liberal given the number of tests that were done. However, the pattern of significance is highly correlated. Given the high degree of variability and the general lack of power due to the number of subjects, a more restrictive alpha level would not have been appropriate (Winer, 1962). Results are reported in terms of the probability associated with a given F statistic.

Adaptation to Research Laboratory and Laboratory Procedures

On two consecutive nights immediately prior to the first simulated work shift, subjects were required to sleep in the laboratory. The purpose of these *adaptation nights* was to acquaint subjects with laboratory facilities and procedures, meet technical staff, and to become accustomed to sleeping with electrodes affixed to the scalp and face. Subjects were asked to report to the laboratory at least three hours prior to the scheduled *time in bed* (TIB) on adaptation nights. After the electrodes were applied and tested, there was sufficient time for a final review of the computerized performance tests and operation of the simulator before the scheduled sleep period.

The TIB was the same 8-hr period for all sleep periods (2330 - 0730 $\pm$ 30 minutes for adaptation nights and simulated evening shift work; 0730-1530 $\pm$ 30 minutes for all simulated night shift work). Technicians recorded lights out time on experiment logs, and signaled subjects by intercom at the end of the 8-hr lights out period (no timepieces were allowed in the subject bedrooms). Subjects were instructed to stay in bed and in complete darkness for the entire 8-hr TIB period. Subjects were instructed that if they awakened early, they were to remain in bed, relax, and try to get some more sleep.

These procedures were designed to promote optimal sleep for all subjects during the 8-hr TIB period each day. The goal was to normalize behavioral variation in sleep habits, especially sleep during daytime hours (e.g., lark types who tend to get up at first morning awakening versus owl types who would prefer to sleep later). In fact, many subjects fell back to sleep after prolonged morning or mid-day awakenings as a direct result of this stay-in-bed policy. Most would probably have arisen after their first prolonged awakening had TIB been self-determined, which would have resulted in a subgroup of subjects with exaggerated sleep deprivation.

Upon morning awakening following the second adaptation sleep night, subjects were required to remain awake until beginning their first simulated work shift later the same day at either 1500 (8-hr shift protocol) or 1900 (12-hr shift protocol).

Sleep Following Simulated Work Shifts

Approximate time in bed was 2330 - 0730 ± 30 minutes for the evening shifts (8E), or 0730 - 1530 ± 30 minutes for all night shift conditions (8N, 12N1, 12N2). The ± 30 minute variation in lights out time was determined by subject preference (time desired for meals, toilet, dressing), but lights out time had to occur within 1 hour of completion of the day's simulated work shift.

After awakening, recording devices were turned off, and electrodes were removed or checked and left in place, at the subject's discretion. Subjects were instructed to return 1 hour prior to the start of the next simulated work shift for application of electrodes.

Sleep was permitted only during this 8-hr TIB period each day. The only exception to this policy was brief sleep (at most 1-2 minutes at a time) as part of the *Multiple Sleep Latency Test* (MSLT), which was conducted at 2-hr intervals during the simulated work shifts.

Polygraphic Recording Techniques

Polygraphic recordings were made both during simulated work shift hours and during the 8-hr TIB period scheduled for sleep. They included measurement of brain waves, eye movements, and chin muscle tone, and were made to determine the quantity and quality of off-shift sleep and the sleep onset times during tests conducted every two hours throughout the simulated work shift.

Technicians followed standard clinical research procedures for electrode placement and polygraphic recording of sleep-waking stages (Fig. 3). The *electroencephalogram* (EEG) was recorded using standard *bipolar recording techniques*. The bipolar recordings for this study included two central electrode pairs (C3-A2, C4-A1) and two occipital electrode pairs (O2-A1, O1-A2). The technicians placed the electrodes in precise positions using standard conventions. Further description of these procedures are given in the Appendix.

The *electrooculogram* (EOG: eye movement) was recorded via electrodes attached slightly above and below the right and left outer lateral margins of the eyes. Silver cup electrodes were attached to the skin using adhesive tape. Each electrode was referenced to an electrically indifferent electrode (A1, A2) attached behind the opposite ear (Fig. 3).

The chin *electromyogram* (EMG: chin muscle tone) was recorded via three silver cup electrodes attached under the chin.

Recordings of Sleep-Waking Stages

The EEG was recorded for 8 hours continuously through each of two adaptation nights in the laboratory. During the shiftwork simulation part of the experiment, EEG was recorded from the

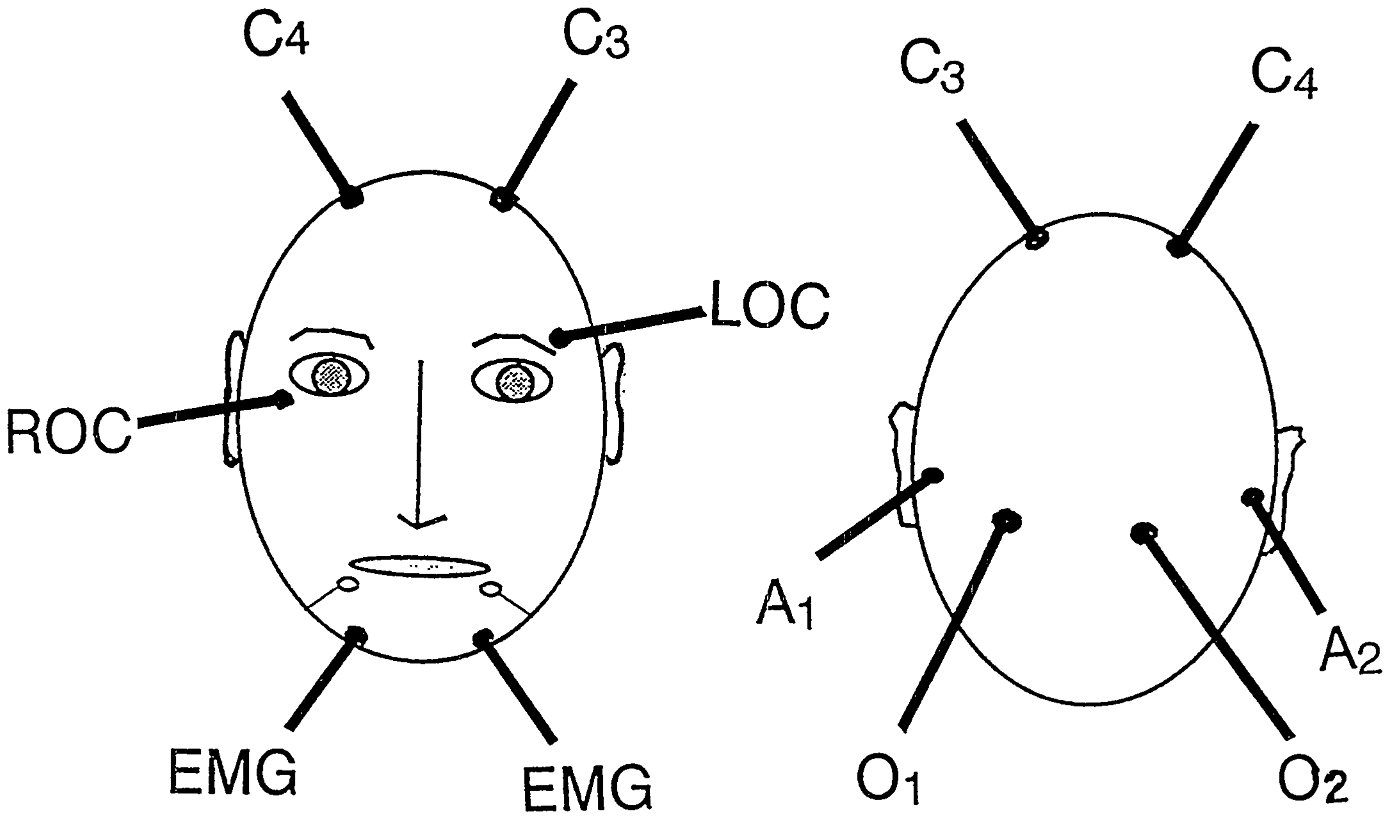

Figure 3 This figure illustrates the placement of surface electrodes for recording electroencephalogram (EEG), electrooculogram (EOG) and chin electromyogram (EMG). For recording the EEG, electrodes were placed on the scalp at precisely measured locations according to standard clinical conventions. Electrode placements used in this study included two central leads (C3 and C4) and two occipital leads (O1 and O2), each referenced to electrically indifferent electrodes (A1 or A2). EOG electrodes were placed either slightly above or below the eyes at locations called the right outer margin of the right eye (ROC) and the left outer margin of the left eye (LOC), and were also referenced to the electrically indifferent electrodes (A1 or A2). EMG electrodes were placed under the chin.

beginning of the work shift through the end of the off-shift sleep period, using either portable tape recorders or polygraphic paper recordings. Thus, in the 8-hr shift protocols, recordings lasted from 1500-0800 (evening shifts) or from 2300-1600 (night shifts). On the 12-hr shift protocols, all recordings began at 1900 and ended at 1600. The EEG was not recorded during free time, when subjects usually opted to have electrodes removed in order to take a shower or go outside.

Analysis of Sleep Data

Each polygraphic sleep record was scored twice by trained technicians, working independently and using the most widely accepted sleep-stage classification system (Rechtschaffen and Kales, 1968). Technicians assigned a sleep/wake stage classification to each page of the polygraphic recording (one page was equal to 30 seconds) by identifying the characteristic EEG pattern of each stage (Fig. 4). One of the following classifications was assigned: *wake, stage 1 sleep, stage 2 sleep, stage 3 sleep, stage 4 sleep, REM sleep, movement time,* or not scorable. A detailed description of sleep/wake stages and the classification system is given in the Appendix. Inconsistently scored sections were reviewed and reclassified by consensus of the two scoring technicians and the senior technician. This double-scoring practice was instituted to improve scoring reliability.

Page-by-page classifications were then entered into computer files and analyzed using a program that calculates a number of standard sleep variables (Vincent, 1977). The program also generates a plot of data which shows changes in sleep/waking stage on a time axis.

Multiple Sleep Latency Test

The MSLT is a standard procedure for determining sleep tendency and impaired alertness, used widely in clinical and research settings (Carskadon and Dement, 1981; 1982). The MSLT measures *sleep latency,* or time subjects took to fall asleep, and was given every two hours during all simulated work shifts. The test was conducted in the subject's sleeping room, removing him from the simulation control room for a period of up to 20 minutes every 2 hours. Because subjects were not permitted to have clocks or watches in the sleeping rooms, they had no direct knowledge of the duration of each MSLT until they returned to the simulated control room to resume their assigned work duties. A more complete description of MSLT procedures is provided in the Appendix.

This test was included in this study to quantify physiological sleep tendency throughout the simulated work shifts. Sleep latency is known to decrease as a function of sleep deprivation and to vary with the circadian rhythm of alertness/sleepiness. Previous research studies using this test have shown that sleep latency declines dramatically over a day and night with no sleep (Carskadon and Dement, 1981; 1982; Walsh et al., 1988). Previous experimental data can be extrapolated to predict sleep latency for each hour in any given shiftwork scenario, such as the night shifts simulated in the present research study (Fig. 5). A typical scenario for a shiftworker starting a week of night shifts begins with him awakening from an overnight sleep period at about 0700, remaining awake throughout the day before the first night shift, working through the night shift until about 0700, and finally sleeping again at some time

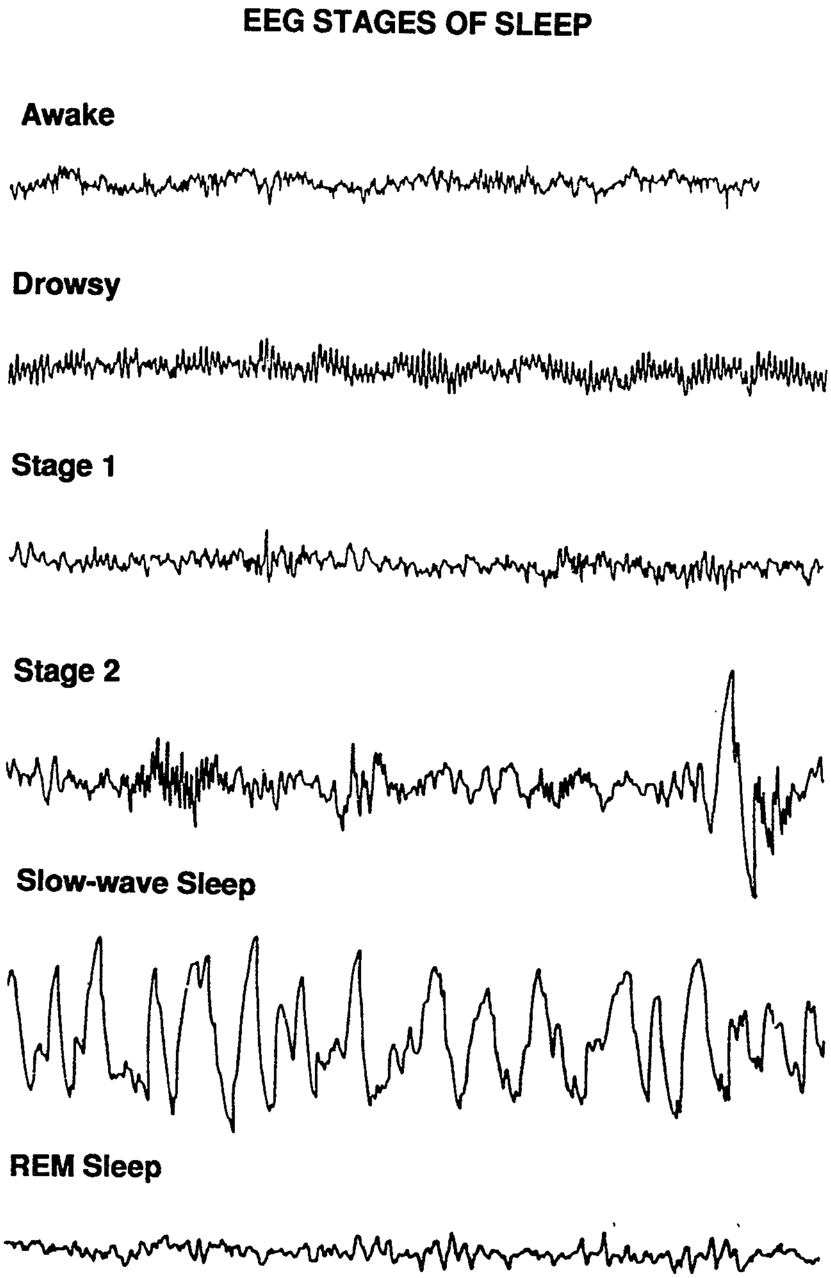

Figure 4 These are examples of electroencephalographic (EEG) tracings of the various stages of sleep and waking in an adult subject. Shift workers who must sleep during the daytime after working night shifts often show greater than normal amounts of light sleep (Stages 1 and 2) and less slow-wave sleep and REM sleep. Note that waking and REM sleep stages are remarkably similar, which is the reason that other physiological parameters, eye movements and muscle activity, were also recorded. Muscle activity is highest in waking and nearly absent in REM sleep.

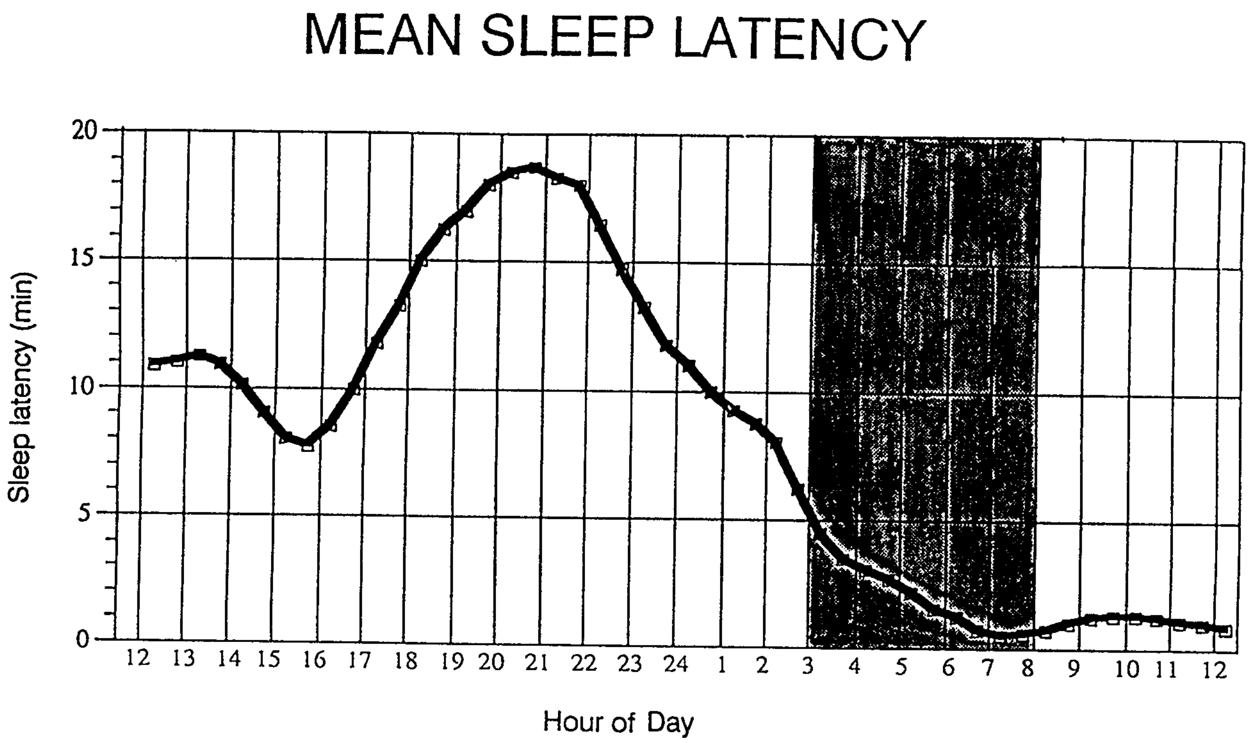

Figure 5 This figure illustrates the predicted time in minutes that it would take a shift worker to fall asleep (sleep latency) during a Multiple Sleep Latency Test (MSLT) on the day preceding and during a first night shift. In this scenario, it is assumed that no daytime nap is taken prior to reporting to work. The sleep latency predictions are based on combined results of several studies of adult subjects. In the MSLT, a person is asked to lie in bed in a dark and quiet room and to try to fall asleep. Sleep latency on this test is a sensitive and validated measure of physiological sleep tendency. Shorter sleep latency is indicative of greater physiological sleepiness. The figure illustrates that after an afternoon increase in sleepiness (1400-1700), subjects reach peak alertness and lowest sleepiness levels during the evening (1900-2100). Thereafter, sleepiness increases gradually over the night shift. The shaded section indicates the lowest point of the circadian rhythm, when sleepiness becomes more pronounced. Alertness remains very low (short sleep latency) until the shift worker is able to sleep.

the following morning, at least 24 hours since the last sleep period. Sleep latency is greatly reduced by the end of the night shift. If allowed to sit quietly or to lie down, particularly if the room is dimly lit, the shiftworker will typically fall asleep within just a few minutes. The tendency to fall asleep remains very high (i.e. very short sleep latency) until recuperative sleep has occurred.

Daily Free Time

Free time was spent primarily in the residential apartments, but subjects were also allowed to go outside for walks or exercise. Free time for 8-hr shift work varied according to simulated work shift hours; approximately 0830-1400 for evening shifts and 1630-2200 for night shifts. Free time on the 12-hr shift protocol was extremely brief; approximately 1630-1800 each day during both weeks of night shifts.

Free Days Between Work Shifts

After completion of the final work shift in a set of consecutive shifts, subjects were required to again spend 8 hours TIB for sleep. After they were awakened and electrodes and recording devices were removed, subjects were free to leave the laboratory until 2 hours before the start of the next scheduled work shift. They were instructed to abstain from alcoholic beverages, caffeine, or any other *psychotropic substances* during the breaks and at all times during the two weeks of the research study.

No instructions or training were given to the subjects for scheduling their sleep during the break days, but they were asked to complete sleep time diaries, noting times of day for, and duration of, sleep periods.

Work Simulation Control Room

This research study took place at the Continuous Operations Simulation Facility at the Human Alertness Research Center in Boston, Massachusetts (see floor plan, Fig. 6). Work shift simulation time was spent in a simulation laboratory control room, which included wall-mounted control panels, a Process Control Simulator [Foxboro Corporation processor unit FGW1-PB and console bay FGW1-TA], and personal computer work stations for giving standard tests of cognitive performance.

Control room temperature (68 degrees F) and illumination were maintained at a constant level 24 hours per day. Illumination recorded at seated eye level at the simulator console, looking toward the control console CRT screens was 86 lux; standing in the room looking toward the simulated wall-mounted controls, 112 lux; seated with direction of gaze just over the top of the simulator console, 210 lux.

An experiment control room, from which technicians monitored the experiment and the recording equipment 24 hours per day, adjoined the simulation laboratory. This room housed electrophysiological recording equipment, a video monitor, supplies, and all experiment records. Technicians observed activities of the subjects continuously during simulated work shifts through an observation window and via video monitor. This procedure was followed to ensure that subjects closely followed the assigned duty schedule. During MSLTs or scheduled (TIB) sleep periods, technicians continuously monitored polygraphic recordings to assess the sleep/wake state of the subjects.

Off-duty hours were spent in one of two residential apartments located adjacent to the simulated control room. Apartments were

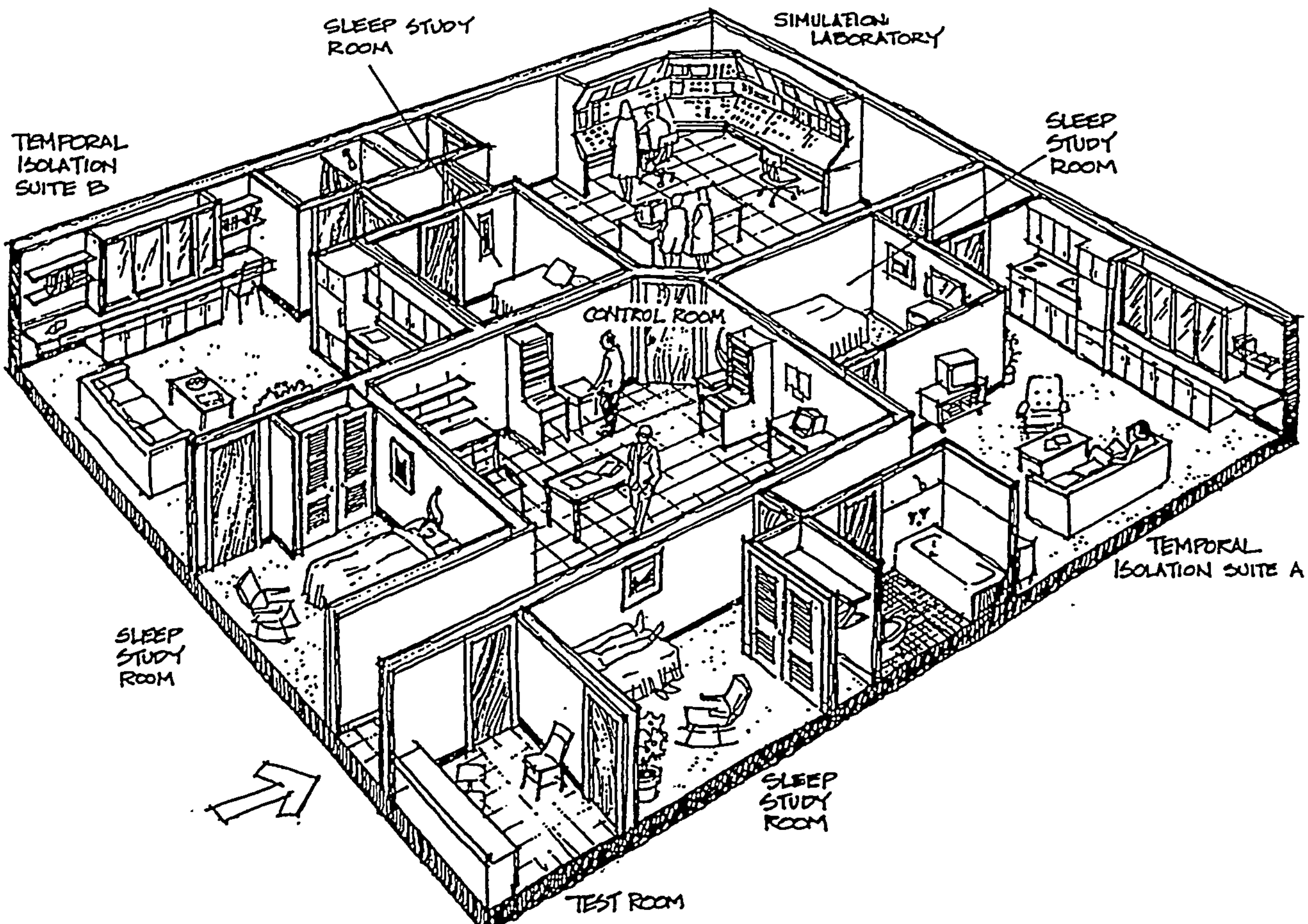

Figure 6 This figure shows the floor plan of the Continuous Operations Simulation Facility at the Human Alertness Research Center in Boston. Experimental subjects worked simulated 8-hr or 12-hr shifts in the simulation laboratory room, which housed a Foxboro process control simulator console in the center of the room. Research technicians monitored the study 24 hours per day from the central control room via video camera and physiological recording equipment. During off-duty hours from simulated work activities, subjects lived in self-contained two-bedroom apartments These were constructed to be sound-proof (double walls and doors) and completely dark (no windows).

temperature-controlled and contained no external windows. The sleeping rooms were completely insulated from external sound and light sources by specially designed double walls and double doors.

Food delivery, housekeeping, and laundry services were provided, but subjects prepared their own meals in fully-equipped kitchens. Each apartment also contained a television, tape recorded music, board games, and a reading library.

Work Shift Activities

During simulated work shifts, subjects were engaged in one of four activities as prescribed by a posted duty schedule: (1) operating the simulator, (2) completing performance tests seated at a computer work station, (3) taking the MSLT, or (4) spending unstructured time in the control room. Subjects did not leave the control room except to go into the adjoining bathroom, or to take the MSLT in their designated sleeping room.

Subjects typically worked in teams of two, so that it was possible to design a work shift protocol in which the simulator was monitored without interruption. Subjects were designated as the A or B operator for each simulated work shift, and were given a detailed individual duty schedule for each work shift. The A and B operator designations were alternated nightly so that the order of tasks and time per task was balanced over the course of the study. A sample duty schedule for an 8-hr night shift protocol is shown in the Appendix. Duty schedules indicated exact times for simulator console operation, multiple sleep latency tests, computerized performance tests, and time for meals, snacks, or walking freely about the control room.

During each simulated work shift, one subject monitored the simulator while the second subject completed hourly subjective rating scales, computerized test batteries, or bi-hourly MSLTs. Casual conversation between the coworkers was permitted during the work shift, with two restrictions: (1) The subject not assigned to monitoring duty could not comment on alarm status to the subject on duty, since alarm recognition was a primary measure of individual alertness and performance in this study; (2) subjects could not talk while either were taking the computer-based performance tests.

In a real operational setting, the backup operator would help to identify conditions requiring response (i.e. alarms), thereby increasing team accuracy and efficiency. In this experiment, the team approach was purposely abandoned in order to accurately gauge performance of individual operators.

In the course of one 8-hr or 12-hr work shift, each subject on the work team typically monitored the simulator for a total of 210 or 300 minutes (8E, 8N shifts versus 12N1, 12N2 shifts). The remainder of the work shift was occupied by computer-based performance tests (120 or 180 minutes), MSLT tests (60-80 or 90-120 minutes), completing subjective rating scales (32 or 48 minutes), filling out questionnaires after each MSLT test and at the end of the work shift (15 or 25 minutes), and functioning as the back-up operator, which included time for breaks (23-43 or 37-77 minutes).

Simulator Operation

Operation of the simulator required the operator to remain seated at the control console (Foxboro Corporation, Model FGW1-TA) (Fig. 7), which was positioned in the center of the simulated

Figure 7 This photograph shows an experimental subject sitting at the simulator console during a work shift. This assignment involved continuous monitoring of three CRT screens for the appearance of alarm signals. Alarm signals were either auditory, or silent (indicated only by color or symbol changes on the control screens). Subjects spent more than 40% of each simulated work shift operating the simulator. Electrodes to record EEG and eye movements are covered with tape. The portable EEG recording unit (Oxford Medilog) is placed on the countertop near the subject's right hand.

nuclear power plant control room. The simulator console was connected to a processor unit (Foxboro Corporation, Model FGW1-PB), located in an adjacent room in the laboratory.

The simulator was programmed to provide a realistic work task that would closely resemble actual operational tasks. Subjects treated the monitoring task seriously and kept accurate alarm logs. Responding to alarm signals became second nature for most subjects. For example, the simulator was at times not staffed at the beginning and end of a simulated work shift, while the simulator alarms already had been activated by the research technician. If a subject was nearby when an alarm occurred, he typically responded even though not technically on duty.

The subject visually scanned three CRT screens for alarms, indicated by color or symbol changes. Some alarms were accompanied by auditory signals (auditory alarms), while others showed color or symbol changes only (silent alarms). Visual indicators were geometric symbols within colored schematic diagrams of nuclear power plant systems (one CRT screen) and multi-colored bar graphs that constantly showed increases or decreases, simulating changes in plant systems (two additional CRT screens). These three CRT displays were standardized for all subjects.

A fourth CRT was used to monitor parameter status and to respond to alarms. This display was controlled by the subject to gauge the precise status of any variable at any given time. The subject could select any bar graph or geometric symbol on the plant schematic displays, then call up a screen that summarized the recent activity (30 minutes) of the selected parameter. This summary display included range of normal values, current status, and threshold for alarm activation. Also located on this parameter status and control screen were the commands for acknowledging alarms. In all, subjects were trained to monitor eleven simulated plant systems selectively.

The continuous fluctuation in the status of all monitored parameters was program-generated. Thresholds for alarm activation were not indicated on the parameter summary screens; this information appeared only on the status and control screens for individual parameters.

When a given target parameter exceeded the range of normal values, an alarm was activated. Silent alarm signals were indicated only by a color change of the bar or geometric symbol. Auditory alarms included both a color change and an auditory signal.

Subjects were trained to follow precise procedures to acknowledge the alarms. Their instructions were to perform each of the following steps as quickly as possible: (1) identify the target parameter with the changed color and press silence-alarm button (auditory alarms only); (2) record the alarm identification number on alarm record log sheets; (3) call up the parameter status and control displays; (4) activate alarm acknowledge, and simultaneously note computer clock time displayed; and (5) record on log sheets the alarm acknowledgment time, the name of the parameter, and type of alarm (silent or auditory).

Once the alarm was correctly acknowledged, the subject immediately returned to the task of monitoring all screens. Because each of the parameters were linked to oscillators, alarms sometimes occurred in clusters of several in 1 minute, while at other times intervals as long as 15 minutes elapsed with no alarm activity.

The subject's next task was to monitor the alarm summary screens visually, determine when a given parameter's value returned to normal limits, and note the time on log sheets. These *return to normal* events (RTN) were difficult to detect; they were indicated by a color change of symbols without auditory signal, and the RTN event often did not occur until several minutes after the associated alarm. Consequently, the *recognized return to normal* time (RRTN) was often much greater than the actual RTN latency recorded by the simulator program.

Subjects were informed that all alarm times and alarm responses were recorded by the computer, and were instructed to be as accurate as possible in their simulator performance and log keeping. The simulator was connected to a printer located in the experimental control area adjacent to the control room that continuously recorded alarm numbers and event times. The *time of alarm* (TOA), *acknowledgment time* (ACK), RTN, the alarm tag number, and a value indicating the parameter status at the time of acknowledgment were recorded for each alarm event. This provided a complete record of simulator alarm activity and of subject response times for the entire work shift, which could later be compared with the subject's alarm logs.

To determine the time that it took a subject to either respond to an alarm (response latency) or notice when an out-of-limits parameter returned to within normal limits, technicians entered selected data from simulator print-outs and from subject log records into computer files. TOA was subtracted from ACK to yield an *alarm acknowledgment latency* (AAL) for each alarm. Similarly, RTN was subtracted from RRTN to calculate a *return to normal latency* (RTNL).

Early in the experiment, it was determined that ACK response latencies for auditory alarms were identical for all shift conditions, all days of shift, and all times of day. Therefore, only data from silent alarms and RRTN data from both silent and auditory alarms were analyzed.

Stanford Sleepiness Scale (SSS)

Every hour on the half-hour during simulated work shifts, subjects were asked to complete a *Stanford Sleepiness Scale* (SSS) before beginning the computerized performance battery. This is a standard self-rating scale used in research and clinical settings to quantify changes in subjective sleepiness. The Appendix provides a more detailed description of the SSS and how it is used.

Subjective Rating Scale for Global Vigor and Affect (GVA)

A second pencil-and-paper self-assessment scale given to subjects before beginning hourly performance tests required completing a visual analog scale to assess mood and subjective alertness and energy level. The test, called the *Global Vigor and Affect Instrument* (GVA) (Monk, 1988), was initially developed to provide a quick, easily administered scale for assessing affective state (feelings, mood) and level of vigor (alertness, vigilance). The Appendix provides for a more detailed description of the GVA scale.

Computer Performance Tests

Performance was assessed hourly using a personal computer program called the *Performance Assessment Battery* (PAB), developed by researchers at the Walter Reed Army Research Institute (Thorne et al., 1985). The test battery was selected for this study because it requires only simple reading and mathematical abilities, uses a standard alpha numeric keyboard with number pad, and does not require touch typing skills.

The PAB offers an extensive menu of performance tasks, which can be combined into a customized and automatically administered battery of tests. Six performance tests were selected for this research study on the basis of the following criteria: (1) **Brevity.** All six could be completed in 12-15 minutes with practice; (2) **Repeated tests in a set order.** Each subject completed 96 test batteries during the experiment, each consisting of five tasks presented in the same order; (3) **Ease of training subjects.** Training sessions took place during the week before the experiment. Each subject completed at least 10 practice test batteries; (4) **Task variety.** The PAB inventory of problems for mathematical, spatial, and logical tasks was sufficiently large that no task ceased to be challenging. Also, the individual tests were sufficiently different that the battery did not become monotonous; (5) **Sensitivity to physiological and psychological variables.** Tasks were selected that were known to be affected by sleep loss or by the normal circadian variation in cognitive function.

The test battery included the following tests (in this order) Logical Reasoning (Baddeley, 1968); Two-Column Addition; Wilkinson Four-Choice Serial Reaction Time (Wilkinson and Houghton, 1975); Interval Production; Serial Add/Subtract; Manikin; and the Stroop (Stroop, 1935). A brief description of each of the performance tasks is given in the Appendix.

Training of the subjects included a precise description of how to perform the test (how to sit, what keys to place the fingers on, not to talk). They were also coached to try to achieve accurate results, rather than to try to complete the task rapidly. Feedback on the performance accuracy (percent correct) was provided only during the first 10 practice sessions; a number for percent correct was flashed on the screen after each test. No rewards were offered for better performance, and competition was neither encouraged nor observed.

Subjects initiated performance tests every hour on the half-hour starting 30 minutes after the work simulation shift began. For 8-hr evening shifts, subject A began the first test at approximately 3:30 p.m., subject B at approximately 3:45 p.m. Subjects worked from the posted duty schedule and initiated their own performance test battery. Once begun, the PAB proceeded automatically.

The PAB program computed precise performance data, including response time and accuracy for every trial within each test. These data files were automatically stored to disk. At the end of each work shift, data were archived onto floppy disks. These data were then analyzed using commercially available statistical software packages.

Summary of Significant Experimental Results

These data suggest a consistent and general effect of duration of work shift on cognitive performance, as measured by the Walter Reed Performance Assessment Battery. Subjects who worked 12-hr night shifts were consistently slower in their responses than subjects on 8-hr shifts, but they were generally more accurate. The one exception to this was the Manikin test, on which those working 12-hr shifts were both slower and less accurate.

There were no significant effects of shift duration on simulator operating efficiency, which was measured by the speed and accuracy of responses to silent and auditory alarm cues and accuracy of alarm log records.

Results for subjective mood and alertness measures were inconclusive. The 8-hr shift subjects rated themselves significantly higher on a happiness scale. However, all significant differences between 8-hr and 12-hr shifts disappeared when the measures were combined using Monk's (1980) formulae for global vigor (GV) and global affect (GA). Other trends are clearly evident, but differences failed to reach statistical significance due to high variability.

There were clear differences between night shifts and evening shifts on many measures of quality and quantity of off-shift sleep, although most of the differences were limited to the first two or three night shifts. Adaptation of subjects to night shift work was remarkably rapid, considering earlier reports of much longer periods of adjustment to night shift work.

The major effects of day of shift were related to this adaptation to night work. Adaptation to night shifts was most clearly evident in MSLT data, which showed a progressive decline in sleepiness across days of shift for all shift conditions. On some cognitive performance tests, the day-of-shift effect suggested continued learning throughout the experiment.

These data show very little evidence of circadian variation in alertness or performance. However, end-of-shift fatigue was evident in many measures, particularly sleep tendency as measured by MSLT. Subjects working night shifts became progressively more sleepy between the hours of 2300 and 0700, showing no increase in alertness toward the end of their shifts.

Simulator Operation: Auditory and Silent Alarms

Response latency to auditory alarms showed little variation and was not analyzed. Silent alarms showed more variability in response latency, but no consistent patterns emerged when these data were analyzed for the effects of shift duration, shift condition, day of shift, or hour of shift. Silent alarms were selected for comprehensive analysis because they operated correctly during the majority of experimental work shifts, and because their frequency provided a sufficient number of samples for all shift conditions and hours of shift.

The only effect that reached statistical significance was that of hour of shift on response time for silent alarm XC41 [$F(172,2053)=1.2$; $P<.05$]. On this alarm, subjects showed decreased speed in responding to the alarm in the later hours of shift in all night shift conditions (Fig. 8).

A significant effect of shift condition was also present for the silent alarm labeled 130B [$F(2,16)=3.48$; $P=.0556$] (Fig. 9). Mean response

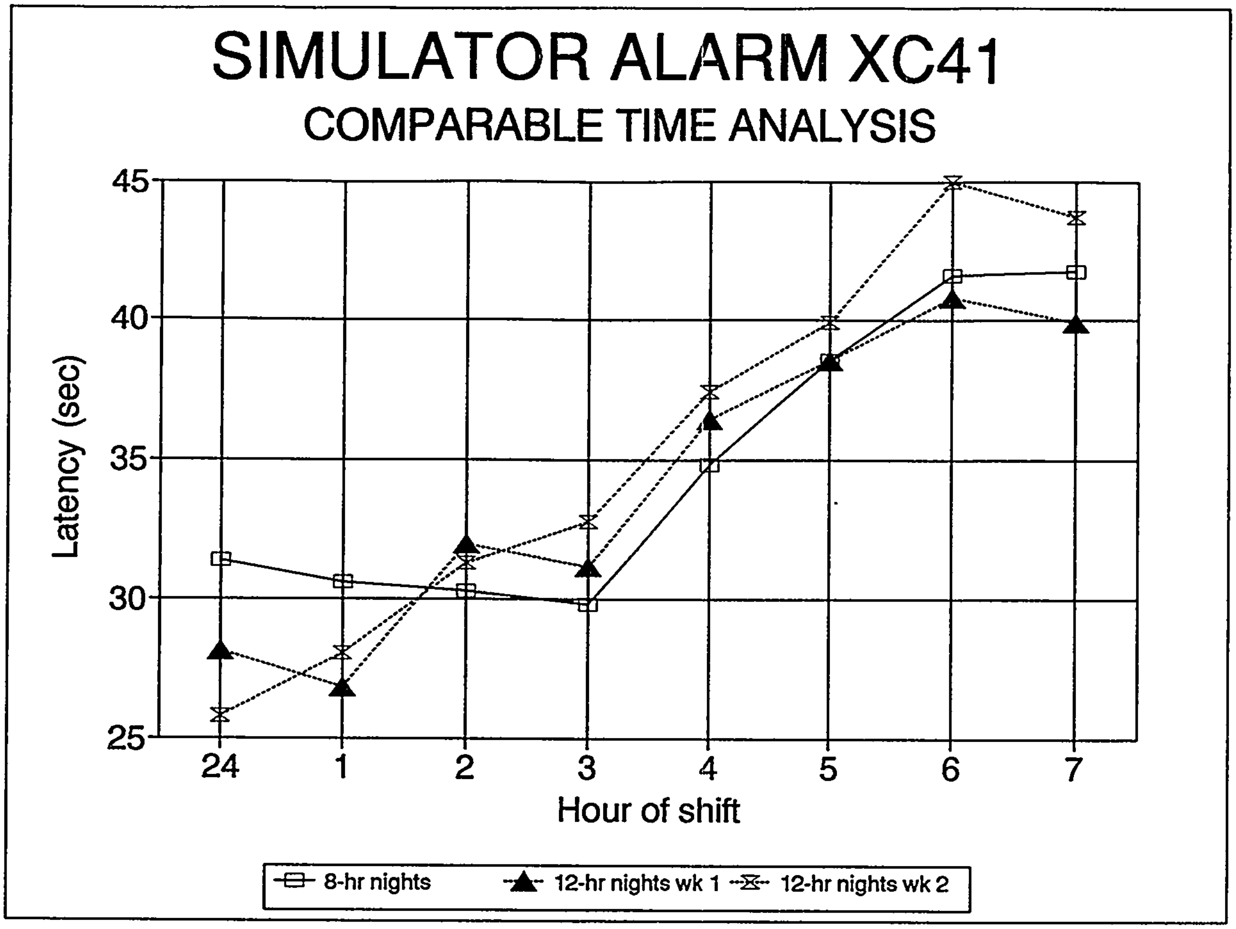

Figure 8 This figure shows response latency for a silent alarm signal (only visual cues on a CRT screen) labeled *XC-41*, on the laboratory process control simulator (Foxboro Corporation). These data represent only comparable time data, extracted from the hours and shifts that overlapped in the three night shift conditions used in this experiment. Comparable time data included the hours 2300-0700 on the first through fourth consecutive night shift. Each symbol represents a mean value for 10 subjects, pooling data from all days of shift to yield mean response time for each 1 hour period of simulator operation. The figure illustrates the progressive increase in response latency in the later hours of shift for both 8-hr and 12-hr night shifts.

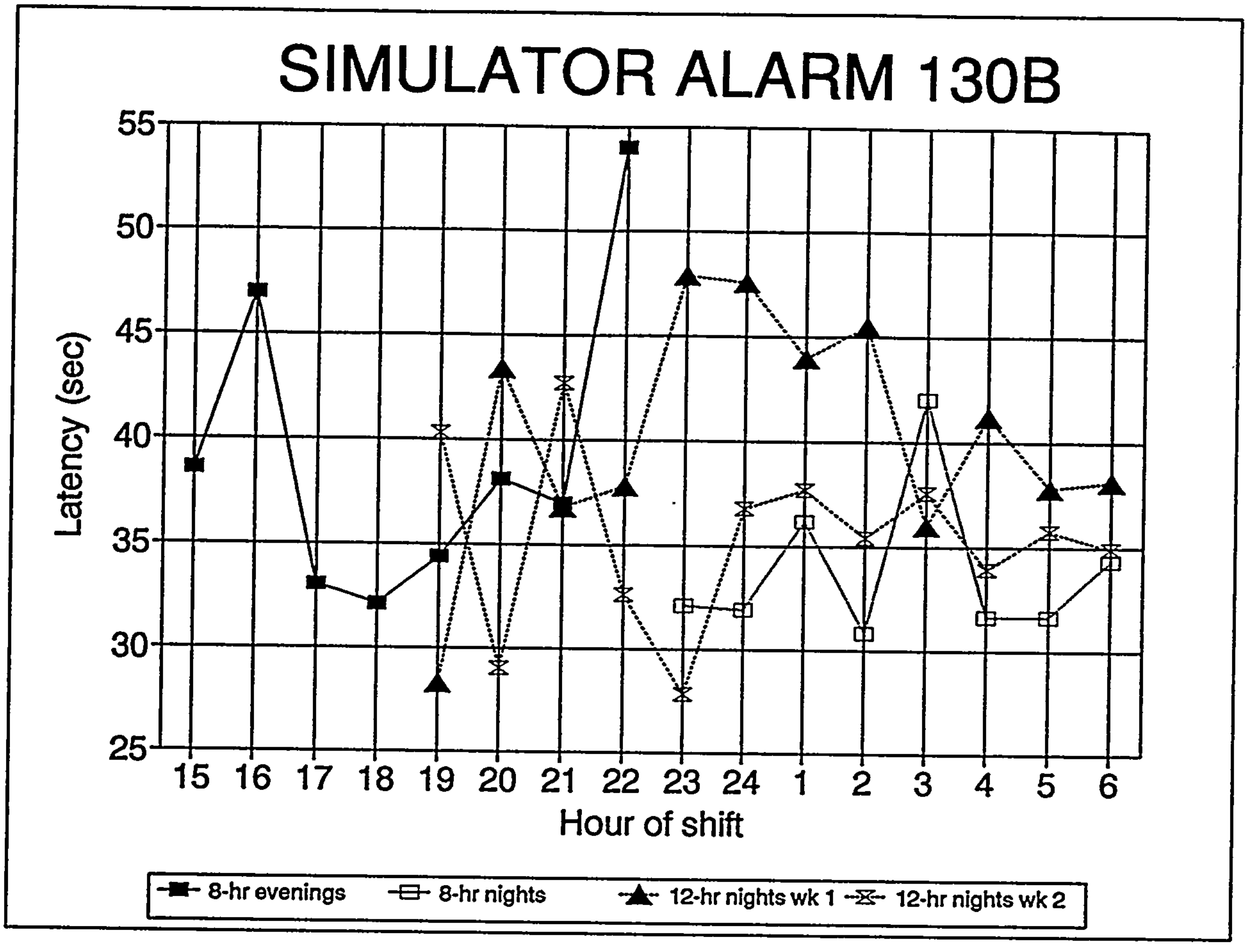

Figure 9 This figure shows response latency for a silent alarm signal (visual cues on a CRT screen only) labeled *130-B*, on the laboratory process control simulator (Foxboro Corporation). Each symbol represents the mean of all data collected, pooled across days of shift to yield an average response latency for 10 subjects for each hour of simulator operation. The figure illustrates the typical high variability in response latency. It also shows the higher mean response latency in subjects working their first week of 12-hr night shifts, particularly during the hours 2300-0300.

latency was longer for 12-hr shift workers during their first week of night shifts (40.4 sec), compared with the 8-hr night shift workers (33.8 sec). This result may simply represent differences between the 8N and 12N1 groups in levels of practice; 8N subjects had already spent 48 hours operating the simulator during their six evening shifts, while 12N1 subjects were just beginning the study.

There were no other results that could be interpreted as approaching significance. Multiple sources of variability can be identified: (1) development of individual strategies by subjects for scanning the three CRT screens for presence of alarms, with varying degrees of success; (2) variable speed and skill in responding to an alarm; (3) the frequency (density) of alarms, which was determined by variable oscillators in the central processor unit; (4) fatigue; (5) circadian variation in performance; (6) distraction due to activities in the control room. These sources of variability contributed to the very high intra-individual and inter-individual variability in the speed of responding to simulator alarms. Therefore, group differences were absent.

A majority of subjects rated the alarm monitoring duties at the simulator as the most difficult in terms of maintaining alertness. Furthermore, 8-hr shift subjects rated the simulator duties as more difficult than did the 12-hr shift subjects. Percent of questionnaires on which subjects rated simulator-based alarm monitoring duties as most difficult for alertness were: 8E = 80%; 8N = 80%; 12N1 = 56%; 12N2 = 63%. More subjects in the 12-hr shift protocol rated the PAB tests as most difficult, probably because of the higher number of tests (12 vs. 8) in the 12-hr protocol. Percentage of responses on which subjects rated the computer-based cognitive performance tests as more difficult than simulator operation and alarm monitoring were: 8E = 49%; 8N = 58%; 12N1 = 79%; 1?N2 = 84%.

Subjects in both shift protocols rated the pace of work tasks as "about right" versus "too slow" or "too fast". Percentage of post-shift questionnaires on which work pace was rated as "about right" was: 8E = 81%; 8N = 85%; 12N1 = 80%; 12N2 = 89%. The remainder of the responses were primarily "too slow", with fewer than 4% answering "too fast" for any shift condition.

Performance Assessment Battery

Logical Reasoning Task

These data are represented in Tables 1-2 and in Figures 10-13.

Shift condition. There was a significant effect of shift condition on percent correct in this task [$F(2,16) = 7.94$; $P<.01$] (Figs. 10,11). Subjects working their second of two consecutive weeks of 12-hr night shifts (12N2) were more accurate on this task than those on 8-hr night shifts. The comparable time analysis of performance accuracy also showed a significant effect for shift condition [$F(1,9) = 11.03$; $P<.01$]; the percent correct for 12N2 (94.5%) was significantly better than either 8N (88.9%) or 12N1 (90.5%).

There was also a significant difference in response latency as a function of shift condition when all data were included [$F(2,16) = 10.65$; $P<.01$]. The significant effect reflects the difference between shift weeks 12N1 and 8N. Mean response latency was 3.5 seconds vs. 2.0 seconds, respectively (Figs. 12, 13).

Day of shift. There are significant differences in both percent correct [$F(16,172) = 3.95$; $P<.0001$] (Fig 10) and response latency [$F(16,172) = 8.14$; $P<.0001$] (Fig. 12), as a function of day of shift, in the analysis which included all data. Day of shift also produced a significant effect for both

Response latency and percent correct on PAB tests
All data

Performance Tests	12-hr shifts response latency (seconds)	8-hr shifts response latency (seconds)	12-hr shifts percent correct	8-hr shifts percent correct
Logical reasoning	3.4	2.4	92.7	88.8
Two-column addition	15.0	13.6	88.7	84.4
Wilkinson 4-choice serial reaction time	0.4	0.4	98.3 *	95.6
Interval production	0.92	0.97	45.8	34.1
Serial add/subtract	0.9	0.8	95.1 *	88.9
Manikin	1.6	1.0 ***	90.7	94.5 **
Stroop: neutral	0.5	0.4 **	98.1 **	95.0
Stroop: incongruent	0.5	0.4 **	98.1 **	94.4

Table 1 This table gives the mean response latency in seconds and the mean percent correct for the analysis that combined all data for the 8-hr (8N and 8E) and 12-hr (12N1 and 12N2) shift conditions, respectively. This table combines data from all evening and night shifts for the 8-hr protocol and from all night shifts in both first and second weeks of 12-hr night shifts. Significant effects of shift duration are marked with asterisks indicating level of statistical probability ($p<.05$=*, $p<.01$=**, $p<.001$=***). Subjects on 8-hr shifts performed the Manikin test faster and with greater accuracy than those on 12-hr shifts. Mean response latency on the Stroop test was also significantly shorter on 8-hr shifts. Subjects on 12-hr shifts showed significantly greater accuracy on the Serial add/subtract test, Wilkinson 4-choice serial reaction time test, and the Stroop test.

Response latency and percent correct on PAB tests
Comparable time data

Performance Tests	12-hr shifts response latency (seconds)	8-hr shifts response latency (seconds)	12-hr shifts percent correct	8-hr shifts percent correct
Logical reasoning	3.4	2.1	92.6	88.9
Two-column addition	15.3	13.9	89.3	84.3
Wilkinson 4-choice serial reaction time	0.4	0.4	98.4 ***	95.9
Interval production	0.92	0.97	46.8	35.6
Serial add/subtract	1.05	0.75 **	96.0 *	90.1
Manikin	1.6	1.0 *	90.9	94.9 *
Stroop: neutral	0.5	0.4 *	98.0 *	96.0
Stroop: incongruent	0.5	0.4 **	98.0	95.5

Table 2 This table gives the mean response latency in seconds and the mean percent correct for the analysis that combined only tests conducted during comparable times and days of shift on the simulated 8-hr and 12-hr shifts (i.e. 2300-0700 on the first through fourth consecutive night shifts). Significant effects of shift duration are marked with asterisks indicating level of statistical probability ($p<.05$=*, $p<.01$=**). $p<.001$=***). Subjects on 8-hr shifts performed the Manikin test faster and with greater accuracy than those on 12-hr shifts. Subjects on 12-hr shifts showed significantly greater accuracy on the Wilkinson 4-choice serial reaction time test, Serial add/subtract test and the Stroop test.

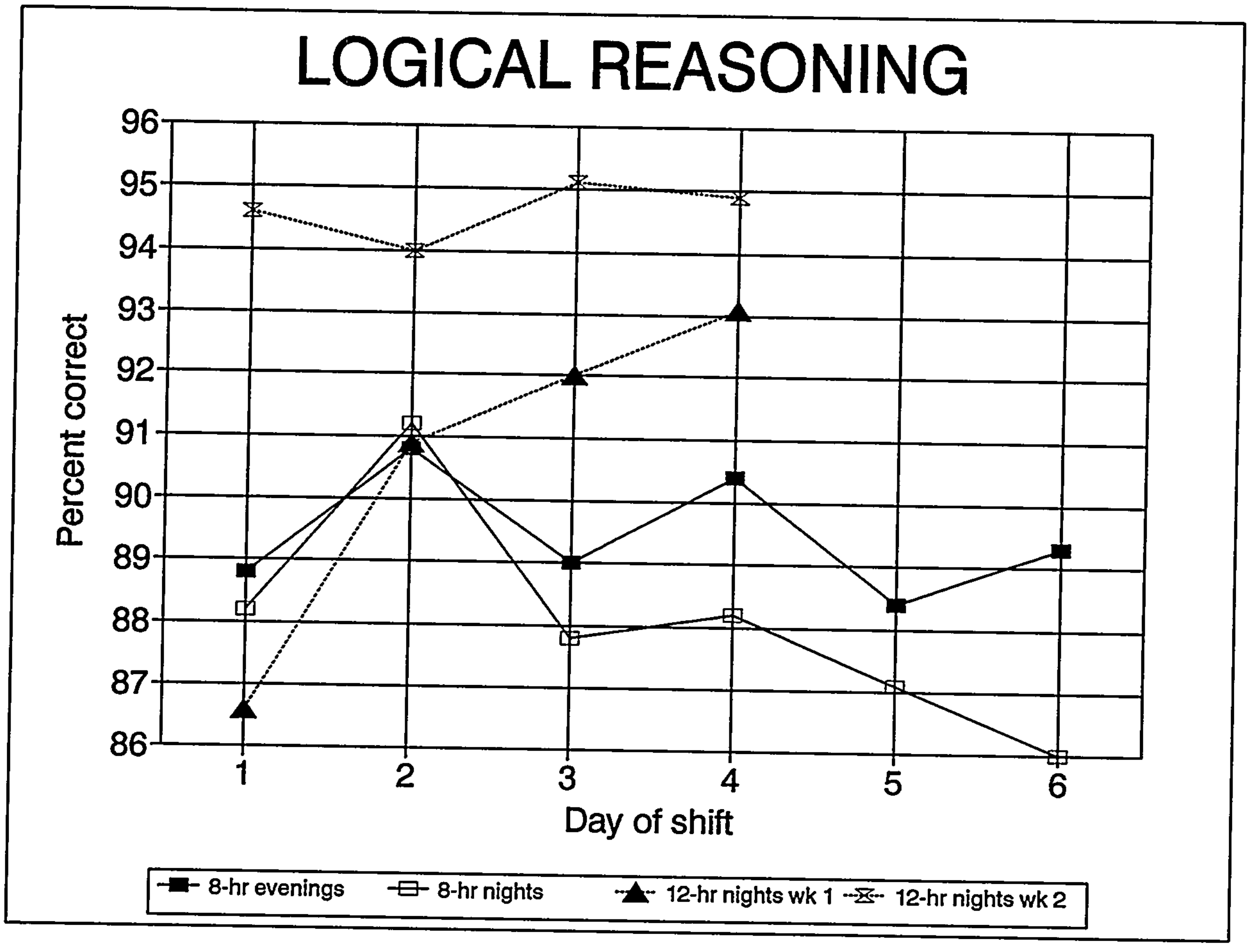

Figure 10 This figure shows mean percent correct for the Logical Reasoning task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates a significant daily improvement over the first week of 12-hr night shifts. Performance accuracy was significantly higher on 12-hr shifts than on 8-hr shifts. Furthermore, there was a non-significant trend for performance accuracy to decrease across successive 8-hr night shifts.

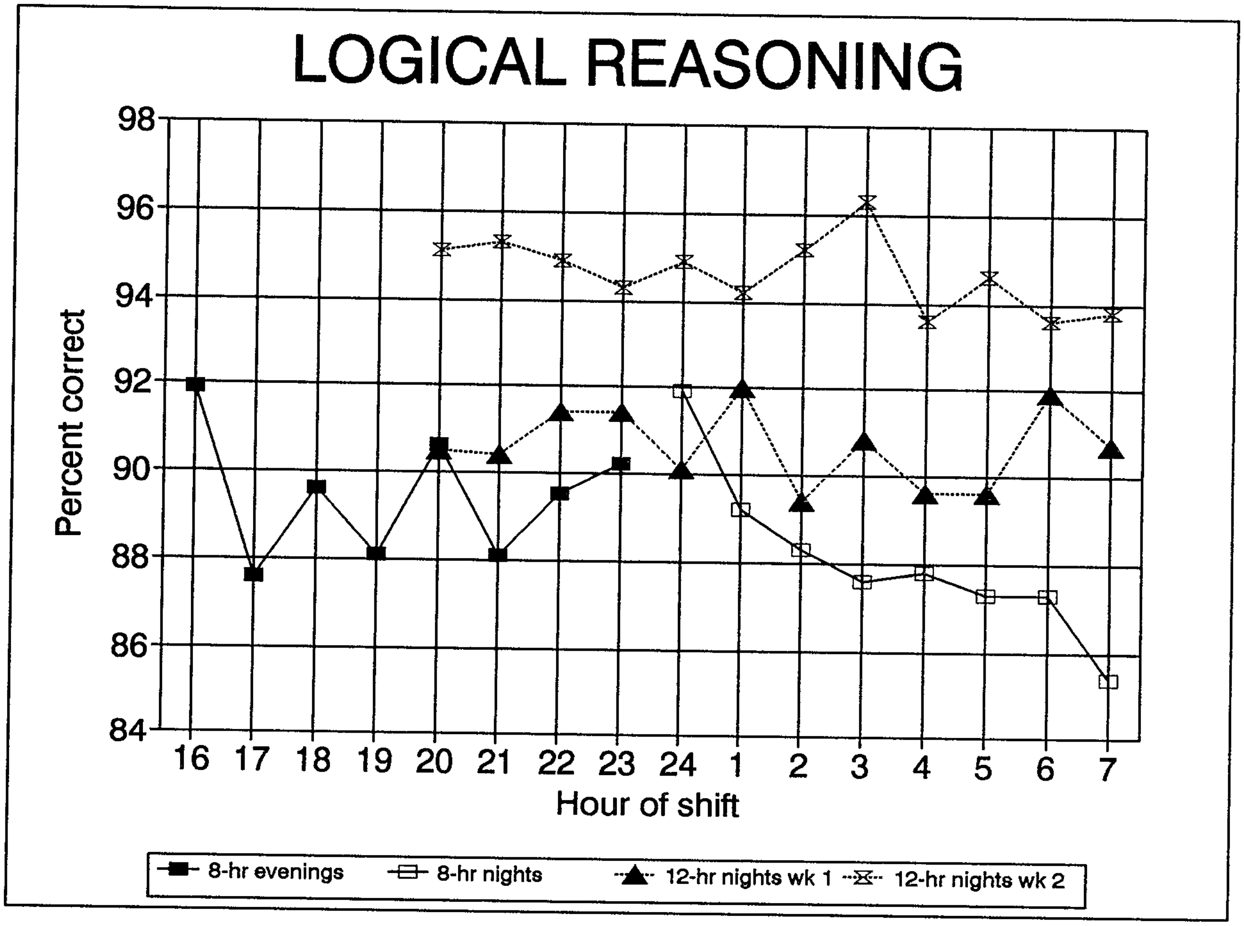

Figure 11 This figure shows mean percent correct for the Logical Reasoning task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates that performance was significantly more accurate during the second of two consecutive weeks of 12-hr night shifts. The figure also indicates a trend for accuracy to decrease in the later hours of 8-hr night shifts.

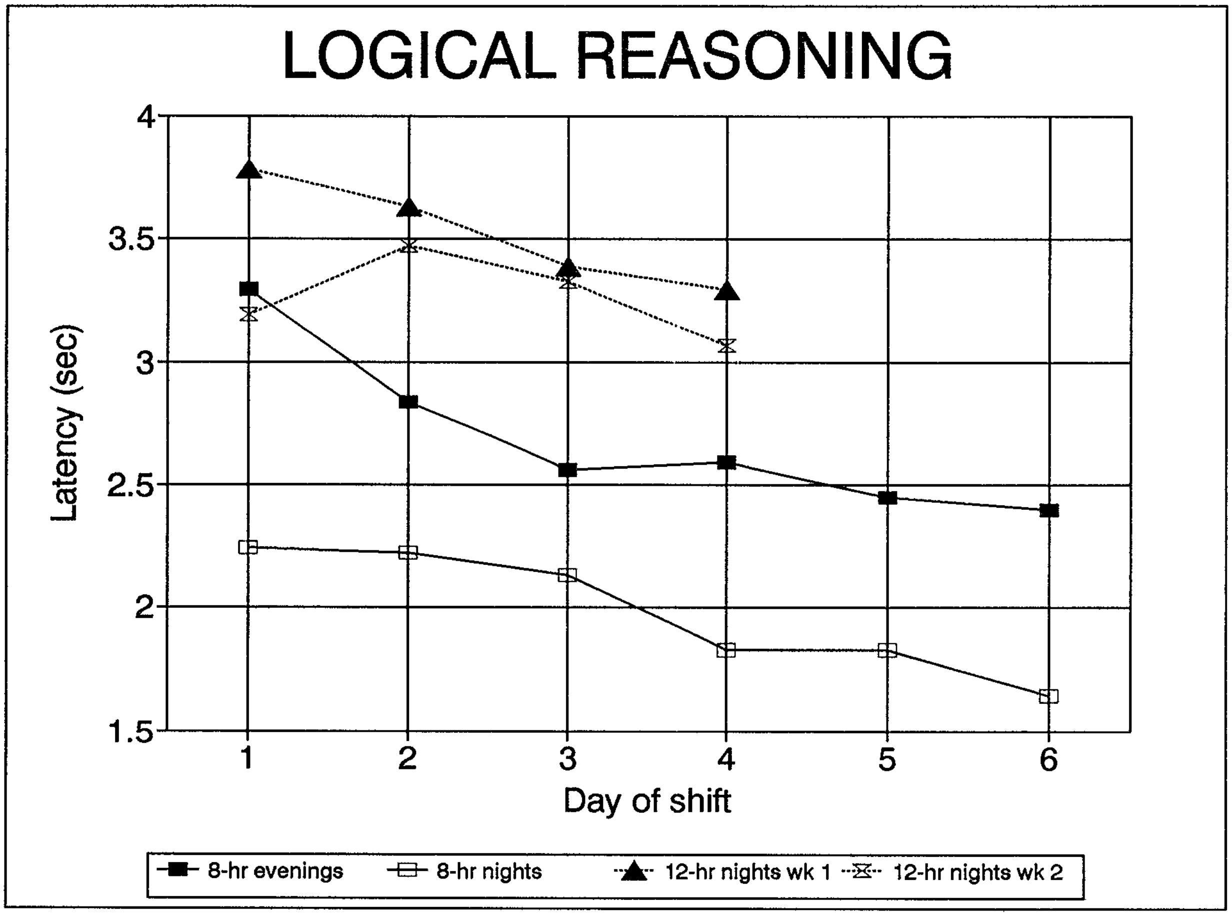

Figure 12 This figure shows mean response latency for the Logical Reasoning task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure shows that response latency was significantly shorter among subjects in the 8-hr shift protocol. Response latency decreased across days of shift for both 8-hr and 12-hr shifts protocols.

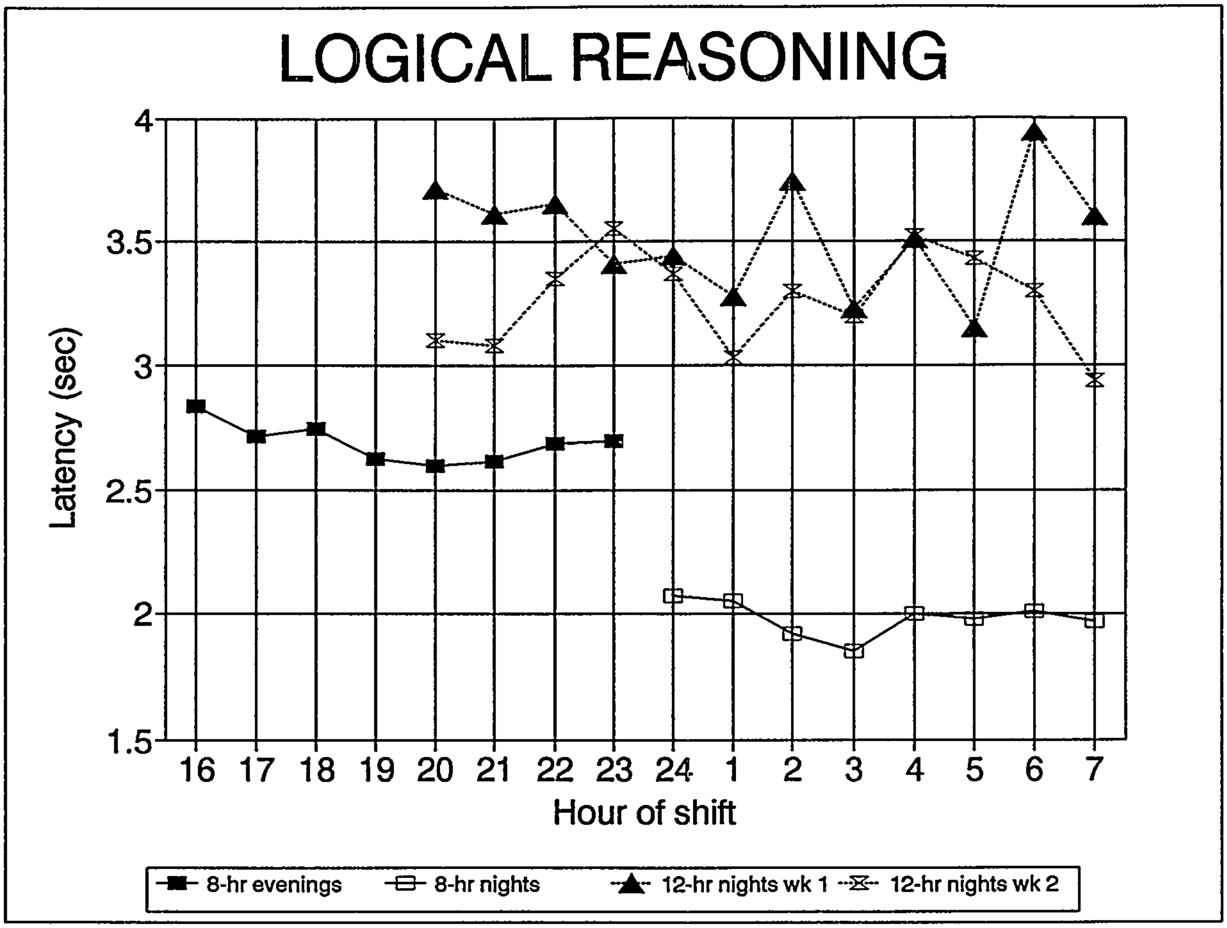

Figure 13 This figure shows mean response latency for the Logical Reasoning task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure shows that response latency was significantly shorter among subjects working 8-hr night shifts than in those working 12-hr night shifts. There was little variation in response latency across hour of shift for any shift condition.

response latency [F(9,84) = 2.65; P<.01] and for percent correct [F(9,84) = 4.16; P<.001] in the comparable time analysis. The effect for response latency was a consistent reduction in latency across successive night shifts (Fig. 12).

There was a progressive improvement in performance accuracy across nights during the first week of 12-hr shifts (12N1), followed by consistent performance across the second week of 12-hr night shifts (Fig. 10). By contrast, there was a trend toward decreased performance accuracy on 8N shifts, both across subsequent nights of shift (Fig. 10) and across hours of shift (Fig. 11).

Two-Column Addition Task

These data are represented in Tables 1-2 and in Figures 14-17.

Shift condition. Subjects performed this task with significantly more accuracy during the 12N2 week (Figs. 14, 15), as compared with all other shift conditions [F(2,16) = 4.11; P<.05] when all data were included in the analysis.

Day of shift. The day-of-shift effect was significant for percent correct [F(16,172) = 1.67; P<.057], with subjects showing improvement over the successive 12N1 shifts, but a progressive reduction in performance accuracy over successive shifts in both the 8E and 8N shift conditions (Fig. 14).

There is a strong effect of day of shift for response latency, with all data included in the analysis [F(16,172) = 8.97; P<.0001], and when only comparable time data were considered [F(9,84) = 7.04; P<.0001]. All shift conditions showed faster response times across successive days of shift (Fig. 16).

Hour of shift. There was no significant hour-of-shift effect, although there appeared to be a low point in performance accuracy among the 8N subjects during the hours from 0200-0400, which corresponds with the circadian nadir in physiological and cognitive function (Fig. 15). Interestingly, this period of low performance accuracy on 8-hr night shifts was associated with faster response times (Fig. 17). This inverse relationship between speed of response and accuracy of response was noted in several measures of cognitive performance in this study.

Four-Choice Serial Reaction Time Task

These data are represented in Tables 1-2 and in Figures 18-21.

Shift condition. There are significant differences in percent correct as a function of shift condition in both the analysis that included all data [F(2,16) = 4.32; P<.05] and the comparable time analysis [F(1,9) = 47.1; P<.0001]. Percent correct was significantly higher for 12N1 and 12N2, as compared to 8N (Figs. 18, 19).

In the analysis of all data, response latency was significantly shorter for 8N (.33 seconds) versus 12N1 (.41 seconds), 12N2 (.37 seconds) and 8E (.37 seconds) [F(2,16) = 13.29; P<.0001] (Figs. 20, 21). Comparable time analysis also revealed a significant effect of shift condition for response latency [F(1,9) = 8.30; P<.05], with mean response times longer in 12N1 (.41 seconds) than in 8N (.34 seconds) (Figs. 20, 21).

Day of shift. In the analysis including all data, the main effect was that accuracy was significantly reduced on nights five and six of 8N, relative to the first four night shifts [F(16,172) = 3.68; P<.0001] (Fig. 18). This is analogous to the fifth and sixth night effect seen in the data for the two-column addition tests.

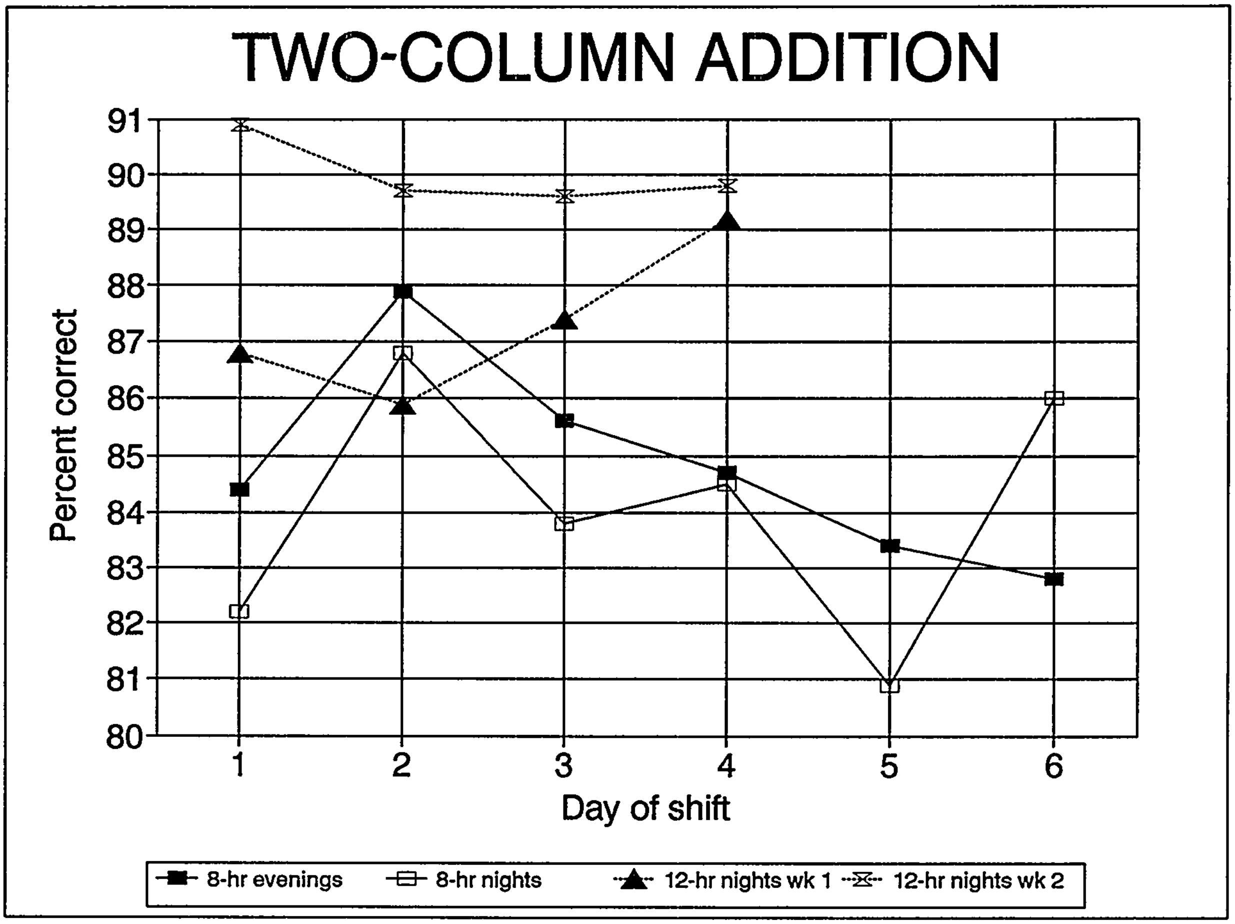

Figure 14 This figure shows mean percent correct for the Two-Column Addition task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance tests to yield an average value for each consecutive day of shift. The figure illustrates that subjects performed significantly more accurately during the second week of 12-hr night shifts, as compared with all other shift conditions.

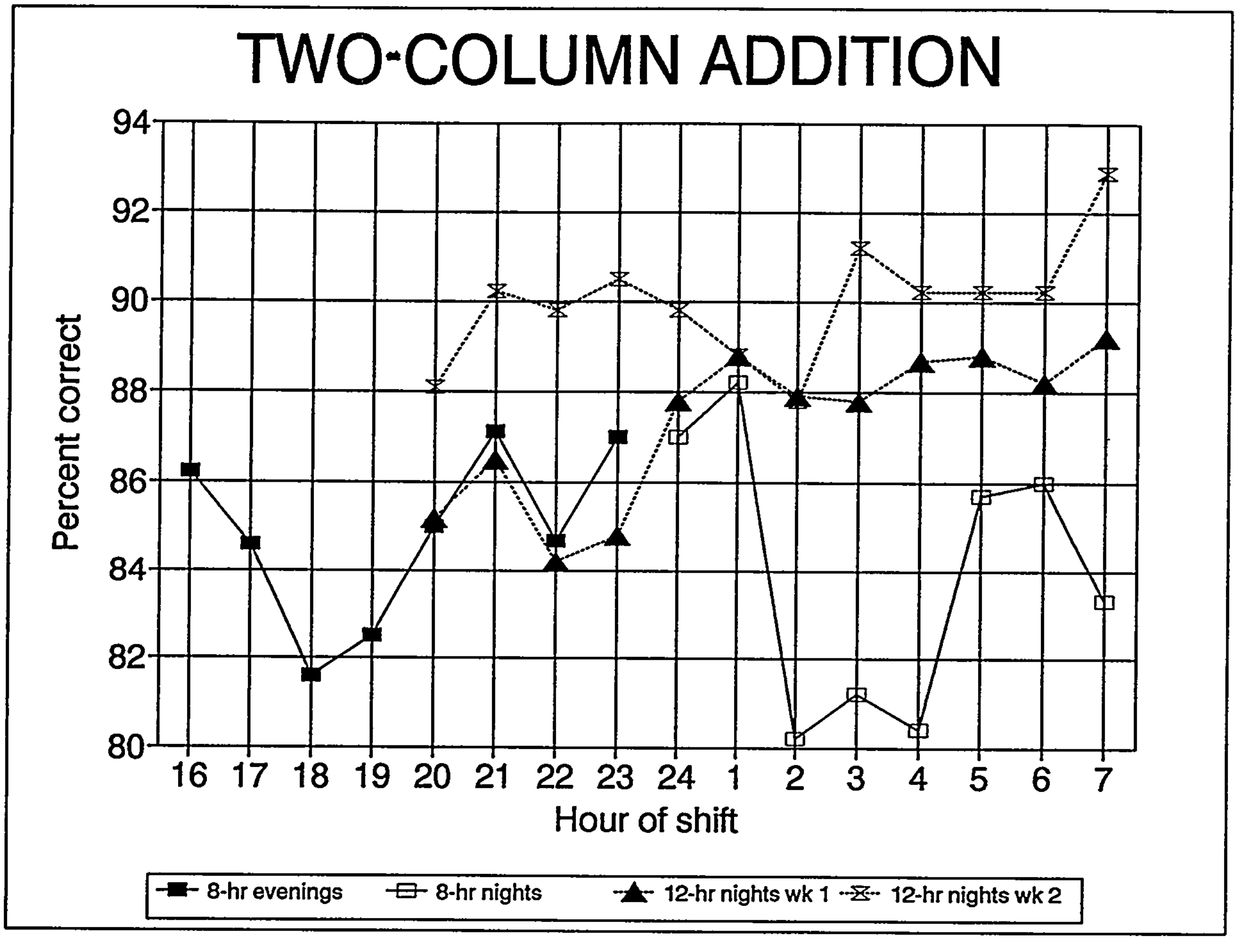

Figure 15 This figure shows mean percent correct for the Two-Column Addition task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The difference between 8-hr and 12-hr night shifts was not significant. However, the figure shows the trend for subjects working 8-hr night shifts to exhibit lower accuracy between the hours 0200-0400. This suggests lower performance accuracy around the nadir of the human circadian rhythm.

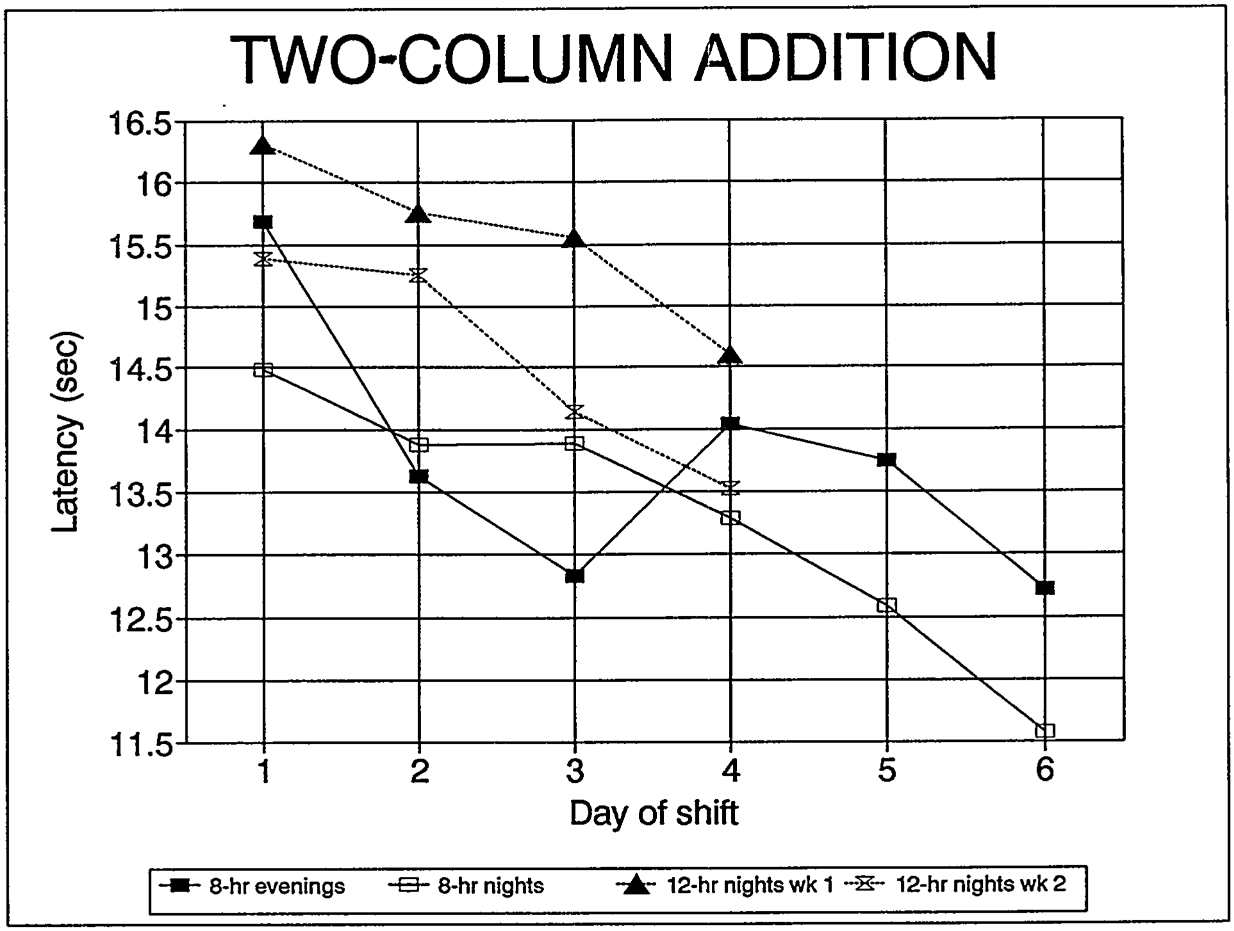

Figure 16 This figure shows mean response latency for the Two-Column Addition task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates reduced response latency across successive shifts in all 8-hr and 12-hr shift conditions. The data strongly suggest continued practice effect throughout the experiment.

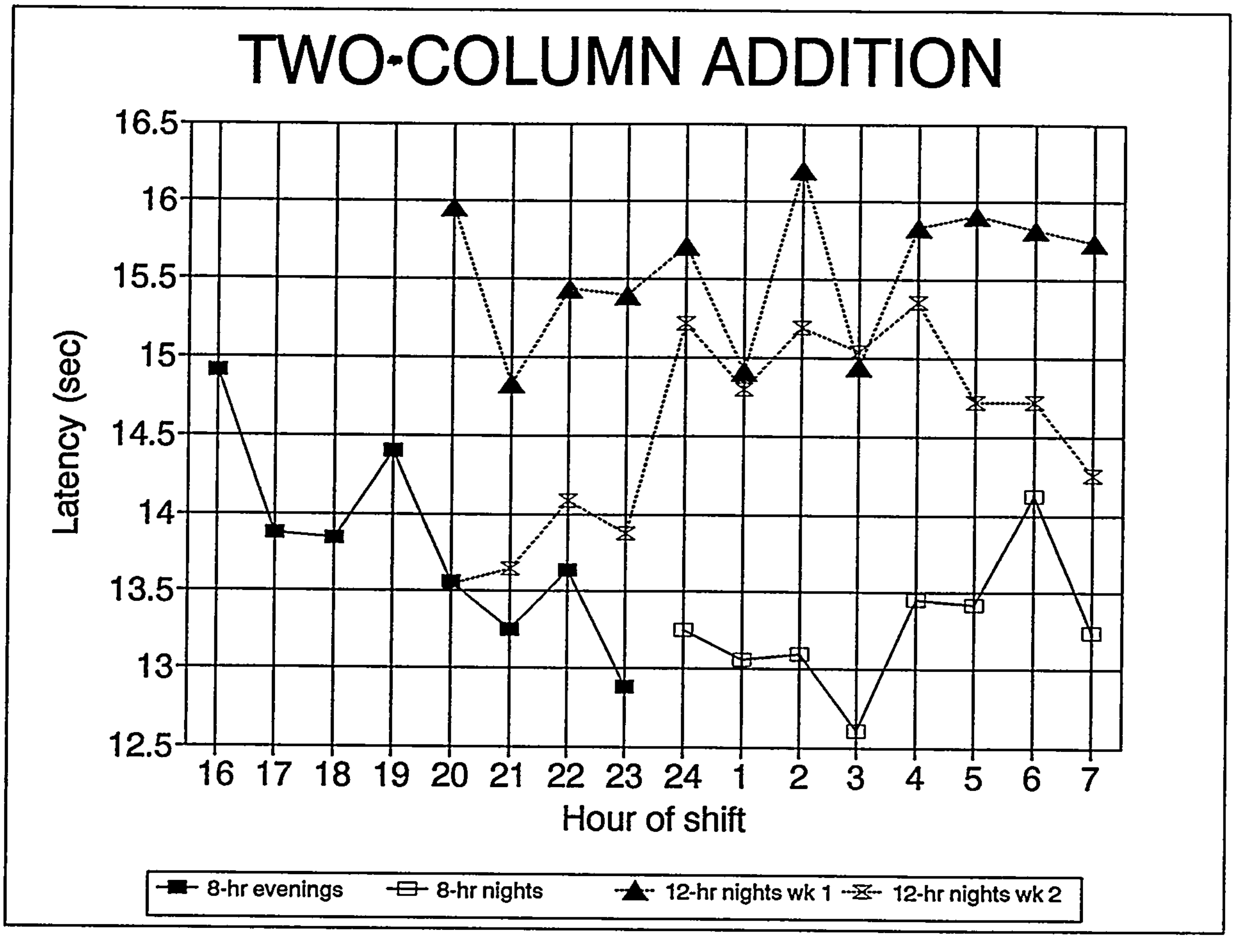

Figure 17 This figure shows mean response latency for the Two-Column Addition task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure indicates the trend toward lower response latency among subjects working 8-hr shifts. It also shows that the most rapid responses occurred during the early morning hours on 8-hr night shifts, when performance accuracy was lowest (Fig. 15).

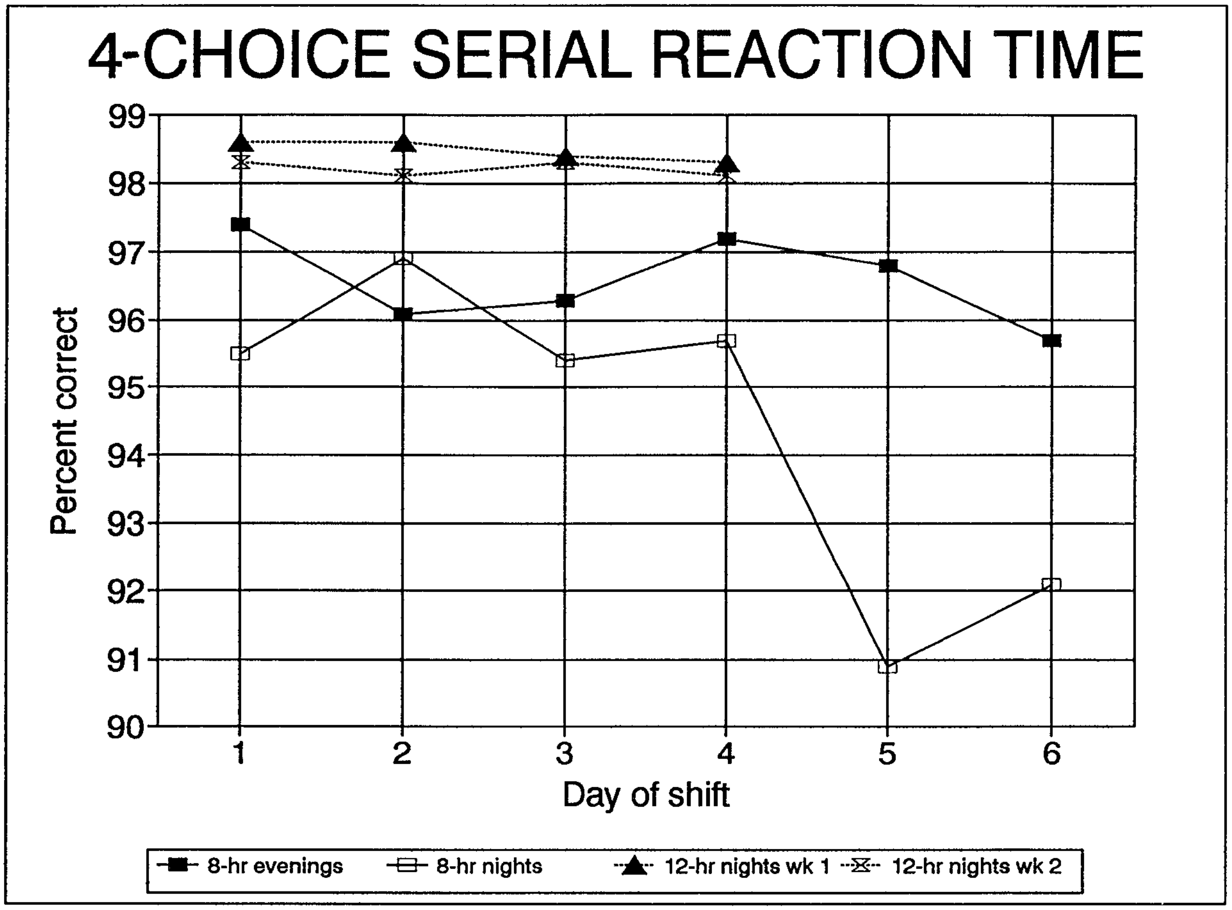

Figure 18 This figure shows mean percent correct for the Four-Choice Serial Reaction Time task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates consistent performance at a high level of accuracy across days of shift for 8-hr evening shifts and 12-hr night shifts. However, 8-hr night shifts showed a significant decrement in performance accuracy on the fifth and sixth consecutive 8-hr night shifts. The lowest reaction times were also recorded on the fifth and sixth 8-hr night shifts (Fig. 21).

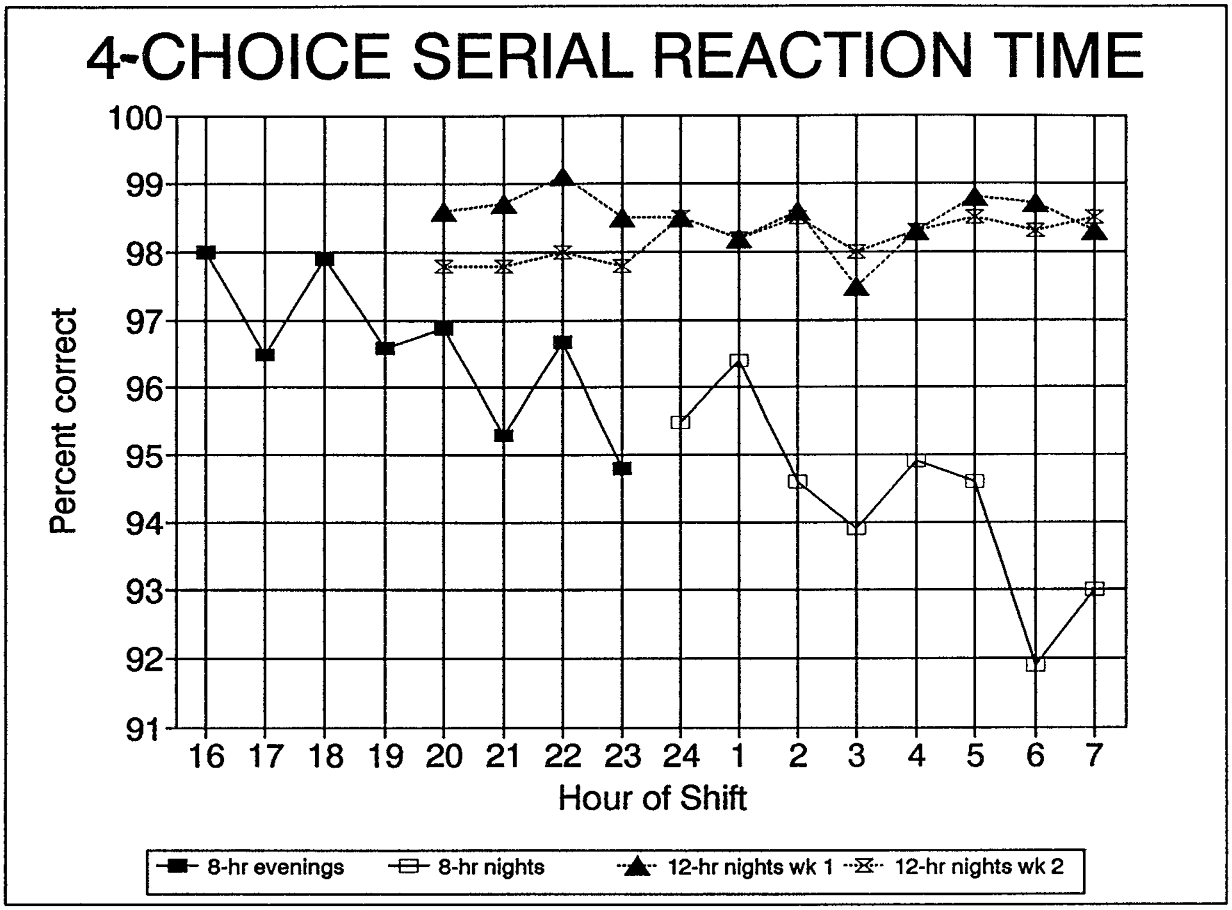

Figure 19 This figure shows mean percent correct for the Four-Choice Serial Reaction Time task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates the consistent and accurate performance across hours of shift for the subjects working 12-hr night shifts. Performance was significantly more accurate for subjects in the 12-hr shift protocol, as compared with subjects working 8-hr night shifts. The figure also shows that accuracy tended to decrease across shift hours in the 8-hr night shift condition, which suggests an effect of circadian rhythm or the effect of fatigue.

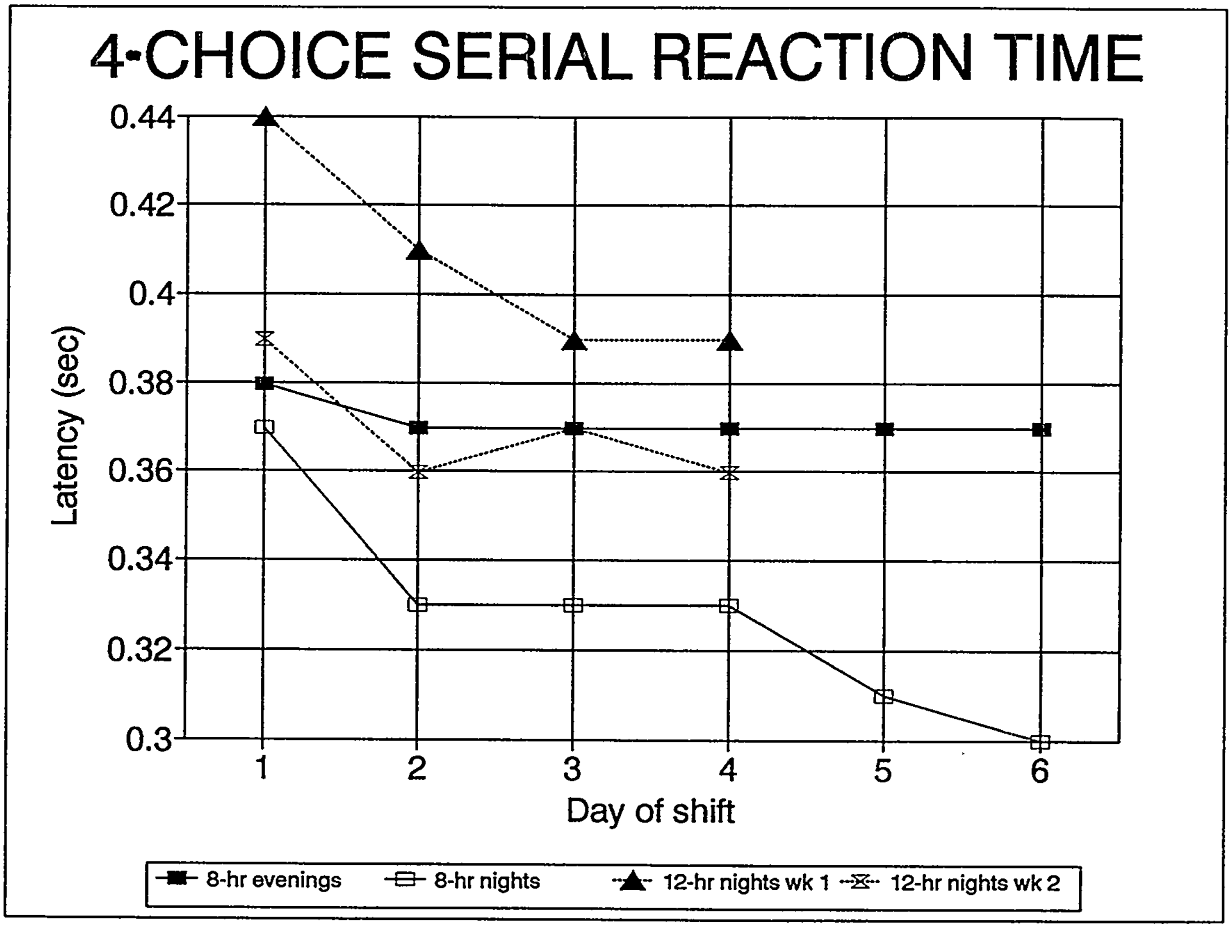

Figure 20 This figure shows mean reaction time (latency) for the Four-Choice Serial Reaction Time task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates that mean reaction time was significantly shorter on 8-hr night shifts, as compared with the first week of 12-hr night shifts. Across the six consecutive days of 8-hr evening shifts, subjects showed remarkably consistent reaction times.

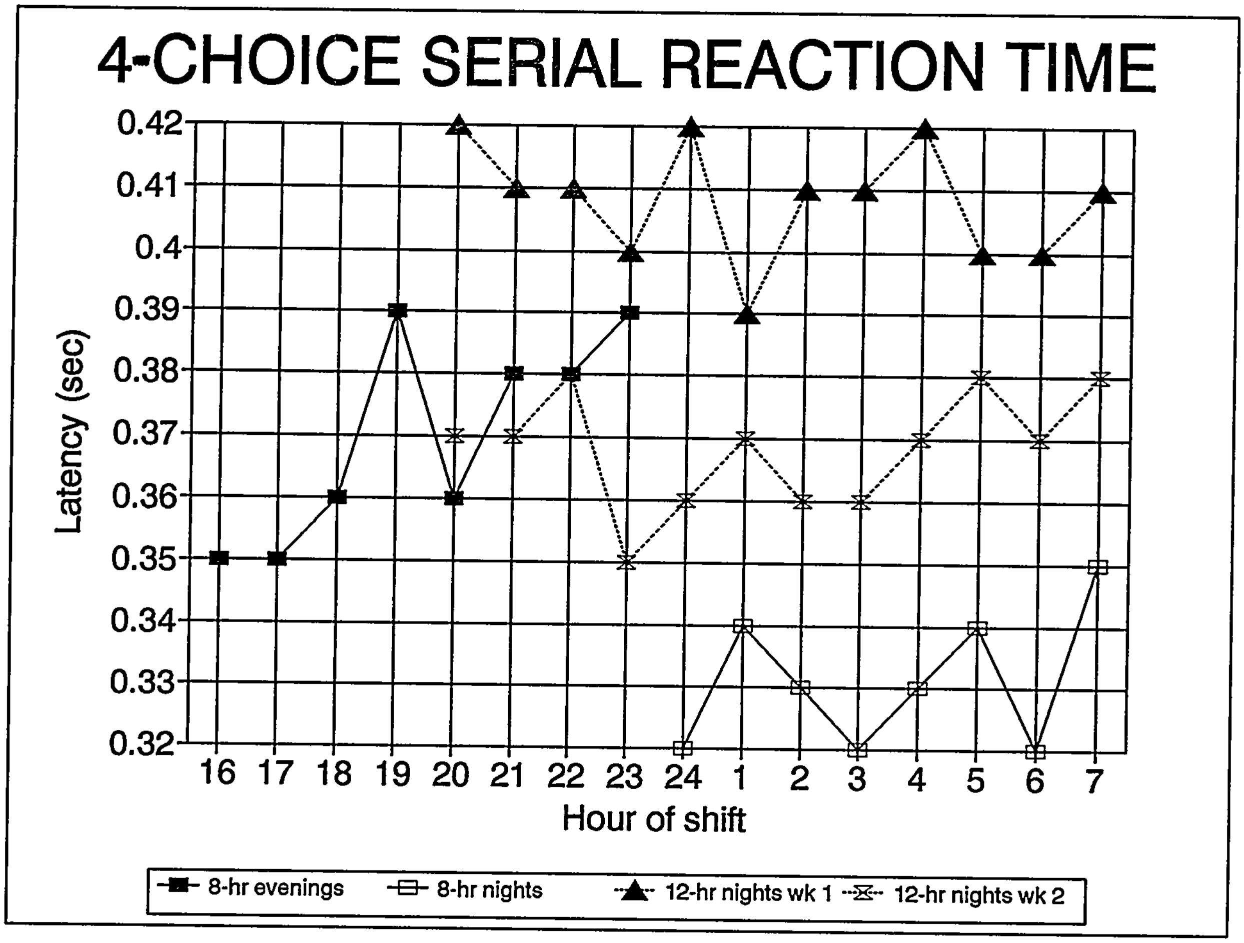

Figure 21 This figure shows mean reaction time (latency) for the Four-Choice Serial Reaction Time task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates that mean reaction time was significantly faster among subjects working 8-hr night shifts, as compared with all other shift conditins. However, subjects working 8-hr night shifts also showed significantly reduced accuracy on this task (as shown in Fig. 19).

As the percent of correct choices on the four-choice serial reaction time test decreased on the fifth and sixth night shifts of 8N, there were associated reductions in reaction time, as indicated by either the analysis of all data [F(2,172) = 4.65; P<.0001] or the comparable time analysis [F(9,84) = 7.92; P<.0001] (Fig. 20). In the 12-hr shift protocol, reaction time was slowest on the first one or two night shifts, then became progressively faster across the remaining night shifts. By contrast, reaction time remained remarkably stable across the 8-hr evening shifts.

Interval Production Task

These data are represented in Tables 1-2 and in Figure 22.

Day of shift. The ability to accurately estimate time intervals was significantly affected only by day of shift, as indicated by both the analysis of all data [F(16,172) = 2.79; P<.01] and the comparable time analysis [F(9,84) = 4.28; P<.05]. The precision of time estimation gradually degraded across nights of shift. This effect is most evident in the 8N and 12N2 shift conditions (Fig. 22).

Serial Add/Subtract Task

These data are represented in Tables 1-2 and in Figures 23-26.

Shift duration. Mean percent correct for all trials during 12-hr shifts was 95.1, as compared to 88.9 for all trials on 8-hr shifts. This difference was significant [F(1,2) = 34.67; P<.05] (Figs. 23, 24).

Shift condition. Only the analysis using comparable times on night shifts showed a significant effect of shift condition on percent correct on the serial add/subtract task [F(1,9) = 6.81; P<.05]. The performance on the 8N shift was significantly poorer (90.1%) than that of subjects on the 12N2 shift (96.0%).

In the analysis including all data, mean response latency varied significantly as a function of shift condition [F(2,16) = 8.14; P>.001]. This effect is attributable to slower response times only during the first week of 12-hr night shifts, as compared with 8E or 8N shift conditions (Fig. 25, 26). The analysis which included only comparable times also showed that mean response latency was significantly shorter for the 8N shifts (0.75 seconds) than for 12N1 shifts (1.05 seconds) [F(1,9) = 7.82; P<.01].

Day of shift. There were significant effects for day of shift on response accuracy using the analysis of all data [F(16,86) = 3.04; P<.001]. Accuracy decreased across 8-hr shifts, for both evenings and nights (Fig. 23).

Similarly, there was a significant reduction in mean response latency as a function of day of shift for all shift conditions, either including all data in the analysis [F(16,86) = 15.43; P<.0001], or using the comparable time analysis [F(9,84) = 17.57;P<.0001]. All night shift conditions showed progressively shorter response times over successive days of shift (Fig. 25).

Hour of shift. Hour-of-shift effects were not significant, although an end-of-shift fatigue effect is clearly indicated in the trends of response accuracy data for 8-hr night shifts (Fig. 24).

Manikin Task

These data are represented in Tables 1-2 and in Figures 27-30.

Shift duration. Percent of correct responses was significantly higher for subjects who worked

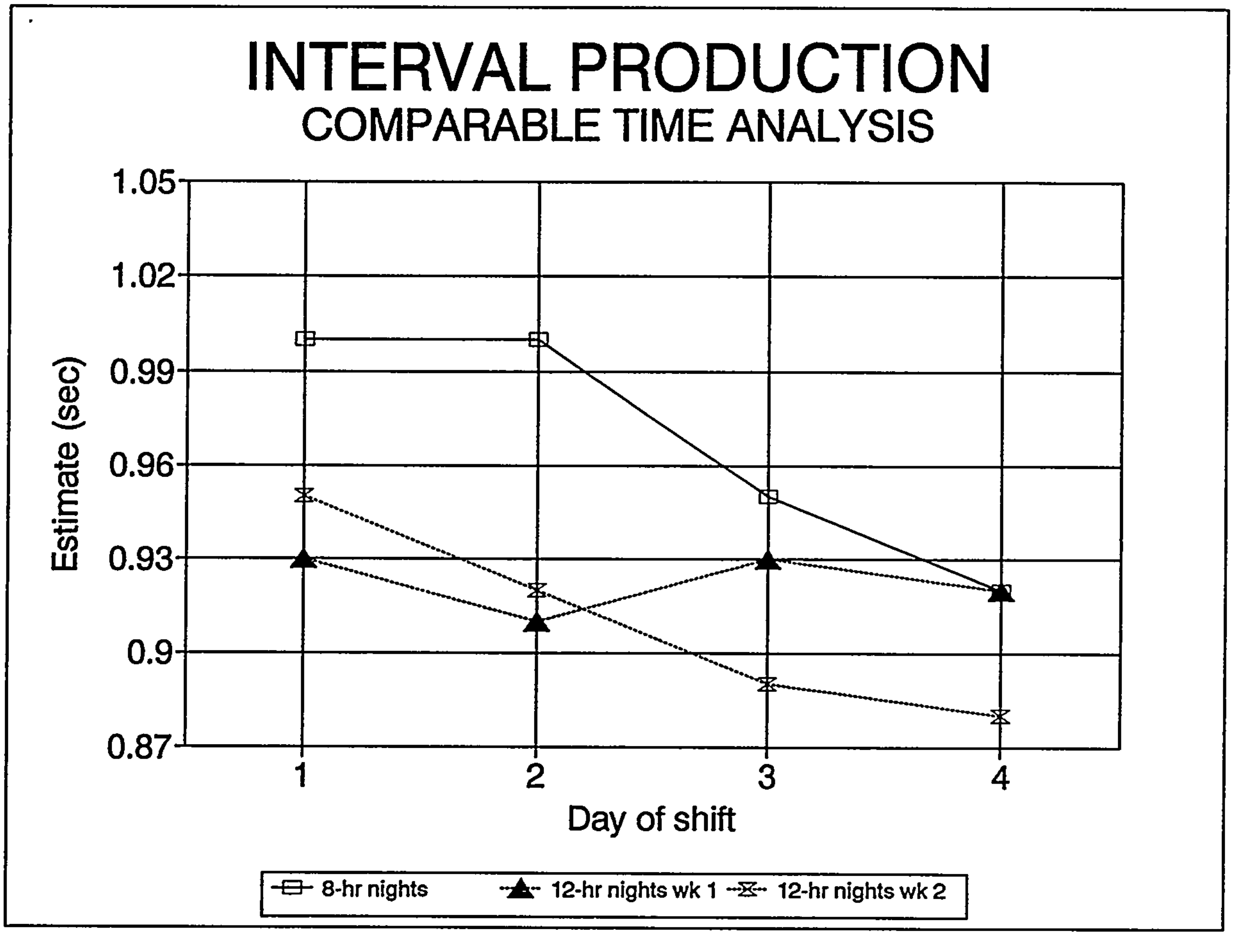

Figure 22 This figure shows accuracy at estimating sixty 1-second intervals, indicating the mean estimate for the Interval Production Task of the Walter Reed Performance Assessment Battery (optimal score is 1.0). Each symbol represents the average of 10 subjects, pooling the results of all hourly performance tests for each work shift to yield an average value for each consecutive day of shift. These data were derived only from comparable shift hours and days of shift in the 8-hr and 12-hr night shift protocols (i.e., 2300-0700 on the first through fourth consecutive night shift). The figure illustrates the significant day of shift effect, with accuracy of time estimation dropping across consecutive 8-hr night shifts, and across 12-hr night shifts in the 12N2 shift condition only.

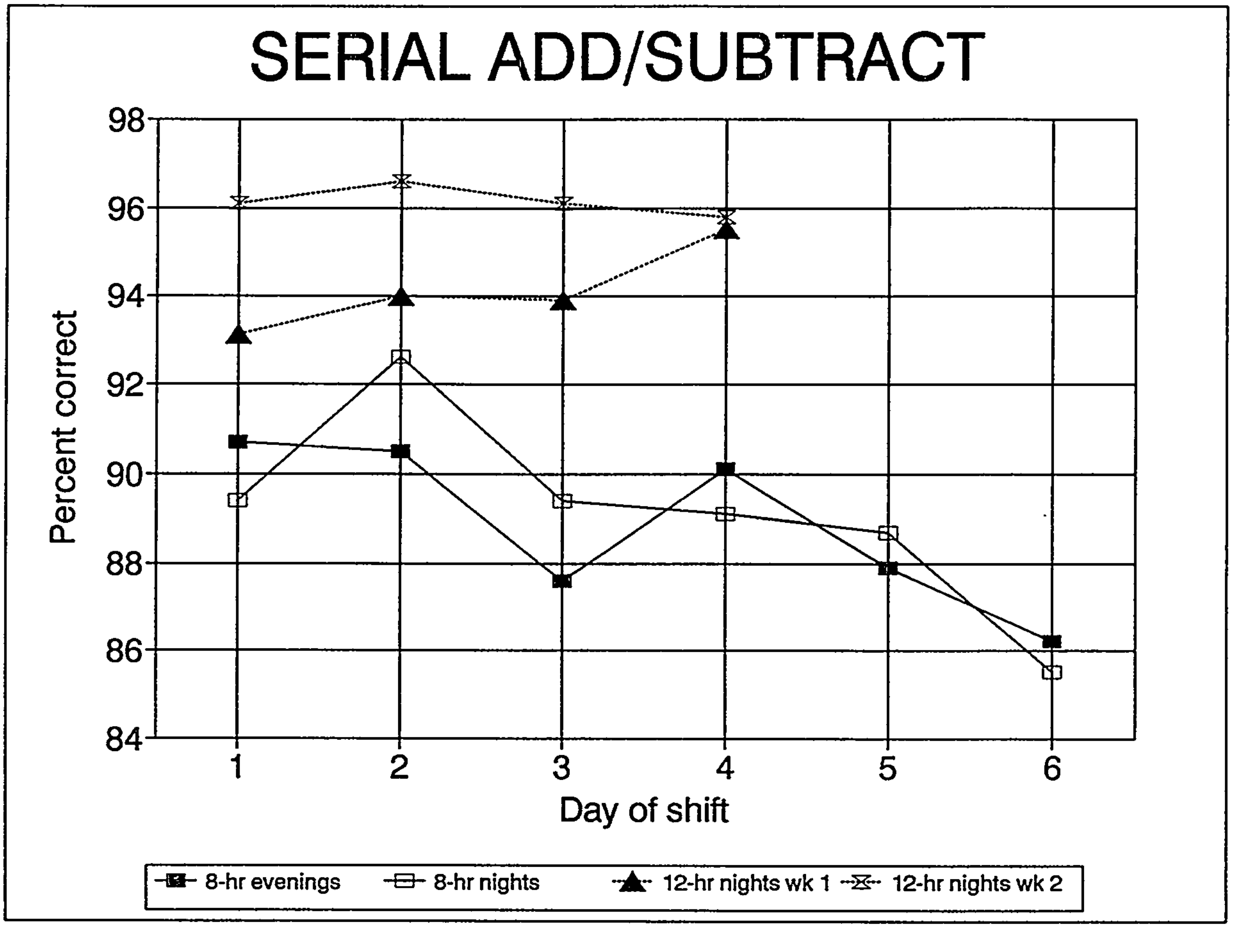

Figure 23 This figure shows mean percent correct for the Serial Add/Subtract task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates that performance accuracy was significantly greater for subjects in the 12-hr shift protocol than for those in the 8-hr shift protocol. The figure also indicates the significant day of shift effect only for 8-hr work shifts, on which accuracy decreased across days of shift.

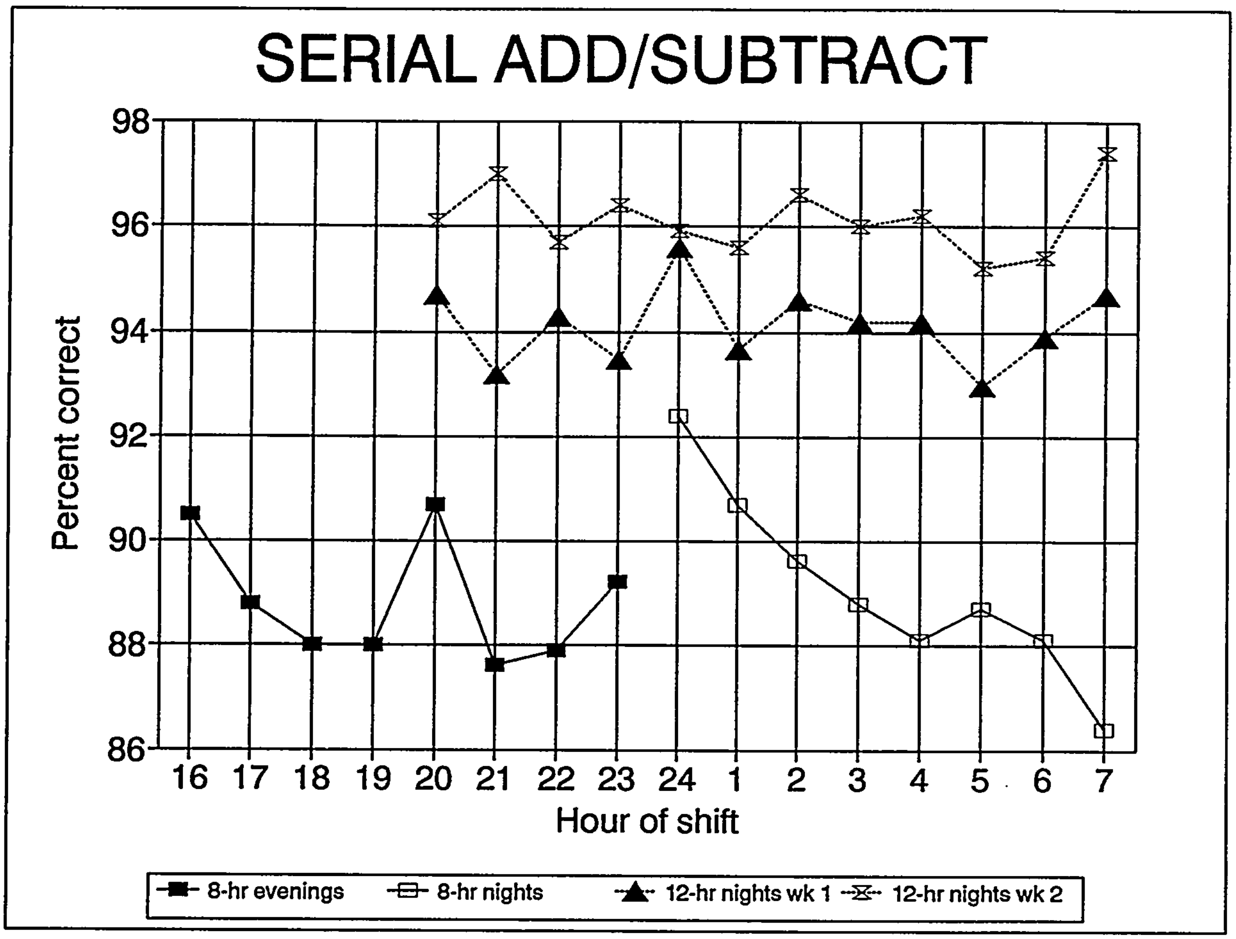

Figure 24 This figure shows mean percent correct for the Serial Add/Subtract task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates that subjects working 12-hr night shifts exhibited remarkably consistent and accurate performance across all hours of the work shift. By contrast, subjects working 8-hr shifts showed progressive performance decrements across the night shift, which suggests an effect of the circadian nadir or end-of-shift fatigue.

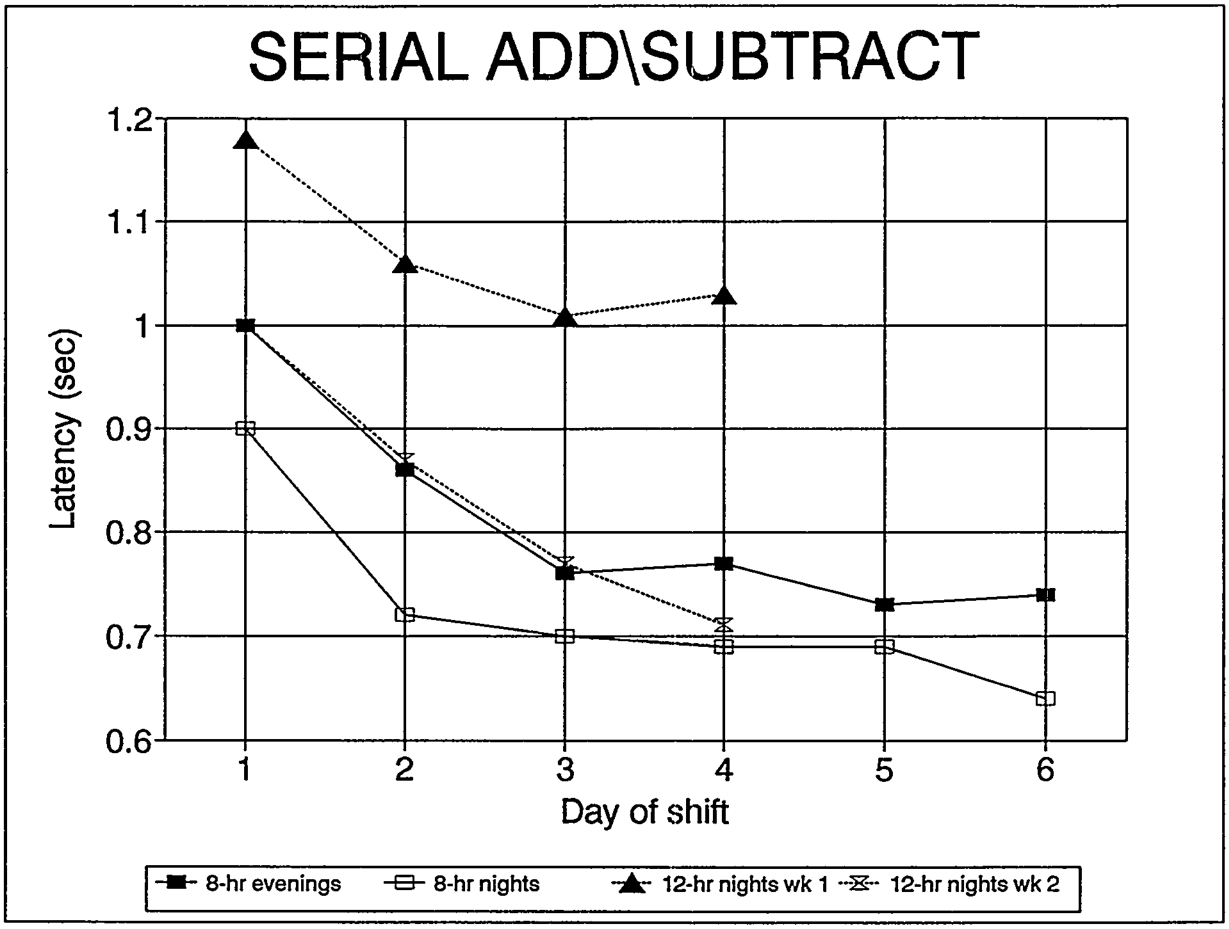

Figure 25 This figure shows mean response latency for the Serial Add/Subtract task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates that response latency was significantly longer during the first week of 12-hr night shifts than in any other shift condition. It also shows that response latency declined as a function of day of shift for all shift conditions, suggesting a continued practice effect. For example, mean response latency was 1.18 seconds on the first of eight 12-hr night shifts, but declined steadily to 0.71 seconds by the last night.

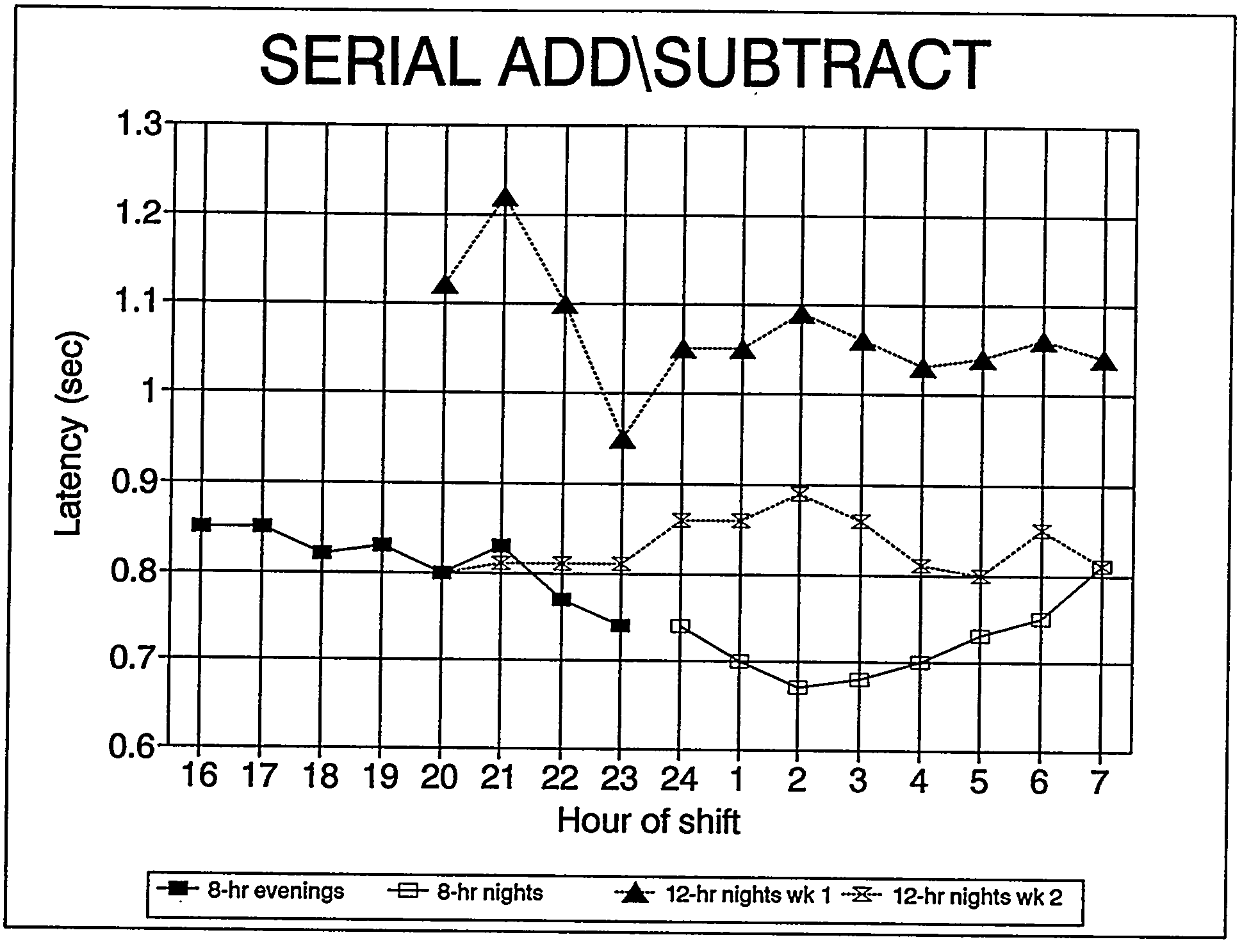

Figure 26 This figure shows mean response latency for the Serial Add/Subtract task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. Mean response latency was significantly longer during the first week of 12-hr night shifts, relative to all other shift conditions. Response latency was significantly improved from the first to the second week of 12-hr night shifts. For all shift conditions, mean response latency remained relatively consistent across hours of shift.

8-hr shifts (mean 94.5%), versus 12-hr shifts (mean 90.7%), by either the analysis including all data [F(1,2) = 443.3; P<.01], or by analysis of data restricted to comparable times [F(1,1) = 1023.1; P<.05] (Tables 1, 2). This was a reversal of the typical pattern seen in other PAB tests. On this test, subjects on 12-hr shifts performed less rapidly and less accurately.

Shift condition. Response latency varied significantly as a function of shift condition in the analysis of all data [F(2,16) = 13.90; P<.001] or the analysis of comparable time data [F(1,9) = 21.56; P<.05]. Subjects working 8-hr shifts performed this task faster than those on 12-hr shifts (Figs. 29, 30).

Day of shift. There was a significant effect for day of shift on percent correct by either the all data analysis [F(16,172) = 3.43; P<.001] or the comparable time analysis [F(9,84) = 5.92; P<.0001]. However, the day-of-shift effect for percent correct was not clear, as none of the values appeared to be outside the 95% confidence interval (Fig. 27).

There were also significant effects for day of shift on response latency by either analysis for percent correct [all data analysis; F(16,172) = 14.98; P<.0001] [comparable time analysis; F(9,84) = 8.90; P<.0001]. The effects for response latency are much more distinct. Mean response latency was significantly longer on the first two 12-hr night shifts of 12N1 (Fig. 29).

Stroop Task, Neutral Stimuli

These data are represented in Tables 1-2 and in Figures 31-34.

Shift duration. There was a significant effect for shift duration on percent correct [analysis of all data; F(1,2) = 201.95; P<.01] [comparable time analysis; F(1,1) = 395.9; P<.05], with better performance on all 12-hr night shifts compared with all 8-hr shifts (Tables 1, 2).

Shift condition. As determined by analysis of all data, response latency was significantly affected by shift condition [F(2,16) = 4.89; P<.01]. Response latencies were greater for 12-hr shifts as compared with either 8E or 8N shifts (Figs. 33, 34). The first and second weeks of 12-hr shifts did not differ in their mean response latency, nor did 8E differ from 8N.

Analysis of comparable time data also showed a significant effect of shift condition on response latency [F(1,9) = 7.84; P<.05]. The 8-hr night shift group was significantly faster at the Stroop task than the 12-hr group during the first week of night shifts, but 8N and 12N2 conditions did not differ significantly.

Day of shift. For subjects in the 8-hr shift protocol, performance accuracy on the Stroop task decreased significantly on shifts five and six of both evening and night shift weeks [all data analysis; F(16,172) = 3.26; P<.0001] (Fig. 31).

There was also a day-of-shift effect on response latency [analysis of all data; F(16,172) = 9.73; P<.0001] [comparable time analysis; F(9,84) = 4.62; P<.0001]. The most noticeable day-of-shift effect by least squares comparison was a decreasing response latency after the second 12N1 and 8E shifts, which probably represents a learning effect (Fig. 33).

Stroop Task, Incongruent Stimuli

These data are represented in Tables 1-2 and in Figures 35-38.

Duration of shift. The effect of shift duration on percent correct in this task is significant by analysis of all data [F(1,2) = 44.34; P<.01]. The 12-hr shift group performed the task more

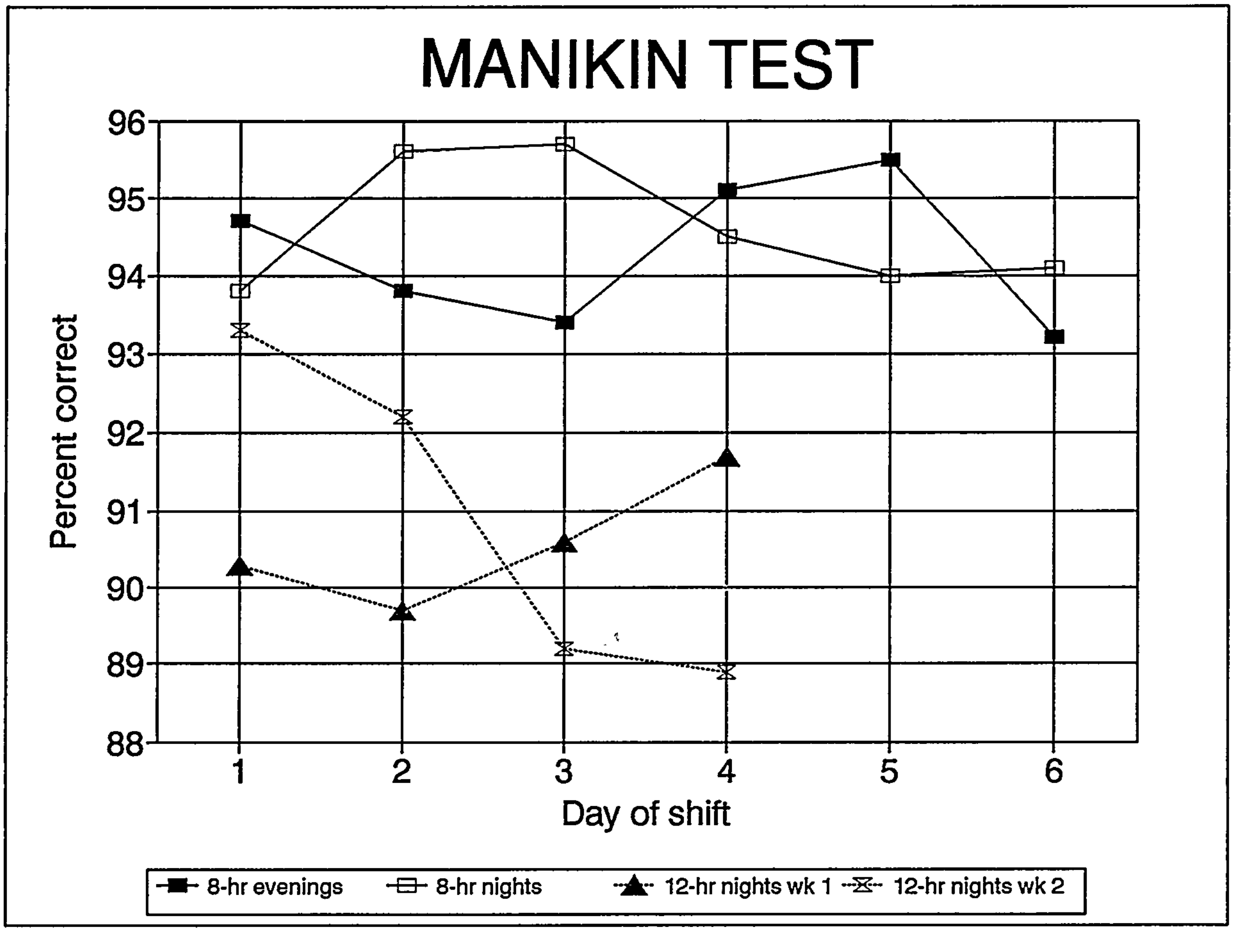

Figure 27 This figure shows mean percent correct for the Manikin task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates significicantly lower performance accuracy of subjects in the 12-hr shift protocol, as compared with those in the 8-hr shift protocol.

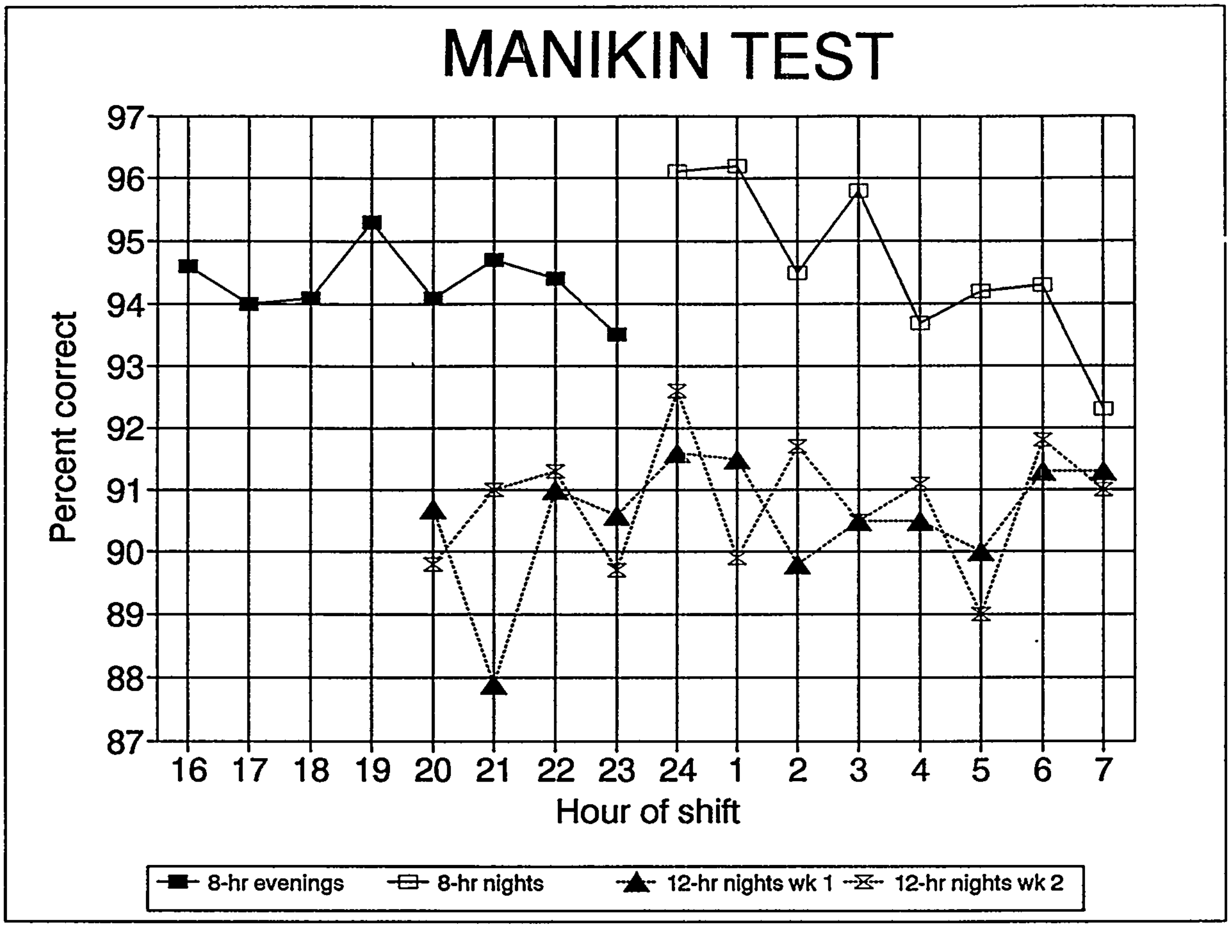

Figure 28 This figure shows mean percent correct for the Manikin task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates lower performance accuracy of subjects in the 12-hr shift protocol, as compared with those in the 8-hr shift protocol. There was also a tendency for performance accuracy to fall during the later hours of the 8-hr night shifts, although the hour-of-shift effect did not achieve statistical significance.

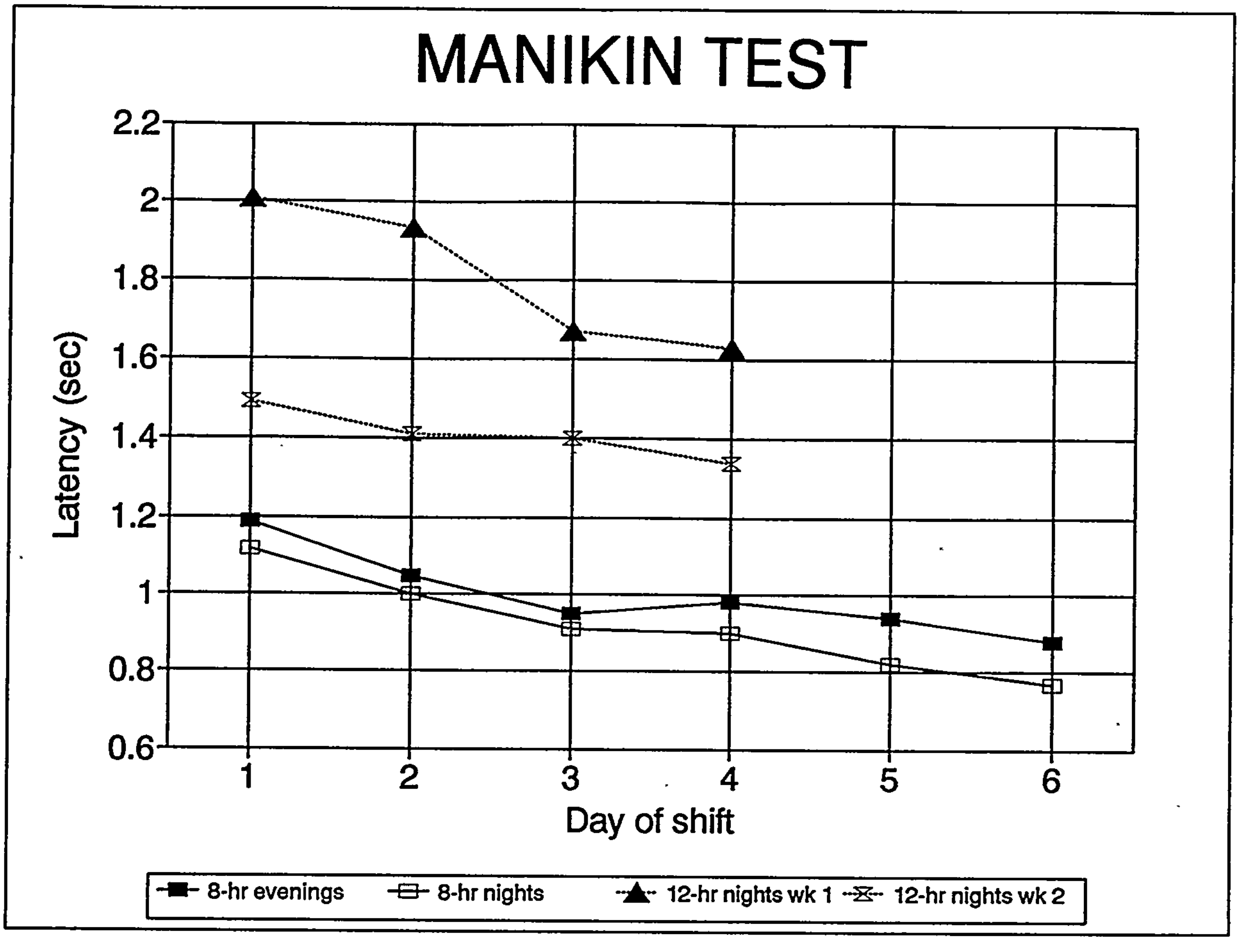

Figure 29 This figure shows mean response latency for the Manikin task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates the significantly shorter mean response latency for subjects in the 8-hr shift protocol. All shift conditions showed a progressive reduction in response latency over successive days of shift. A significant day-of-shift effect was restricted to the significantly longer response latency on the first two 12-hr night shifts.

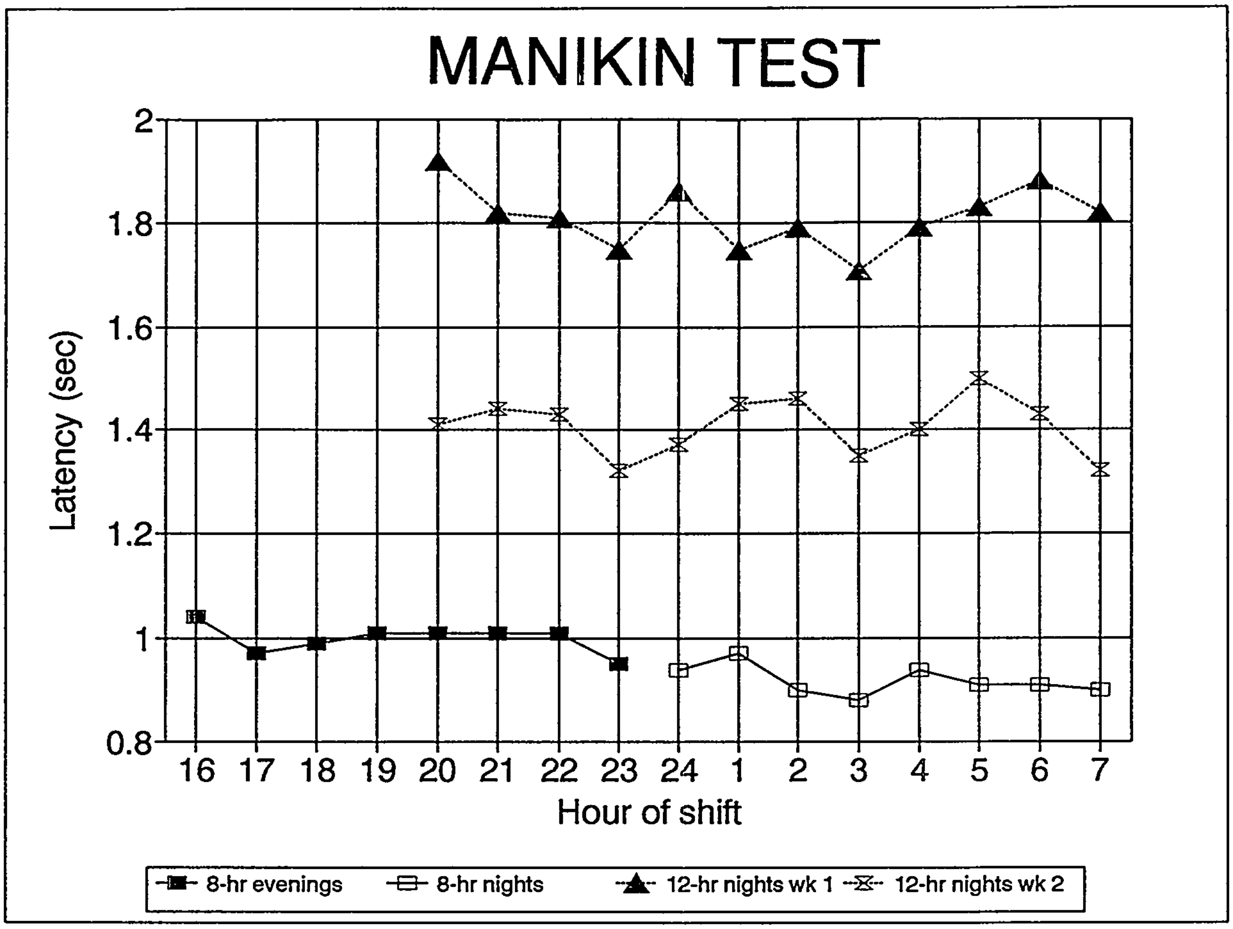

Figure 30 This figure shows mean response latency for the Manikin task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. Mean response latency remained remarkably consistent across hours of shift in all subjects. Response latency was significantly shorter for those working 8-hr shifts, as compared with those working 12-hr shifts. The figure also shows that mean response latency decreased significantly from the first to the second consecutive week of 12-hr night shifts.

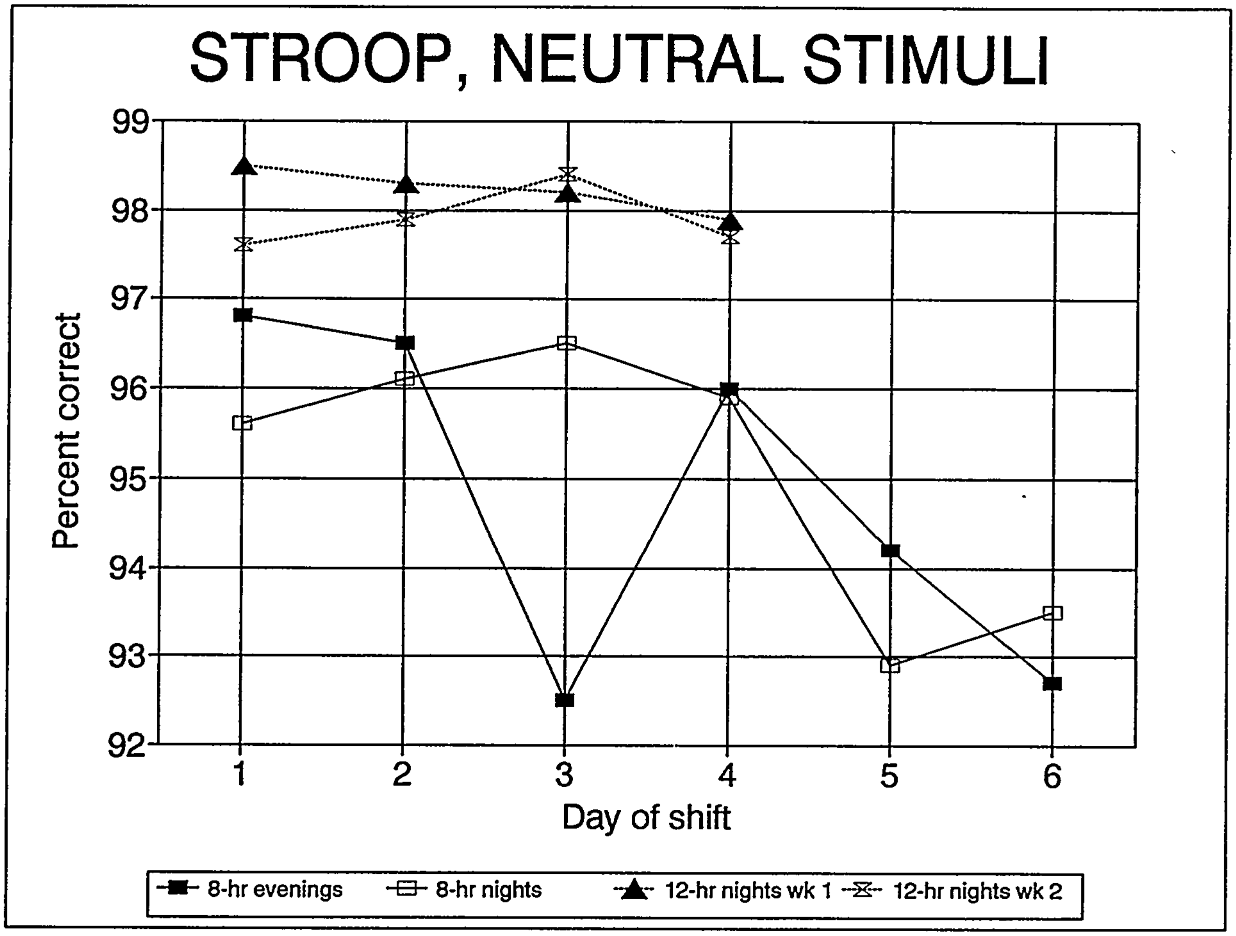

Figure 31 This figure shows mean percent correct for the *neutral stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates that subjects working 12-hr night shifts performed the task more accurately that those working 8-hr shifts. It also shows the significant day-of-shift effects on accuracy in the 8-hr shift protocols, including both evening and night shifts. Performance accuracy was significantly reduced on the fifth and sixth consecutive 8-hr evening and night shifts.

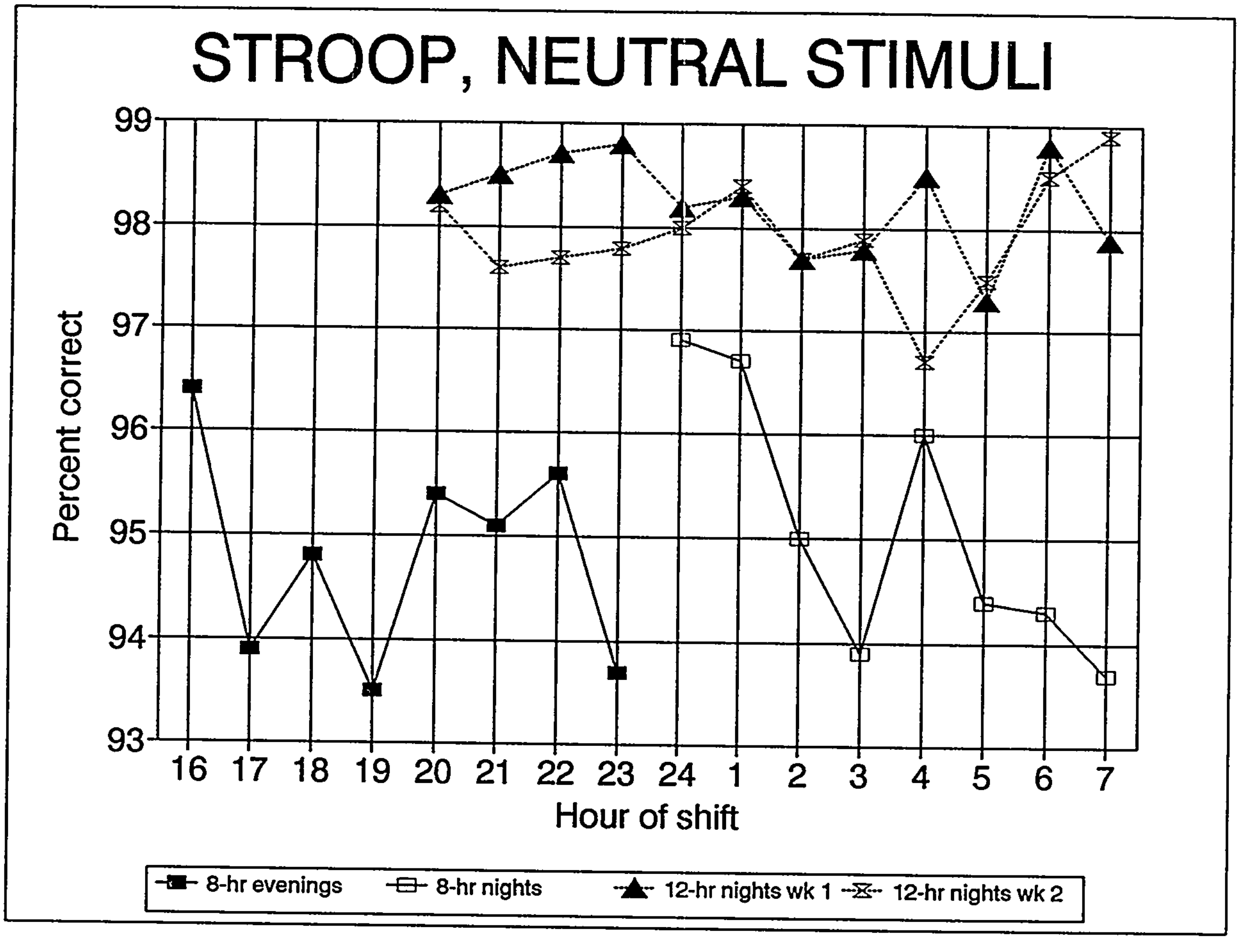

Figure 32 This figure shows mean percent correct for the *neutral stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. Subjects on 12-hr night shifts showed significantly more accurate performance than their counterparts working 8-hr evening or night shifts. Performance accuracy also remained consistent across hours of shift in the 12-hr night shift protocol, but tended to fall slightly across the 8-hr night shifts.

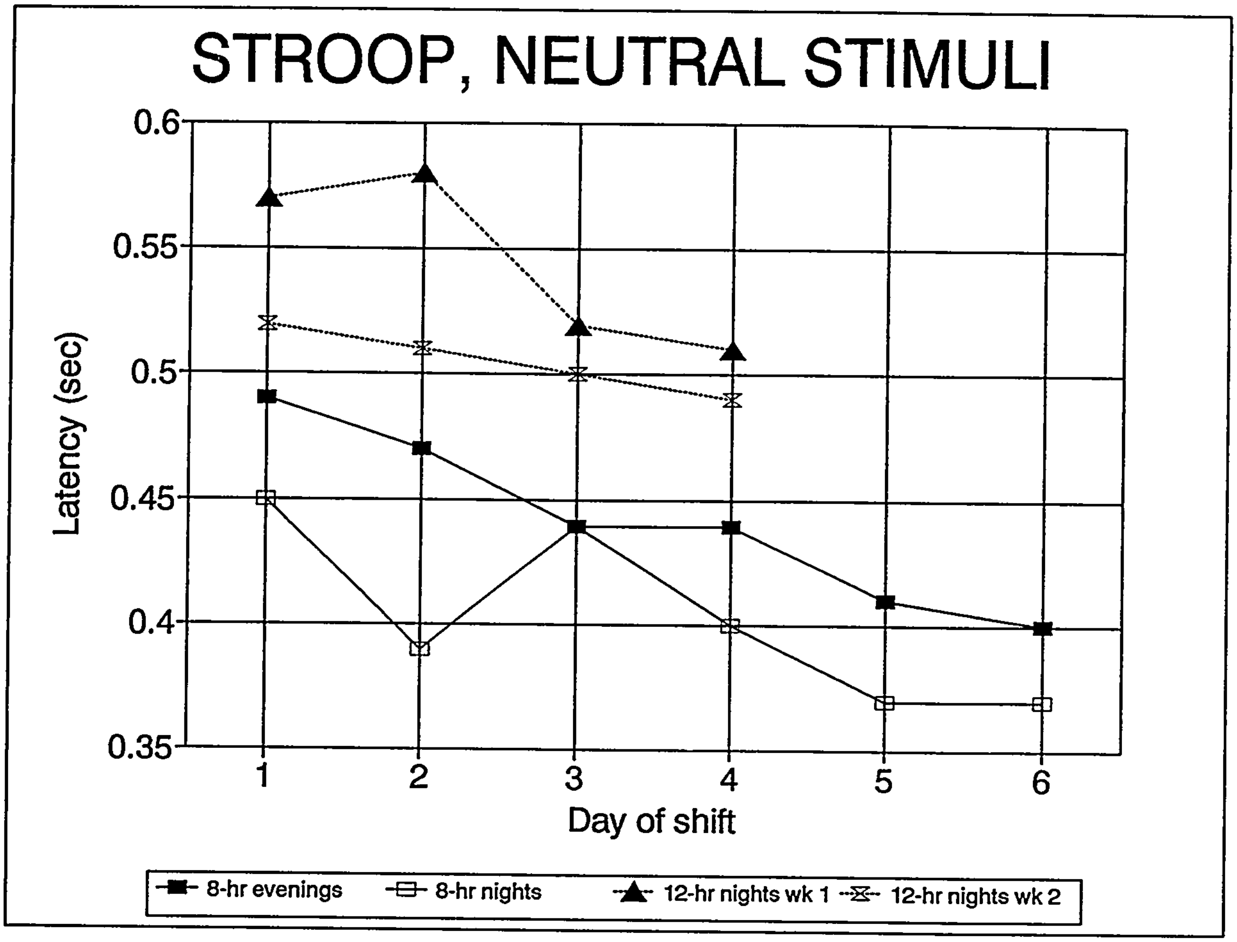

Figure 33 This figure shows mean response latency for the *neutral stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates the reduction in response latency that occurred across day of shift for both 8-hr and 12-hr shift conditions, which suggests a continued practice effect. Subjects working 8-hr evening and night shifts showed significantly shorter mean response latency, as compared with subjects working 12-hr night shifts.

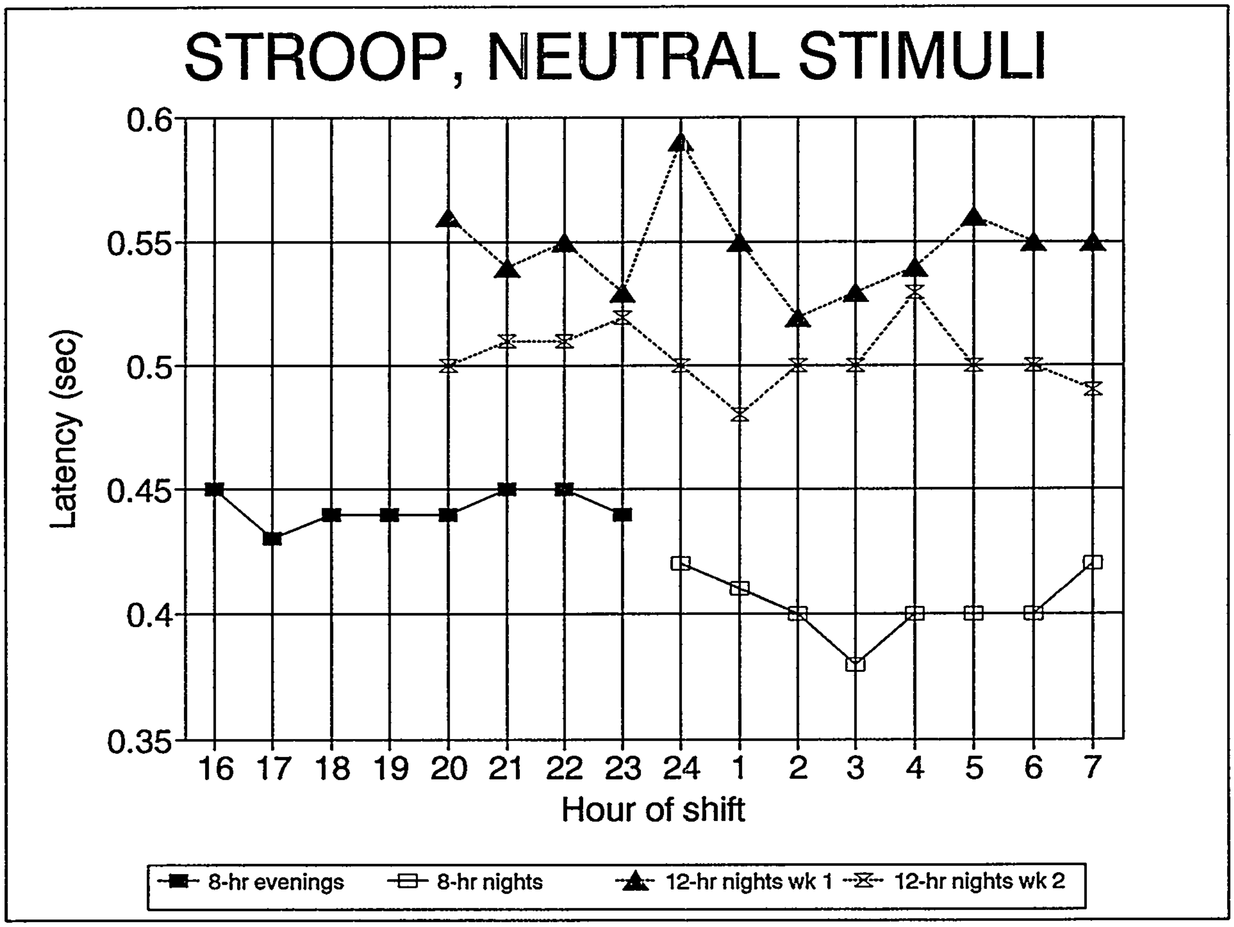

Figure 34 This figure shows mean response latency for the *neutral stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. Mean response latency was consistent across hours of shift for both 8-hr and 12-hr shift protocols. Mean response latency was significantly shorter for subjects working 8-hr shifts, as compared with those working 12-hr shifts.

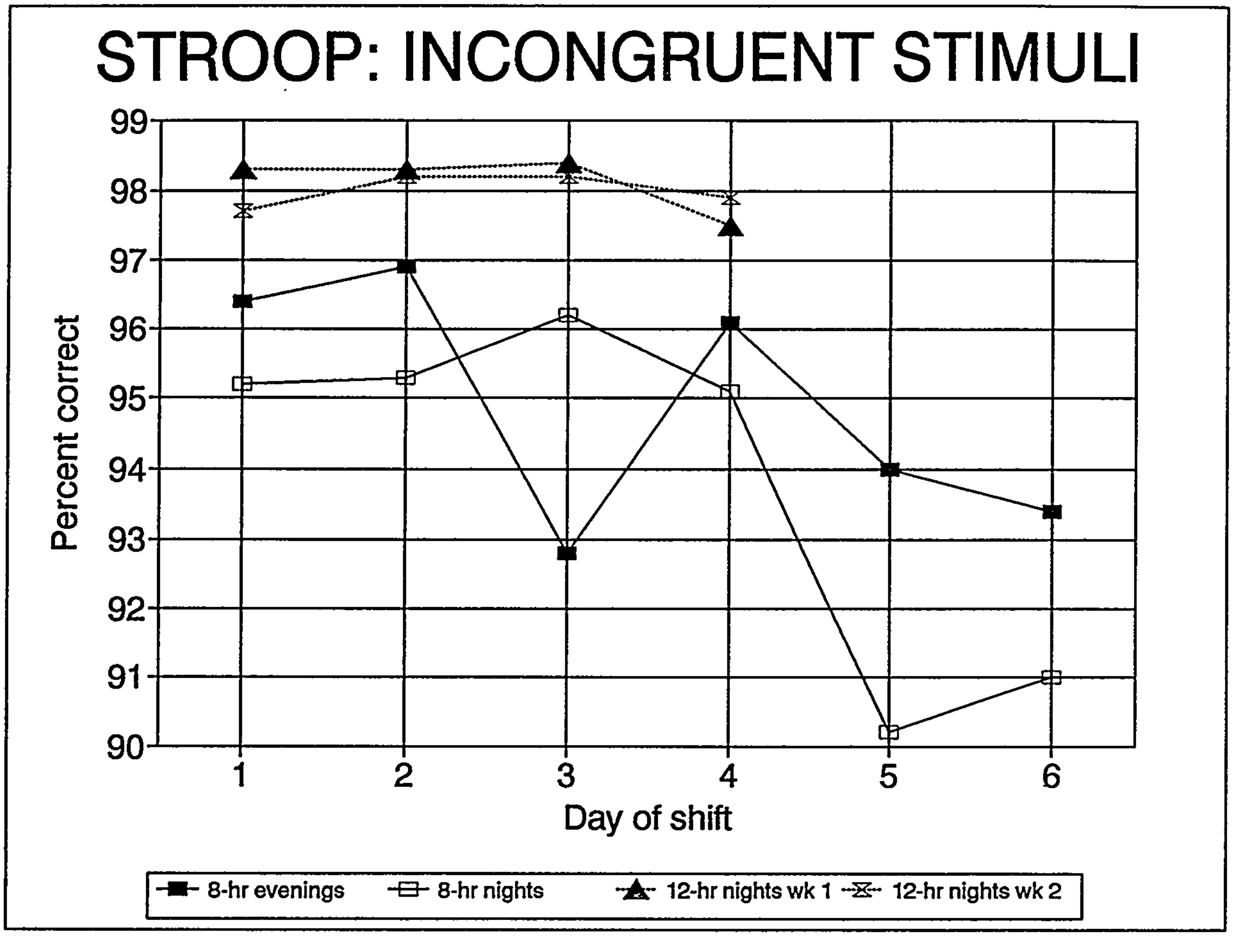

Figure 35 This figure shows mean percent correct for the *incongruent stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates the consistent and significantly more accurate performance of subjects working 12-hr night shifts, as compared to subjects working 8-hr evening or 8-hr night shifts. The figure also shows a significant day-of-shift effect. Performance accuracy was significantly lower on the fifth and sixth consecutive 8-hr night shift.

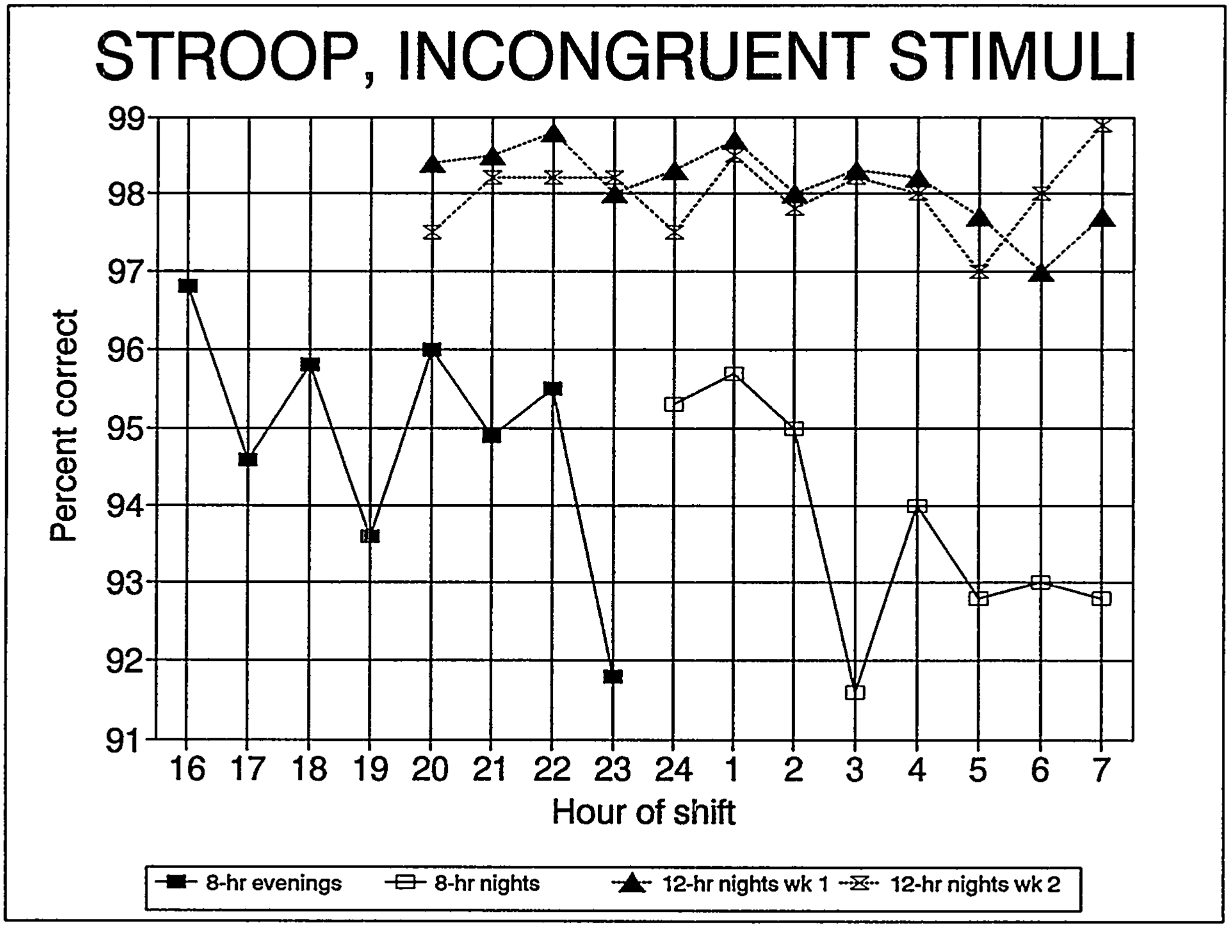

Figure 36 This figure shows mean percent correct for the ***incongruent stimulus*** of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates the significant difference in percent of correct responses between subjects working 12-hr shifts and those working 8-hr shifts. Performance accuracy on 12-hr shifts remained consistently high across hours of shift, while accuracy tended to drop off in the early morning hours of 8-hr night shifts (0300-0700).

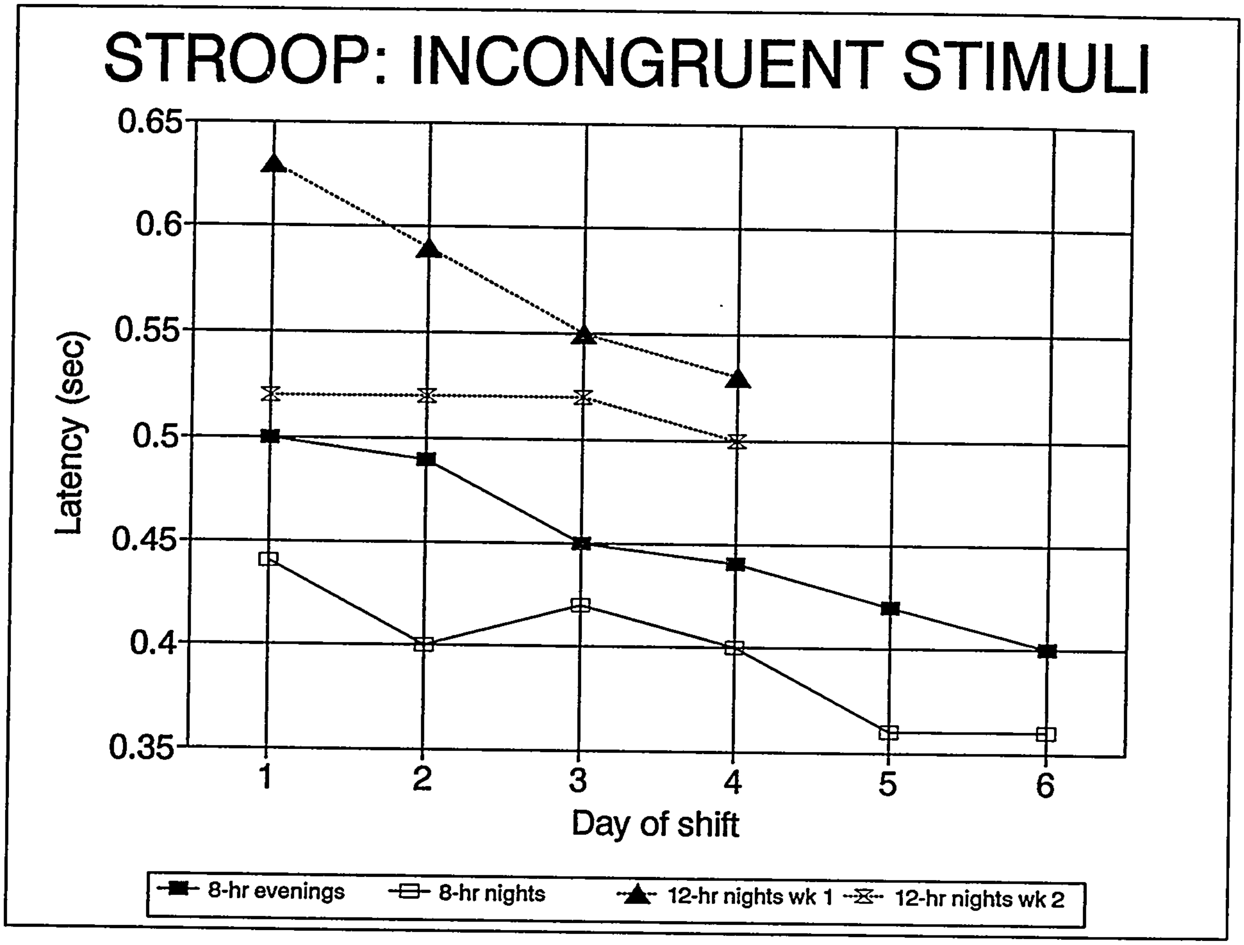

Figure 37 This figure shows mean response latency for the *incongruent stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive day of shift. Each symbol represents the average of 10 subjects, pooling the results of all hourly performance trials to yield an average value for each consecutive day of shift. The figure illustrates the significant day-of-shift effect for response latency on this task. Response latency shortened progressively across days of shift on 8-hr evening and night shifts and the first week of 12-hr night shifts. Response latency remained stable across the second week of 12-hr night shifts.

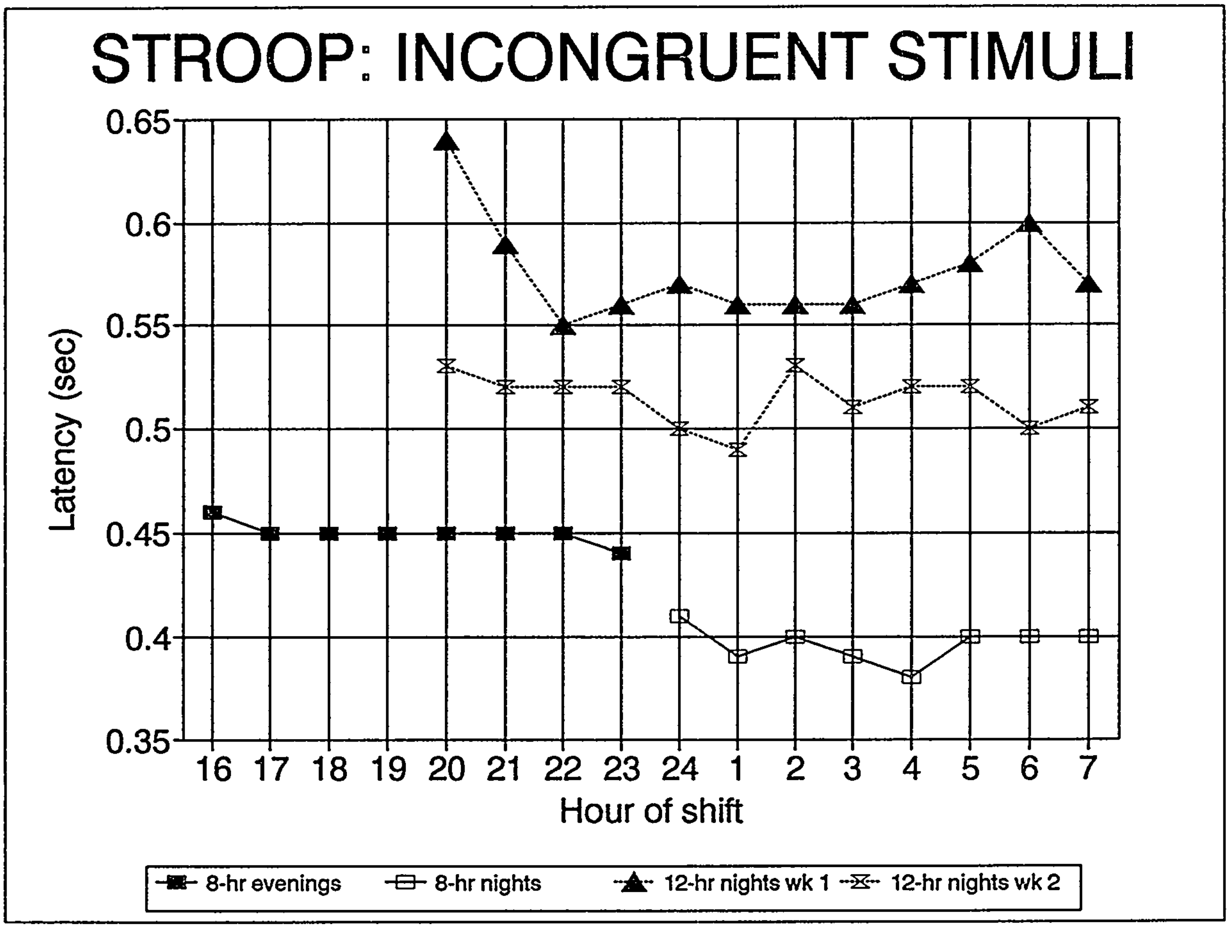

Figure 38 This figure shows mean response latency for the *incongruent stimulus* of the Stroop task of the Walter Reed Performance Assessment Battery, plotted as a function of consecutive hour of shift. Each symbol represents the average of 10 subjects, pooling same-hour data from all days of shift to yield an average value for each hour of the work shift. The figure illustrates the consistent response latency across hours of shift for all experimental work shift conditions. Mean response latency was significantly shorter for subjects working 8-hr evening or night shifts, as compared to those working their first week of 12-hr night shifts.

accurately than the 8-hr shift group (Figs. 35, 36). Interestingly, there was no reduction in percent correct for incongruent stimuli, as compared to neutral stimuli. That is, there was no classical "Stroop effect" evident in these data.

Shift condition. Response latency showed a significant effect of shift condition [all data analysis; F(2,16) = 7.05; P<.01]. Subjects on 12-hr night shifts completed the tasks more slowly those working 8-hr night shifts (Figs. 37, 38). Comparable time analysis showed that the first week of 12-hr night shifts, but not the second, was significantly different from the 8-hr night shifts [F(1,9) = 11.26; P<.01].

Day of shift. Response latency was significantly affected by day of shift [all data analysis; F(16,172) = 11.23; P<.05] [comparable time analysis; F(9,84) = 6.95; P<.0001]. Mean response latency decreased on successive days of shift for all but the 12N2 shift condition (Fig. 37).

Subject Self-Rating Scales for Global Vigor and Affect (GVA)

Global Affect: Sadness Scale

These data are represented in Table 3 and in Figures 39-40.

Shift condition. There was a significant effect for shift condition on self-rated *sadness* [F(2,16) = 4.64; P<.05]. The *sadness* score of the 8E group was less than for night shift conditions.

Day of shift. There was a significant effect for day of shift on self-rated *sadness* by analysis of all data [F(16,172) = 2.91; P<.001] or by comparable time analysis [F(9,84) = 3.92; P<.001]. The differences appear in the 12-hr shift groups, who show significantly higher *sadness* ratings by least squares analysis on the last 12-hr night shift of the 12N1 week and the first 12-hr night shift of the 12N2 week (Fig. 39).

Hour of shift. Although there was no significant hour-of-shift effect, there was a clear trend for self-rated *sadness* to increase during the later hours of the night shifts (Fig. 40).

Global Affect: Tension Scale

These data are represented in Table 3 and in Figures 41-42.

Day of shift. There was a significant effect for day of shift on self-rated *tension* in the analysis of all data [F(16,172) = 4.59; P<.0001] or comparable time data [F(9,84) = 5.29 P<.0001]. Subjects working 12-hr shifts rated themselves as significantly more *tense* on the first night of week 2. For subjects working 8-hr shifts, self-ratings of *tension* were significantly higher for the fifth and sixth evening shifts, or the second and fifth night shifts (Fig. 41).

Hour of shift. Hour-of-shift effects were not significant, but the combined data show a trend for progressive increase in *tension* ratings across hours of the 12-hr night shifts (Fig. 42).

Global Affect: Calmness Scale

These data are represented in Table 3 and in Figures 43-44.

Day of shift. There was a significant effect for day of shift on self-rated *calmness* either by analysis of all data [F(16,172) = 4.17 P<.0001], or analysis of comparable time data [F(9,84) = 2.05 P<.05]. Subjects in the 8-hr group rated themselves as more *calm* on the second and third nights of shift, while 12-hr shift subjects showed little night-to-night variability (Fig. 43).

Mean Scores on Global Affect Scales
Analysis of all data

Global Affect Scales	12-hr shifts week 1	12-hr shifts week 2	8-hr shifts evenings	8-hr shifts nights
Sad	23.4	21.7	19.6 *	23.1
Tense	37.3	37.9	38.4	41.0
Calm	56.8	57.3	68.2	63.1
Happy	42.9	41.3	54.4 *	50.8 *
Global Affect	59.8	59.9	66.0 *	62.4

Mean Scores on Global Affect Scales
Analysis of comparable time data

Global Affect Scales	12-hr shifts week 1	12-hr shifts week 2	8-hr shifts nights
Sad	24.5	23.2	23.9
Tense	38.8	39.0	40.5
Calm	55.1	56.2	62.1
Happy	40.0	39.2	48.2 *
Global Affect	57.9	58.5	61.5

Table 3 This table gives mean of subject self-ratings on the Global Vigor and Affect scale (GVA). The GVA is an analog scale with ratings ranging from 1-100. Analysis of all data includes all hourly tests during any of the four shift conditions (four 12-hr night shifts (1900-0700), week 1 and week 2; six 8-hr evening shifts (1500-2300); or six 8-hr night shifts (2300-0700). Analysis of comparable time data includes only the hours 2300-0700 of the first four consecutive 12-hr or 8-hr night shifts. The only significant difference, higher self-rated happiness for the 8-hr shift subjects, is indicated ($p<.05=*$).

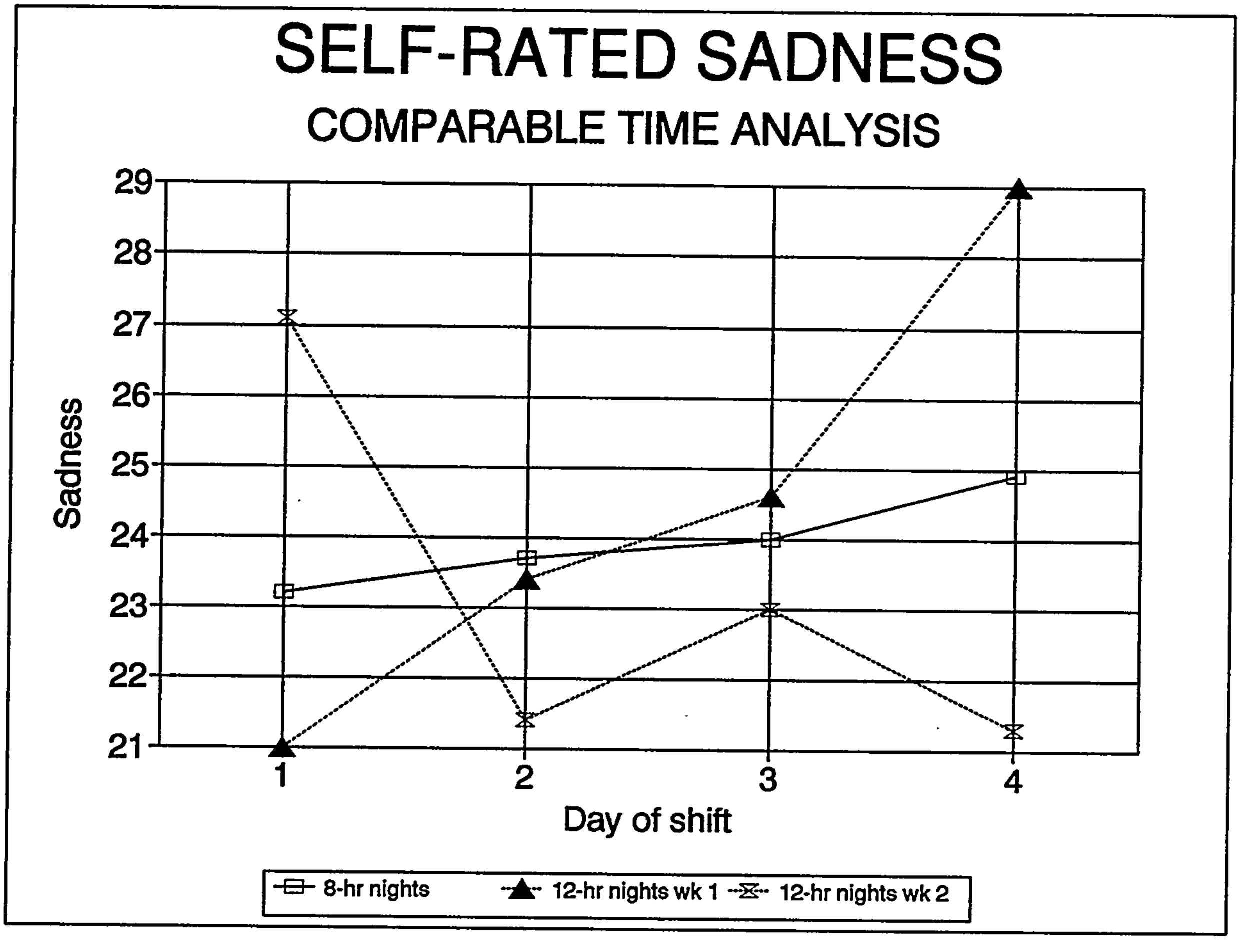

Figure 39 This figure shows the mean response to the question *"How sad are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more sadness on a 1-100 scale. This figure includes only data derived from comparable shift hours and days of shift in the 8-hr and 12-hr night shift protocols (i.e., 2300-0700 on the first through fourth consecutive night shift). Each symbol represents an average score for 10 subjects, pooling the results of eight hourly self-ratings to yield an average of all subjects for each consecutive day of shift. Mean subjective *sadness* was significantly higher on the last shift of the 12N1 week and the first shift of the 12N2 week.

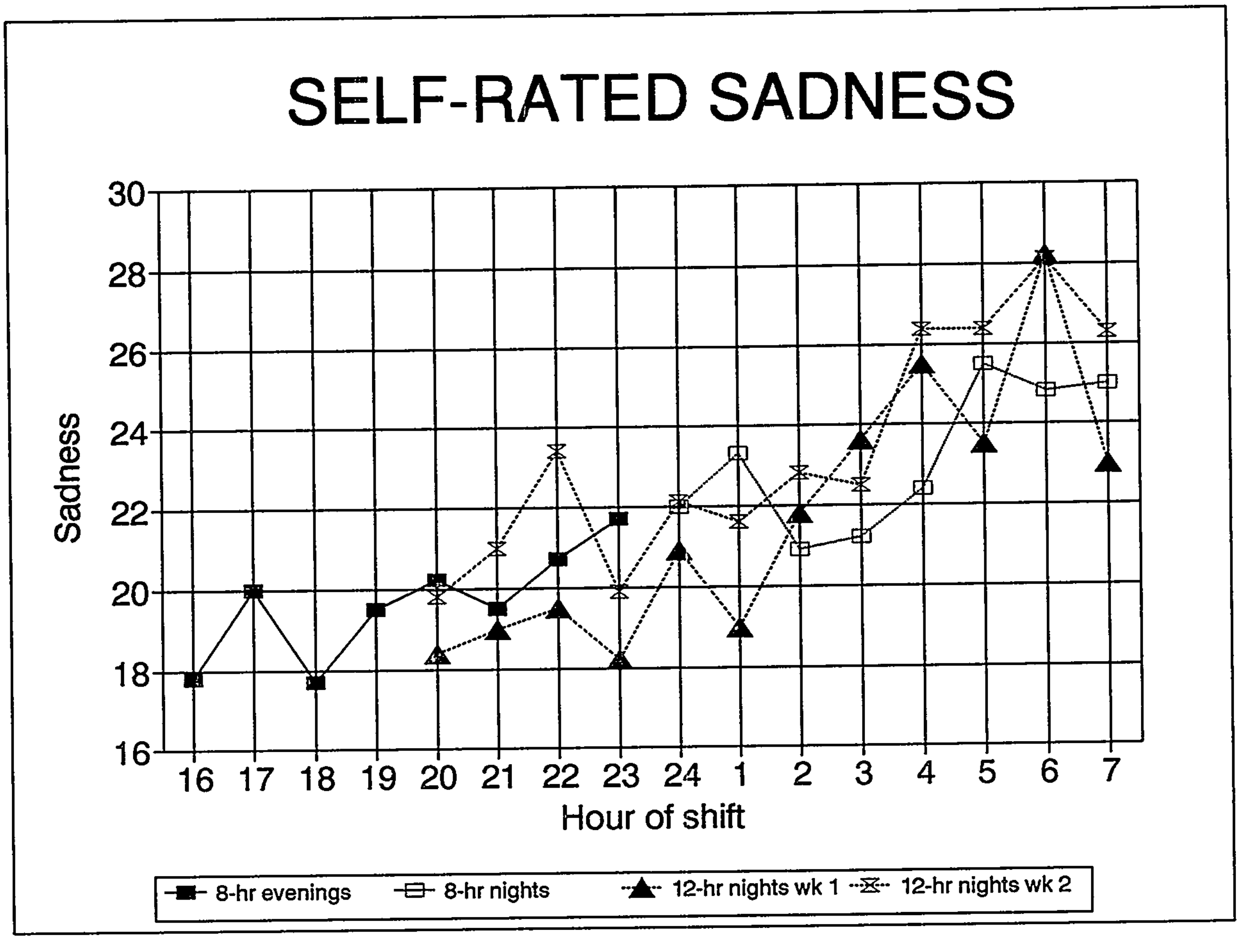

Figure 40 This figure shows the mean response to the question *"How sad are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more sadness on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. There was no significant effect of hour of shift, but subjects in all shift conditions showed a trend toward progressively higher ratings of sadness during the later hours of night shifts.

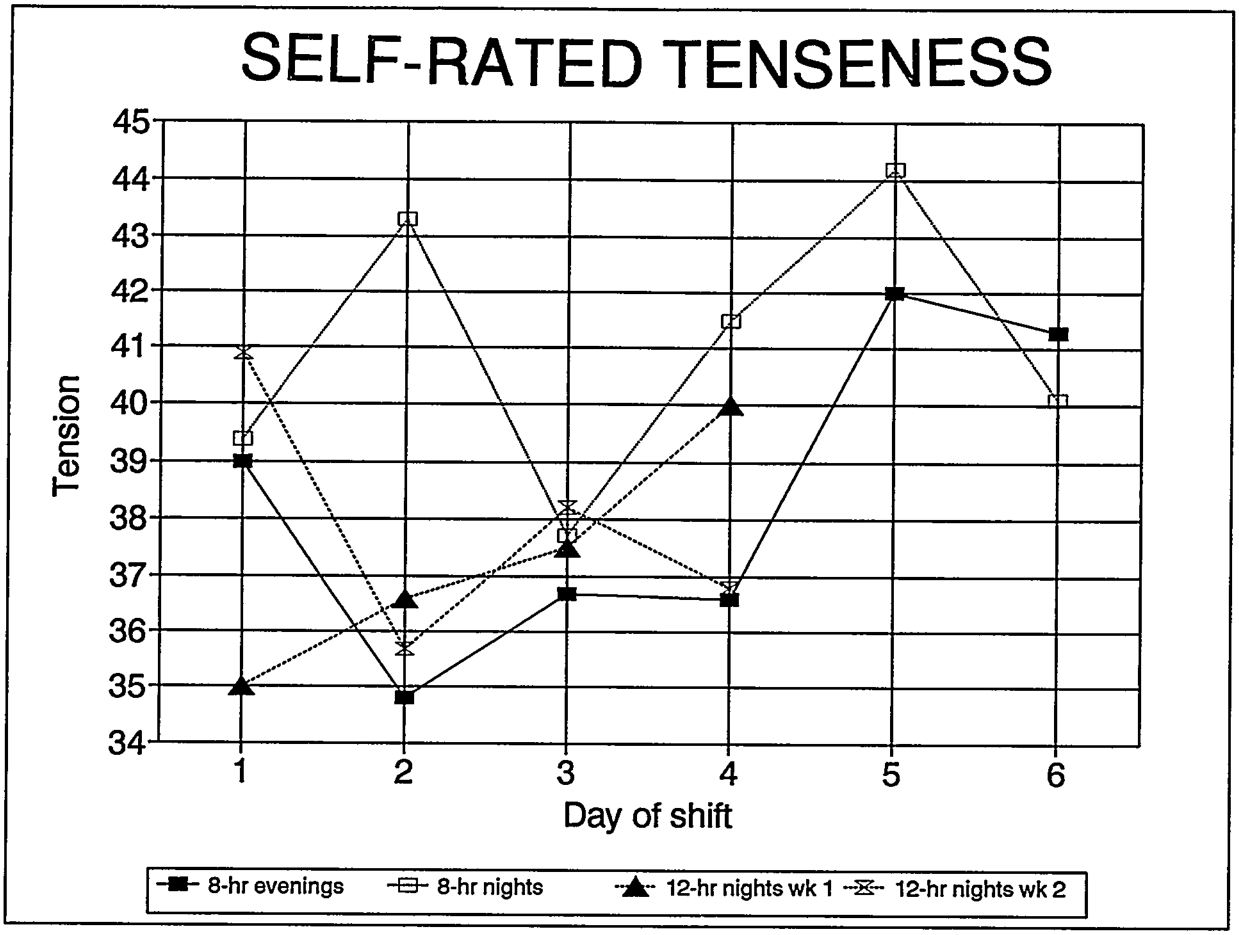

Figure 41 This figure shows the mean response to the question *"How tense are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more tension on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. This figure illustrates significant changes in self-rated tension across days of shift. Tension was highest among subjects in the 8-hr shift protocol, who showed significantly increased subjective tension on the second and fifth 8-hr night shift and on the fifth and sixth evening shifts.

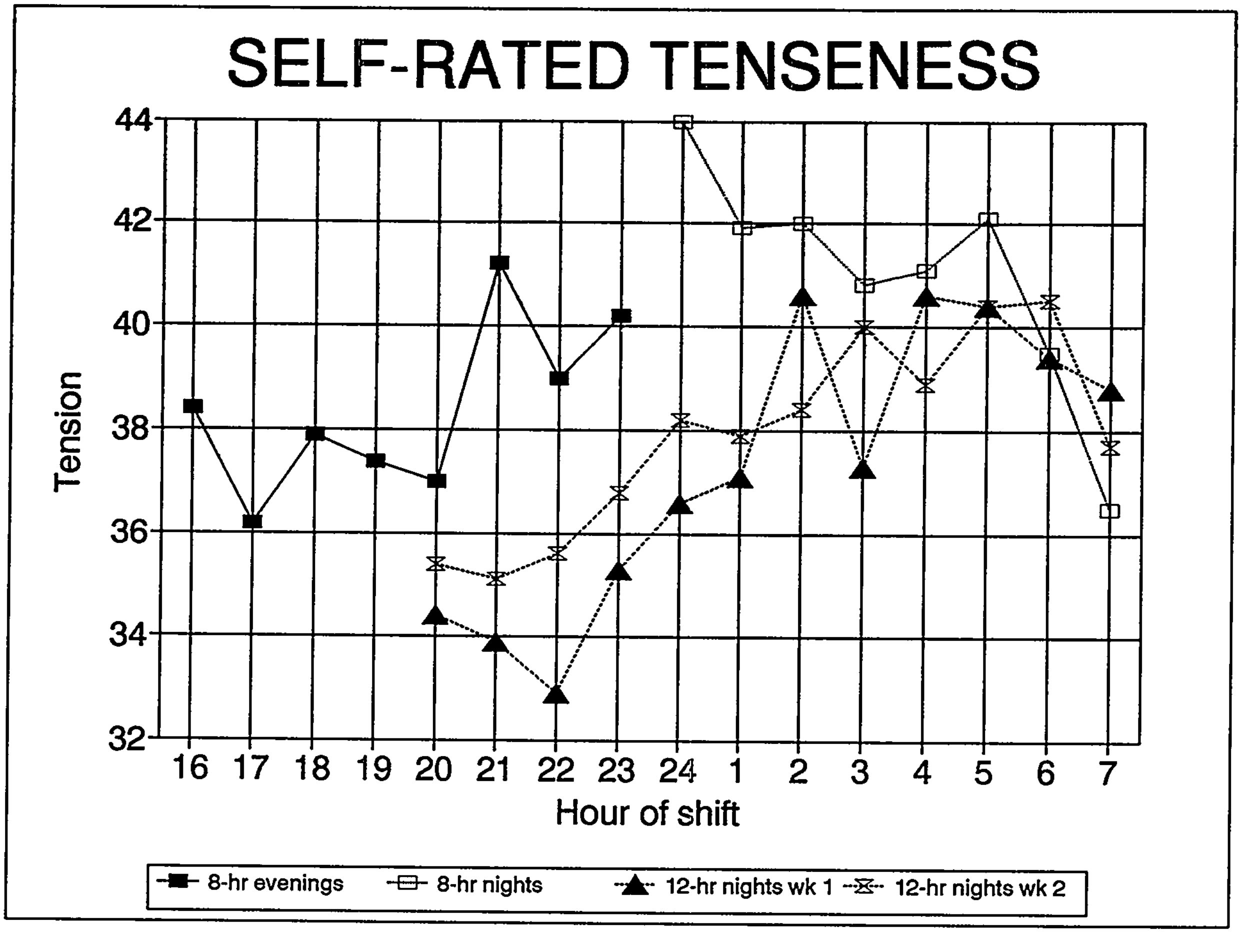

Figure 42 This figure shows the mean response to the question *"How tense are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more tension on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. There was no statistically significant effect of hour of shift on self-rated tension, but subjects on 12-hr shifts showed a trend toward progressively increasing tension across the night shift hours. Subjects on 8-hr night shifts appeared to begin their work shift at higher tension levels, but then recorded lower tension toward the end of their work shifts.

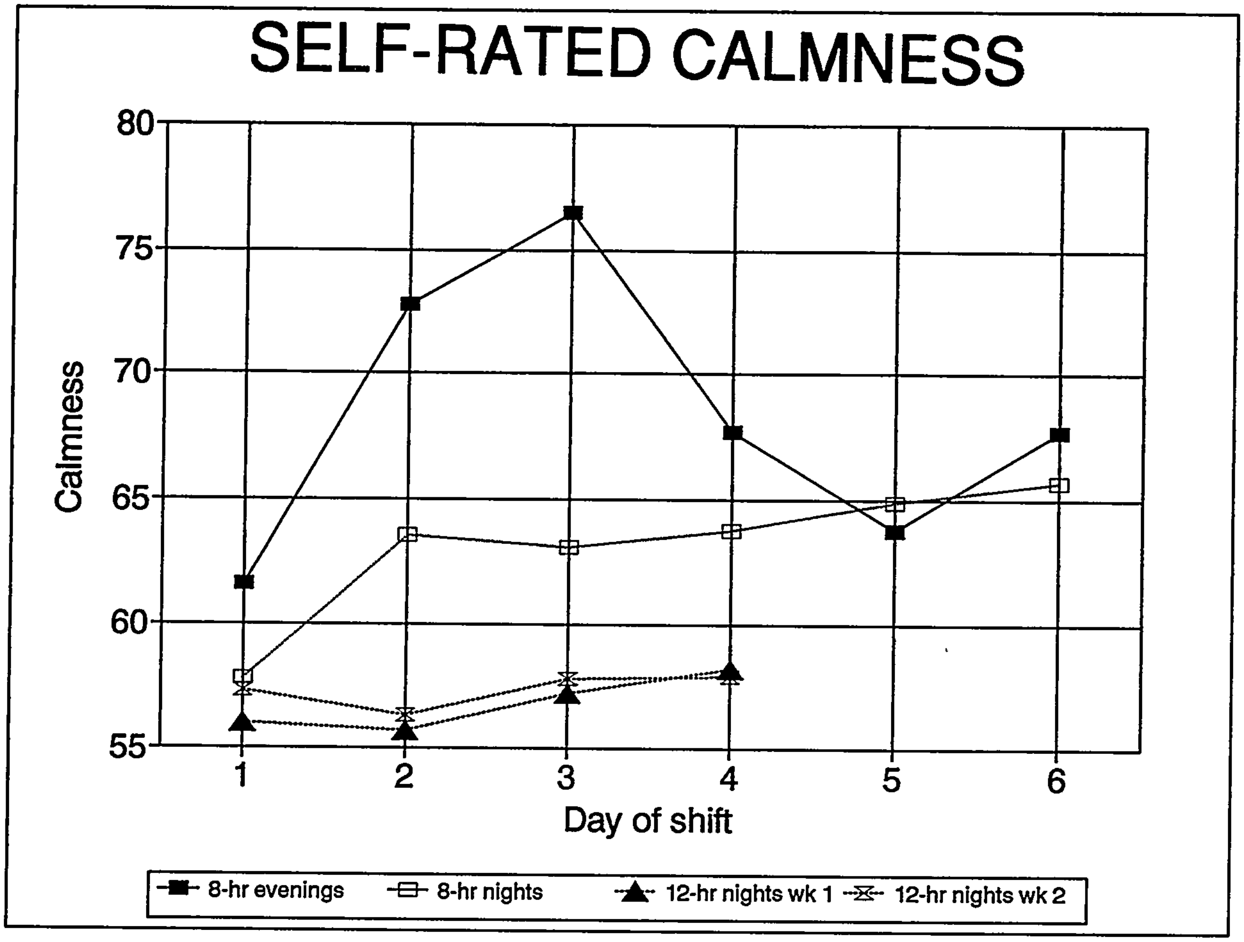

Figure 43 This figure shows the mean response to the question *"How calm are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more calm on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. The figure illustrates that self-rated calm was significantly higher on the second and third 8-hr evening shifts, as compared with all other shift conditions and days of shift. Subjects on 12-hr shifts showed little night-to-night variability in their mean self-rating on the calm scale.

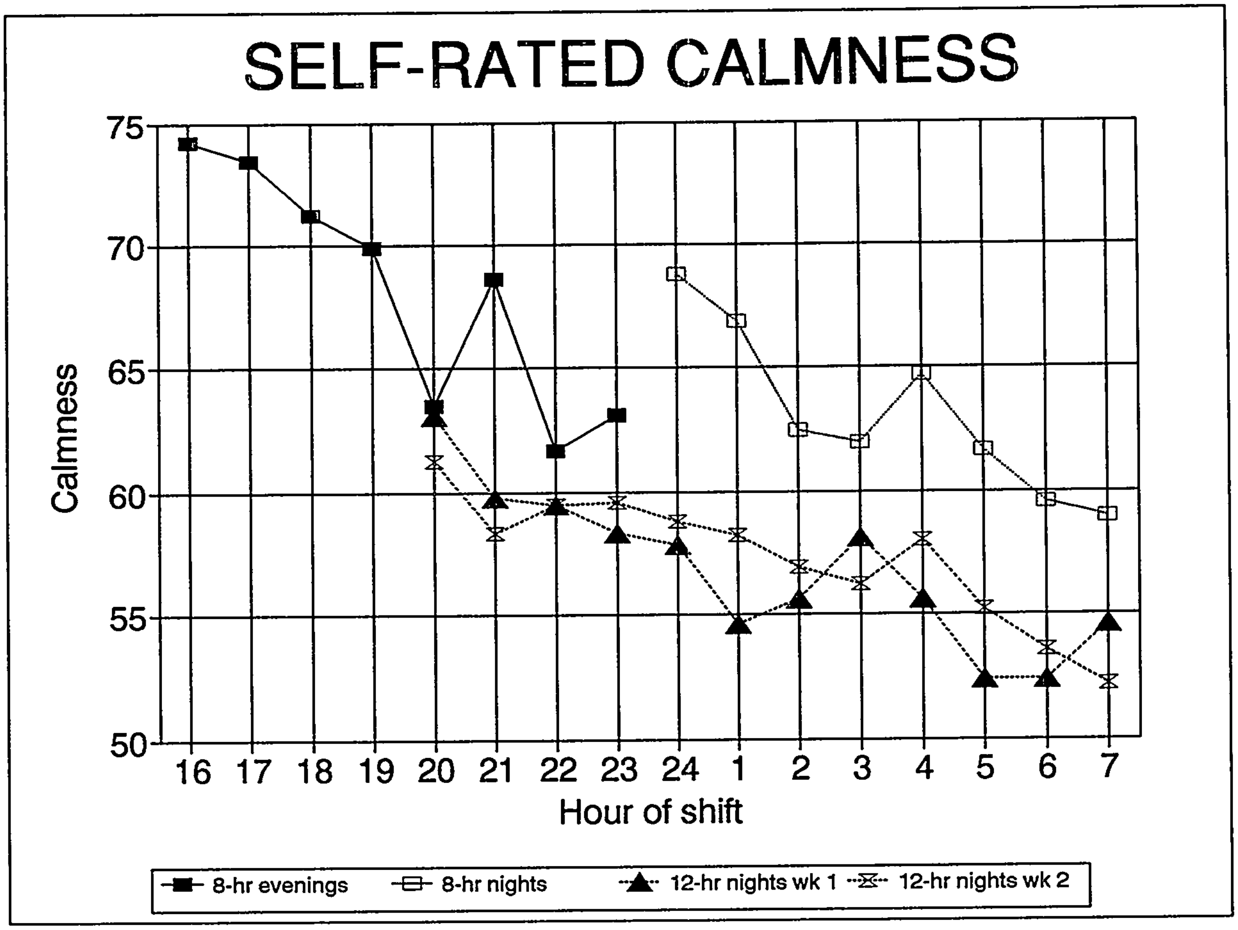

Figure 44 This figure shows the mean response to the question *"How calm are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more calm on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. This figure illustrates the trend toward decreasing subjective calm as a function of hour of shift for either 8-hr or 12-hr work shifts.

Hour of shift. The effect of hour of shift, although not statistically significant, showed a clear trend toward progressively diminished self-rated *calmness* as a function of consecutive hour of shift for all shift conditions (Fig. 44).

Global Affect: Happiness Scale

These data are represented in Table 3 and in Figures 45-46.

Shift duration. There was a significant effect of shift duration on self-rated *happiness* [F(1,2) = 28.03 P<.05]. The 8-hr group rated themselves as subjectively *happier* than the 12-hr group (52.6 vs. 42.1; analog scale) (Figs. 45, 46).

Day of shift. There was a significant effect for days on *happiness* by the analysis that included all data [F(16,172) = 4.59 P<.05] and by the comparable time analysis [F(9,84) = 5.2 P<.0001]. This was the result of increased self-rated *happiness* across the first three 8-hr night shifts in the 8N condition only (Fig. 45).

Hour of shift. Subjective *happiness* tended to decrease across hours of shift, particularly on 12-hr night shifts (Fig. 46). This trend was not statistically significant.

Global Affect Scale

These data are represented in Table 3 and in Figures 47-48.

Shift condition. There was a significant effect of shift condition on *global affect* [F(2,16) = 5.69 P<.05]. The 8E shift condition had significantly higher *global affect* ratings (66.0) than either of the 12-hr night shift conditions (59.8, 59.9) (Fig. 47). The *global affect* score of the 8N shift condition was intermediate, and not significantly different from the other shift conditions.

Day of shift. There was a significant effect for *global affect* as a function of days in the analysis that included all data [F(16,172) = 2.95 P<.001] and in the comparable time analysis [F(9,84) =3.88 P<.001]. *Global affect* scores were consistently higher on the final night shifts in the 8N condition.

Hour of shift. *Global affect* decreased progressively over consecutive hours worked for all shift conditions (Fig. 48). Due to high variability in the subjective ratings, this trend did not reach levels of statistical significance.

Global Vigor: Alertness scale

These data are represented in Table 4 and in Figures 49-50.

Shift condition. There was a significant effect of shift condition on the *alertness* rating [F(2,16) = 8.18 P<.05]. Subjects working 8-hr evening shifts had higher self-rated *alertness* than in any of the three night shift conditions (Figs. 49, 50). On the last two 8-hr night shifts, however, self-rated *alertness* was not significantly different than on the 8-hr evening shifts.

Day of shift. There was a robust day-of-shift effect on *alertness* analyzing all data [F(16,172) = 3.33 P<.0001] or comparable times [F(9,84) = 5.37 P<.0001]. There was progressive improvement in subjective *alertness* across night shifts in the 8N condition, and a progressive decrement in subjective *alertness* over the second week of 12-hr night shifts (Fig. 49).

Hour of shift. The non-significant but clear trend in these data was for self-rated *alertness* to progressively decrease across hours of night shifts (Fig. 50). *Alertness* ratings remained remarkably stable over 8-hr evening shifts.

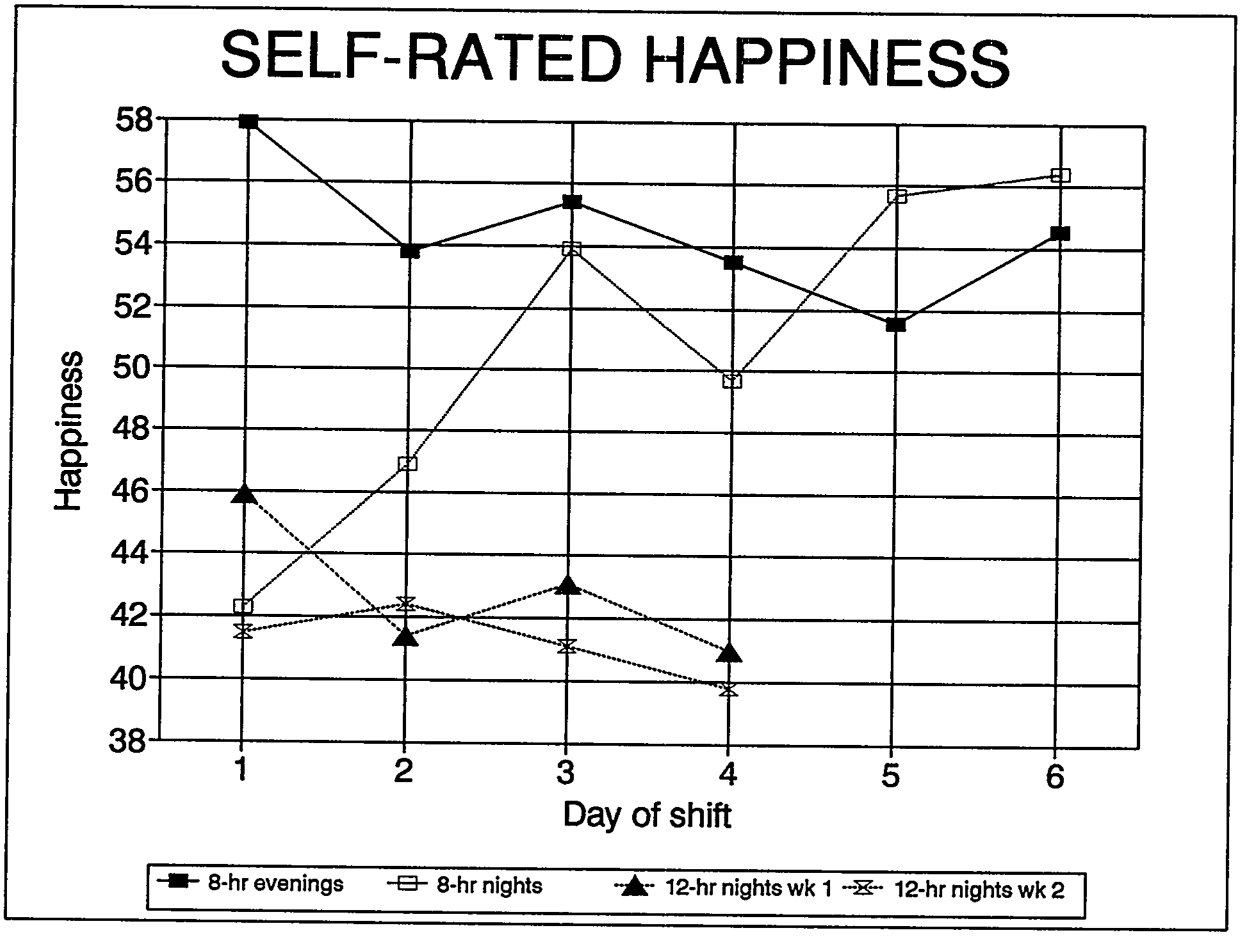

Figure 45 This figure shows the mean response to the question *"How happy are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more happiness on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. The figure illustrates the significantly higher self-ratings of happiness among the group of subjects working 8-hr shifts, as compared to those working 12-hr shifts. The figure also indicates the significant increase in subjective happiness over the first three 8-hr night shifts.

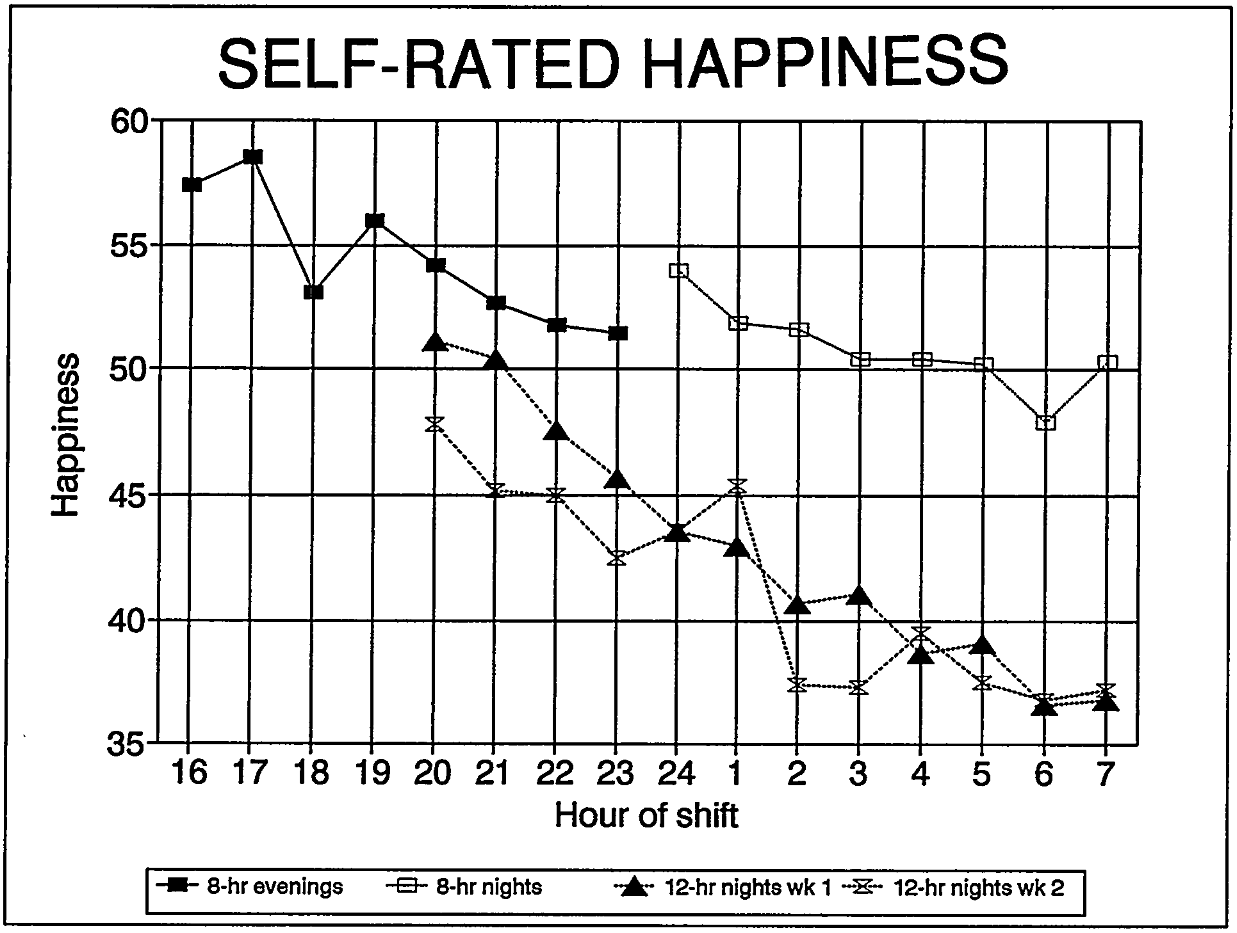

Figure 46 This figure shows the mean response to the question *"How happy are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more happiness on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. Subjective happiness showed a tendency to decrease progressively across hours of shift in all shift conditions. The figure also illustrates the significant difference between 8-hr and 12-hr night shifts on this measure.

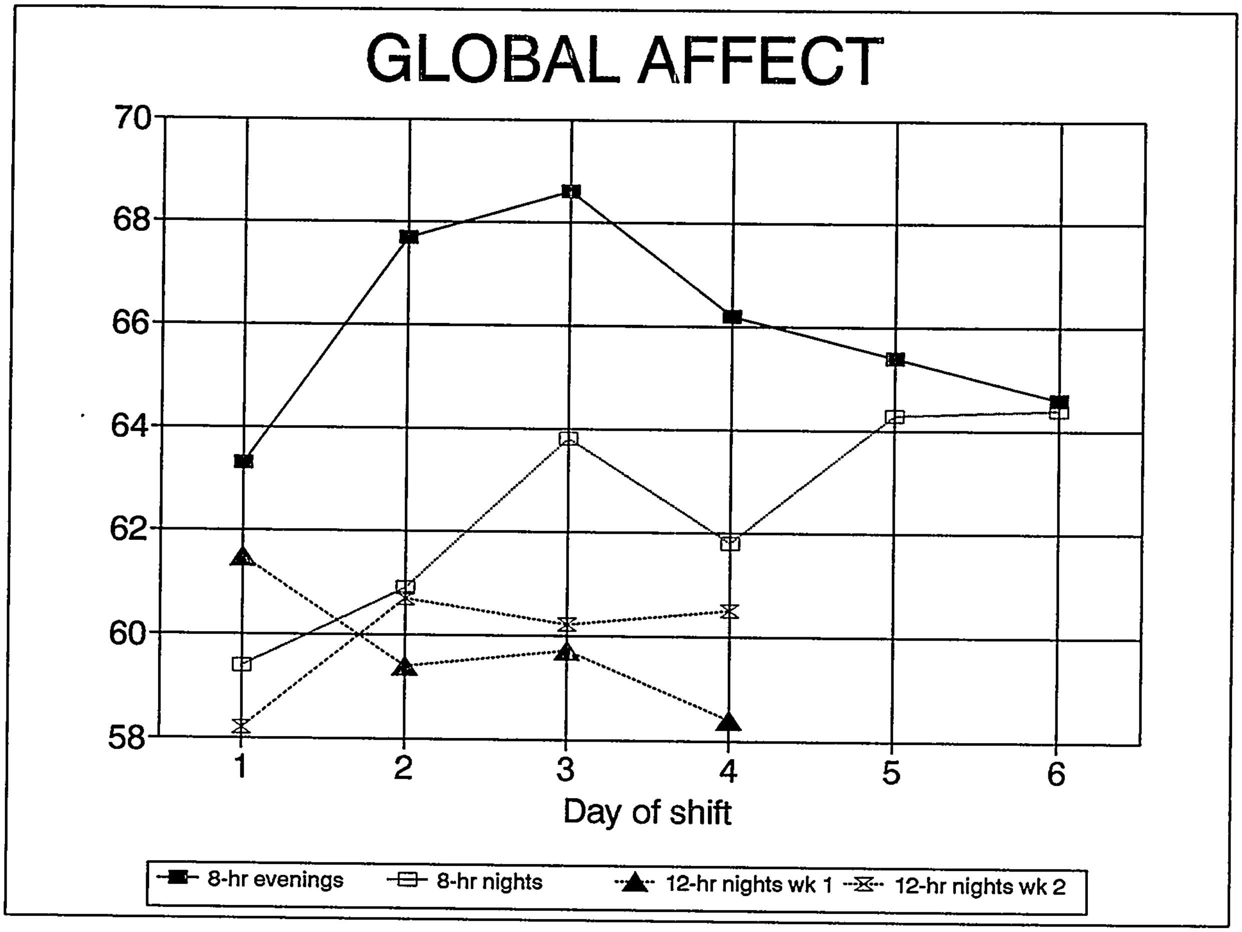

Figure 47 This figure shows the mean score for *Global Affect* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more positive affect on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. Global affect is a computed variable which combines the sad, tense, calm, and happy scales. Subjects had significantly higher global affect scores when working 8-hr evening shifts, as compared with 12-hr night shifts. Global Affect scores increased over successive 8-hour night shifts.

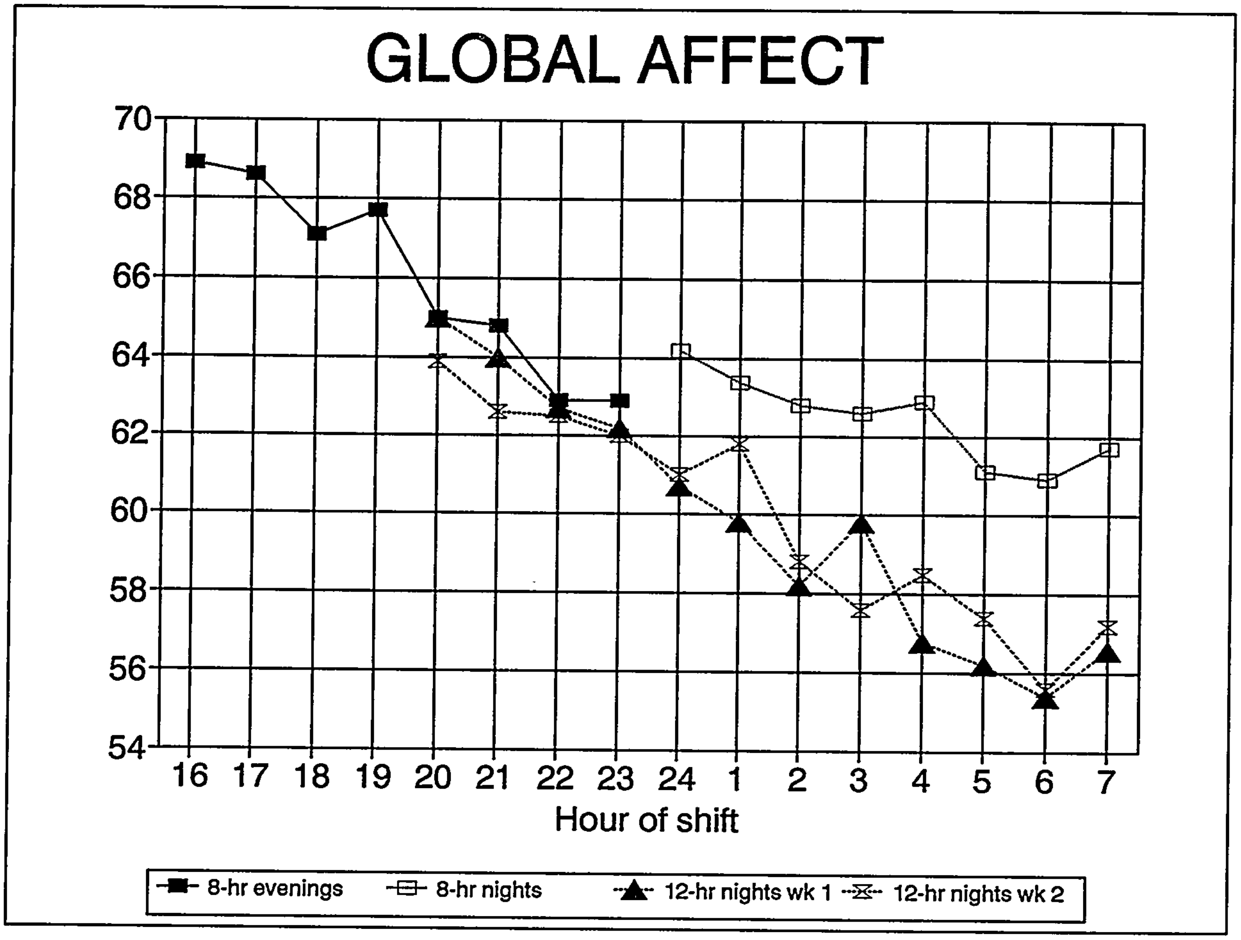

Figure 48 This figure shows the mean score for *Global Affect* on the analog scale of Global Vigor and Affect, plotted as a function of consecutive hour of shift. Higher numbers indicate more positive affect on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. Global affect is a computed variable which combines the sad, tense, calm, and happy scales. Subjects had significantly higher global affect scores when working 8-hr evening shifts, as compared to 12-hr night shift conditions. Global Affect scores significantly decreased over successive hours of shift.

Mean Scores on Global Vigor Scales
Analysis of all data

Global Vigor Scales	12-hr shifts week 1	12-hr shifts week 2	8-hr shifts evenings	8-hr shifts nights
Alert	60.1	62.6	76.0 *	64.6
Weary	30.4	30.8	27.4	32.6
Sleepy	31.1	29.5	23.5 *	35.7
Effort	28.1	28.1	27.1	32.3
Global Vigor	67.6	68.4	74.3 *	67.1

Mean Scores on Global Vigor Scales
Analysis of comparable time data

Global Vigor Scales	12-hr shifts week 1	12-hr shifts week 2	8-hr shifts nights
Alert	55.5	57.6	61.4
Weary	34.2	35.5	34.9
Sleepy	36.2	34.4	40.1
Effort	32.3	31.5	34.6
Global Vigor	63.2	64.0	64.4

Table 4 This table gives mean of subject self-ratings on the Global Vigor and Affect scale (GVA). The GVA is an analog scale with ratings ranging from 1-100. Analysis of all data includes all hourly tests during any of the four shift conditions (four 12-hr night shifts (1900-0700), week 1 and week 2; six 8-hr evening shifts (1500-2300); or six 8-hr night shifts (2300-0700). Analysis of comparable time data includes only the hours 2300-0700 of the 12-hr or 8-hr night shifts. There were no significant differences between 8-hr and 12-hr night shifts, but 8-hr evening shifts showed significantly higher alertness and global vigor, and lower sleepiness.

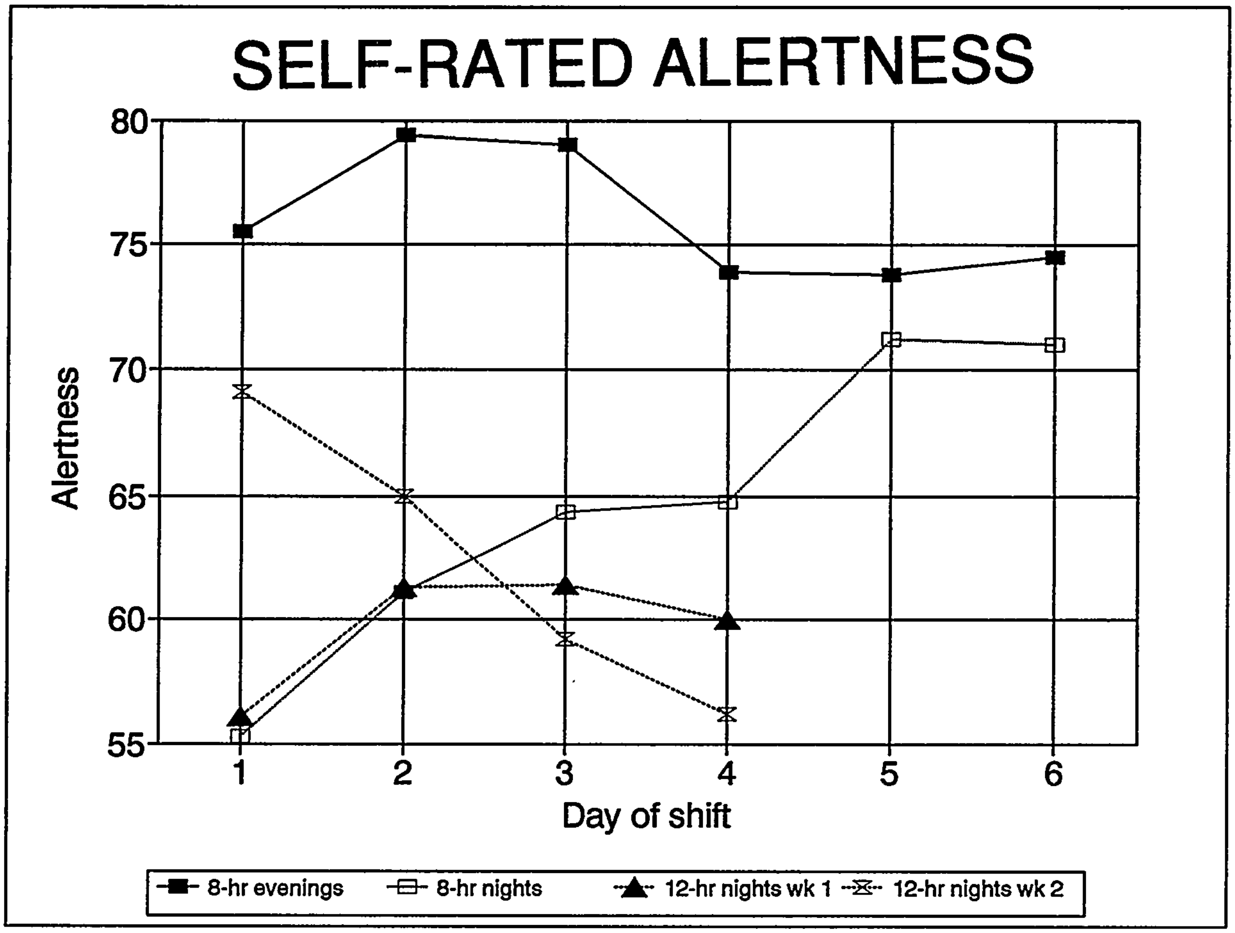

Figure 49 This figure shows the mean response to the question *"How alert are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more alertness on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. The figure illustrates the significantly greater alertness ratings for subjects working 8-hr evening shifts, as compared with all of the night shift conditions. It also shows the significant day of shift effects, which included an increase in subjective alertness over successive 8-hr night shifts and decreasing alertness during the second of two consecutive weeks of 12-hr shifts.

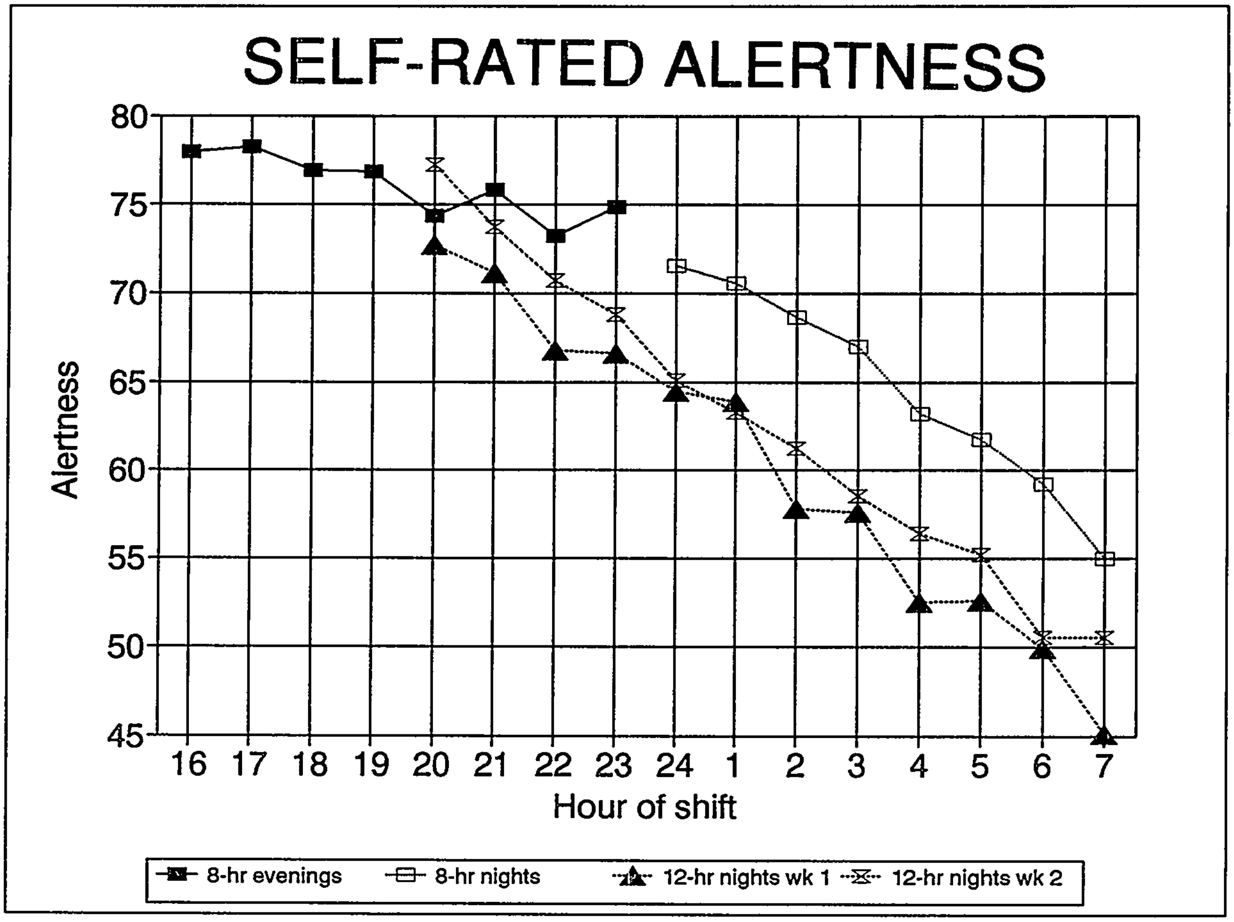

Figure 50 This figure shows the mean response to the question *"How alert are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more alertness on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. This figure clearly indicates a non-significant trend toward progressively decreasing self-rated alertness over successive hours of shift on both 8-hr and 12-hr night shifts.

Global Vigor: Weariness Scale

These data are represented in Tables 3-4 and in Figure 51.

There were no significant effects for self-rated *weariness*. There was a clear trend for *weariness* ratings to increase across hours of shift in all night shift conditions, and to remain stable across 8-hr evening shifts (Fig. 51).

Global Vigor: Sleepiness Scale

These data are represented in Tables 3-4 and in Figures 52-53.

Shift condition. The primary effect of shift condition was that subjects gave significantly lower *sleepiness* ratings on 8-hr evening shifts, as compared to all night shift conditions [$F(2,16) = 5.84$; $P<.05$]. Night shift conditions did not vary significantly.

Day of shift. There was a significant effect of day of shift on self-rated *sleepiness*, both in the analysis that included all data [$F(16,172) = 3.58$ $P<.05$], and in the comparable time analysis [$F(9,84) = 2.84$ $P<.01$]. Subjects working 8-hr night shifts became progressively less *sleepy* as they worked each successive shift (Fig. 52).

Hour of shift. There was also an effect of hour of shift on self-rated *sleepiness* in the analysis that included all data [$F(172,1307) = 1.70$ $P<.0001$], and in the comparable time analysis [$F(84,669) = 1.49$ $P<.0001$]. Self-rated *sleepiness* increased progressively as a function of the hour of shift after midnight (Fig. 53).

Global Vigor: Effort Scale

These data are represented in Tables 3-4 and in Figures 54-55.

Day of shift. There was a significant effect of day of shift on self-rated *effort* by analysis of all data [$F(16,172) = 2.66$ $P<.001$], or by comparable time analysis [$F(9,84) = 2.45$ $P<.05$]. This effect was restricted to the first two 8-hr night shifts, on which subjects rated subjective *effort* significantly higher than on subsequent night shifts (Fig. 54). The subjects working 12-hr night shifts did not vary their *effort* ratings across successive night shifts.

Hour of shift. Subjective *effort* scores showed a distinct, but non-significant increase across hours of shift for all night shift conditions (Fig. 55).

Global Vigor

These data are represented in Tables 3-4 and in Figures 56-57.

Shift condition effects. There was a significant effect of shift condition on *global vigor* [$F(2,16) = 5.75$ $P<.05$], with significantly higher *global vigor* scores on 8-hr evening shifts than on any of the night shift conditions (Fig. 56).

Day of shift. There was also a significant effect of day of shift on *global vigor* [$F(16,172) = 2.06$ $P<.05$]. This effect was due to the first two 8-hr night shifts, for which *global vigor* was significantly lower than on the remaining four night shifts in the 8N shift condition (Fig. 56).

Hour of shift. There was a significant effect for hour of shift on *global vigor* [$F(172,1210) = 1.31$ $P<.05$]. This is due to reduced *global vigor* scores after midnight in all night shift conditions (Fig. 57).

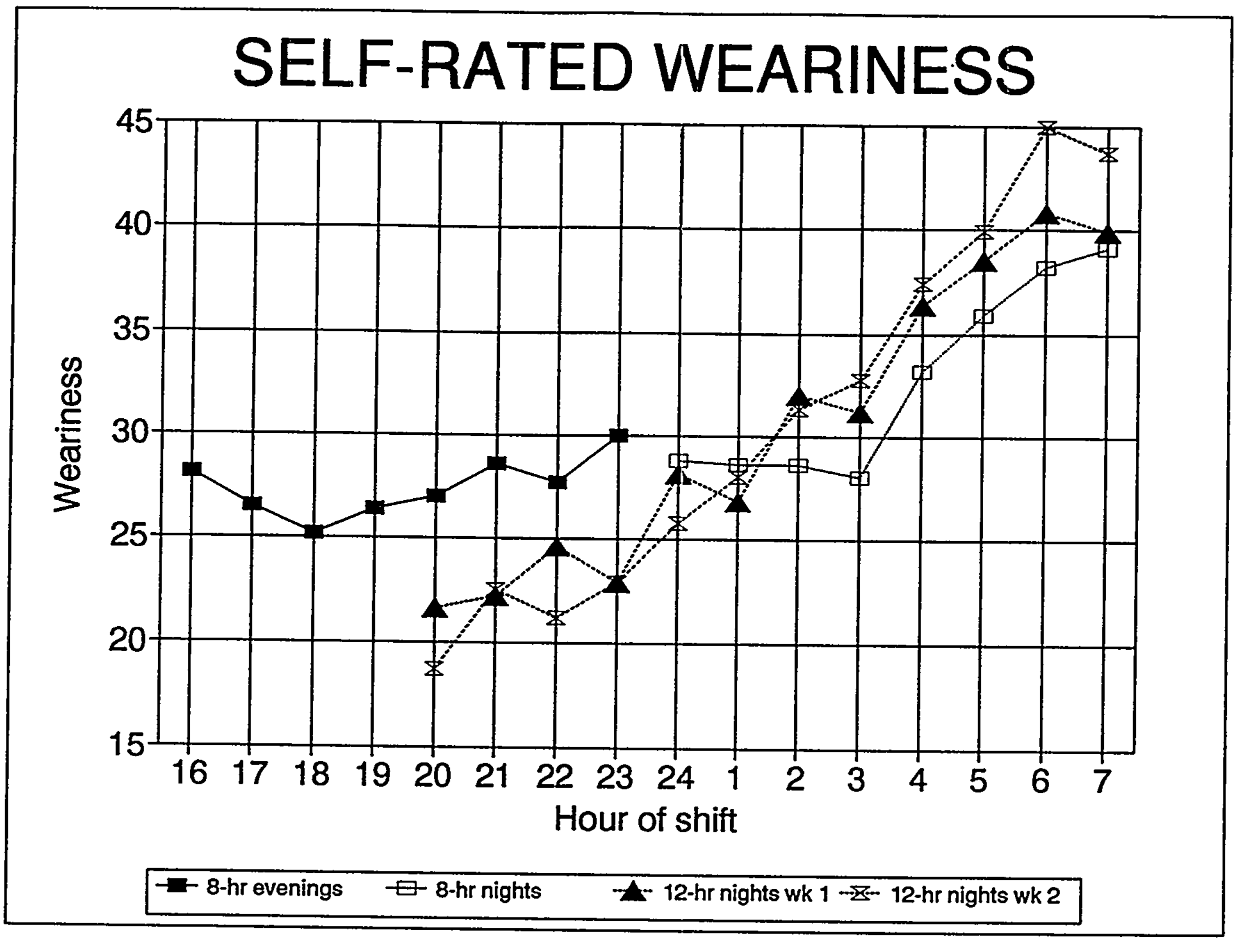

Figure 51 This figure shows the mean response to the question *"How weary are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more weariness on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. There were no significant differences between conditions on the weariness scale. However, subjective weariness clearly tended to increase over hour of shift on both 8-hr and 12-hr night shifts, as illustrated in this figure.

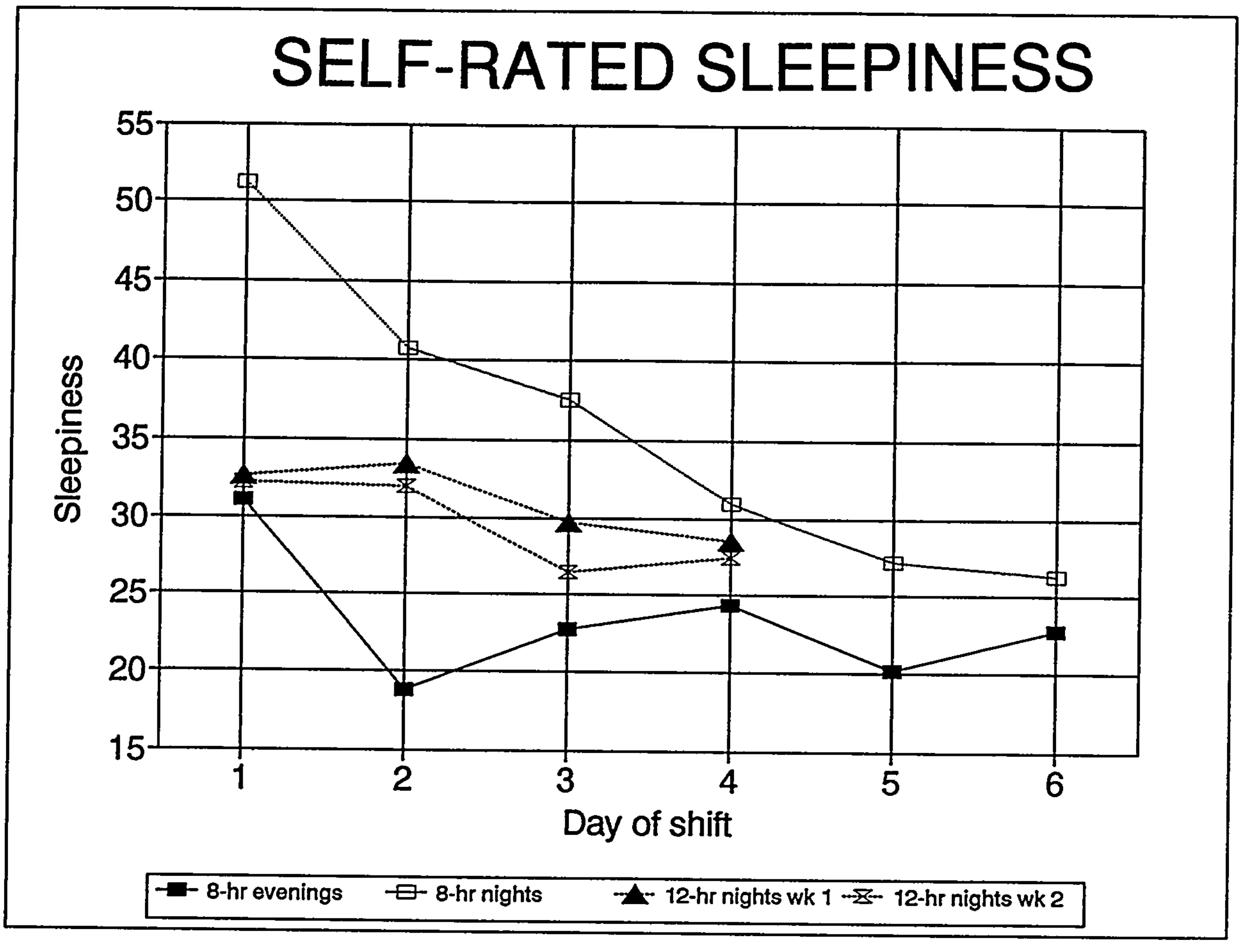

Figure 52 This figure shows the mean response to the question *"How sleepy are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more sleepiness on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. Subjects working 8-hr evening shifts gave significantly lower sleepiness ratings than subjects in any of the night shift conditions. The significant effect of day of shift for 8-hr shifts is also evident, with subjective sleepiness decreasing progressively over successive night shifts.

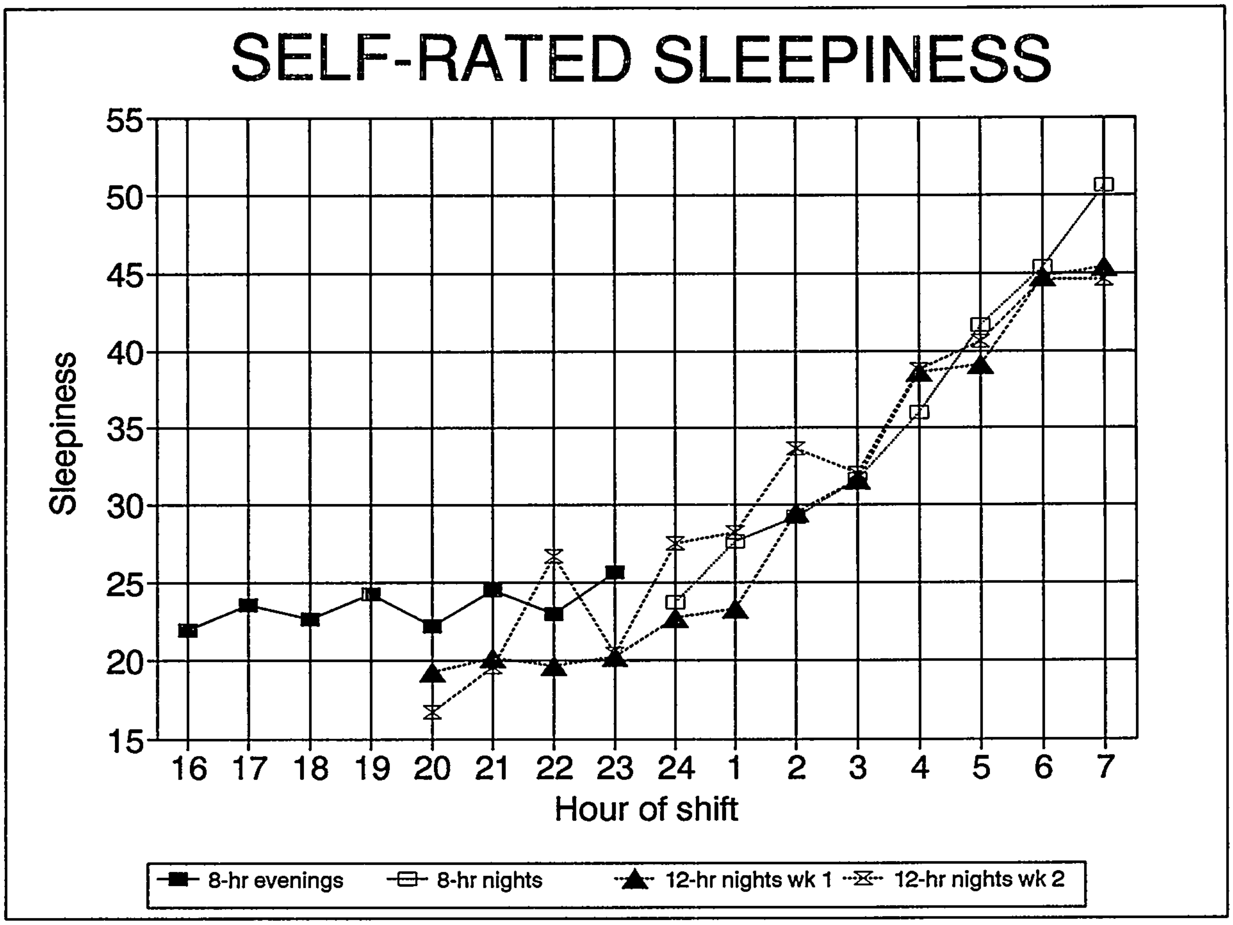

Figure 53 This figure shows the mean response to the question *"How sleepy are you?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate more effort on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. This figure illustrates that self-rated sleepiness changes significantly as a function of hour of shift, increasing progressively each hour after midnight in all night shift conditions. Subjective sleepiness remained consistently low across all hours of 8-hr evening shifts.

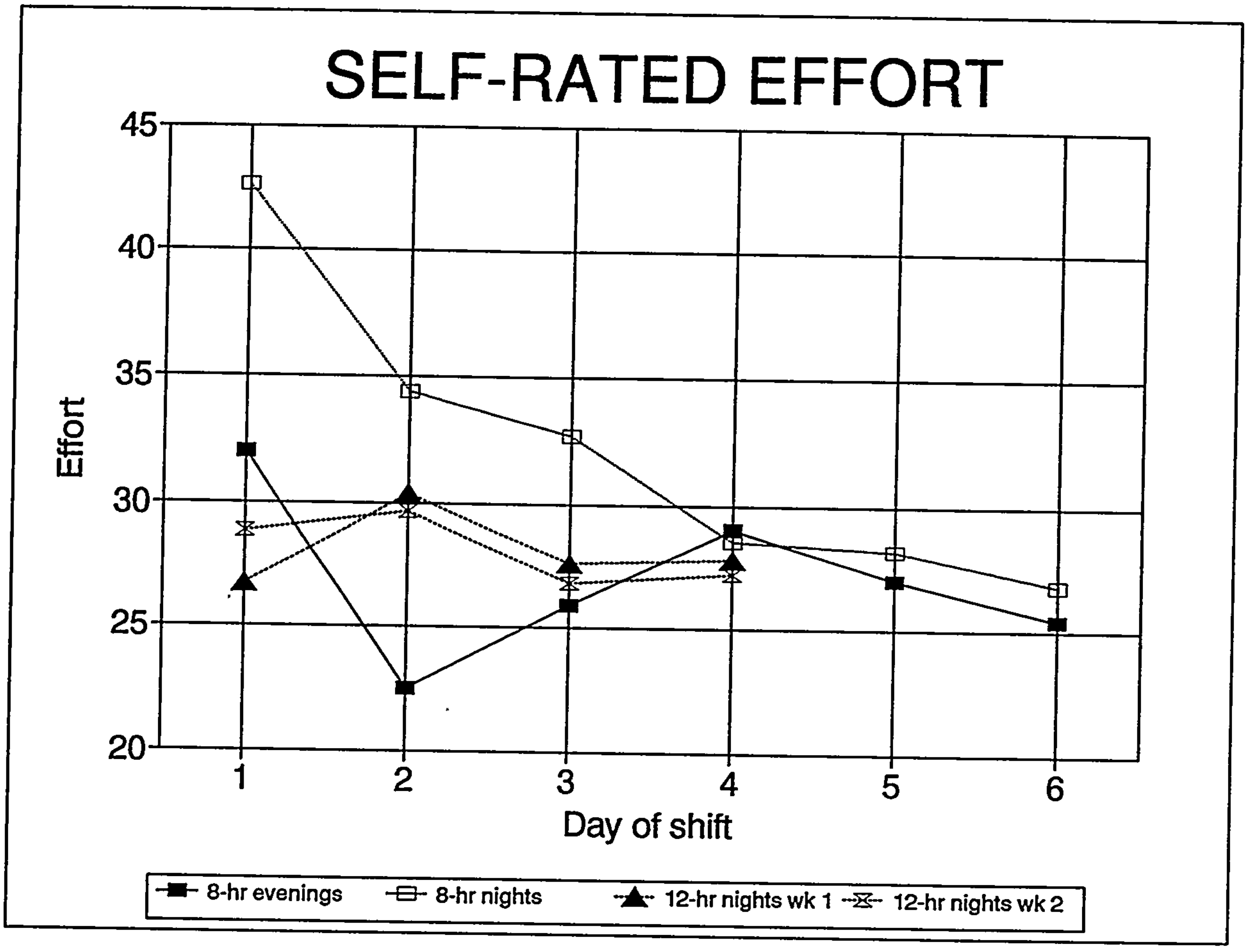

Figure 54 This figure shows the mean response to the question *"How much effort does it take to do anything?"* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate more effort on a 1-100 scale. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. The figure illustrates the significant effect of day of shift on subjective effort. Effort was significantly higher on the first two 8-hr night shifts, as compared with all other shift conditions and days of shift. The figure also shows that there was little variation in effort ratings across consecutive 12-hr night shifts.

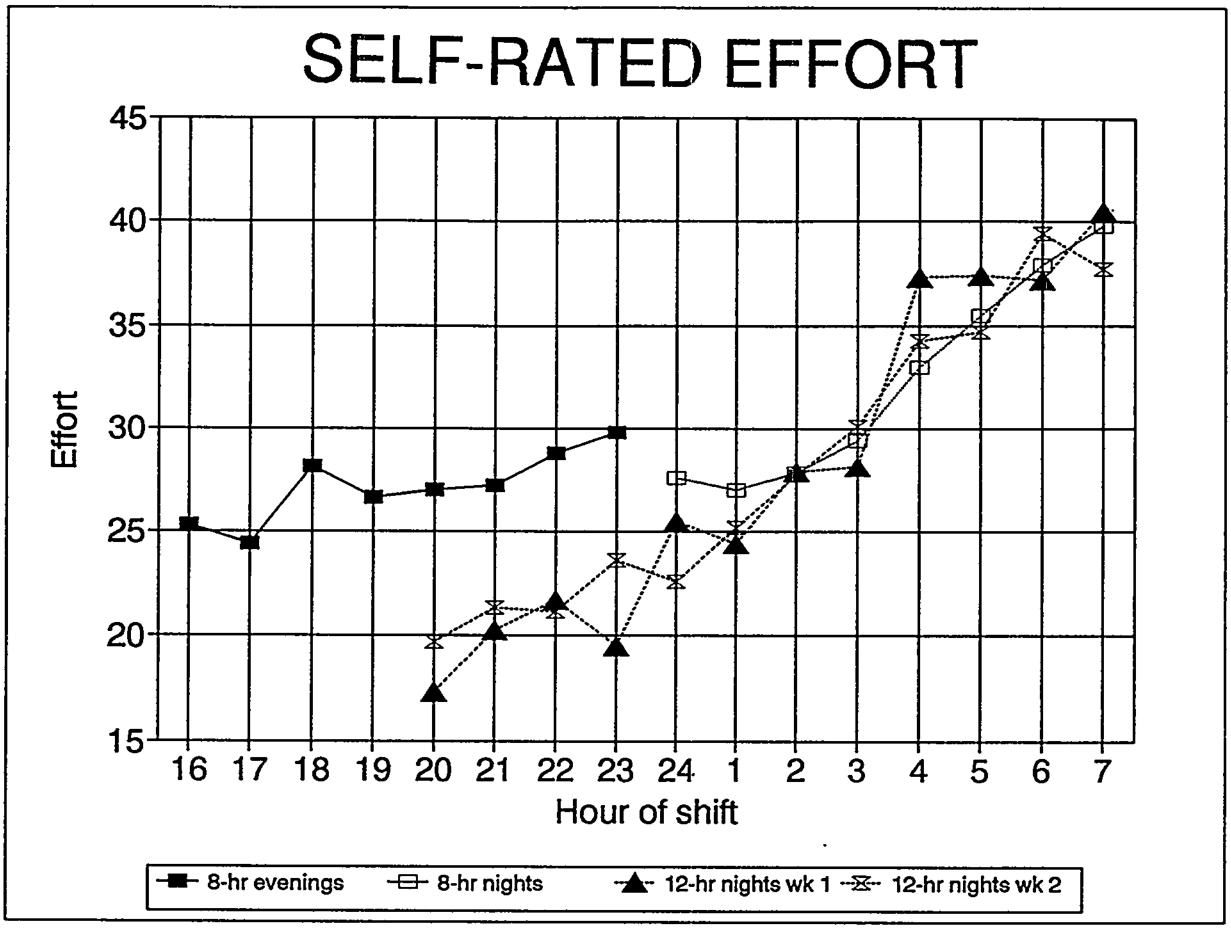

Figure 55 This figure shows the mean response to the question *"How much effort does it take to do anything?"* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Higher numbers indicate greater effort on a 1-100 scale. Each symbol represents the average score of 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. The figure illustrates that self-rated effort tended to increase across hours of shift in all night shift conditions. There was comparatively little variation in subjective effort across 8-hr evening shifts.

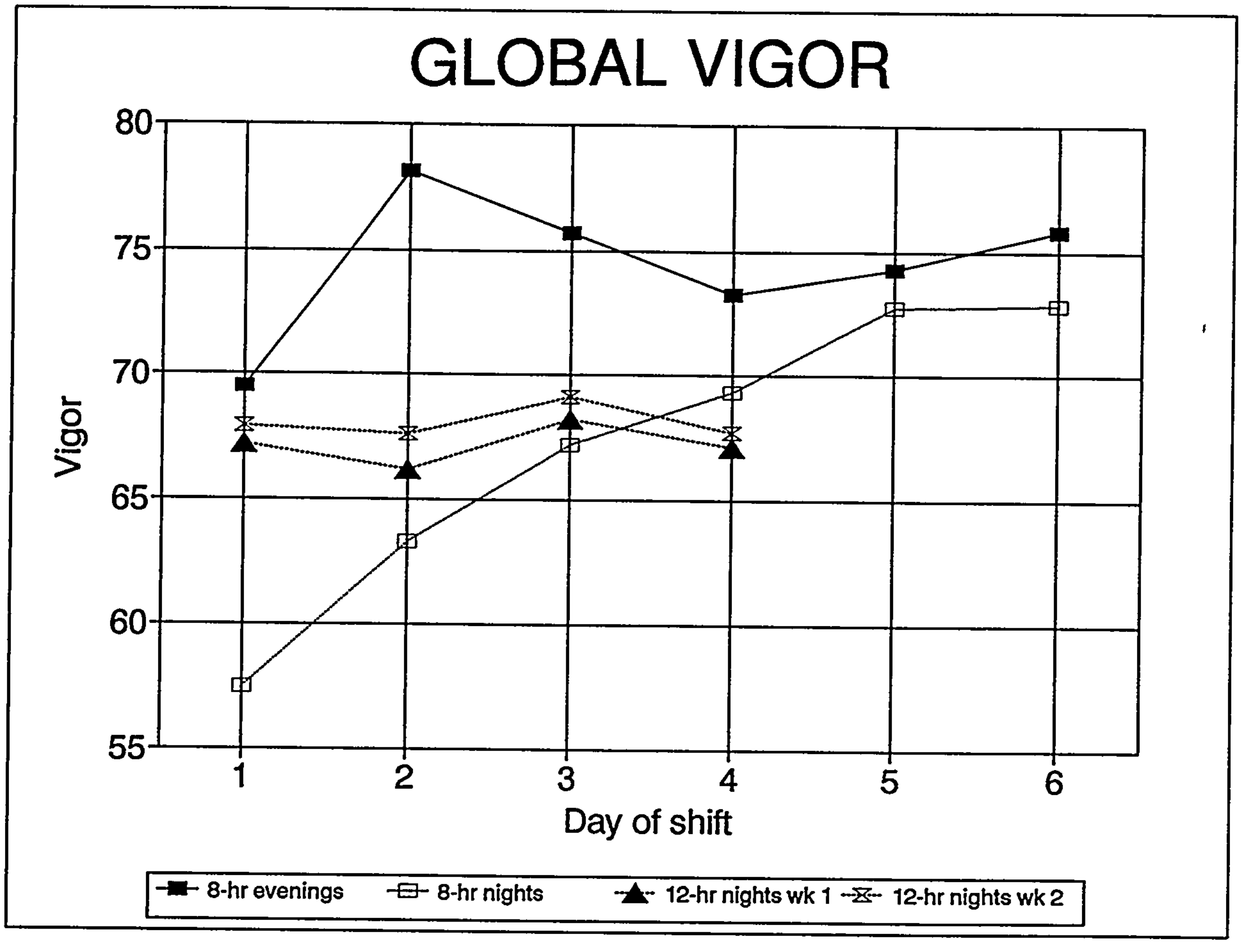

Figure 56 This figure shows the mean score for *Global Vigor* on the analog scale of Global Vigor and Affect, plotted as a function of day of shift. Higher numbers indicate greater vigor on a 1-100 scale. Global vigor is a computed variable which combines scores on the alertness, weariness, sleepiness, and effort scales. Each symbol represents an average score for 10 subjects, pooling the results of all hourly self-ratings to yield an average score for all subjects for each consecutive day of shift. As indicated in the figure, global vigor was significantly higher on 8-hr evening shifts than any of the night shift conditions. Global vigor also showed a significant effect for day of shift in the 8-hr night shift condition. Subjects had significantly lower global vigor scores on the first and second night shifts, but global vigor increased steadily over consecutive night shifts. Subjects working 12-hr night shifts showed little variation across successive shifts.

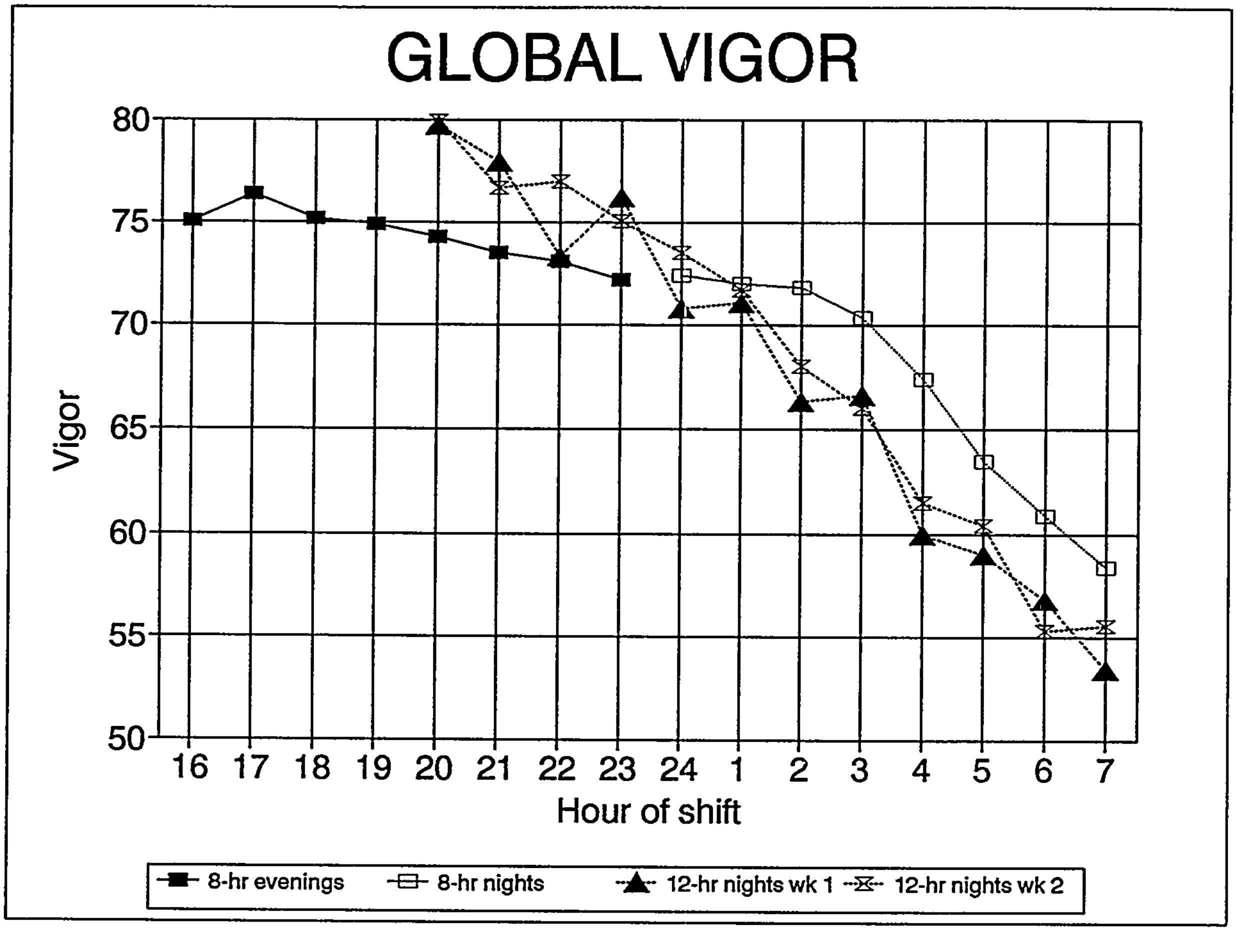

Figure 57 This figure shows the mean score for *Global Vigor* on the analog scale of Global Vigor and Affect, plotted as a function of hour of shift. Global vigor is a computed variable which combines scores on the alertness, weariness, sleepiness, and effort scales. Each symbol represents an average score for 10 subjects, pooling same-hour data from all days of shift to yield an average score for each hour of the work shift. The figure illustrates the significant effect of hour of shift on the computed global vigor variable. Global vigor diminished steadily across hours of work in all night shift conditions.

Sleep Measurements
Summary of Significant Results

These data are represented in Table 5 and in Figures 58-66.

Total Stage 2 Non-REM Sleep (TS2)

There was significantly more stage 2 sleep on 8E shifts (mean TS2 = 180 minutes) as compared with any of the night shift conditions (mean TS2 from 149.5-153 minutes) [$F(2,16) = 4.37$; $p<.05$]. By the fourth consecutive 8-hr night shift, stage 2 sleep approached, but never surpassed, the amount of stage 2 non-REM sleep recorded after 8-hr evening shifts (Fig. 58).

Total Non-REM Sleep (TNREM)

TNREM was significantly greater during sleep that followed 8E shifts, as compared with that following 8-hr or 12-hr night shift conditions [$F(2,16) = 11.67$; $p<.05$]. Subjects working 12N2 shifts showed significantly more TNREM than on 12N1 shifts (mean TNREM 286.8 minutes vs. 267.2 minutes) (Fig. 59).

Rapid Eye Movement Sleep (TREM)

This variable did not show any significant differences associated specifically with length of shift or day of shift. However, subjects tended to have more minutes of REM sleep following 8-hr evening shifts (mean TREM = 107.9 minutes) and during the second week of 12-hr night shifts (106.3 minutes), as compared with the first week of 12-hr night shifts (89.7 minutes) (Fig. 60). Both comparisons would have been significant with a less rigid confidence interval (i.e. $p<.1$ vs. $p<.05$).

Total Sleep Time (TST)

When all shifts in each shift condition were averaged, mean total sleep time (TST) for all 8-hr evening shifts (8E) was 421.7 minutes, which was significantly greater than TST on 8-hr night shifts (376 minutes) or the first week of 12-hr night shifts (373.5 minutes) [$F(2,16) = 4.1$; $p<.05$] (Fig. 61).

Mean TST during the second week of 12-hr night shifts was significantly greater than that of the first week of 12-hr night shifts, averaging of nearly 35 minutes more total sleep per day. This increase in TST was present even in the first daytime sleep period following a 3.5 day (84 hour) break between weeks of 12-hr night shifts.

Mean TST during daytime sleep was initially low after the first few 8-hr night shifts and during the first week of 12-hr night shifts. Daytime sleep following the fourth through sixth 8-hr night shifts, and sleep following the fifth through eighth 12-hr night shifts (12N2 week) did not significantly differ from TST during the week of 8-hr evening shifts. These data indicate that the major detrimental effect of night work on total amount of sleep was restricted to the first few night shifts.

As further evidence of the effect of the first few night shifts on length of daytime sleep, the range of TST for individual subjects after working their first 8-hr night shift was very wide (116.5-476.5 minutes). In fact, the 8-hr shift subjects could be divided into two distinct groups simply on the basis of the total sleep following the first night shift. The first group had relatively good day sleep (N = 5; mean TST = 432.2 minutes, range 396.4-476.5 minutes), while the second group had very poor day sleep (N = 5; mean TST = 240.5 minutes, range 116.5-297.4 minutes). Three of the five

Sleep stages, waking time, and sleep latencies
Off-duty sleep periods

Sleep-wake Measure	12-hr night shifts week 1 (minutes)	12-hr night shifts week 2 (minutes)	8-hr night shifts (minutes)	8-hr evening shifts (minutes)
stage 2 non-REM sleep	149.5	150.8	153.0	180.0 *
total non-REM sleep	267.2	286.8	278.9	303.0 *
REM sleep	89.7	106.3	100.1	107.9
total sleep time	373.5	393.9	376.0	421.7 *
wake after sleep onset	77.8	39.4	36.8	24.8 ***
movement time	2.3	3.6	4.6	1.9 *
wake after final awakening	31.3	34.9	31.2	12.4 *
lights out to sleep onset	9.5	11.7	9.2	30.3 *
total wake time	112.5	86.1	80.8	65.0 *
lights out to stage 2 sleep	11.8	13.9	11.3	34.4 *
lights out to slow wave sleep	26.8	30.3	34.1	47.1 *
sleep onset to slow wave sleep	15.5	14.1	17.1	16.4
sleep onset to REM sleep	51.2	51.9	49.2	58.8

Table 5 This table shows average number of minutes spent in different sleep-wake stages, and average time to sleep onset. Descriptions of the sleep-wake states and sleep latency measures are given in the Appendix. Sleep was allowed only during a 480 minute time in bed period, which began within one hour of the end of the simulated work shift. To encourage maximum sleep, subjects were required to remain in bed in a darkened room, other than restroom breaks, even if they awakened during the sleep period. There were no significant differences between the 12-hr and 8-hr night shifts. However, sleep following evening shifts was significantly better than the daytime sleep following all night shift conditions. Significant differences are indicated ($p<.05=*$, $p<.001=***$).

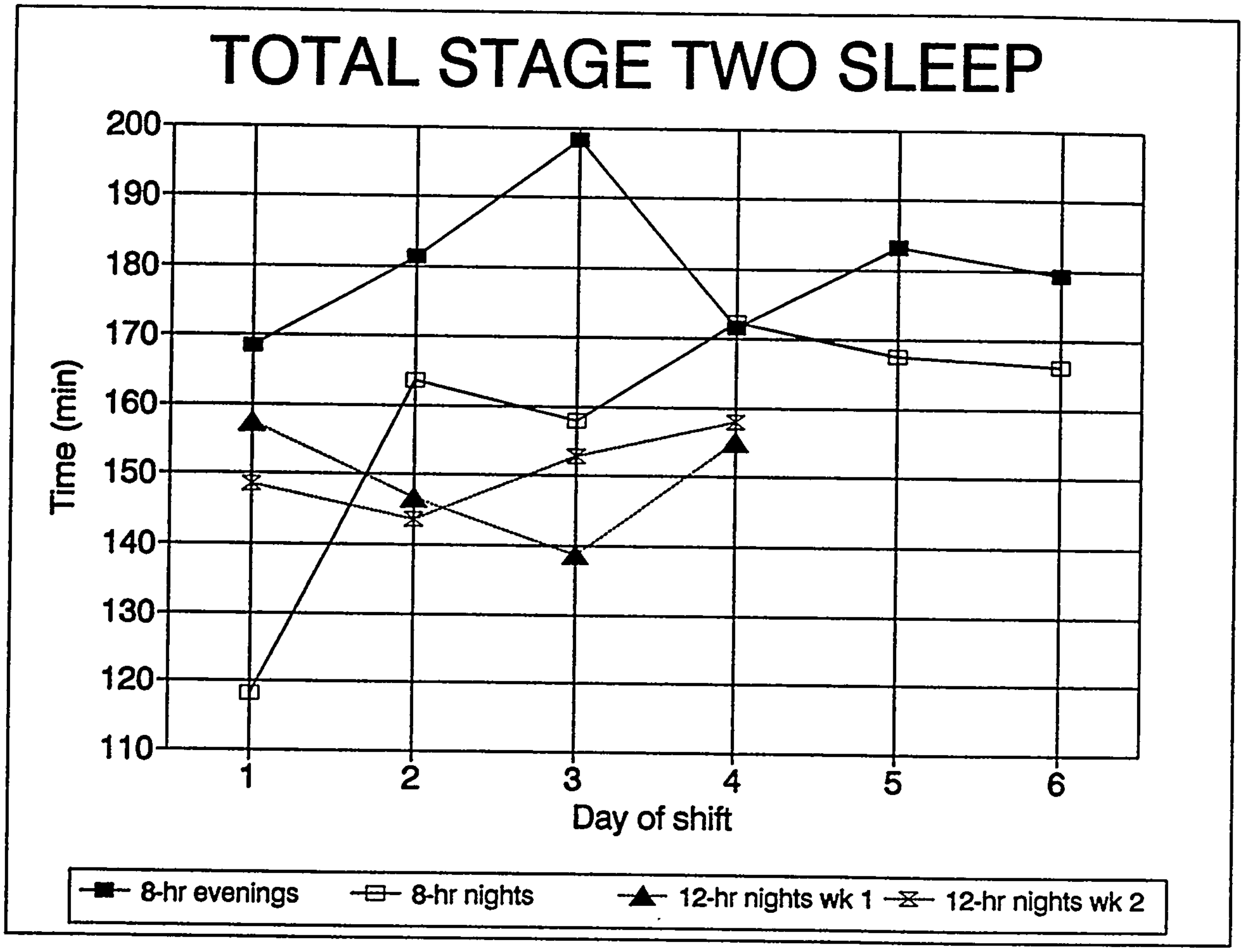

Figure 58 This figure shows average stage 2 non-REM sleep time in minutes per 8 hours in bed. Each symbol represents average stage 2 non-REM sleep time of 10 subjects, plotted as a function of day of shift for all shift conditions. It shows that subjects working 8-hr evening shifts, who slept from 2400-0800, had significantly more stage 2 non-REM sleep than those who slept 0800-1600, after working 8-hr or 12-hr night shifts. Mean stage 2 non-REM sleep time was low after the first 8-hr night shift, but increased by over 40 minutes per day after the second through sixth night shifts.

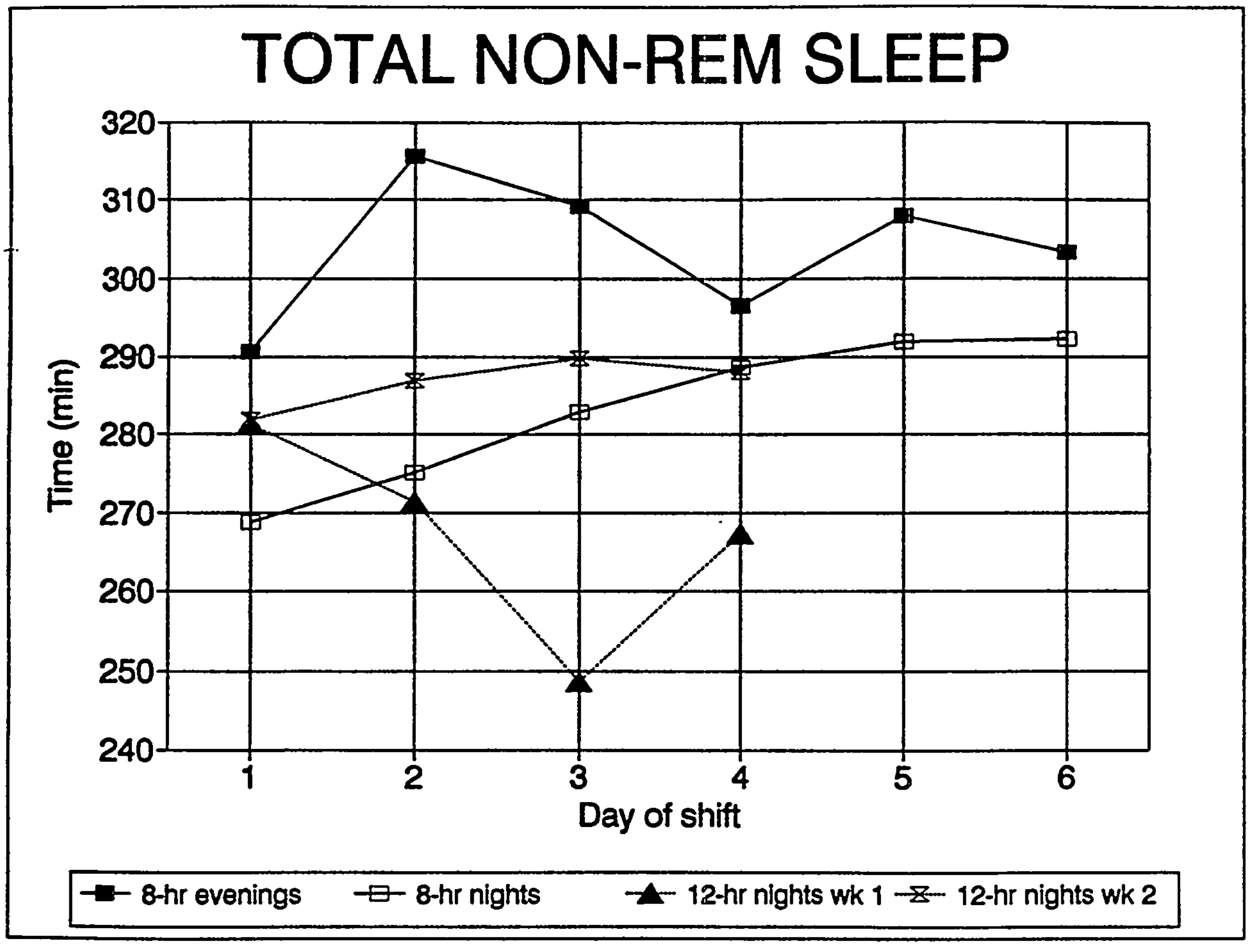

Figure 59 This figure shows average non-REM sleep time (sleep stages 1-4 combined) in minutes per 8 hours in bed. Each symbol represents the average non-REM sleep time of 10 subjects, plotted as a function of day of shift for all shift conditions. Subjects who worked 8-hr evening shifts, then slept from 2400-0800, had significantly more non-REM sleep than subjects in any of the night shift conditions, who slept during daytime hours. Subjects had significantly more non-REM sleep when working their second of two consecutive weeks of 12-hr shifts.

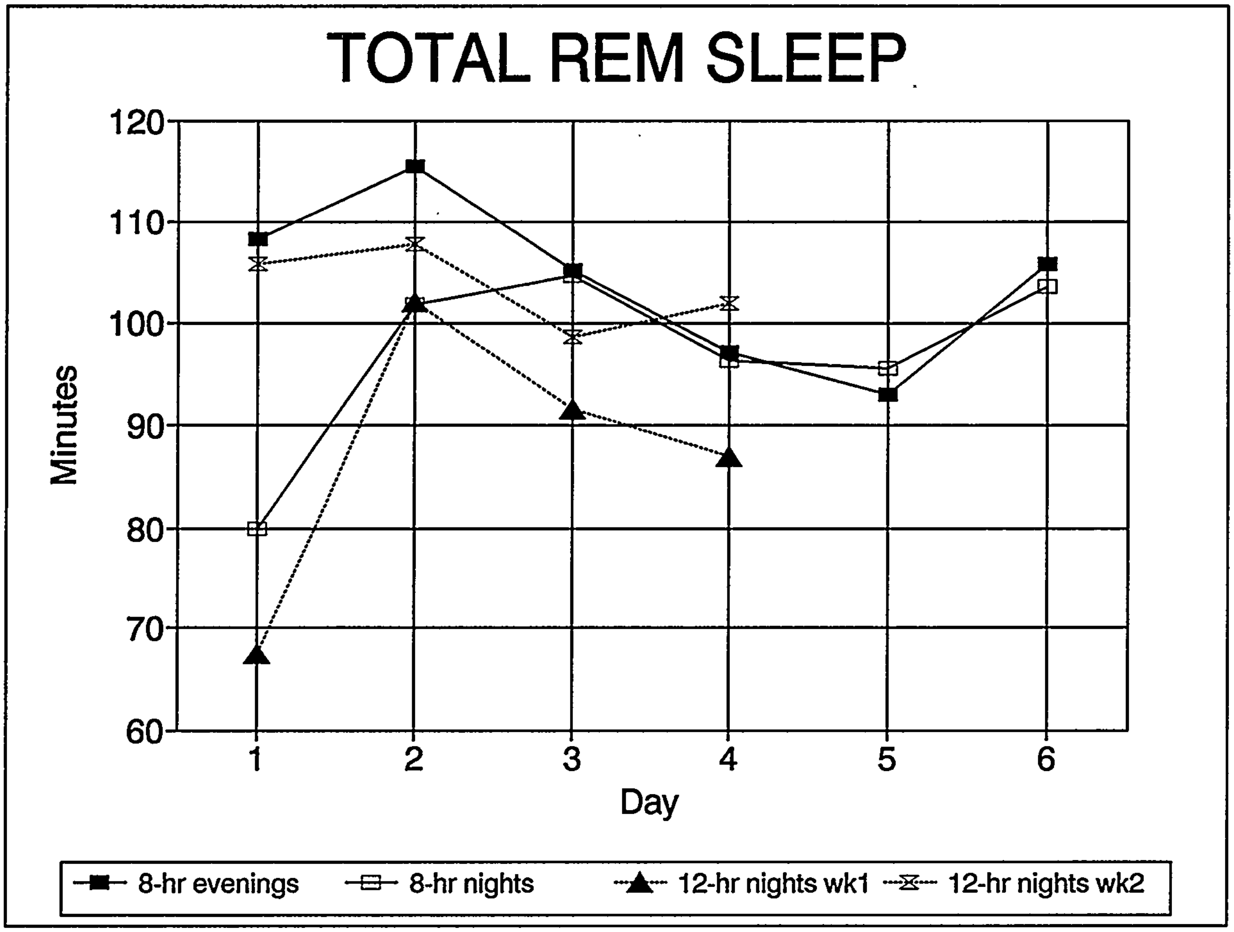

Figure 60 This figure shows average REM sleep time in minutes per 8 hours in bed. Each symbol represents the average REM sleep time of 10 subjects, plotted as a function of day of shift for all shift conditions. Mean REM sleep time was lowest after the first night shift in either the 8-hr or 12-hr experimental protocols.

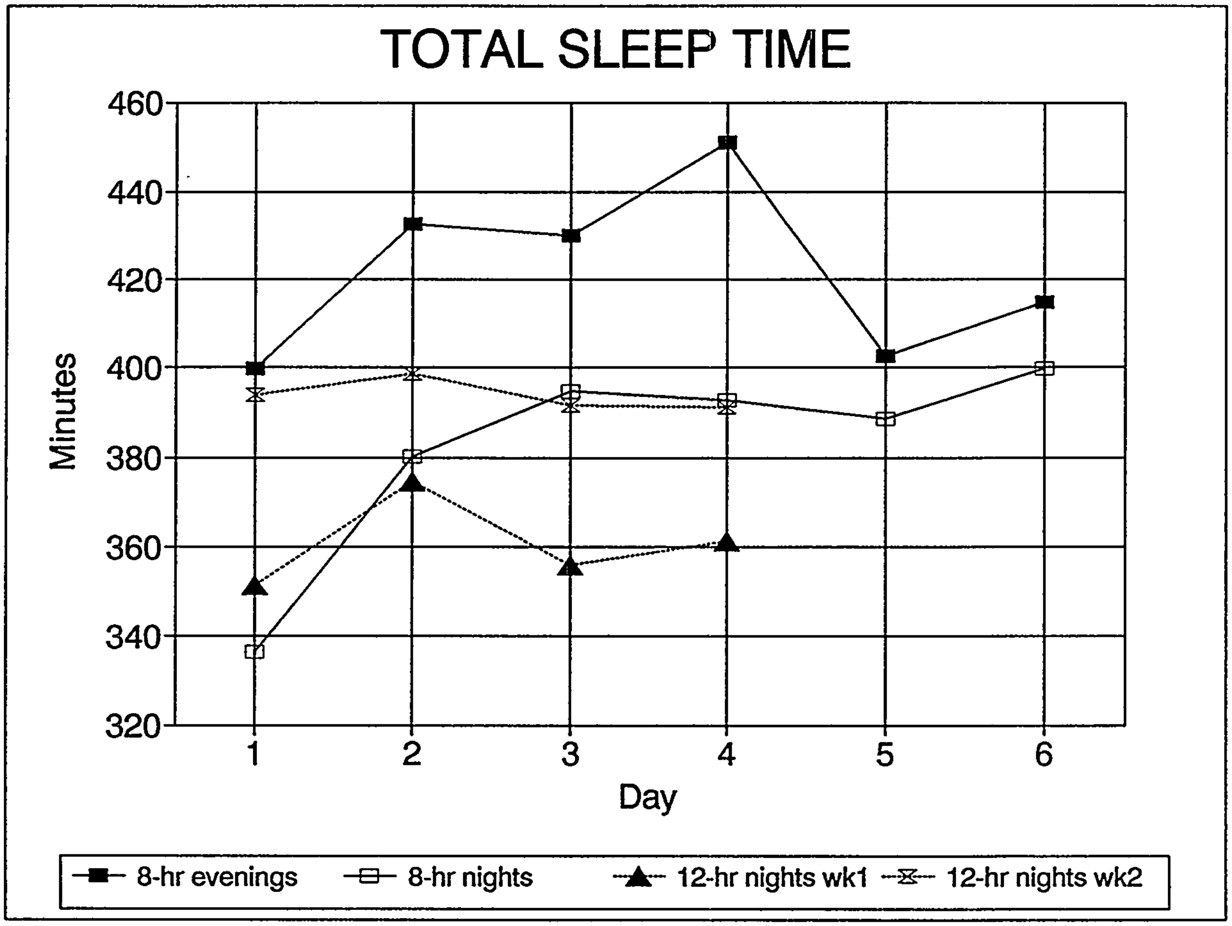

Figure 61 This figure shows average total sleep time (TST, or non-REM sleep and REM sleep combined) in minutes per 8 hours in bed. Each symbol represents the average TST of 10 subjects, plotted as a function of day of shift for all shift conditions. TST was significantly greater on 8-hr evening shifts, as compared with 8-hr night shifts or the first week of 12-hr night shifts. There was also a day of shift effect; TST increased significantly after subjects worked the third 8-hr night shift. TST also increased significantly on the second week of 12-hr night shifts, as compared with the first week.

poor first-day sleepers continued to experience abbreviated and interrupted sleep after each subsequent night shift. The most typical pattern of disrupted daytime sleep consisted of lighter stages of sleep and early awakening with difficulty returning to sleep (Fig. 62). Two subjects appeared to adapt to the night shift, showing greatly improved daytime sleep after working just two or three consecutive nights (Fig. 63). Similar patterns of individual variability in sleep time were seen in the group of subjects working 12-hr night shifts.

Wake After Sleep Onset (WASO)

Mean waking time after sleep onset was lowest for 8E shifts (24.8 minutes), which varied significantly from 12N1 shifts (77.8 minutes) [$F(2,16) = 16.1$; $p<.001$], but not from 12N2 or 8N shifts. WASO was significantly reduced during the second week of 12-hr night shifts as compared to the first week (Fig. 64). WASO was much higher after the first two 8-hr night shifts than after night shifts three through six.

Total Movement Time (TMT)

Movement time was significantly less during the sleep that followed 8-hr evening shifts (mean 1.87 minutes), as compared to mean TMT in the 8-hr night shift (4.6 minutes) or the second week of 12-hr night shifts (3.6 minutes) [$F(2,16) = 4.08$; $p<.05$].

Wake After Final Awakening (WAFA)

Subjects sleeping at night after 8E shifts had significantly less wake time after final awakening compared with all day sleep following night shift work. Mean WAFA on 8E shifts was only 12.4 minutes, as compared to 31.3, 34.9, or 31.2 minutes on 12N1, 12N2, and 8N shifts, respectively [$F(2,16) = 4.08$; $p<.05$] (Fig. 65).

Lights Out to Sleep Onset (LO/SO)

The LO/SO measure of sleep latency was significantly shorter for all night work shifts, as compared to 8E shifts [$F(2,16) = 4.08$; $p<.05$], but did not differ either as a function of length of shift or day of shift. On average, subjects took about 20 minutes longer to fall asleep at 2400 (after evening shifts) than at 0800 (after night shifts). Average LO/SO times were 8E = 30.3 minutes, 8N = 9.2 minutes, 12N1 = 9.5 minutes, 12N2 = 11.7 min (Figure 66).

Total Wake Time (TWT)

Total wake time included all non-sleep time spent in bed during the 8-hr lights out period (LO/SO + WASO + TMT = TWT). On this measure, the sleep after 8-hr evening shifts differed from sleep after all night shift conditions [$F(2,16) = 10.0$; $p<.05$], having significantly less total waking time per lights out period (Fig. 67). While still significantly higher than TWT on 8E shifts, average TWT during the second week of 12-hr night shifts was significantly lower than 12N1 TWT.

Lights Out to Stage 2 Sleep (LO/S2)

Latency to stage 2 sleep was also significantly longer for sleep after 8-hr evening shifts than for sleep after all night shift conditions [$F(2,16) = 18.0$; $p<.05$]. Mean sleep latency following 8-hr evening shifts was 34.4 minutes, as compared with 11.3 minutes, 11.8 minutes or 13.9 minutes for 8N, 12N1, and 12N2 shifts, respectively.

Lights Out to Slow Wave Sleep (LO/SW)

Latency to stage 3 sleep showed the same relationship between shift conditions as did other measures of sleep latency. Mean latency to slow wave sleep was significantly longer after 8-hr evening shifts than after any of the night shift

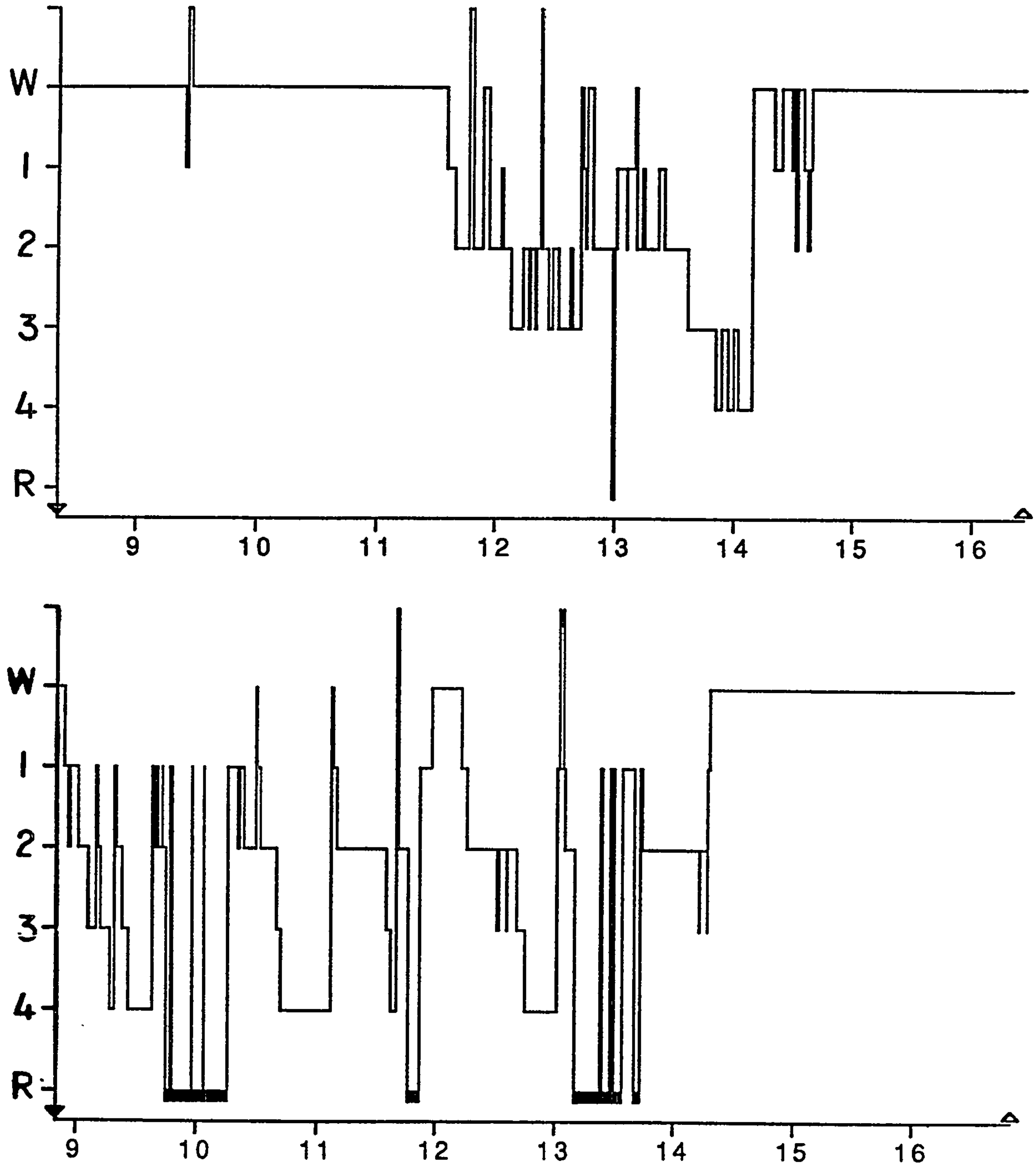

Figure 62 This figure shows two hypnograms, or plots of the temporal pattern of sleep-waking stages. Sleep stages are indicated on the vertical axis (W = waking; 1 = Stage 1, non-REM sleep; 2 = Stage 2, non-REM sleep; 3 or 4 = slow wave sleep; R = REM sleep). These data are derived from EEG recordings of subjects restricted to bed for 8 hours (0800-1600) in a completely darkened room after working either an 8-hr night shift (above) or a 12-hr night shift (below). Both subjects woke up early, while the 8-hr shift subject also had great difficulty falling asleep. As seen in these examples, daytime sleep following night shift work often shows only lighter stages of sleep (stages 1 and 2 non-REM sleep) with inadequate slow-wave sleep (stages 3 and 4) or REM sleep..

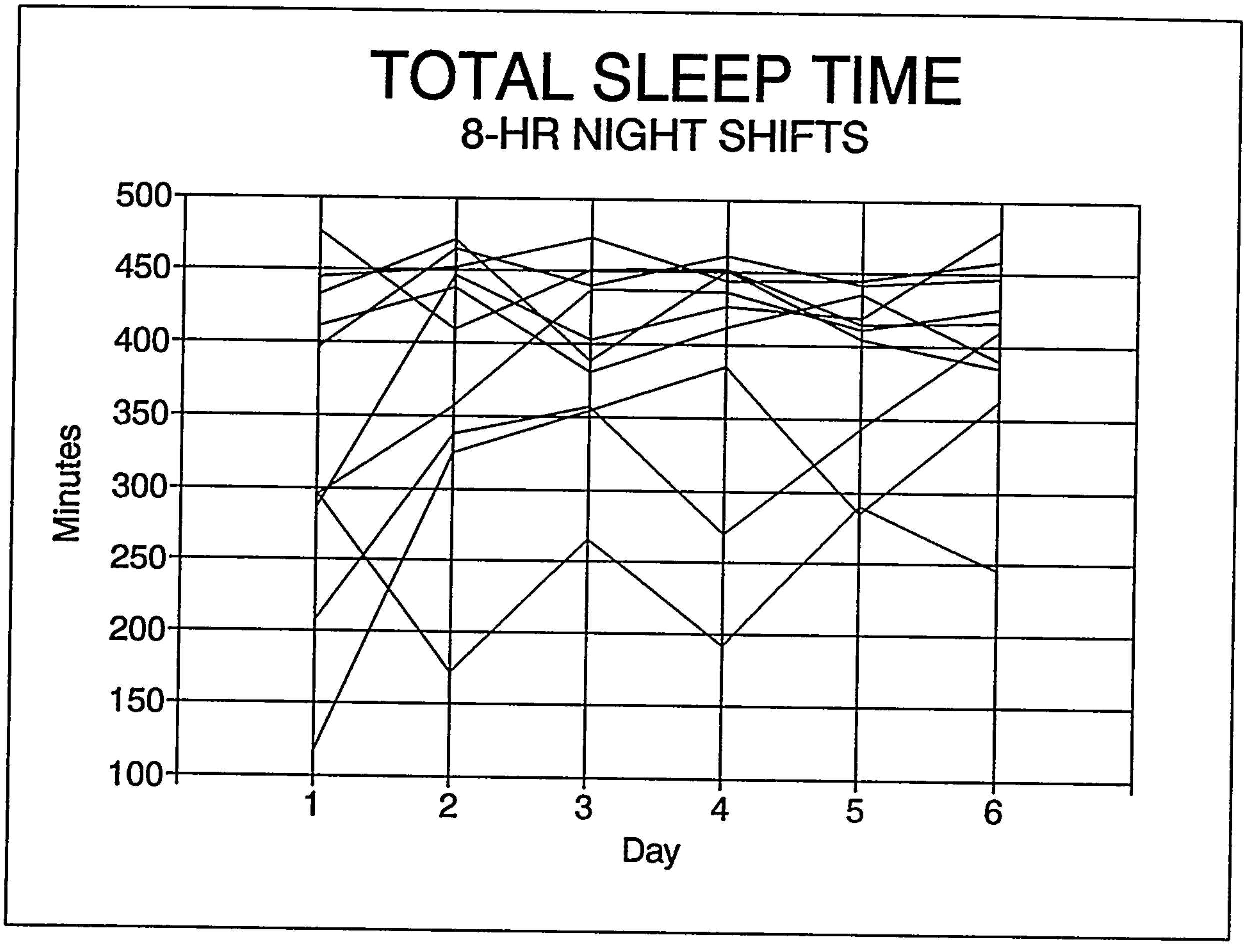

Figure 63 In this figure, total sleep time (TST) is plotted separately for each subject across the six consecutive 8-hr night shifts. The figure illustrates large individual differences in total sleep time. Three subjects show poor daytime sleep throughout the week of night shift work. The others show poor sleep initially, but adapt within two to three nights and show improved daytime sleep by the third daytime sleep period. Five subjects show remarkably stable sleep patterns across the six nights of simulated 8-hr work shifts.

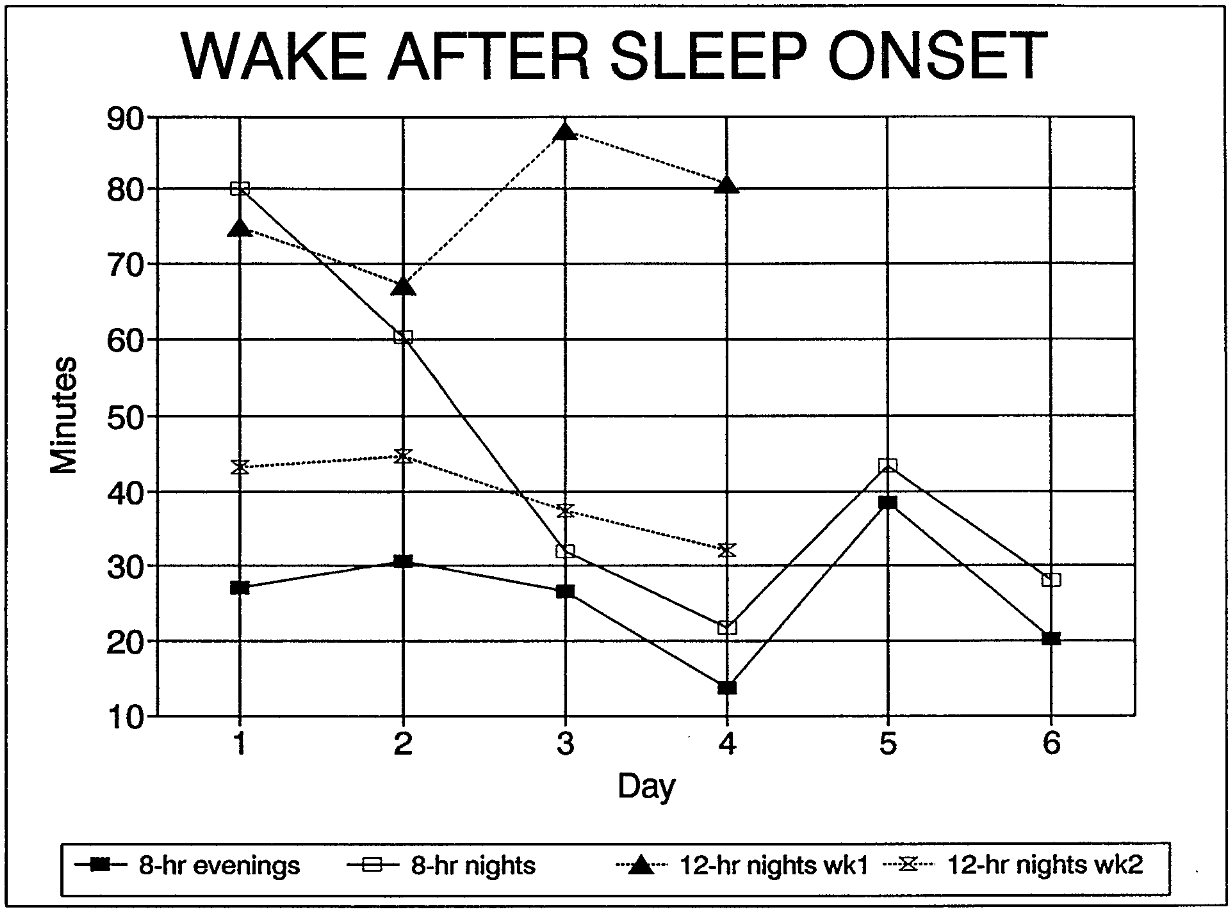

Figure 64 This figure shows average time in minutes that subjects were awake in bed after the initial onset of sleep and before their final awakening of the sleep period. This variable is conventionally called WASO (wake after sleep onset). Each symbol represents the average WASO of 10 subjects per 8 hours in bed, plotted as a function of day of shift for all shift conditions. WASO was significantly higher on the first week of 12-hr night shifts and for the first two 8-hr night shifts. Subjects in the 8-hr shift protocol showed significant reduction in WASO between the first and second week of night shifts, which was associated with longer and less interrupted daytime sleep.

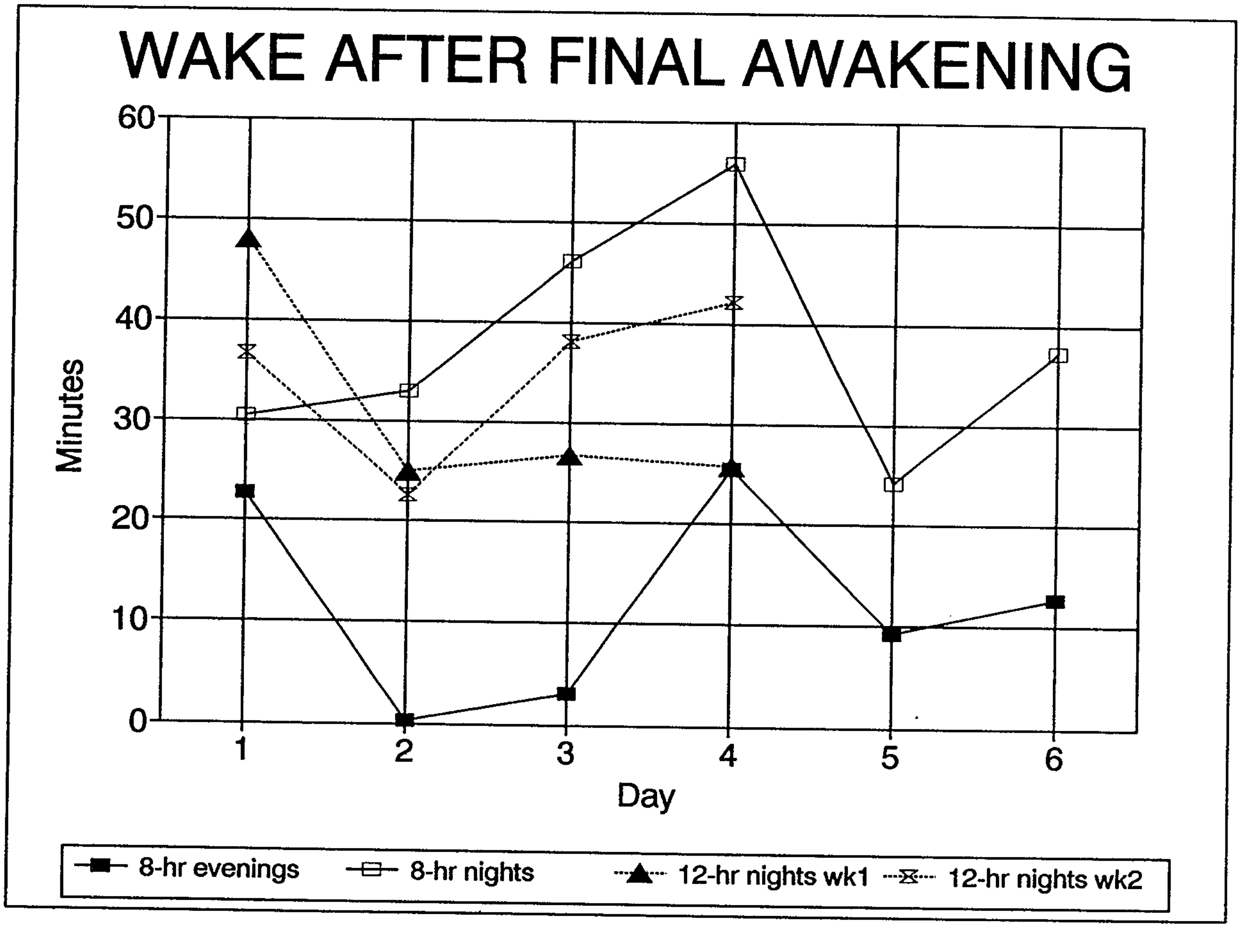

Figure 65 This figure shows the time in minutes that subjects were lying awake in bed after their final awakening from the sleep. Subjects were required to remain in bed in a completely dark bedroom for 8 hours per day. Each symbol represents average wake after final awakening (WAFA) of 10 subjects, plotted as a function of day of shift for all shift conditions. The figure shows that subjects who worked 8-hr evening shifts and who slept at night (2400-0800), had significantly less WAFA time than those who worked at night and slept in the daytime (0800-1600).

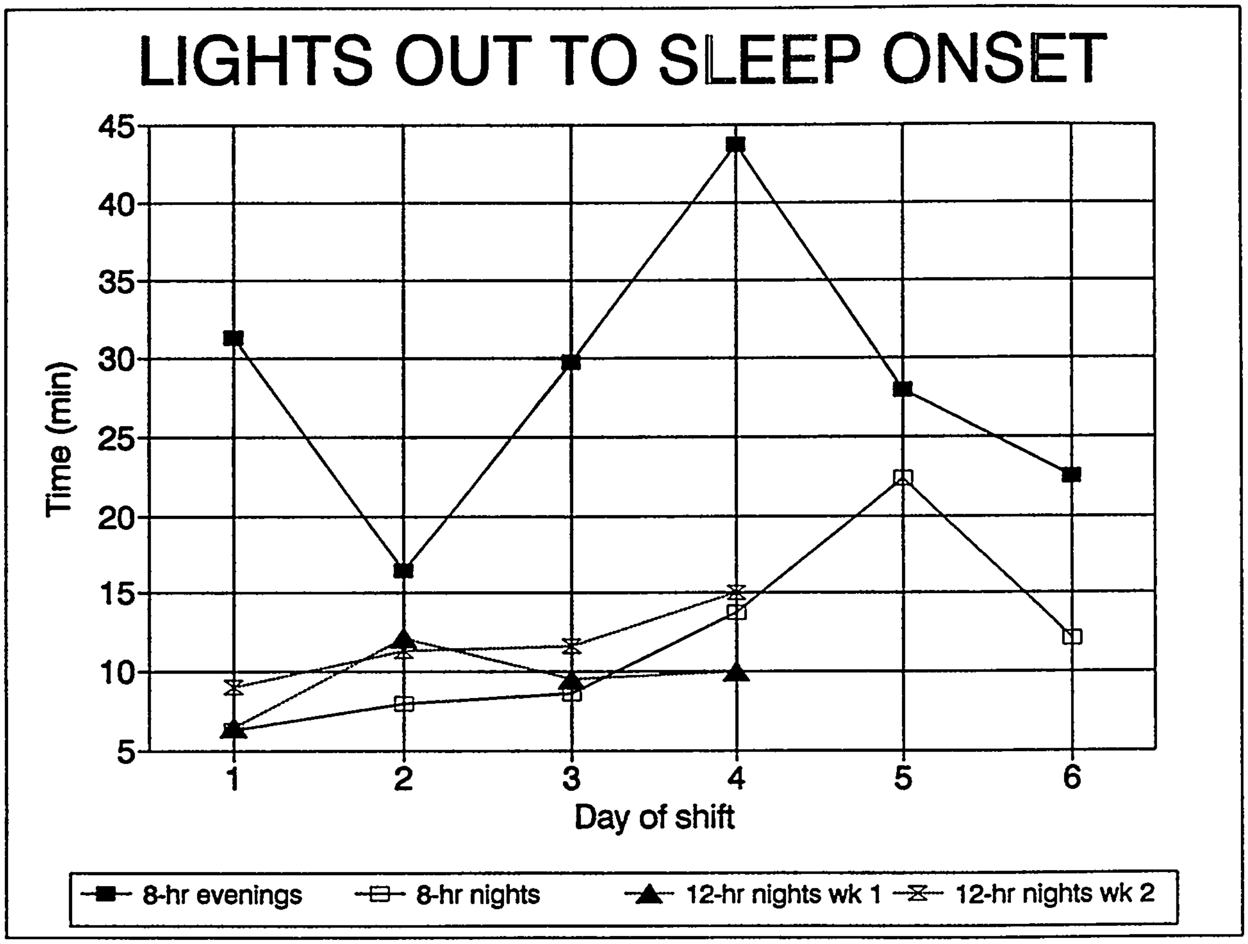

Figure 66 This figure shows how long subjects took to fall asleep once they were in bed and had turned out the room lights. This was measured as time in minutes from lights out to sleep onset (LO/SO), which was defined by examination of electroencephalograph recordings. Each symbol represents the average LO/SO of 10 subjects, plotted as a function of day of shift for all shift conditions. The figure illustrates that subjects working either 8-hr or 12-hr night shifts fell asleep significantly faster than subjects working 8-hr evening shifts. There was no difference between night shift conditions.

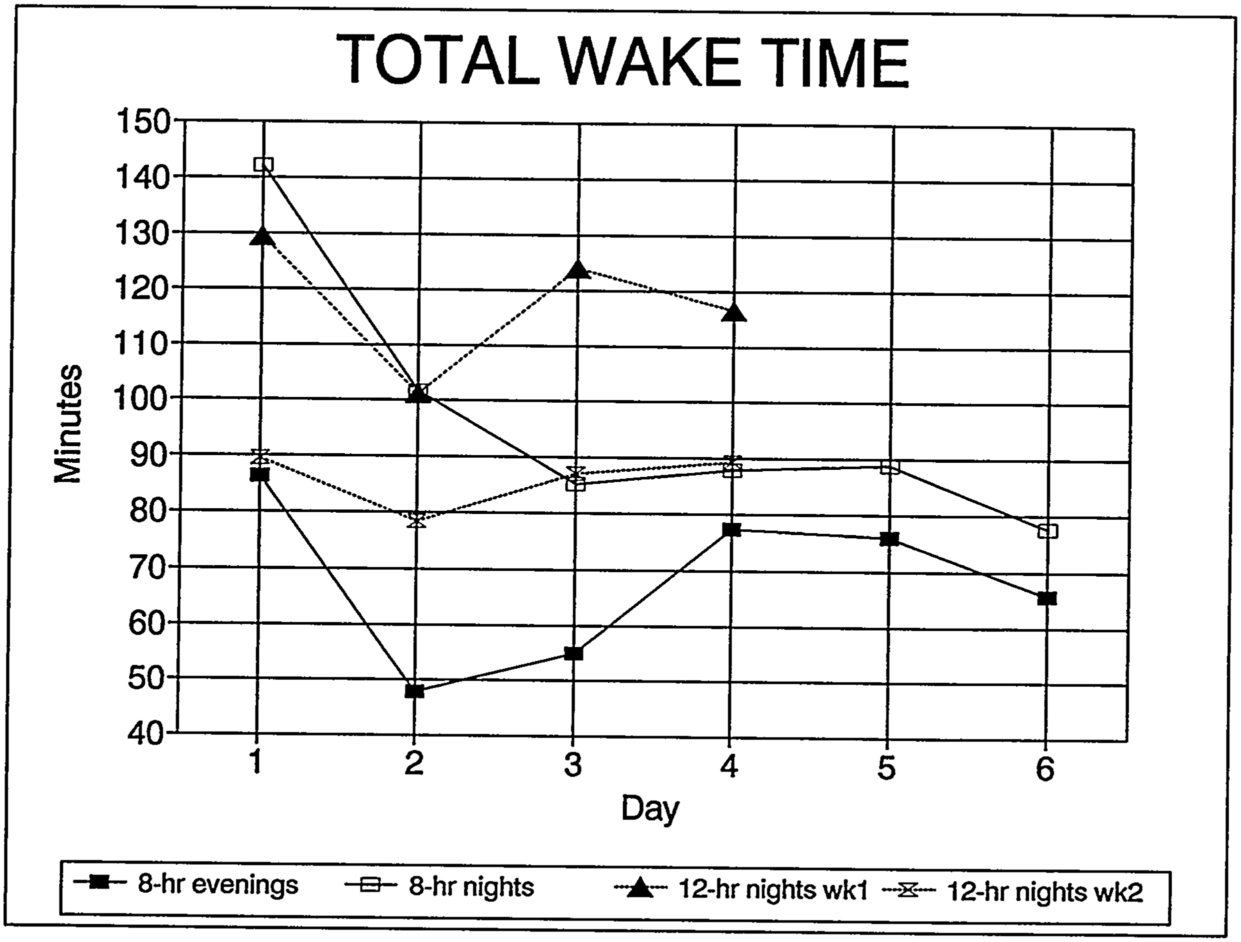

Figure 67 This figure shows average total wake time (TWT) in minutes per 8 hours in bed (LO/SO, WASO, and WAFA time combined). Each symbol represents the average TWT of 10 subjects, plotted as a function of day of shift for all shift conditions. The figure illustrates that there was significantly less TWT during night sleep of subjects who worked simulated 8-hr evening shifts, as compared to any of the night shift conditions. Furthermore, subjects who worked two consecutive weeks of 12-hr night shifts showed significantly less TWT during the second week, as compared to the first week.

conditions (8E = 47.1 minutes, 8N = 34.0 min, 12N1 = 26.8 minutes, 12N2 = 30.3 minutes) [$F(2,16) = 4.37$; $p<.05$].

Sleep Onset to Slow Wave or REM Sleep

In contrast to the above sleep latency measures, the mean interval between sleep onset and first occurrence of slow wave or REM sleep did not vary as a function of shift condition. Slow wave sleep typically occurred within about 15 minutes of sleep onset, and REM sleep onset occurred within 50-60 minutes.

Summary of Findings: Off-Duty Sleep

The most important sleep finding is that there were no significant differences between 8-hr and 12-hr night shifts in the length or quality of daytime sleep after the work shifts. Predictably, sleep duration and quality were better following 8-hr evening shifts (TIB 2400 to 0800) than after either 8-hr or 12-hr night shifts (TIB 0800 to 1600). Subjects fell asleep significantly faster after working night shifts, compared with evening shifts, but they had more awakenings and more movements during sleep. Furthermore, subjects working night shifts were more likely to awaken before the end of the designated TIB period and less likely to fall back to sleep. Thus, total sleep time decreased and total waking time significantly increased, particularly during the week of 8-hr night shifts and the first week of 12-hr night shifts.

Daytime sleep was most impaired after the first one to three night shifts, but quickly recovered to levels that were nearly as good as nighttime sleep (e.g., those recorded during the 8E shifts). Most of the poor initial daytime sleep could be attributed to about half of the subjects in each protocol who began their first week of night shifts with very poor daytime sleep and then rapidly improved. Daytime sleep following the first few night shifts was brief and showed lighter sleep stages and multiple awakenings. These subjects tended to awaken early and to have difficulty returning to sleep. Sleep length and depth improved as they worked successive night shifts. A surprising number of subjects showed reasonably good daytime sleep over all night shifts, presumably helped by the totally dark and quiet conditions of the laboratory sleeping rooms. Finally, a few subjects exhibited consistently poor sleep for the entire week of night shift work, typically enduring several hours of wakefulness while lying in bed in a dark room.

In the second week of 12-hr night shifts, daytime sleep improved markedly, compared with the first week of 12-hr night shifts. Sleep measures showing significant improvement included TST (mean increase = 20.9 min), TNREM (mean increase = 19.6 min), WASO (mean decrease = 38.4 min), and TWT (mean decrease = 24.1 min).

When sleep diaries for days off were examined, clear differences were seen between subject sleep habits on the 8-hr and 12-hr research protocols. Of ten 12-hr shift subjects, six completed accurate sleep diaries. Each of these subjects remained awake most or all of the first night of their break, going to sleep in the early morning hours or even as late as they had when working night shifts in the laboratory. Each of the subjects had three major sleep periods during the 3.5 day break. Total sleep time accumulated during the break ranged from 18.5-28 hours (mean 21.5 hours). Two of the six subjects continued to take most of their sleep during daytime hours throughout the break; the percentage of TST which fell outside the 0800-1600 window of sleep time for these two subjects was only 13.8% and 25.7%, respectively. On the other hand, the remaining four subjects rapidly shifted their sleep to earlier hours. For these four, most of the sleep during the break occurred during the night or evening, but they also spent about one third of their total sleep time (range 29%-35%) within the established daytime sleep window (0800-1600). These subjects seem to have maintained a pattern of *anchor sleep* (Minors and Waterhouse, 1981a; 1981b), which may have helped them adjust more quickly to the second week of night shifts.

Thus, a week of night shifts followed by a 3.5-day break during which subjects appeared to use adaptive sleep/wake strategies, resulted in significantly better daytime sleep during a second consecutive week of night shifts. The significantly improved cognitive performance of subjects during 12N2 may, in part, be attributed to their improved daytime sleep.

Review of the eight sleep diaries completed by the 8-hr shift group did not reveal the same degree of adaptive sleep scheduling seen in subjects in the 12-hr protocol. One subject did regularly nap in the late afternoon, and another progressively delayed the beginning of sleep on each day off, eventually staying awake until 0500 and sleeping until noon on the final day before beginning night shifts. The remaining six subjects, however, continued regular sleep at night, awakening before 0800 on most of their days off. One of these subjects slept until late in the morning (1000), and one took a 2-hour nap in the afternoon before reporting to the laboratory. The others, apparently using no adaptive sleep strategy, awoke in the morning, remained awake all day, and reported to the laboratory at 2200 to be readied for their first night shift.

Albeit a limited sample, it appears that the experimental shift format of six 8-hr evening shifts, followed by a 4-day break, then six consecutive 8-hr night shifts was not conducive to adaptive sleep strategies.

Multiple Sleep Latency Test

These data are represented in Figures 68-73.

In the analysis that included all data, mean sleep latency was significantly shorter for the 8-hr night shift condition than for any other condition, indicating that subjects were, on average, sleepier during the 8-hr night shifts [$F(2,16) = 3.79$; $p<.05$]. However, the 12-hr night shifts included evening hours (1900-2300) that fell during the 8-hr evening shifts, so the appropriate comparisons are seen only in the comparable time analyses (Figs. 68, 69). These analyses clearly show that there were no significant differences in physiological sleep tendency between 8-hr and 12-hr night shift conditions.

There was a significant day-of-shift effect in MSLT scores, with subjects in all night shift conditions showing decreased sleepiness on successive night shifts (Figs. 68, 70-72) [$F(16,76) = 2.52$; $p<.005$]. Least significant difference comparisons showed that sleepiness on shifts three through six of the 8N shift condition was significantly less than on shifts one and two (indicated by higher mean MSLT scores). For both 12N1 and 12N2 conditions, subjects were significantly more sleepy on the first night vs. the last night of each set of four consecutive night shifts.

Interestingly, sleep tendency on the MSLT test also tended to decrease across successive evening shifts (Figs. 68). The mean MSLT score on evening shift one was significantly lower than the MSLT score on shifts four through six.

Mean sleep latency on MSLT tests also varied significantly as a function of consecutive hour of shift [$F(76,914) = 2.09$; $p<.01$] (Fig. 73). The tendency to fall asleep increased after the 2300 MSLT in all night shift conditions, reaching

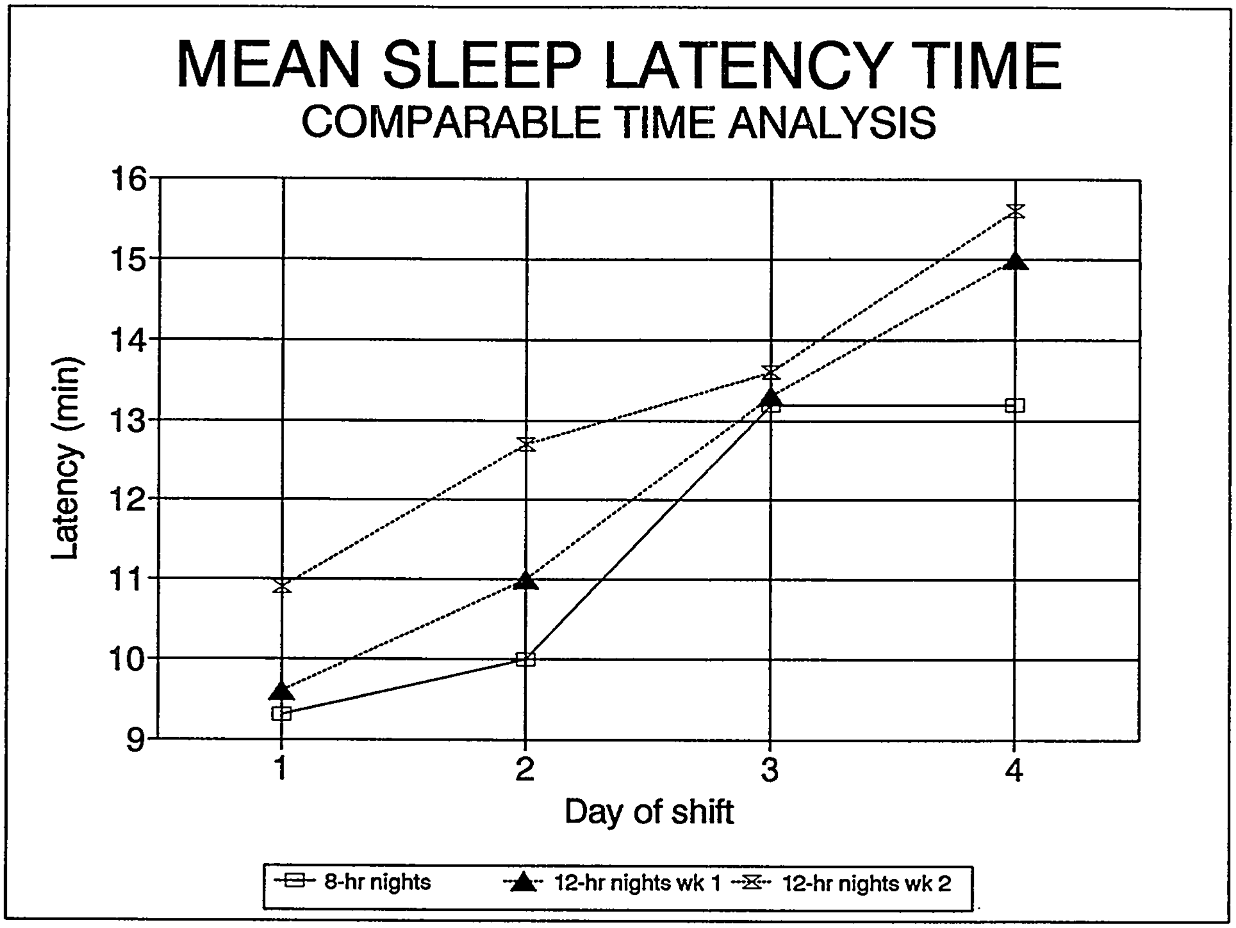

Figure 68 This figure shows mean sleep latency, which is the time in minutes that it took subjects to fall asleep during the 20-minute Multiple Sleep Latency Test (MSLT). Subjects were given this test every 2 hours during their simulated work shifts. Lower values on this test, i.e. shorter sleep latency, signifies greater physiological sleep tendency. Mean sleep latencies for four MSLT trials conducted during comparable work hours (2300-0700) were combined to yield an average value for each of the first four night shifts in both 8-hr and 12-hr shift work simulation protocols. The figure shows that there was no significant difference between 8-hr and 12-hr shifts. The figure also shows the significant reduction in physiological sleep tendency over successive night shifts.

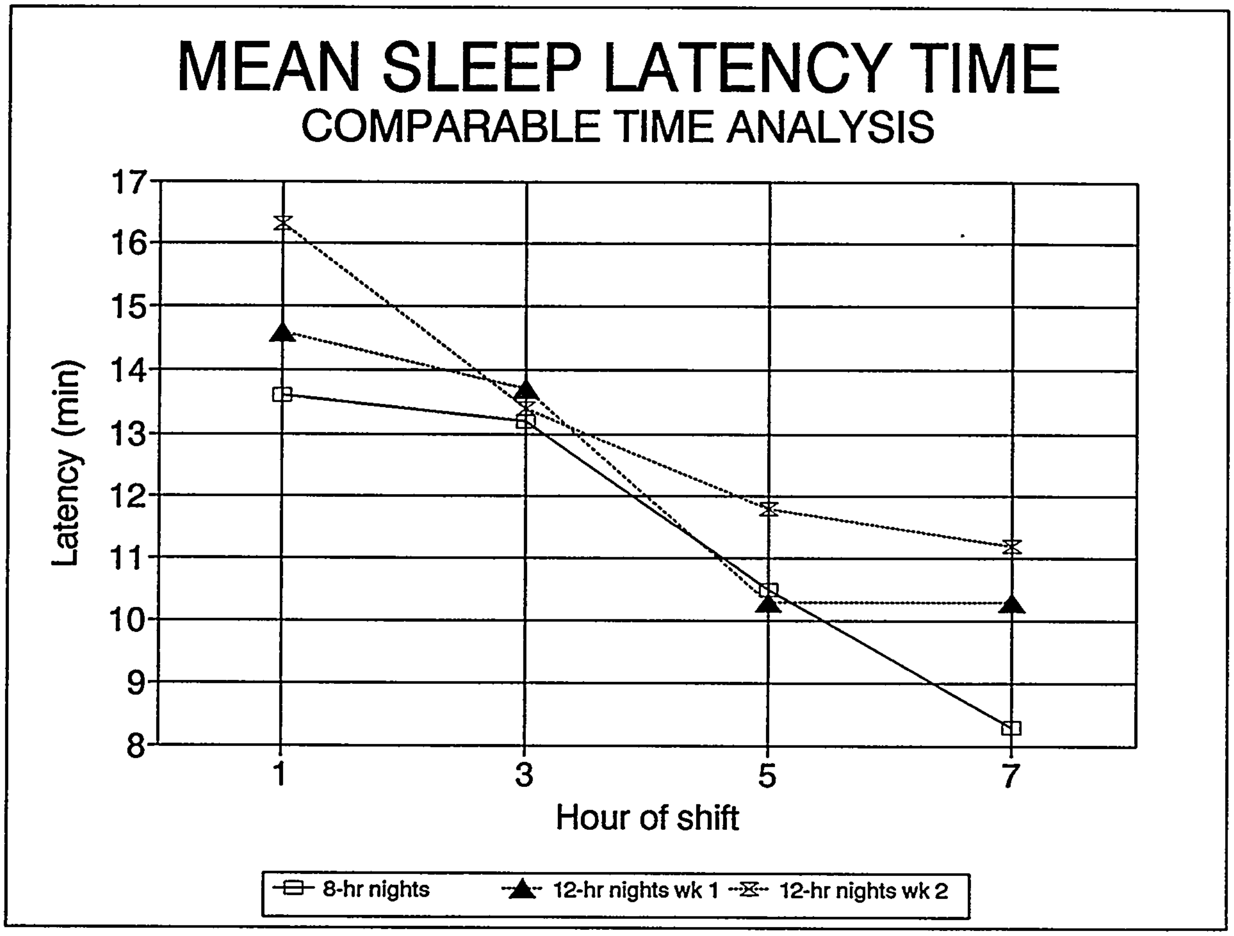

Figure 69 This figure shows mean sleep latency, which is the time in minutes that it took subjects to fall asleep during the 20-minute Multiple Sleep Latency Test (MSLT). Subjects were given this test every 2 hours during their simulated work shifts. Lower values on this test, i.e. shorter sleep latency, signifies greater physiological sleep tendency. Mean sleep latencies for four MSLT trials conducted at the same clock hour over the first four night shifts were combined to yield an average value for each of four tests conducted between 0100 and 0700. This figure shows that physiological sleep tendency, as indicated by sleep latency, increased steadily across hours of shift. Sleep tendency was not significantly different on 8-hr versus 12-hr night shifts.

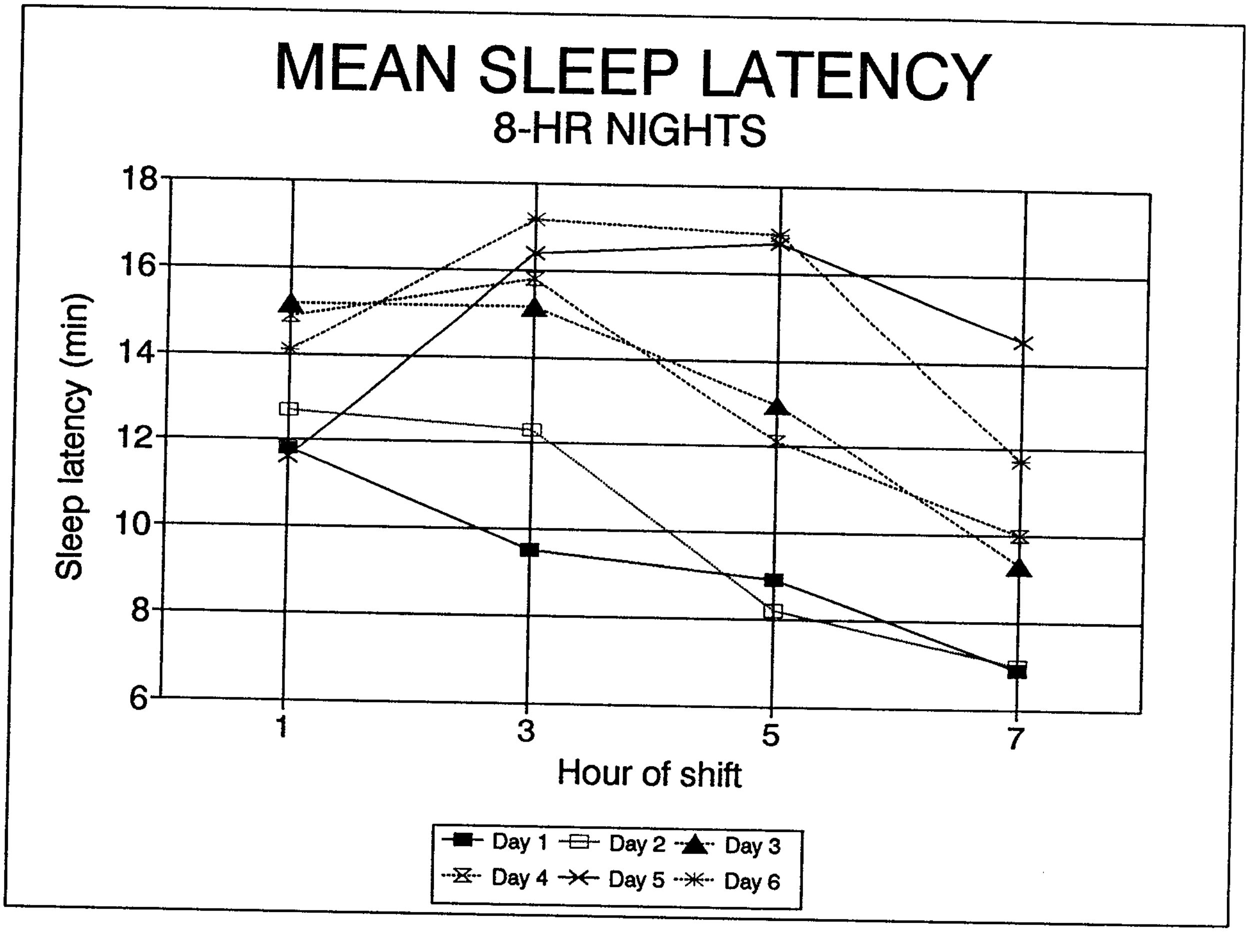

Figure 70 This figure illustrates mean sleep latency for all subjects at each test hour, separately plotting data for each of six consecutive 8-hr night shifts. The data show that mean sleep latency increased progressively across nights of shift, indicating that subjects had progressively less tendency to fall asleep on successive night shifts.

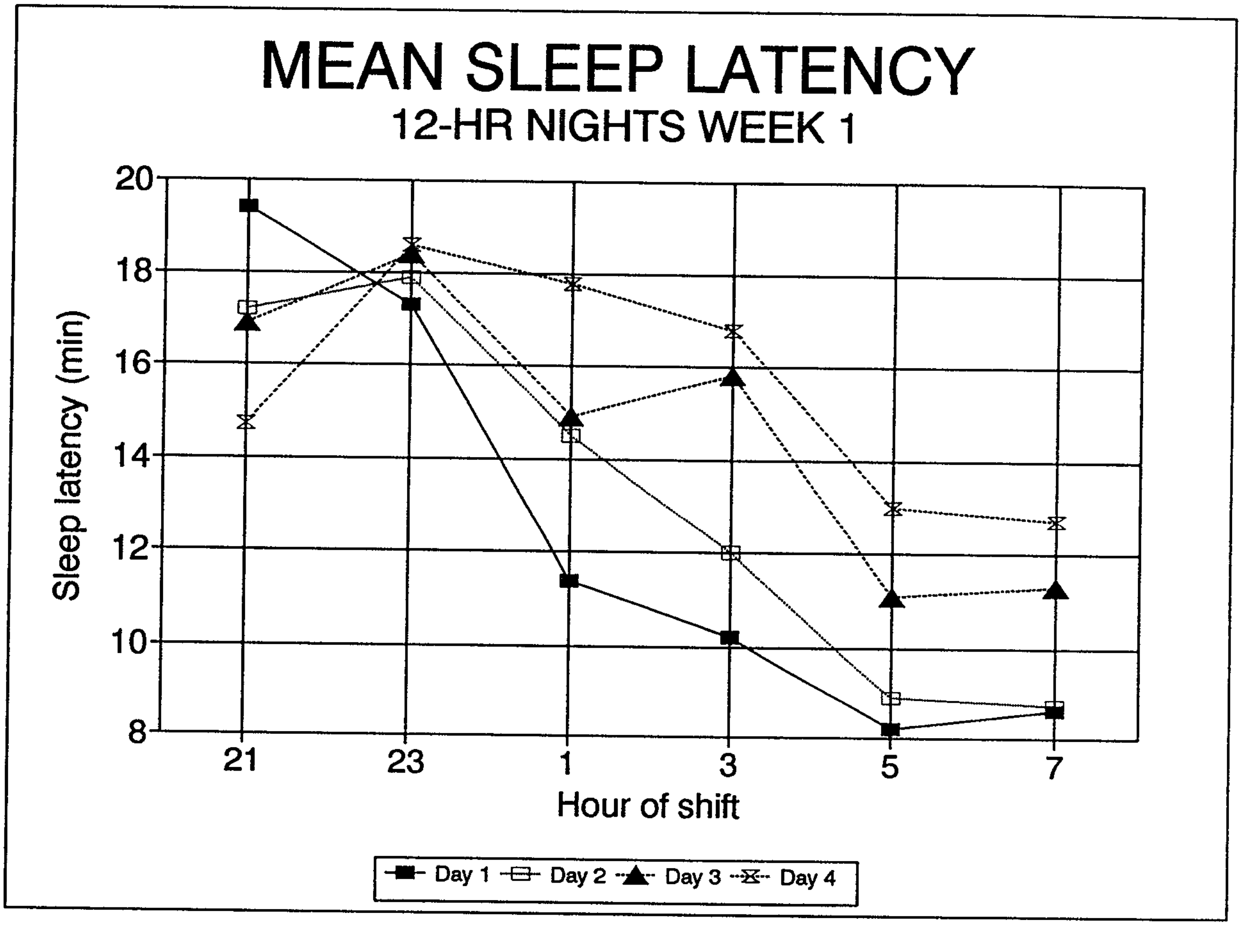

Figure 71 This figure illustrates mean sleep latency for all subjects at each test hour, separately plotting data for each of four consecutive 12-hr night shifts during the first of two consecutive weeks of 12-hr night shifts. The data show that mean sleep latency increased progressively across nights of shift, indicating that subjects had progressively less tendency to fall asleep on successive night shifts.

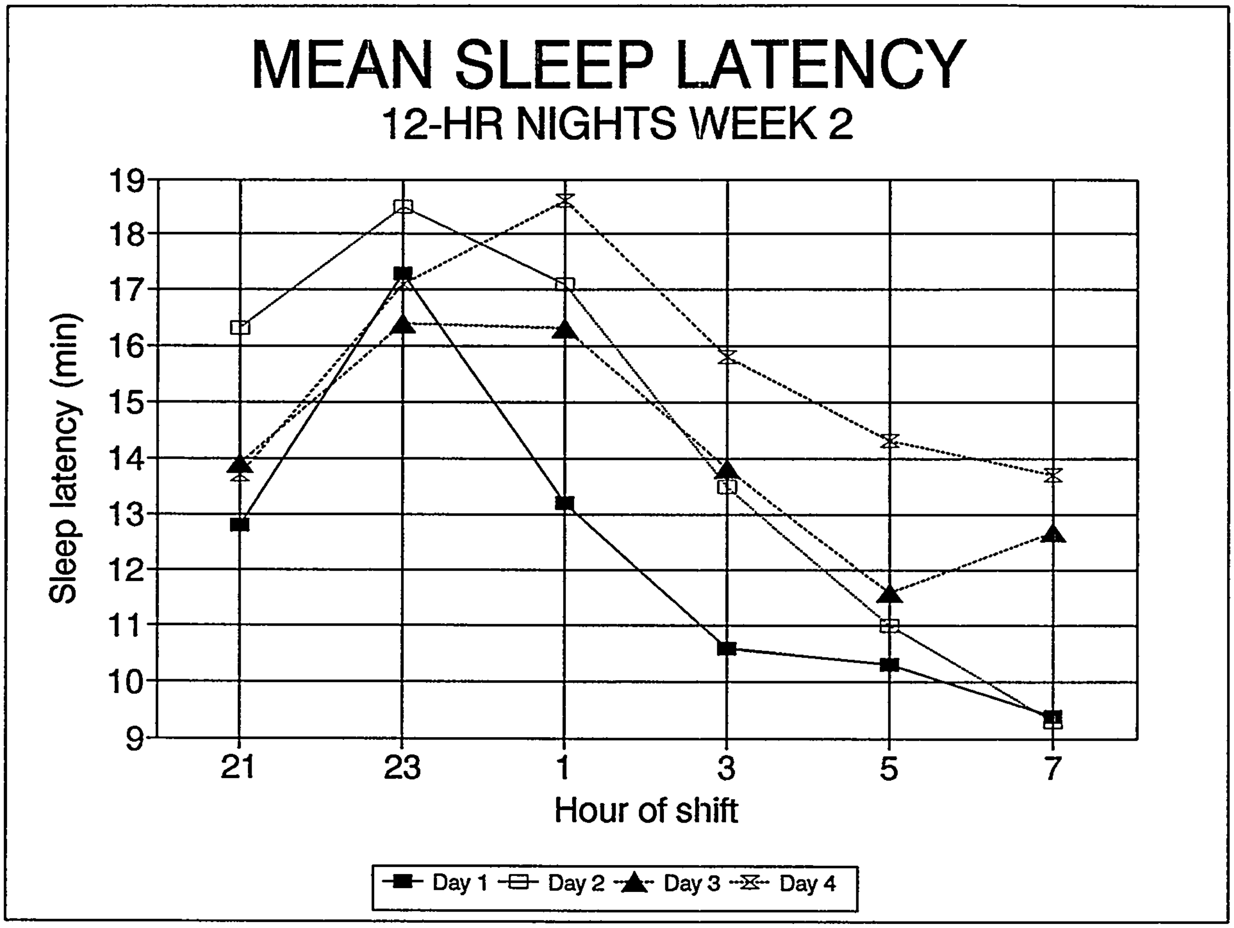

Figure 72 This figure illustrates mean sleep latency for all subjects at each test hour, separately plotting data for each of four consecutive 12-hr night shifts during the second of two consecutive weeks of 12-hr night shifts. The data show that mean sleep latency increased progressively across nights of shift, indicating that subjects had progressively less tendency to fall asleep on successive night shifts.

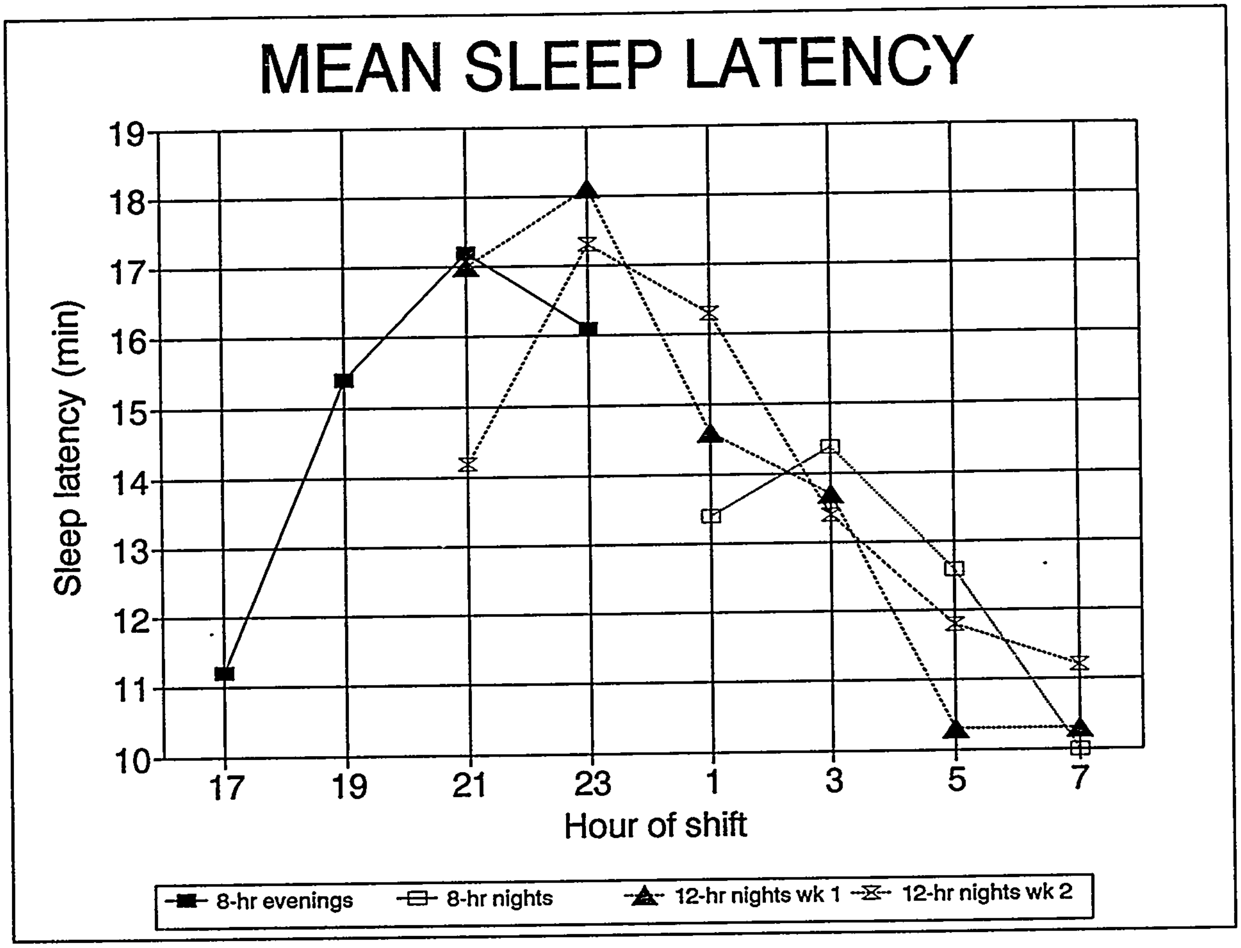

Figure 73 This figure shows mean sleep latency, which is the time in minutes that it took subjects to fall asleep during the 20-minute Multiple Sleep Latency Test (MSLT). Subjects were given this test every 2 hours during their simulated work shifts. Lower values on this test, i.e. shorter sleep latency, signify greater physiological sleep tendency. Mean sleep latencies for all MSLT trials conducted at the same clock hour for each shift condition were combined to yield an average value for every MSLT test performed during the simulated work shifts. This figure illustrates that physiological sleep tendency decreased over the course of 8-hr evening shifts, reaching peak alertness (minimum sleep tendency) at 2100. Sleep tendency was low at the beginning of all night shifts, but progressively increased across hours of shift. By 0700, subjects working 8-hr or 12-hr night shifts fell asleep on average within 10-11 minutes of lights out.

maximal sleepiness (lowest MSLT score) on the final test at 0700. The relationship between hour of shift and mean MSLT score was the same on all night shifts and across all night shift conditions. On 8E shifts, sleep tendency decreased over the course of the shift, reaching lowest sleep tendency (highest MSLT score) at 2100.

From night four of 12N1 through all 12N2 shifts, sleepiness progressively increased on the first MSLT test (2100). That is, sleep tendency at the beginning of the 12-hr shift increased as more consecutive nights were worked, while sleep tendency later in the shift progressively decreased. This may indicate a gradual phase shift in the rhythm of sleepiness tendency, with the typical early morning peak (3 to 6 a.m.) moving into later morning sleep hours and afternoon peak sleepiness moving into the early evening hours.

Post-MSLT Questionnaire

Subject questionnaires were completed at the end of each MSLT and compared with actual sleep latencies determined by EEG analysis. The first question subjects were asked was "Did you fall asleep?". The percent correct was calculated, based on the number of subjects that correctly assessed whether or not they fell asleep during the 20-minute test. The percent of false negatives was also calculated, based on the number of subjects who said that they did not fall asleep when, in fact, they did. Finally, percent false positive indicated the proportion of subjects that said they did fall asleep when, in fact, they did not.

Percent correct in this self-assessment of whether or not sleep had occurred was not significantly different across shift conditions; subjects were correct between 63% and 77% of the time, depending on shift condition. Accuracy was inversely proportional to the sleep probability at any given hour of shift. For example, percent of correct responses was only 37% on the 1700 test of the 8E shift condition, when over 65% of subjects fell asleep, but increased to 79% correct on the 2100 test, when less than 20% percent of subjects fell asleep.

For all shift conditions, false negative responses were at least twice as common as false positives. For the 8N condition, 25 percent of responses were false negatives, while only 12 percent were false positives. For the 8E condition, false negatives were 27% and false positives were 12%. Combining the data from 12N1 and 12N2 (which did not differ), percent false negative was 18% with only 5% percent false positives.

Subjects were also asked the question, "How long did it take you to fall asleep?" Subjects who correctly identified sleep onset were very accurate in their assessments of sleep latency, regardless of shift condition. Mean error in the sleep latency estimate was less than one minute (comparing estimated sleep latency with EEG-defined sleep latency). By contrast, subjects were remarkably inaccurate in their estimates of sleep duration when asked the final question, "How long did you sleep?" Subjects consistently underestimated the duration of sleep (mean difference between estimated and actual sleep time was 5.7 minutes).

Stanford Sleepiness Scale (SSS)

Self-rated sleepiness was significantly lower in the 8E condition than on any of the night shift conditions [$F(2,16) = 3.87$; $p<.05$], but 12-hr and 8-hr nights did not vary (Fig. 74). Subjects rated sleepiness as greatest on the first and second night shifts for both the 8N and 12N1 shift conditions, but these differences failed to reach statistical significance due to high

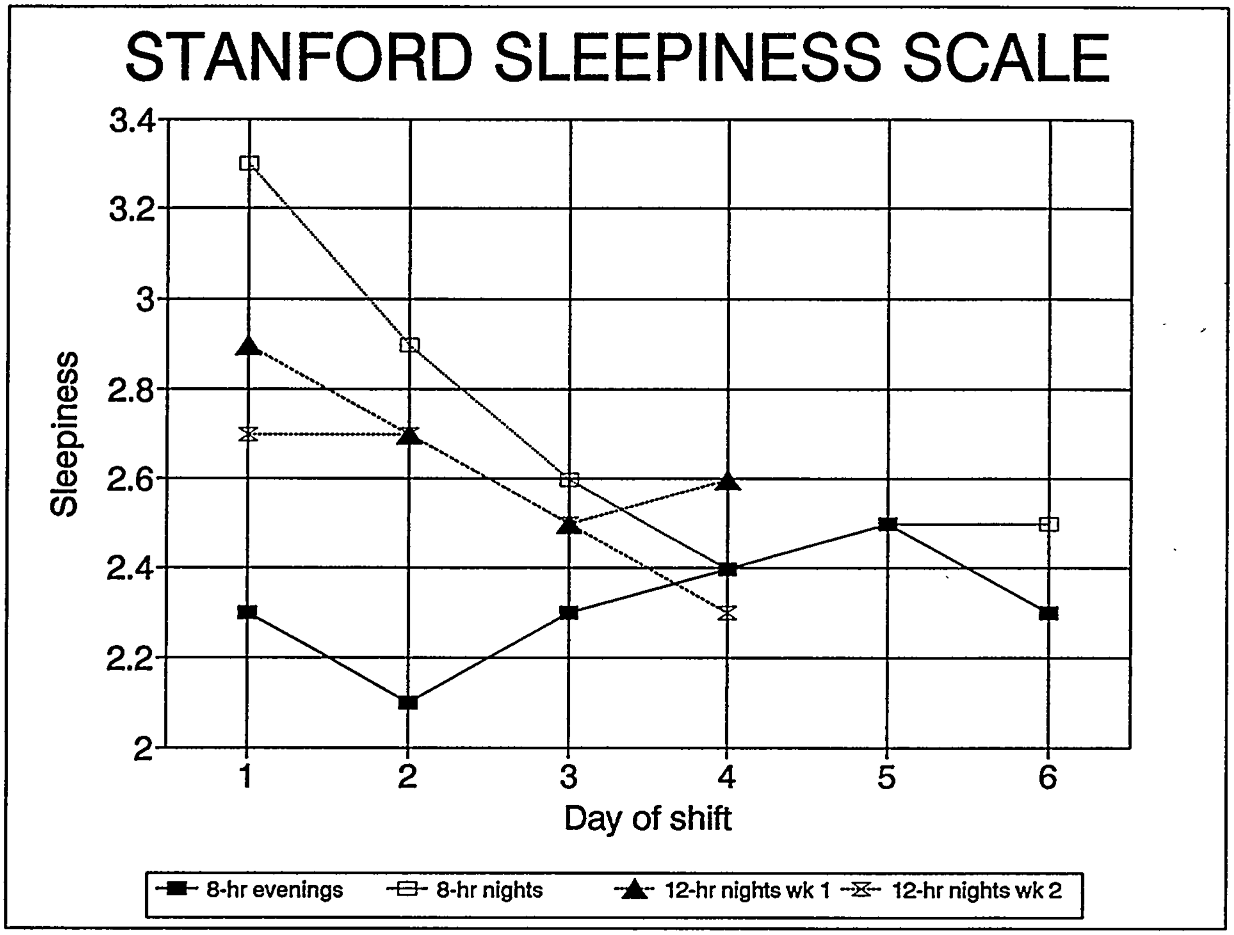

Figure 74 This figure shows mean scores on the Stanford Sleepiness Scale, a 7-point scale that subjects completed every hour to rate themselves on a sleepiness/alertness axis. Lower numbers signify higher alertness. Each symbol represents a mean of all data, plotted as a function of consecutive day of shift for each shift condition. The figure shows that subjects rated themselves as significantly more alert on evening shifts, compared with 8-hr and 12-hr night shifts. Self-rated sleepiness tended to decrease across successive 12-hr night shifts, but this trend did not reach statistical significance.

variability. Mean SSS ratings also indicated increasing subjective sleepiness across hours of the night shifts regardless of shift condition (Fig. 75).

Post-Shift Alertness and Performance Questionnaire

Independent validation of the sleepiness-alertness trends indicated by the SSS subjective rating scale was provided by post-shift questionnaires, which asked the question, "At what time of the night or evening did you feel least alert?" Responses were tabulated in two-hour blocks.

On 8-hr night shifts, over 80% of subjects indicated that minimal alertness occurred during the last two hours of shift (0500-0700). In general, minimal alertness was reported earlier by many subjects working 12-hr night shifts. For 12N1 and 12N2 shift conditions, the lowest alertness level was assigned either to the 0300-0500 time block (38% and 43%, respectively) or to the last two hours of shift, 0500-0700 (59% and 43%, respectively).

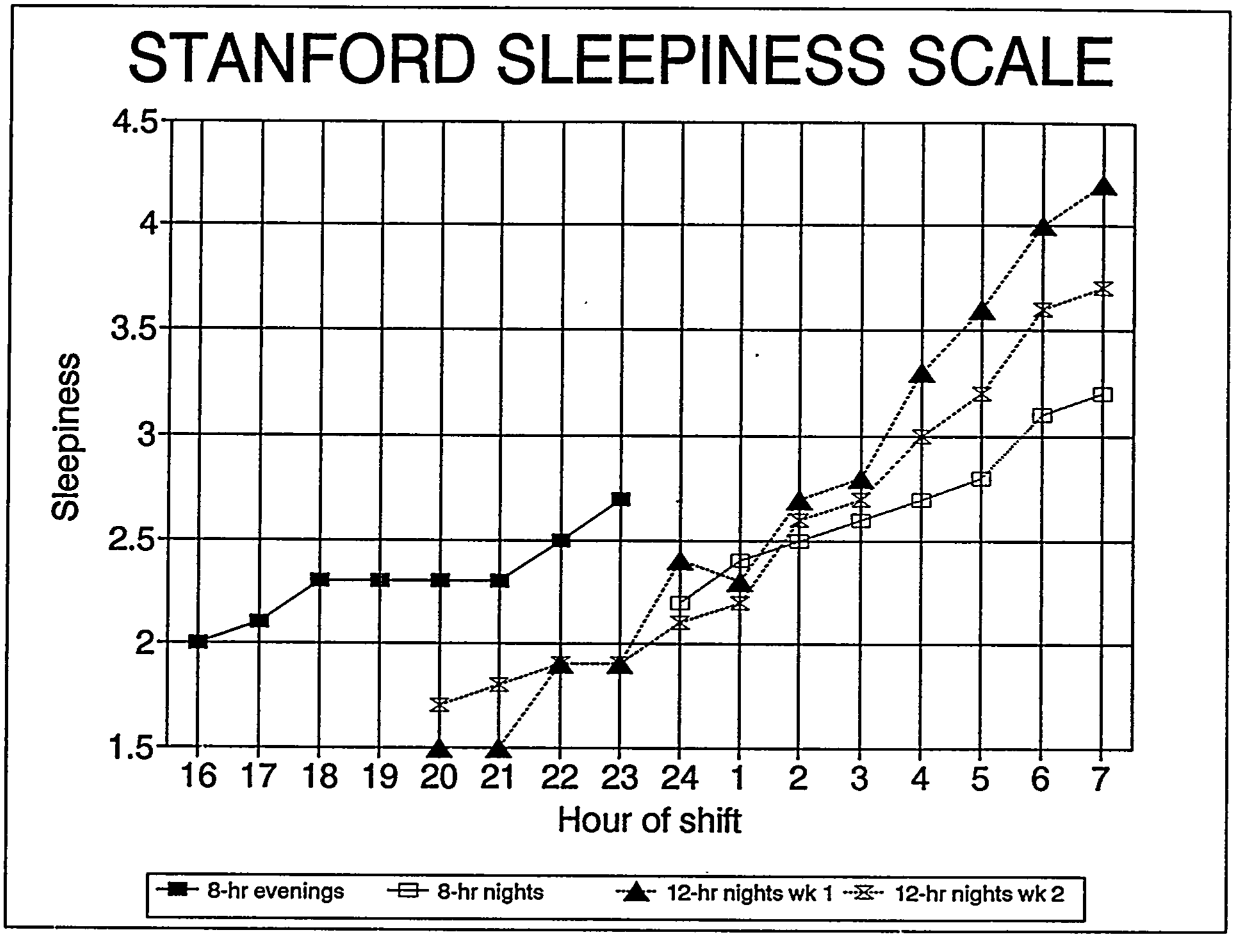

Figure 75 This figure shows mean scores on the Stanford Sleepiness Scale, a 7-point scale that subjects completed every hour to rate themselves on a sleepiness/alertness axis. Lower numbers signify higher alertness. Each symbol represents a mean of all same-hour data for all days of the study, plotted as a function of consecutive hour of shift for each shift condition. The figure illustrates the trend for self-rated sleepiness to increase over hours of shift, particularly in all night shift conditions.

DISCUSSION

The goal of this research study was to assess performance, alertness, mood, and sleep quantity and quality in operators performing simulated control room duties during 12-hr and 8-hr work shifts. The study focuses specifically on the night shift hours of 2300 - 0700. All research was conducted in a laboratory setting and included simulator operation and other activities resembling those in a nuclear power plant control room.

Because of the controlled conditions of the work simulation laboratory (e.g. dark and quiet sleeping rooms, constant temperature and lighting in the workplace, and fixed protocols for work time and sleep time), many confounding variables usually associated with both on-shift and off-shift activities were eliminated or greatly reduced. For example, the protocol eliminated commutes to and from the workplace, provided optimal off-shift sleeping conditions, limited exposure to bright light during off-shift hours, and assured that family and social obligations did not impinge upon time allotted for off-shift sleep. There was also an attempt in this study to make the work routine more realistic by having subjects perform a simulated monitoring function for several hours during each work shift. These conditions made it easier to determine to what extent work shift duration may reduce alertness and work performance under conditions similar to those in a nuclear power plant control room.

In the real world, however, noisy or lighted sleeping rooms, interference of family and social schedules with sleep times, long commutes to and from work, unscheduled overtime, and deviation from scheduled work periods are a fact of life for many shiftworkers. Such factors must be taken into account before attempting to extrapolate findings from these controlled and, to some extent, artificial laboratory studies to the industrial workplace.

The chief findings of this study are: (1) subjects working 12-hr night shifts compared to those on 8-hr night shifts, showed longer response times on several short-duration (approximately 1-4 minute) tests of cognitive performance, interval estimation, and choice reaction time; (2) those working 12-hr shifts showed higher performance accuracy on six out of eight performance tests. Subjects working 8-hr shifts showed better performance accuracy on one performance test; (3) there were no differences between 8-hr and 12-hr night shifts in the length and quality of off-shift sleep associated with duration of the work shift; (4) there were no significant differences between 8-hr and 12-hr shifts in sleepiness and alertness as measured by periodic MSLT tests; (5) there were minimal differences between 8-hr and 12-hr work shifts in subjective ratings of mood, fatigue, and subjective alertness; (6) there were no significant differences in ability to recognize and respond to alarms generated by a computerized simulator; and (7) alertness, performance, mood, and the duration and quality of sleep are better for those who work evening shifts (and sleep at night) than for those who work at night (and sleep during the daytime).

Comparison of 8-hr and 12-hr Night Shifts: Cognitive Performance

A key finding in this study is that subjects working 12-hr shifts had higher average response latency while performing standardized computer tests of reaction time, mathematical computation, logical reasoning, ability to visualize objects in three-dimensional space, and time estimation. This finding is consistent with other reports that response latency and reaction times are increased on 12-hr day and night shifts (Rosa et al., 1985, 1989; Rosa and Colligan, 1988).

A possible explanation for this difference between 8-hr and 12-hr groups is that there are differences in off-shift sleep that resulted in decreased alertness and greater fatigue on shift. Studies have shown that, on tests of cognitive performance, response latency increases as a function of cumulative sleep deprivation (Weiskotten and Ferguson, 1930; Wilkinson, 1961; Corcoran, 1964; Naitoh, 1968; Naitoh and Townsend, 1970; Hamilton et al., 1972; Kjellberg, 1977; Tilley et al., 1982; Babkoff et al., 1985; Monk and Folkard, 1985; Patrick and Gilbert, 1986). When humans are sleep deprived, mean response latency is thought to increase because of significantly longer response times (several times normal) on some trials, while the majority of performance trials are completed within normal response intervals. The proportion of trials with long response latency, and hence mean response latency, increases proportionately as sleep deprivation becomes more pronounced. These long response times may represent brief lapses in cognitive ability, short periods of inattention to task, or *microsleep* periods, which are ultra-short intrusions of EEG sleep into wakefulness.

There are other possible explanations for the increased response time during cognitive performance tasks in sleepy persons. For example, they may represent time spent by a person mentally correcting recognized errors, or time spent rechecking responses because of lower self-confidence in performance accuracy when fatigued or sleepy. By contrast, performance *accuracy* stays relatively stable much longer in fatigued subjects, even in subjects deprived of sleep for as long as three days, depending on the type of cognitive task.

Previous shiftwork studies cited suggest that decreased performance on 12-hour shifts is attributable to increased fatigue and decreased alertness, indicated by subjective self-rating scales (Rosa et al., 1985, 1989; Rosa and Colligan, 1988). In these earlier studies, sleep diaries collected from persons working 12-hour shifts suggested that the decreased alertness and fatigue were a consequence of sleep loss. In the present study, however, sleep duration, sleep efficiency, and time since last sleep were not different on the 8-hr and 12-hr shift protocols, perhaps because the timing of sleep in the 24-hour day and time in bed were tightly controlled and equivalent.

It is therefore reasonable to attribute the higher response times measured on the 12-hr shifts to factors other than sleep loss, such as fatigue related to duration of the work shift. However, this study did not demonstrate any clear association between level of fatigue and number of hours worked on the night shift. Subjective ratings of alertness, sleepiness, weariness, effort, and global vigor were not significantly different on 8-hr and 12-hr shifts, and MSLT measures of sleep tendency were equivalent. In fact, the trend was in the opposite direction; subjects working the first of six 8-hr night shifts reported *higher* weariness, sleepiness, and effort than those working the first 12-hr night shift. Global vigor, a calculated variable, was also significantly lower on the first 8-hr night shift than on the first 12-hr night shift.

An unexpected outcome of this study is that subjects working the 12-hr shifts in most cases completed the cognitive performance tests with greater accuracy than the 8-hr shift group. Those in the 12-hr shift protocol improved their performance accuracy in the second week of 12-hr night shifts, while reducing response times. Perhaps even more remarkable was the consistency of their performance, both across hours of shift and across nights of shift within the work week. Circadian and fatigue effects were expected to interactively impair performance near the end of the 12-hr night shift, but neither of these effects were observed. These data suggest that for some reason the 12-hr shift subjects used different performance strategies than those on 8-hr shifts. They seem to have selected a slower and more deliberate pace to perform their duties and performance tests. Whether this difference between 12-hr and 8-hr shifts is due to differences in arousal or fatigue remains entirely speculative.

The least likely reason for different performance characteristics in the two protocols is that there were variations in instruction. The 8-hr and 12-hr shiftwork simulation experiments were alternated throughout the two year experimental phase of this research study. Subjects in each protocol were trained by the same technical staff according to a set training protocols, and for the same number of practice sessions.

A more likely explanation for the apparent differences between the two groups of subjects is that chance assignment to one of the two protocols yielded subject groups that used different approaches to performance testing; the 12-hr shift group by chance including more individuals who tended to be careful and deliberate in their responses, while the 8-hr shift subjects were those who tended to respond more quickly but placed less emphasis on accuracy. Uncontrolled effects due to chance assignment of subjects to one of the two experimental protocols is a distinct possibility because of the small number of subjects in this study.

The interesting exceptions to the pattern of more accurate performance by those on 12-hr shifts is that subjects working 8-hr shifts performed more accurately on both the Manikin and interval production tasks. One possible explanation of this finding comes from classical performance research (Yerkes and Dodson, 1908; Colquhoun 1971). The classic theory states that there is an inverted-U relationship between performance and arousal. Performance is impaired when arousal and stimulation are too low or too high. Furthermore, the theory predicts that the optimal arousal level for a given task is inversely related to the difficulty of a task, such that more complex tasks are best accomplished at lower levels of arousal. Conversely, simpler tasks are better performed when arousal level is higher. The interval production and Manikin tasks are simpler than other PAB tasks that involve higher memory load and more sequential processing of information.

It is also possible that the Manikin task, which taps different cognitive skills such as the ability to visualize an object in three dimensions, is more sensitive to extended working hours. However, there are no standard conventions for classifying cognitive performance tasks by difficulty, complexity, or by types of cognitive abilities tested. In fact, most tasks involve combinations of several fundamental cognitive processes (DeVries-Griever and Meijman, 1987). The results of this study suggest that individuals can perform remarkably well at a variety of short-duration cognitive tasks, effectively masking both circadian and fatigue effects.

Other factors besides task difficulty that exaggerate performance decrements are: (1) continuous nature of the performance task (Alluisi, 1972; Angus and Heselgrave, 1985); (2) lack of variability in the task; (3) external control of the rate of performance, as occurs in the experimenter-paced tasks (Wilkinson, 1961; Williams and Lubin, 1967); and 4) feedback of results, or lack thereof, given to the subject (Williams et al., 1959; Wilkinson, 1961; 1964). In this research study, the performance and monitoring schedule was rigorous, but the work tasks were variable, brief, and allowed frequent breaks. All computer-based performance tasks except the serial add/subtract task were subject-paced, rather than externally-paced, and feedback was given only during training. Vigilance tasks incorporate each of the above characteristics: constant attention to the task for extended periods (typically 30 minutes or more), monotony, invariability of the task, and external control of the pace of the test. Vigilance tasks are more likely to show fatigue-related changes in performance accuracy than the conventional performance tests but are time-consuming and less acceptable for laboratory work simulation studies or for field studies of shiftworkers.

In this study, the simulator monitoring task most closely approximated a vigilance task. However, there were no significant differences between the 8-hr and 12-hr shifts in proficiency of detecting, recording, and acknowledging simulator auditory and visual alarms.

Performance of the task proved to be insensitive even to differences between evening and night shifts. However, high variability of the simulator performance results suggests that the task did not provide a meaningful measure of cognitive performance. It is possible that a vigilance test designed to amplify the effects of fatigue would have yielded more conclusive results concerning the effects of shift duration on performance. However, the goal of this study was to closely approximate the nature and pace of actual operations tasks, rather than to amplify subject performance problems by using a test scenario that had no resemblance to an actual operational setting.

Comparison of 8-hr and 12-hr Night Shifts: Sleep Duration and Sleep Stages

Earlier reports of reduced sleep on 12-hour shifts were not replicated in this study, which measured sleep length and quality via continuous EEG recording. Rather, the study shows that sleep time and quality, objectively and subjectively assessed alertness, and self-rated fatigue are no different on 8-hr or 12-hr shifts in a controlled laboratory setting. Therefore, if shortened sleep time is indeed associated with 12-hr shifts in field studies or actual shiftwork experience, the effect is more likely due to behavioral factors (e.g. long commute times or undertaking too many activities during off-shift hours, at the expense of sleep time), rather than physiological factors.

There is little doubt that many shiftworkers have poor daytime sleep when they work night shifts, regardless of shift duration. The typical shiftworker awakens in the morning at the habitual hour (e.g. 0600-0800), remains awake throughout the day, and reports for the first night shift (1900-2400). By the time this first shift and commute home are completed, the worker has been deprived of sleep for 24 or more hours before daytime sleep can begin. The first daytime sleep period is typically the shortest and least efficient because of conflicting circadian factors. In the present study, the average sleep duration for the first daytime sleep was between 5.5 and 6 hours for both 8-hr and 12-hr shifts. Daytime sleep is often much worse at home than under controlled laboratory conditions, with increased interference from ambient noise, sunlight, and social obligations. Thus, by the time a shiftworker completes the second night shift, he has typically been awake for 50 or more hours, and has had less than 6 hours of hours of recuperative sleep.

Perhaps the more surprising finding in this study is that many subjects slept extremely well during the daytime in the controlled sleeping environment provided, even after their initial night shift. Sleep duration and efficiency were far better than would be expected from previous reports of shiftworker sleep patterns. This leads to interesting speculation about the importance of a perfectly dark and quiet sleeping room for improving daytime sleep efficiency. In this study, the subjects went directly from their control room duty assignments to their sleeping apartments, with no exposure to morning sunlight. Thus, conflicting circadian *zeitgebers*, particularly ambient light, were effectively controlled in this study and may have improved daytime sleep by facilitating circadian readjustment to a degree not typically achieved.

A few subjects demonstrated persistent sleep difficulties throughout their week of night shifts. These individuals appear to have been most affected by the mismatch between their circadian phase and the sleep time permitted in this protocol. A typical pattern was to awaken after 4 or 5 hours of sleep (1100-1300), and then have difficulty reinstating sleep. Previous sleep research studies have shown that it is very difficult to begin or to maintain sleep between 1100-1300 or between 1800-2000. For this reason, these time periods are referred to as *wake maintenance zone*s (Strogatz et al., 1987).

This emphasizes another important limitation of these laboratory studies. The 0800-1600 sleep time was selected because it encompasses the hours when most rotating shiftworkers and night workers schedule their daytime sleep. Ideally, shiftworkers would try many different daytime sleep schedules to avoid the wake maintenance zones. The typical shiftworker pattern of sleeping during the morning hours may be dictated more by family-social considerations than by physiological need or ability to sleep well. Working spouses and school-aged children typically arrive home in the afternoon and early evening hours, which can mean increasing noise and the expectation of social interaction with the shiftworker.

Some shiftworkers have learned that alternative strategies are better for achieving longer and more restorative daytime sleep. The most popular alternative strategy is to divide sleep between a main sleep period in the morning and an early evening nap. Another strategy used more commonly by older shiftworkers is to delay the entire sleep period until the afternoon hours (e.g. 1400-2200). The subjects who exhibited the greatest difficulty sleeping during the 0800-1600 TIB required by the research protocol would probably resort to an alternative sleep strategy in a real-life shiftwork scenario.

This brings to light a potential disadvantage of 12-hr shifts not addressed by this research study. By virtue of the fact that most 12-hr night shifts start between 1800-1900, and that preparing for work, commuting, and shift turnover require an additional one or two hours before start of shift, alternate daytime sleep strategies are not easily achievable when working 12-hr shifts. For the majority of workers who can sleep within the hours available on a 12-hr shift schedule, this is not a problem. However, common start times of current 12-hr shifts are a distinct disadvantage for operators who have learned to rely on a pre-shift nap or to delay their entire daytime sleep period. These may be individuals whose physiology is most affected by the wake maintenance zone, and are therefore unable to achieve adequate daytime sleep when forced to take all of their sleep in the morning hours. The subject of defining optimal sleep strategies for 12-hr and 8-hr work schedules warrants further research.

The importance of setting aside a dedicated time for off-shift sleep can not be over-emphasized for those working 12-hr shifts. Commuting long distances, in effect, adds extra hours to the work shift and, when one-way commute times are an hour or more, this can severely restrict the time available for daytime sleep. It is clearly preferable to live relatively close to the plant when working 12-hr shifts. This factor is perhaps even more critical for day shifts, particularly when the start time of day shift is before 0700. Family and social obligations such as meal times and television viewing can easily keep an operator awake late into the evening. An early start of day shift, combined with a long commute, can require awakening as early as 0400, severely shortening the only available time for sleep. Again, this points to the usefulness of sleep training for workers.

Comparison of Evening and Night Shifts

This study confirms earlier research findings that daytime sleep following night work is shorter and less efficient than night sleep following day or evening shifts (Akerstedt et al., 1982; Kogi, 1982; Anderson and Bremer, 1987; Akerstedt, 1988). Approximately equal disruptions of daytime sleep were found in the 8-hr and 12-hr shift protocols. As stated earlier, the root cause of the sleep problems associated with night work is that sleep is out of synchrony with circadian rhythms. Body temperature and physiological alertness increase during the daytime; thus, subjects who are kept awake all night actually show significantly shorter sleep duration when daytime sleep is initiated during the morning hours (Akerstedt and Gillberg, 1981; Winfree, 1982; Gillberg and Akerstedt, 1982; Akerstedt, 1988; Czeisler et al., 1982; Strogatz et al., 1987; Czeisler et al., 1990). This occurs even though time elapsed since previous sleep progressively increases during this same period, which would intuitively suggest increased sleep need. This effect persists even when sleeping rooms are dark and quiet, when there are no social interferences, and when time in bed is held constant.

The comparative ease of working evening shifts that is confirmed in this study is entirely consistent with common shiftwork experience. Subjects working the evening shift were able to sleep at night. Sleep at night is deeper and more restorative than daytime sleep, which is out of synchrony with natural circadian rhythms (Czeisler, et al., 1982; Akerstedt, 1988). Furthermore, alertness and performance reach their daily circadian peak during the evening shift hours. This makes it much easier to remain alert and function at peak capacity during evening shift. Additionally, less time has elapsed since prior sleep when one starts an evening shift (8 hours), as compared to starting a night shift (12 - 16 hours).

Subjects working 8-hr evening shifts rated themselves as more energetic (higher ratings on subjective global vigor scales) than those on the night shifts. Subjects working 8-hr night shifts were less vigorous for the first few night shifts, but improved across successive nights until their subjective ratings were equal to the 8-hr evening shift condition. Surprisingly, 12-hr night shift workers scored in an intermediate range and did not show substantial improvement or deterioration as a function of consecutive nights on shift. Their subjective ratings of vigor and affect closely mirror their cognitive performance, which also showed little variation across hours of shift or days of shift.

Time of Day (Circadian) Effects on Night Shift Alertness and Performance

Changes in performance of shiftworkers over the 24-hr day have been described repeatedly (Bjerner, 1949; Browne, 1949; Bjerner et al., 1955; Knauth, 1980; Borland et al., 1986). Previous research has shown that performance decrements are usually most pronounced during the early morning hours, toward the end of night shifts, as workers approach the circadian nadir in alertness and performance (Klein et al., 1968; Colquhoun, 1971; Johnson and Naitoh, 1974; Kjellberg, 1977; Winget et al., 1978; Monk and Leng, 1982; Meddis, 1982; Johnson et al., 1992). In this study, performance remained relatively stable throughout the night shift, even though alertness decreased. Circadian patterns in cognitive performance were seen only in the 8-hr night shift condition, and only for two of the performance tests. Performance accuracy typically degraded as a function of hour of shift, with no evidence of an early morning recovery of performance toward the end of the simulated night shift. Only one silent alarm in the simulator monitoring task showed a progressive increase of response latency after 0400, reaching about 150% of values recorded earlier in the night by 0600-0700. The general lack of robust circadian variation in performance measures was a surprising outcome of this study.

As discussed previously, the 12-hr shift group showed remarkably consistent performance over the entire night shift and across nights of shift. A possible explanation for the absence of circadian effects on performance for both 8-hr and 12-hr shifts is that they were masked by the effects of fatigue or sleep deprivation, since all subjects began their first night shift having been awake all day.

Normal circadian variation in sleepiness and alertness, in combination with cumulative sleep deprivation, causes objectively measured alertness to be lower (sleep tendency higher) for night shift conditions. However, the main finding in this study is that objectively measured alertness did not differ between 12-hr and 8-hr shifts. There was improvement in objective alertness across nights of shift in both protocols, which corroborates previous laboratory simulation studies of 8-hr night shifts (Walsh et al., 1988).

A positive feature of most 12-hr shift schedules in the industry is the 1900 start time of night shift. Thus, the additional four hours worked on 12-hr night shifts (1900-2300) encompass the circadian peak in performance and alertness. In other words, operators perform their first few hours of work at an optimal phase in the circadian cycle. As they work beyond 8 hours and become more fatigued, nearing the circadian nadir, work activity usually slows to a manageable pace. The additional four hours of shift from 1900-2300 also occurs during the evening, so they do not encroach upon optimal sleep hours. Of the various options for scheduled start time, the 1900-0700 shift is clearly preferable to a 2300-1100 night shift. The first option incorporates hours of peak performance; while the second encompasses additional hours nearer the circadian nadir. Also, near the end of a 2300-1100 shift, more time has elapsed since last sleep. In the last four hours of shift, when alertness and cognitive performance are most impaired, work activity and the number of distractions in the control room increase dramatically.

Day of Shift Effects on Night Shift Alertness and Performance

Response latency was consistently lower on 8-hr shifts, both evening and night, as compared with either 12-hr night shift condition. In the 8-hr shift protocol, the response latency tended to decrease across successive evening shifts. Surprisingly, response latency decreased even further on 8-hr night shifts, but often at the expense of performance accuracy. This is contrary to the expectation that response latency would increase because subjects were sleep deprived, working during the circadian nadir in performance and alertness, and because more time had passed since their last sleep period. In the case of 8-hr night shifts, the influence of these fatigue factors seems to be reflected more clearly in performance accuracy than in response latency.

In both the 8-hr and 12-hr shift protocols, mean response latency progressively decreased across days. There was a dramatic change in response latency between the first and second week of 12-hr night shifts, often associated with gains in performance accuracy. For 12-hr shifts, the improved performance between consecutive weeks of night work was more pronounced than the improvement across successive days of shift.

The two most likely explanations for the progressive improvement in performance across successive work shifts are adaptation to night shift work and increased familiarity with the task (learning effect). Results that support the adaptation hypothesis are the increases in length and quality of daytime sleep, and the gains in subjectively and objectively assessed alertness over successive night shifts.

The results also clearly suggest that learning effects persist throughout the shiftwork simulation phases of the study for both 8-hr and 12-hr protocols. On the 8-hr shift protocol, most of the continued learning took place from 1500-2300 hours (i.e., during the six consecutive evening shifts), but on the 12-hr shift protocol continued learning took place in the hours from 1900-0700 (four consecutive 12-hr night shifts). The effect of time of day on efficiency of learning and training is an area which has received little experimental attention. It is tempting to speculate that variability in performance was influenced by the time of day when the learning occurred. Learning during the evening shift (1500-2300), when the circadian rhythm of alertness and performance is at its peak, may be superior to learning during the night shift, when circadian rhythms are moving toward their nadir. This may have contributed to shorter response latency for both 8E and 8N shifts, as compared to 12N shifts.

Sleep duration and quality also show significant day-of-shift effects. That is, sleep after the first two night shifts tends to be worse than sleep after subsequent night shifts for either 8-hr or 12-hr shift protocols. However, closer inspection of the data reveals that the day-of-shift effects in this study were attributable to a subset of subjects who were poor daytime sleepers, many of whom showed dramatic improvement in sleep duration and efficiency over the first three night shifts. Some process of adaptation seems to have occurred in these few individuals. It is unlikely that this adaptation was the result of shifts in their circadian rhythms, since earlier research studies have found minimal changes in circadian phase position, even after working six or more consecutive night shifts (Colquhoun et al., 1968; 1969; Dahlgren, 1981). However, it is quite possible that the special circumstances of these studies (no external windows, darkened sleeping rooms, fixed times in bed) facilitated circadian adjustment to a greater extent than did previous laboratory and field studies that did not adequately control these factors. Since there were no measurements of circadian phase in the studies reported here, improved circadian adjustment is speculative. Another explanation is that adaptation was simply related to increased sleep need due to the cumulative sleep deprivation over the first few night shifts. In other words, the accumulated sleep debt overwhelmed the circadian factors that were interfering with sleep quality and length.

Effects of Working Consecutive Weeks on Night Shift Alertness and Performance

One of the most important observations from this study may be that there is an advantage to working adjacent blocks of night shifts. Quantity and quality of daytime sleep, accuracy and speed in cognitive performance, and some subjective mood ratings improve significantly in the second of two consecutive weeks of 12-hr night shifts. Daytime sleep during the second block of 12-hr nights was better than sleep after the first block, which probably directly improved cognitive performance, alertness, and mood. This suggests adaptation to night work occurred during the first week of night shifts, which then carried over to the second week in spite of the 4-day break between duty shifts.

Inspection of sleep-wake logs kept voluntarily by seven of ten subjects during the four off days revealed an important pattern; without coaching on sleep strategies, a majority of subjects had adopted a sleeping strategy which has been described as *anchor sleep* in previous studies (Minors and Waterhouse, 1981). Thus, by taking a large proportion of their sleep on days off within the daytime sleep window dictated for the 12-hr night shifts, they were able to avoid backsliding to inefficient daytime sleep during the second week of night shifts. It is not clear why the majority of subjects independently adopted an anchor sleep strategy. The simplest explanation is that they learned this through previous shiftwork experience. Alternatively, it is feasible that in the controlled laboratory environment used in this study there was a greater degree of circadian realignment than has been previously reported. If the circadian nadir were delayed by a few hours from the usual time of 0400-0500, the preferred time of sleep onset and wake up would be equally delayed. While this appears to have been the case, there were no circadian measurements included in this study to support the hypothesis.

This finding has interesting implications for shift scheduling practices. Most nuclear operations schedules, both 8-hr and 12-hr, alternate between day and night shifts weekly or twice weekly. Six nuclear power plants currently use schedules that have adjacent blocks of night shifts. However, the advantages of a slower rotation pattern will be realized only if operators know of the anchor sleep strategy and are able to practice it on days off. Attempts to shift rapidly back to an "early to bed, early to rise" sleep pattern in order to participate in morning activities on off days will be counterproductive. The shift back to a daytime schedule will be difficult, as always, and the subsequent readjustment to night shifts will be the same as if operators had come directly from working day shifts.

Again, it is important to keep in mind that these studies were conducted under optimal and controlled laboratory conditions. Subjects had no commute home in bright sunlight after night shifts; they had only to walk next door to their apartments. Commuting in bright outdoor light in the early morning is believed to have potent effects on circadian rhythms. In the case of night shift workers, the effect would be to *advance* the circadian nadir to earlier clock hours (Czeisler et al., 1990). This works against the preferred phase *delay* of the circadian low point to later clock hours, which would improve daytime sleep. Many shiftworkers have independently learned that wearing dark sunglasses during the morning commute helps them sleep better during the daytime. Similarly, exposure to bright morning light on days off will work against the preferred anchoring of daytime sleep hours. For this reason, an effective training program in sleep would be a useful addition to any shift schedule that involves successive blocks of night shifts.

In contrast to the finding that the second of two consecutive blocks of 12-hr shifts is much easier to work, a week of 8-hr evening shifts worked before a week of 8-hr night shifts did not appear to improve daytime sleep, or on-shift alertness and performance. In fact, performance actually declined significantly across the 8-hr night shifts, suggesting that there was no lasting adaptation from having worked a week of evening shifts before the week of night shifts. This finding weakens the argument that continued learning is chiefly responsible for the performance improvement seen during the second week of 12-hr night shifts. It is likely that improved sleep quality and alertness played an important role in this improvement.

The subjects working on 8-hr shifts did not adopt an anchor sleep strategy for days off between blocks of shifts. Despite comparable prior experience with shiftwork and night work, nearly all subjects chose to sleep during normal nighttime hours on their off days, as they had during the week of 8-hr evening shifts. This suggests that unless an adjustment process takes place -- either a shift in circadian phase or a physiological change (as yet undefined) that increases daytime sleep propensity -- it is unlikely that workers will self-select an anchor sleep strategy on days off.

Some subjects in the 8-hr shift protocol had great difficulty adjusting to an 8-hr delay in their sleeping time when they started night work. A comparison of this week to the first week of 12-hr night shifts speaks against any distinct advantage of a clockwise rotation pattern. There was no apparent difference in sleep duration or efficiency between these two duty shifts, even though those beginning 12-hr night shifts had been restricted to sleeping only at night for two days prior to beginning their duty shifts. There was no opportunity for daytime sleep or pre-shift naps, options clearly available to those in the 8-hr shift protocol during their off days between evening and night shifts. In summary, this study found no advantage to working a block of evening shifts before a block of night shifts.

The possibility remains that pre-adjustment to night shifts can be accomplished during a week of evening shifts. Specific training and a self-disciplined sleep strategy would presumably lead to progressively later bedtimes and later wake-up times during the week of evening shifts. In practice, only a small proportion of shiftworkers adhere to such a pattern in their actual working lives. Rather, the majority maintain a schedule that does not include large amounts of morning sleep, which allows them to participate in the family or social activities in a primarily daytime society. This study further suggests that shiftworkers are unlikely to independently favor an anchor sleep strategy on days off unless there has been some physiological adjustment during a prior week of night shifts.

Experiment versus Actual Shiftwork

There are several caveats to keep in mind when evaluating the results of this study:

- The simulated 8-hr or 12-hr work schedules used in this experiment were not the same as those actually used in the nuclear power industry. In the work routines selected, total number of work hours were equalized (96), but the 12-hr shift protocol compressed these working hours into a period of 11.5 days, while the 8-hr shift protocol was nearly 15 days. Thus, subjects in the compressed workweek experienced increased working hours in fewer days, without reaping the benefit of more days off for recuperation and recreation. This may have some bearing on the only significant difference between the two protocols in terms of self-rated mood: those on 8-hr shifts rated themselves with significantly higher *happiness* scores than their counterparts on 12-hr shifts. This outcome is not surprising, since the subjects in the 12-hr protocol worked all 96 hours as night shifts, had little free time on experiment days, and had no more days off between blocks of simulated work shifts. In the industrial setting, it is more typical that employee satisfaction is higher on 12-hr shifts, since the compressed work week and long work shift are balanced by many more days off.

• The 8-hr shift schedules used in industry typically include seven consecutive evening and night shifts, but only six consecutive evening or night shifts were used in this study. This difference is relevant in that nuclear power plant operators report that they begin to feel less alert as the number of consecutive work shifts increases beyond five (EPRI NP-6748, 1990). This trend is apparent in some of the cognitive performance measures used in this study. Extrapolating from these data, even greater fatigue or performance decrements might have been expected on the seventh consecutive 8-hr night shift.

• In electrical installation work, productivity decreases as consecutive work hours per day or work days per week increase, the latter effect being the strongest (National Electrical Contractors Association, 1969). However, these data were derived from daytime labor only. The present study suggests that the drawbacks associated with extended work hours per day (12-hr shifts), are counterbalanced by the fact that fewer consecutive workdays per week are required (2 to 4 days on 12-hr shifts versus 6 to 7 days on 8-hr shifts).

• Waning motivation, rather that decreased alertness or performance *capacity*, may account for decrements in cognitive performance when there are many consecutive work shifts. This seems to have been the case in the 8-hr shift protocol, where performance accuracy decreased on the final nights of the study, but the subjects continued to perform tasks at an equal or even faster rate. This finding is more suggestive of disinterest than cognitive impairment due to fatigue or reduced alertness.

Reduced motivation in repetitious test batteries has plagued many laboratory and field studies, including the field study on 12-hr shifts conducted at the Fast Flux Test facility (Lewis et al., 1986; and D. Swaim, plant manager, personal communication). Furthermore, if performance testing is not conducted with the same frequency across all hours and days of shift, resulting data can be misleading. It is likely that monotonous tasks over many consecutive work shifts in the industrial setting similarly diminish motivation and negatively affect working efficiency.

• Alertness, fatigue, and circadian influences on performance are qualitatively and quantitatively different for day shift and night shift. This study does not address the effect of work shift duration (12-hr or 8-hr) for daytime work hours. Many operators who work regularly scheduled 12-hr shifts report that fatigue and the potential for human error is a greater problem for 12-hr day shifts than for 12-hr night shifts, due to the significantly higher workload and greater number of distractions (EPRI NP-6748, 1990). Also, the type of work tasks and number of coworkers differ greatly between day shifts and night shifts. For this reason, further studies of 12-hr shifts under conditions of high continuous mental or physical workload, comparable to day shift conditions, are warranted and important. Considering the above caveats, the reader should be cautious when extrapolating the findings of this study to the design of work schedules or to shiftwork practices and policies.

Summary

In summary, recent experience with 12-hr shifts in the nuclear power industry has been extremely positive. Little doubt remains concerning the acceptability of compressed work week schedules among the operators themselves: in most cases employees initiate the process of changing the work schedule. There is also little doubt that the primary motivation for implementing 12-hr work shifts is a desire to improve quality of life outside of working hours, rather than a desire to improve alertness and performance on shift. Over one half of all operators in the nuclear power industry now work regularly scheduled 12-hr shifts, and surveys have indicated that the majority strongly prefer not to return to 8-hr work schedules (EPRI NP-6748, 1990).

In light of the tremendous popularity of 12-hr shifts, employee self-ratings of alertness, fatigue, and performance in actual industrial trials must be viewed cautiously. Employees are unlikely to negatively rate a schedule that they feel vastly improves the quality of life outside of the workplace. It is therefore important that additional laboratory and field studies, such as this one, determine whether there is sufficiently robust objective evidence of performance deficit and fatigue to justify the widespread concerns about 12-hour shifts.

Regulatory agencies and company management are faced with the difficult task of deciding whether 12-hr schedules should be discouraged or even disallowed, particularly in industries for which fatigue-related human error or accident rates could seriously jeopardize public safety or create high costs or liabilities for the company. Considering the strong preferences of workers, and reported benefits in improved employee morale and plant operating efficiency, the case against working 12-hr shifts must include evidence that employee alertness and performance is compromised to an extent that is detrimental to safe and efficient plant operation. Field studies must also include assessment of the longer-term physiological and psychological well-being of employees.

The results of this study are encouraging for those plants that have had positive experience with 12-hr shifts, because they do not show that impairment in cognitive performance, reduced subjective or objective alertness, negative subjective mood and vigor, or lowered quality and quantity of daytime sleep are necessary consequences of working 12-hr shifts. Thankfully, dire predictions about the consequences of 12-hr shifts in terms of human error, accidents, and potential risks in terms of public safety (Kelly and Schneider, 1982) have simply not been borne out in actual industry experience.

However, 12-hr work shifts should be subject to continued scrutiny because of the distinct potential for fatigue, particularly when work load demands increase. Such would be the case during an emergency, or during a prolonged refueling or maintenance outage. In fact, the case could be made that 12-hr shifts are acceptable during normal operating conditions, but briefer shifts should be used during plant outages. Ironically, this is the reverse of present practices at many utilities.

In view of the growing popularity of compressed work week schedules and the evidence that plant operating efficiency can actually improve on 12-hr shifts, it is likely that these schedules will become even more prevalent in the nuclear power industry in the foreseeable future.

This report calls attention to some realistic shortcomings of 12-hr shifts, including the potential for fatigue and more frequent transitions to and from night shifts. Efforts to improve shiftworker alertness and performance should be intensified, with special emphasis placed on developing techniques for improving the amount and quality of sleep and for easing adjustment to night work and frequently rotating shiftwork schedules. Continuing efforts should also be made to define optimal practices for shift scheduling, overtime assignment, and work planning, so that inadvisable practices do not exaggerate the otherwise manageable problems of 12-hr work shifts.

REFERENCES

Journal Articles

Akerstedt, T., and Gillberg, M., "The circadian variation of experimentally displaced sleep," *Sleep*, 4:159-169, 1981.

Akerstedt, T., Torsvall, L., and Gillberg, M., "Sleepiness and shiftwork: Field studies," *Sleep*, 5:S95-S106, 1982.

Akerstedt, T., "Sleepiness as a consequence of shift work," *Sleep*, 11:17-34, 1988.

Anderson, R.M., and Bremer, D.A., "Sleep duration at home and sleepiness on the job in rotating twelve-hour shift workers," *Human Factors*, 29:477-481, 1987.

Angus, R.G., and Heselgrave, R.J., "Effects of sleep loss on sustained cognitive performance during a command and control situation," *Behavioral Research Methods, Instruments and Computers*, 17(1):55-67, 1985.

Babkoff, H., et al., "Dynamic changes in work/rest duty cycles in a study of sleep deprivation," *Behavior Research Methods, Instruments and Computers*, 604-613, 1985.

Baddeley, A., "A 3-min reasoning task based on grammatical transformation," *Psychonomic Science*, 10:341-342, 1968.

Bjerner, B., "Alpha depression and lowered pulse rate during delayed actions in a serial reaction test: A study in a sleep deprivation," *Acta Physiologica Scandinavica*, 19(S65):1-93, 1949.

Bjerner, B., Holm A., and Swenson, A., "Diurnal variation of mental performance. A study of three-shift workers," *British Journal of Industrial Medicine*, 12:103-110, 1955.

Borland, R.G., et al., "Performance overnight in shiftworkers operating a day-night schedule," *Aviation Space and Environmental Medicine*, 57:241-249, 1986.

Browne, R.C., "The day and night performance of teleprinter switchboard operators," *Occupational Psychology*, 23:121-126, 1949.

Carskadon, M.A., and Dement, W.C., "Cumulative effects of sleep restriction on daytime sleepiness," *Psychophysiology*, 18:107-113, 1981.

Carskadon, M.A., and Dement, W.C., "The multiple sleep latency test: What does it measure?," *Sleep*, 5:S67-72, 1982.

Colquhoun, W.P., Blake, M.J.F., and Edwards, R.S., "Experimental studies of shift work II: Stabilized 8-hour shift systems," *Ergonomics*, 11:527-546, 1968.

Colquhoun, W.P., Blake, M.J.F., and Edwards, R.S., "Experimental studies of shift work III: Stabilized 12-hour shift systems," *Ergonomics*, 12:856-882, 1969.

Czeisler, C.A., Weitzman, E.D., Moore-Ede, M.C., Zimmerman, J.C., and Knauer, R.S., "Human sleep: Its duration and organization depend on its circadian phase," *Science*, 210:1264-1267, 1980.

Czeisler, C.A., Johnson, M.P., Duffy, J.F., Brown, E.N. Ronda, J.M., and Kronauer, R.E., "Exposure to bright light and darkness to treat physiologic maladaptation to night work," *New England Journal of Medicine*, 322:1253-1259, 1990.

Corcoran, D.W.J., "Changes in heart rate and performance as a result of loss of sleep," *British Journal of Psychology*, 55(3):307-314, 1964.

Dahlgren, K., "Adjustment of circadian rhythms and EEG sleep functions to day and night sleep among permanent night workers and rotating shift workers," *Psychophysiology*, 18:381-91, 1981.

Daniel, J. and Potasova, A., "Oral temperature and performance in 8 h and 12 h shifts," *Ergonomics*, 32(7):689-696, 1989.

DeVries-Griever, A.G.H., and Meijman, T.F., "The impact of abnormal hours of work on various modes of information processing: A process model on human costs of performance," *Ergonomics*, 30(9):1287-1299, 1987.

Gillberg, M., and Akerstedt, T. "Body temperature and sleep at different times of day," *Sleep*, 5(4):378-388, 1982.

Hoddes, E., et al., "Quantification of sleepiness: A new approach," *Psychophysiology*, 10(4):431-436, 1973.

Johnson, M.P., Duffy, J.F., Jan Dijk, D., Ronda, J.M., Dyal, C.M., and Czeisler, CA., "Short-term memory, alertness and performance: a reappraisal of their relationship to body temperature," *Journal of Sleep Research*, 1:24-29, 1992.

Kelly, R.J., and Schneider, M.F., "The twelve-hour shift revisited: Recent trends in the electric power industry," *Journal of Human Ergology*, 11:369-384, 1982.

Kjellberg, A., "Sleep deprivation and some aspects of performance. I. Problems of arousal changes," *Waking and Sleeping*, 1:139-143, 1977a.

Kjellberg, A., "Sleep deprivation and some aspects of performance. II. Lapses and Other attentional effects," *Waking and Sleeping*, 1:145-148, 1977b.

Klein, K.E., Wegman, H.M., and Bruner, J., "Circadian rhythm in indices of human performance, physical fitness and stress resistance," *Aerospace Medicine*, 39:512-518, 1968.

Knauth, P., et al., "Duration of sleep depending on the type of shift work," *International Archives of Occupational Health*, 46:167-177, 1980.

Kogi, K., Takahashi, M., and Onishi, N., "Experimental evaluation of frequent eight-hour versus infrequent longer night shifts," *International Journal of Chronobiology*, 3:14-15, 1975.

Kogi, K., "Sleep problems in night and shift work," *Ergonomics*, 11(suppl.):217-231, 1982.

McKenzie, R.E., and Elliot, L.L., "Effects of secobarbitol and d-amphetamine on performance during a simulated air mission," *Aerospace Medicine*, 36: 774-779, 1965.

Mills, M.E., Arnold, B., and Wood, C.M., "Core-12: A controlled study of the impact of 12-hour scheduling," *Nursing Research*, 32:356-361, 1983.

Minors, D.S., and Waterhouse, J.M., "Anchor sleep as a synchronizer of rhythms on abnormal routines," *International Journal of Chronbiology*, 7(3):165-188, 1981.

Monk, T.H., and Leng, V.C., "Time of day effects on simple repetitive tasks: Some possible mechanisms," *Acta Psychologica*, 51:207-221, 1982.

Monk, T.H., "A visual analogue scale technique to measure global vigor and affect," *Psychiatry Research*, 27:89-99, 1988.

Naitoh, P., and Townsend, R.E., "The role of sleep deprivation research in human factors," *Human Factors*, 12(6):575-585, 1970.

Northrup, H.R., Wilson, J.T., and Rose, K.M., "The twelve-hour shift in the petroleum and chemical industries," *Industrial and Labor Relations Review*, 32(3): 312-326, April 1976.

Patrick, G.T.W., and Gilbert, J.A., "On the effects of loss of sleep," *Psychological Review*, 3:469-483, 1896.

Peacock, B., et al., "Police officers' responses to 8 and 12 hour shift schedules," *Ergonomics*, 26:5, 479-493, 1983.

Rosa, R.R., et al., "Extended work-days: Effects on performance and ratings of fatigue and alertness," *Behavioral Research Methods, Instruments & Computers*, 17(1):6-15, 1985.

Rosa, R.R., and Colligan, M.J., "Long workdays versus rest days: Assessing fatigue and alertness with a portable performance battery," *Human Factors*, 30(3):305-317, 1988.

Rosa, R.R., Colligan, M.J., and Lewis, P., "Extended workdays: Effects of 8-hour and 12-hour rotating shift schedules on performance, subjective alertness, sleep patterns, and psychosocial variables," *Work and Stress* 3(1):1-32, 1989.

St. John, D.E., "This plant uses a 12-hour workday," *Hydrocarbon Processing*, 183-190, June 1978.

Strogatz, S.H., Kronauer, R.E., and Czeisler, C.A., "Circadian pacemaker interferes with sleep onset at specific times each day: role of insomnia," *American Journal of Physiology*, 253:R172-R178, 1987.

Stroop, J.R., "Studies of interference in serial verbal reactions," *Journal of Experimental Psychology*, 18:643-662, 1935.

Thorne, D.R., "The Walter Reed Performace Assessment Battery," *Neurobehavioral Toxicology and Teratology*, 7:415-418, 1985.

Tilley, A.J., et al., "The sleep and performance of shift workers," *Human Factors*, 24:624-641, 1982.

Volle, M., et al., "Compressed work-week: psychological and physiological repercussions," *Ergonomics*, 22(9):1001-1010, 1979.

Walsh, J.K., et al., "Physiological sleep tendency on a simulated night shift: Adaptation and effects of trizolam," *Sleep*, 11:251-264, 1988.

Weiskotten, T.F., and Ferguson, J.E., "A further study of the effects of loss of sleep," *Journal of Experimental Psychology*, 13:247-266, 1930.

Wilkinson, R.T., "Interaction of lack of sleep and knowledge of results, repeated testing and individual differences," *Journal of Experimental Psychology*, 62:263-71, 1961.

Wilkinson, R.T., "The effects of up to 60 hours sleep deprivation on different types of work," *Ergonomics*, 7:175-186, 1964.

Wilkinson, R.T., and Houghton, D., "Portable four-choice reaction time test with magnetic tape memory," *Behavioral Research Methods*, 7:441-446, 1975.

Williams, H.L., Lubin, A., and Goodnow, J.J., "Impaired performance with acute sleep loss," *Psychology Monographs*, 73(14):484, 1959.

Williams, H.L., and Lubin, A., "Speeded addition and sleep loss," *Journal of Experimental Psychology*, 73:313-317, 1967.

Winfree, A.T., "Human body clocks and the timing of sleep," *Nature*, 297:23-27, 1982.

Winget, C.M., Hughes, L., and LaDou, J., "Physiological effects of rotational work shifting: A Review," *Journal of Occupational Medicine*, 20:204-210, 1978.

Technical Reports

American Power Dispatchers Association, Dispatcher Training & Education Committee Upper Midwest Area, "12-Hour Shift Schedules: A Survey of Eight Power System Control Centers in the Upper Midwest and Canada," September 1987.

Baker, T.L. et al., "Control-room operator alertness and performance in nuclear power plants," Circadian Technologies, Inc., EPRI Report NP-6748, February 1990.

Higgins, E.A., et al., "The effects of a 12-hour shift in the wake-sleep cycle on physiological and biochemical responses and on a multiple task performance," (FAA-AM-75-10), prepared for U.S. Department of Transportation, Federal Aviation Administration, 1975.

Johnson, L.C., and Naitoh, P., "The operational consequences of sleep deprivation and sleep deficit," (AGARDograph-193), London: Technical Editing and Printing, 1974.

Lewis, P.M., et al., "Evaluation of the 12-Hour Shift Schedule at the Fast Flux Test Facility," (PNL-6017), Report for Westinghouse Hanford Company, prepared for U.S. Department of Energy by Pacific Northwest Laboratory, Batelle Memorial Institute, September 1986.

Mackie, R., and Miller, J., "Effects of hours of service, regularity of schedules and cargo loading on truck and bus driver fatigue," Report prepared by Human Factors Research, Inc., 1978.

Naitoh, P., "Sleep loss and its effects on performance," Commentary and bibliography, Navy Medical Neuropsychiatric Research Unit, San Diego, CA, Report No. 68-3, 1968.

National Electrical Contractors Association, "Overtime and Productivity in Electrical Construction," Washington, D.C., 1969.

Ontario Hydro Technical & Training Services Division, "Analysis of the Impact of 12-hour Shifts on Human Performance at Ontario Hydro Nuclear Generating Stations," Annual Report, Ontario Hydro, Toronto, April 1986.

Smiley, A., and Moray, N.P., "Review of 12-hour shifts at nuclear generating stations," Research report prepared for Atomic Energy Control Board, Ottawa, Canada, Human Factors North, Inc., April 1989.

Wynn, S.C., "The Impact of the Twelve Hour Shift on Petrochemical Process Operators," Alberta Workers' Health, Safety and Compensation Committee, Occupational Health and Safety Division, Alberta, 1979.

Conference Proceedings

Butterfield, F.N., "Report on Actual Experience With 12-Hour Shift Schedule in an Operating Plant," *American Petroleum Institute Meeting*, Salt Lake City, Utah, 1979.

Moller, D.J., "The twelve-hour shift concept," *National Industrial and Labor Relations Conference, National Petroleum Refiners Association*, Denver, 1979.

Riemersma, J.B.J., et al., "Performance decrement during prolonged night driving," *Proceedings of the NATO Symposium on Vigilance II: Relationships among theory, physilogical correlates, and operational performance*, St. Vincent, Italy, 1976.

Books

Alluisi, E.A., "Influence of work-rest scheduling and sleep loss on sustained performance" (W.P. Colquhuon, ed.), *Aspects of Human Efficiency*, English Universities Press, London, 1972.

Campbell, D.T., and Stanley, J.C., *Experimental and Quasi-experimental Design for Research: Handbook for Research on Teaching*, Chicago, Rand McNally, 1963.

Colquhoun, W.P., "Circadian variations in mental efficiency" (W.P. Colquhoun, ed.), *Biological Rhythms and Human Performance*, Academic Press, New York, 39-107, 1971.

Hamilton, R., Wilkinson, R.T., and Edwards, R.S., "A study of four days of partial sleep deprivation" (W.P. Colquhoun, ed.), *Aspects of Human Efficiency*, English Universities Press, London, 101-113, 1972.

Li, J.C.R., *Statistical Inference I*, Ann Arbor, Michigan, Edwards Brothers, 1964.

Meddis, R., "Cognitive dysfunction following loss of sleep" (A. Burton, ed.), *The Pathology and Psychology of Cognition*, Methuen, London, 1982.

Monk, T.H., and Folkard, S., "Shiftwork and performance," (T.H. Monk and S. Folkard, eds.), *Hours of Work*, Chicester: John Wiley, 239-252, 1985.

Rechtschaffen, A., and Kales, A., *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects*, Public Health Service, U.S. Government Printing Office, Washington, D. C., NIH Publication No. 204, 1968.

Wilkinson, R.T., "Effects of sleep-deprivation on performance and muscle tension" (G. Wolstenholme and M. O'Connor, eds.), *Ciba Foundation Symposium on the Nature of Sleep*, Little, Brown, Boston, 329-342, 1961.

Winer, B.J., *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962.

Doctoral Thesis

Vincent, F.A., "Page-state data entry program (PSDENT), Ph.D. dissertation, Stanford University, 1977.

GLOSSARY OF TERMS

adaptation night A standard research laboratory procedure when studying sleep EEG is to have subjects spend one or two nights sleeping in the laboratory environment. It has been found that the unfamiliar bed and sleeping environment, and the application of electrodes for EEG recordings often causes disrupted and atypical sleep for the first one or two nights. The adaptation night served another purpose in this study. Eight hours of time in bed (TIB) from 2330-0730 was strictly enforced, and this was the only sleep allowed during the 56-60 hours before the first simulated work shift. Therefore, total duration and quality of sleep during the two days before beginning the experimental protocol was a known variable.

alarm acknowledgment event This term describes the primary activity of subjects while they operated the Foxboro process control simulator during simulated work shifts. Subjects' first duty was to recognize an alarm, which was indicated by an auditory signal or by a change in the color or form of a screen symbol. Alarm acknowledgment was a multi-step process that included calling up a screen that summarized alarm status, moving a cursor, then clicking on a screen target to enter in the computer record that the alarm was recognized. The computer recorded the clock time of acknowledgment, and calculated the total time that it took the subject to recognize the presence of the alarm and to take the appropriate steps to acknowledge it. Throughout the simulated work shifts, these data were recorded continuously at a printer located in the technician control room.

alarm acknowledgment time (ACK) This is the clock time when subjects properly responded to an auditory or silent alarm generated by the simulator. The time was recorded to the nearest second in the simulator computer record.

alarm acknowledgment latency (AAL) This is the time in seconds between the actual occurrence of a simulator auditory or silent alarm and the time when the subject properly responded to the alarm (ACK).

analysis of all data This is one method of data analysis used in this study. This analysis included data from all shift days and shift hours for each of the four shift conditions. Hence, the analysis of all data included hourly data for 48 hours of simulated work shift activity for 8-hr evening shifts, 48 hours for 8-hr night shifts, and 96 hours for the 12-hr night shifts.

anchor sleep This is a theory which states that sleep patterns can influence the circadian adjustment process. For example, workers on night shift schedules can benefit by maintaining a few hours of daytime sleep on days off.

bipolar EEG recordings This is a conventional technique for recording brain waves or other electrical signals from humans in which two electrodes are references to one another. Typically, an electrode over an active electrical site (one at which there are many electrical potentials) is referenced to one located at a relatively inactive site.

central EEG electrodes These are EEG electrodes placed at the top of the head, so named because they are positioned over the central lobes of the brain. These electrodes are optimal for recording K-complexes and vertex sharp waves in the EEG.

circadian rhythm This is the term used to describe the normal daily variation in any of a large number of physiological events, such as body temperature, sleep-wake tendency, hormone secretion, or urine production. This is a rhythm with a period of approximately 24 hours, from the Latin *circa* (about) *dia* (a day).

circadian nadir The nadir is the low point of the daily circadian rhythm in alertness and performance, which generally occurs between 0300 and 0700 for people on normal night sleep schedules.

comparable time analysis This is a type of data analysis used in this study to more directly compare the effects of extended work shifts. The analysis included only hours of shift and days of shift in the 8-hr and 12-hr shift work protocols that were directly comparable (nights one through four of a block of night shifts, and only the mutual hours of 2300-0700). Thus, the analysis included data collected during a total of 32 hours of the 8-hr night shift, and a total of 64 hours of the 12-hr night shifts (32 hours per week of 12-hr night shifts).

compressed work week schedule This term is applied to any of a variety of work schedules that compress the number of working hours into fewer work shifts. The most common types of compressed work week schedule are 10-hr work shifts (which compress 40 hours per week into four work shifts) and 12-hr work shifts (which compress an average of 42 hours work per week into seven work shifts spanning two weeks).

day of shift This term refers to the consecutive day of shift in a sequence of simulated work shifts. Day of shift effect on a measured variable was a significant difference between consecutive days in a sequence of simulated work shifts.

double shifts This is a standard technique used to provide additional staffing to fill vacant positions in an 8-hr shift work system. An employee simply works an additional consecutive 8-hr shift (16 consecutive hours of work), often at short notice and typically with overtime pay. Double shifts can seriously compromise employee alertness and performance.

electroencephalogram (EEG) These are commonly called brain wave recordings. Very small electrical potentials from the brain can be recorded at the scalp, amplified several thousand times, and recorded on paper or on analog recording devices.

electrooculogram (EOG) These are recordings of eye movement. The eye is an electrical dipole, having an electrical difference between its front and back. Small electrical potentials can be recorded from electrodes placed at the corners of the eye, which makes it possible to determine whether they are moving up, down, left or right.

electromyogram (EMG) These are muscle tone recordings. There are small electrical potentials from the muscle fibers that can be recorded from the skin directly over the muscle tissue.

exclusion criteria There are certain conditions or circumstances that can eliminate potential subjects from further consideration for research study participation (i.e. exclude them from the study). For example, one exclusion criterion used in this experiment was the current use of prescription medications that could alter alertness or sleep patterns. Another exclusion criterion was a history of epilepsy or of neurological trauma which had resulted in unconsciousness.

fixed shifts This is a type of shift work system in which employees are assigned to work one shift (day, evening, night) for extended periods of time. Typically, shift selection is determined by seniority on an annual basis or when vacancies occur.

hour of shift This term describes the consecutive hour of shift from the beginning of the simulated work shift. Hour of shift effect on a measured variable was a significant difference between consecutive hours of the simulated shift.

lights out to sleep onset (LO/SO) This is the interval from when lights are turned out to appearance of 90 or more consecutive seconds of Stage 1 sleep, or 30 or more seconds of Stage 2 non-REM sleep, SWS or REM sleep.

lights out to slow-wave sleep (LO/SW) This is the interval between lights out and the first epoch of Stage 3 or Stage 4 sleep (first epoch with at least 20% slow wave EEG activity). It is a measure of the latency to onset of deeper stages of sleep, and indicates whether the sequence of sleep stages is normal.

lights out to stage 2 non-REM sleep (LO/S2) This sleep latency measure is a more stringent definition of when sleep actually begins. Many sleep researchers believe stage 1 non-REM sleep is actually a transition stage between wakefulness and sleep, and that stage 2 non-REM sleep is the first sleep stage. Identification of stage 2 non-REM sleep is generally more precise, due to its characteristic EEG markers (spindles, K-complexes). Therefore, some feel that LO/S2 represents a more reliable index of sleep onset.

lux This is a standard measure of the intensity of light. One lux is the amount of light given off by a candle held one meter from the eye. It is the metric equivalent of a foot-candle, which is the amount of light given off by a candle held one foot away.

maintenance of wakefulness zone This is a term applied to periods of the 24 hour day when it is very difficult for humans to begin sleep or to remain asleep if already sleeping. The first zone occurs about 6-8 hours after the circadian nadir, at approximately 1100-1300. The second occurs just before the circadian peak, at approximately 1800-2000. These maintenance of wakefulness zones contribute to the poor sleep experienced by shift workers who must attempt to sleep during daytime hours.

microsleep This is a very brief period of sleep that occurs during a period of extended waking. Microsleeps may be only a few seconds long, and are believed to contribute to performance lapses.

movement time This is one of the possible classifications used in scoring polygraphic records for sleep and waking stage. Movement time was scored only when the polygraphic record was obscured by movement artifact (simultaneous movement of all recording pens) such that sleep/wake stage could not be determined. This typically occurred during sustained body movements during sleep or mid-sleep awakenings, but typically constituted only a few minutes of total recording time.

multiple sleep latency test (MSLT) This is a standard research test that determines the length of time it takes to fall asleep when given the opportunity to nap in a dark room lying in bed. The time to fall asleep, or sleep latency, is an accurate indicator of sleepiness. The test was given to subjects every 2 hours during their simulated work shifts.

muscle tonus Muscle tonus is activity of the muscle fibers. When muscle tonus is high, large numbers of individual muscle fibers generate small electrical potentials and the electromyogram shows high electrical activity. When muscle tonus is absent or very low (hypotonia or atonia), then the electromyogram shows little electrical activity.

occipital EEG electrodes These are EEG electrodes placed on the scalp at the back of the head, over the occipital lobes of the brain. These electrodes are optimal for recording alpha waves in the EEG. Recordings from these electrodes are useful for determining the moment of sleep onset, which is indicated by the disappearance of alpha waves. Further details are given in the Appendix.

polygraphic sleep recordings These are paper recordings made by an electroencephalograph machine. Polygraphic recordings may include multiple physiological variables, such as brain waves, eye movements, muscle tonus, respiration, and heart rate. Polygraphic recordings are more reliable for scoring stages of sleep and wakefulness because they measure characteristic physiological events, such as the muscle atonia and rapid eye movements of REM sleep.

psychotropic substance Psychotropic drugs or substances are those which alter the state of the central nervous system. Included in this category are stimulants, such as amphetamines, or depressants, such as prescription sleeping pills and tranquilizers.

rapid shift rotation This is the most common type of rotating shift schedule, in which the shift worked (day, evening, night) changes with each new set of consecutive shifts. For most schedules, this means that each week the work shifts begin at different times of day. In some schedules, the work shift changes two or three times per week.

recognized return to normal (RRTN) This is the time at which subjects recognized that a simulator parameter returned to within normal limits after having activated an alarm signal. The event was subtle, because it was indicated only by color or symbol changes in the CRT display. The event was marked in subject log books.

response latency This is the time that it takes a subject to complete an individual trial on one of the cognitive performance tests. It is synonymous with response time or reaction time. The PAB software automatically calculated mean response latency over all of the trials completed on a given battery, and stored both the mean response latency and the mean percent of correct responses in data summary files.

return to normal event (RTN) This is an event that occurred in the simulation of plant events after a parameter that had exceeded acceptable limits and activated an alarm spontaneously returned to within acceptable limits. The RTN event was silent, indicated only by a change in color or symbol shape on the simulator display screens. Subjects were instructed to watch their CRT screens carefully to detect the RTN event, which could occur a few seconds or several minutes after the alarm had signaled.

return to normal latency (RTNL) This is a measure of the time between the actual RTN event, recorded by the simulator computer, and the time when the subject noted the RTN event occurrence on his simulator activity log sheets.

rotating shift schedules These are work schedules in which the employees regularly alternate between day, evening and night shifts (or between day and night shift on 12-hr shifts). This is the most common type of shift work system. In the common 8-hr rotating shift schedules with seven consecutive days on each shift, employees change shifts three times in a 28-day period. In the most common 12-hr shift system (3-4 schedule), employees work two sets each of day and night shifts in a 28-day period.

shift condition This term describes four distinct types of work shift schedules used in this study: 8-hr evening shifts (six consecutive simulated work shifts that lasted from 1500-2300 each day), 8-hr night shifts (six consecutive simulated work shifts that lasted from 2300-0700 each day), 12-hr night shifts, week 1 (four consecutive simulated work shifts that lasted from 1900-0700 each day), and 12-hr night shifts, week 2 (four consecutive simulated work shifts that lasted from 1900-0700 each day, after an 84-hour break from 12-hr night shifts, week 1).

shift duration This term describes the total number of hours worked during a simulated work shift. There were two duration of shift conditions in this study: 8-hr shifts (evening and night shifts), and 12-hr shifts (night shifts only).

shift splitting This is a standard technique used to provide additional staffing to fill vacant positions in an 8-hr shift work system. An employee typically works an additional four hours beyond the scheduled 8-hr shift (12 consecutive hours of work), while another employee comes in four hours earlier than the next scheduled 8-hr work shift. Together, they fill the intervening 8-hr shift position that has been left vacant due to sickness, vacation, or other leave. Shift splitting often occurs at short notice and typically is rewarded by overtime pay.

sleep latency This is the time that it took a subject to fall asleep, measured from the moment the lights were turned out in the subject's sleeping room until the appearance of unequivocal signs of sleep on the electroencephalogram. The criterion for sleep onset was at least three consecutive 30-sec periods of stage 1 non-REM sleep, or one 30-sec period of stage 2-4 non-REM sleep, or REM sleep.

sleep onset to slow-wave sleep (SO/SW); sleep onset to REM sleep (SO/REM)
These are common measures of the temporal relationship of stages within sleep, which is also called the sleep architecture. Typically, sleep begins with a gradual progression through lighter stages of sleep (Stage 1, Stage 2) to Slow Wave Sleep. REM sleep typically comes much later, after 60-90 minutes of non-REM sleep stages. The measures serve as indicators of unusual conditions. For example, if a subject has gone much more than the typical sixteen consecutive hours without sleep, the SO/SW and SO/REM may be much shorter than usual.

slow shift rotation This is a type of rotating shift system in which the shift worked (day, evening, night) changes less frequently that in the rapid shift rotation system. More than one block of shifts (sets of consecutively worked shifts with intervening free days) are worked. In slow shift rotation systems, for example, employees may work two or three consecutive blocks of night shifts before rotating to day shifts.

Stanford Sleepiness Scale (SSS) This is a standard scale used to evaluate subjective sleepiness and alertness. It is a self-assessment tool, where individuals select a score of 1-7, each number corresponding to a list of adjectives describing feelings ranging from peak alertness and energy to struggling to remain awake.

3-4 shift schedule This is a variety of 12-hr rotating shift schedule in which employees work one 3-day and one 4-day block of shifts (3 or 4 consecutively worked shifts with intervening free days) in every two week period. The most common variety of 3-4 schedule alternates night and day shifts with each block of shifts. This type of schedule is extremely popular because it can give employees a very long break (7-9 days) in every 28-day shift rotation cycle.

time in bed (TIB) In this research study, the daily time in bed was held constant at 8 hours for all subjects. Time in bed had to begin within 1 hour of the end of the simulated work shift. If a subject awoke during the 8 hours TIB, they were required to remain in bed in their darkened bedroom.

time of alarm (TOA) This is the time, recorded by the simulator computer, when a parameter exceeded acceptable limits and activated an auditory or silent alarm.

total non-REM sleep time (TNREM) This is a measure of all non-REM sleep stages. It is the sum of stage 1 non-REM sleep, stage 2 non-REM sleep, and slow-wave sleep (which is the sum of stages 3 and 4 non-REM sleep).

total sleep time (TST) Total sleep time is the sum of all epochs scored as sleep (any stage), but excludes all mid-sleep awake epochs. Included in TST are: total stage 1 sleep time (TS1), total stage 2 sleep time (TS2), total slow wave sleep time (TSW), and total rapid eye movement sleep time (TREM).

total wake time (TWT) Total wake time is the total number of minutes per 480-minute recording that were scored as wakefulness. This measure includes all waking that occurred before, during, and after the actual sleep period within the 480-minute TIB with lights out. TWT can be subdivided into the following three additional variables: lights out to sleep onset (LO/SO), wake after sleep onset (WASO), and wake after final awakening (WAFA).

2-3-2 shift schedule This is a variety of 12-hr rotating shift schedule in which employees work three blocks of shifts (sets of consecutively worked shifts without intervening free days) in every two week period. The most common variety of 2-3-2 schedule alternates night and day shifts with each block of shifts. This type of schedule is popular because it provides at least Saturday and Sunday off every other weekend.

wake after sleep onset (WASO) This is the total minutes of wakefulness between sleep onset and awakening. Small WASO values indicate sleep that is efficient and not uninterrupted. Large WASO values occur when there are numerous or prolonged mid-sleep awakenings.

wake after final awakening (WAFA) This is the amount of time subjects spent awake in bed between their final sleep period and the end of the mandatory 8-hour TIB. It is measured from the final 30-sec epoch scored as sleep to the end of the scheduled lights out period.

zeitgeber This is a scientific term from the German for "time giver." It is used to define the external cues that indicate time of day to the centers in the brain controlling the internal time keeping system of the human body. Various examples of zeitgebers are the rising or setting of the sun, the timing of meals, and environmental sounds such as traffic noise at commute hour.

APPENDIX

Polygraphic Recordings

Technicians first measured and marked the correct electrode placements. They then exposed the scalp by parting the hair, cleaning and mildly abrading the skin with cotton swabs and alcohol. Silver cup electrodes were filled with conductive electrode paste, placed in the appropriate location on the scalp, and covered with gauze pads soaked in collodion. The collodion in the pads was dried using pressurized air supplied by a pump through flexible surgical tubing. This formed an air-tight seal over the electrodes and fixed them in place until removal with solvent.

Insulated wires leading from electrodes were bundled at the back of the neck. Pins at the cable ends were attached to a Medilog 4-channel recorder (Oxford Medical Instruments Co.) and mounted in a belt-worn pack for portable recordings. This device recorded EEG, EOG, and EMG on cassette tape for the duration of the simulated work shift.

For all recordings of off-shift sleep (in the subject's apartment), the terminal pins from electrode cables were removed from the Medilog recorder and inserted into electrically isolated junction boxes (Nihon-Koden Model JE-106 AB) which were connected via cable to a polygraphic recording machine (Nihon-Koden Model 4317-E electroencephalograph) located in the technician control room. This provided a continuous recording of EEG, EOG, and EMG variables on paper, such that the technicians could at all times determine whether the subject was awake or asleep and, if asleep, what stage of sleep was occurring.

Polygraphic paper recordings were also made at 2-hour intervals throughout the work shift, during Multiple Sleep Latency Tests (5-20 minute duration per test) and during the 8-hr post-work-shift sleep period. Recordings were made at paper speeds of 10 mm/sec, which corresponded to 30 seconds of recording time per page of polygraph paper. Each recording of the 8-hr sleep period generated at least 960 pages of recorded data.

Classification of Sleep and Waking Stages

The following is a description of the stages of sleep and waking classified using the standard criteria outlined in Rechtschaffen and Kales (1968). Four stages of non-REM sleep were defined (non-REM sleep stages 1-4). Stages 3 and 4 of non-REM sleep were combined in the later analysis to yield a single value for Slow Wave Sleep (SWS). REM sleep, wakefulness, and movement time made up the other three classifications. Briefly, the guidelines applied for assigning sleep-stage classifications to each 30-second page of polygraphic data were as follows:

Waking

The EEG during wakefulness predominantly consisted of low-amplitude, high frequency (13 to 35 Hz) beta activity accompanied by high EMG activity and frequent eye movements. When a subject was awake and relaxed, sinusoidal alpha activity (8 to 13 Hz) was superimposed on the beta pattern. Increased relaxation or reduced visual input (eyes closed) enhanced alpha activity. The alpha rhythm was best recorded over the occipital cortex (O1-A2 and O2-A1 electrode placements). As the subject changed from the relaxed, alert condition to drowsiness, the EEG activity slowed to a frequency nearer the lower end of the alpha range. Sleep onset was most clearly indicated by the disappearance of the alpha rhythm in the occipital EEG.

Stage 1 Non-REM Sleep

This is a transitional stage between waking and sleep that occurs when falling asleep or when falling back to sleep after being awakened mid-sleep. Stage 1 sleep typically lasts no more than 1 to 7 minutes. The EEG showed low-amplitude, mixed frequency activity in the beta and theta (4 to 7 Hz) ranges. Late in Stage 1, slower frequencies began to predominate and high amplitude (up to 200 micro volts) vertex sharp waves often appeared. EMG activity was usually higher than in other sleep stages, but amplitude varied greatly. The EOG often showed slow rolling eye movements. This stage makes up about 5 to 10 percent of total sleep time in adults during a normal night's sleep.

Stage 2 Non-REM Sleep

This stage was identifiable by the presence of sleep spindles and K-complexes. Sleep spindles are brief-duration sinusoidal rhythms (12 to 14 Hz) which increase and decrease in amplitude to create a characteristic spindle-shaped tracing. Sleep spindles were not restricted to non-REM 2, but occurred intermittently through Stages 2, 3, and 4 non-REM sleep. They were often obscured by high-amplitude slow waves in the deeper non-REM stages. The K-complex is a high-amplitude negative sharp wave followed immediately by a slower positive component. K-complexes, like spindles, occurred in other sleep stages as well. Stage 2 non-REM sleep usually constitutes the greatest proportion of sleep time in the human adult sleeping at night (45 to 55 percent of total sleep time).

Stage 3 and 4 Non-REM Sleep (Slow Wave Sleep)

Stage 3 non-REM sleep was scored when high-amplitude slow waves (greater than 75 micro volts peak to peak, 2 Hz or slower) appeared in 20 to 50 percent of the 30-second page of data. EMG activity was low, and eye movements were absent during slow-wave sleep (stages 3 and 4 non-REM sleep combined). Stage 4 non-REM sleep was defined by the presence of slow waves in more than 50 percent of the 30-second page. In adult subjects under usual night sleeping conditions, the majority of SWS is seen in the first one-third of the sleep period and constitutes about 10 to 20 percent of total sleep time.

All non-REM sleep stages were physiologically quiet and stable, compared to waking and REM sleep. Heart and respiratory rates tended to be slower and more regular, and the muscles were relaxed, although muscle tone was present to some extent in all non-REM sleep stages. Eye movements were rare, except for the slow rolling eye movements at sleep onset. When subjects were awakened from non-REM sleep (e.g. during MSLT naps), they sometimes reported fragmentary thoughts, vague scenes, or dream-like images.

Rapid Eye Movement (REM) Sleep

The EEG during REM sleep consisted of mixed-frequency, low-voltage activity closely resembling the EEG pattern of Stage 1 non-REM sleep. In the nocturnal sleep periods, such as during adaptation nights and after 8-hr evening shifts, REM sleep periods tended to become longer later in the sleep period. The first REM period was at times only 1 or 2 minutes long, while later episodes sometimes lasted 30 minutes or more. The first REM sleep period during night sleep typically occurred about 60-90 minutes after sleep onset, and rarely occurred before at least 40 minutes of non-REM sleep had elapsed. This pattern changed dramatically during daytime sleep following night shifts, where REM sleep could occur much earlier. REM sleep latency, or time from sleep onset to REM sleep onset, is an important clinical indicator of abnormal sleep stage organization. REM sleep constitutes about 20 percent of total sleep time in the adult under normal night sleep conditions.

REM sleep was accompanied by a broad spectrum of physiological changes. EMG activity reached its lowest levels during REM sleep. *Muscular atonia* (absence of muscle tone) is a characteristic of REM sleep and is known to affect all major muscle groups. The extra-ocular muscles are not paralyzed, however, and rapid eye movements (REM) occurred intermittently throughout this stage.

Dreaming probably occurs throughout each REM sleep episode; when awakened from sleep, adults are able to report dream content more than 70 percent of the time. REM sleep dreams are vivid, active, and filled with colorful and complex ideation. Spinal reflexes are markedly reduced during REM sleep. Cerebral blood flow is greater during REM sleep than either non-REM sleep or wakefulness. Metabolic changes also accompany REM onset, including increased brain temperature and increased brain oxygen consumption. Finally, temperature regulation is poor during REM sleep. Thermoregulatory mechanisms such as sweating, shivering, thermal vasodilation or vasoconstriction (widening or narrowing of blood vessesl), and thermal tachypnea (fast breathing or panting to dissipate heat) are inactive or absent.

Multiple Sleep Latency Test (MSLT)

The following is a more detailed description of procedures followed in the Multiple Sleep Latency Test (MSLT):

At scheduled test times, technicians relieved subjects of their duties and escorted them into the apartment bedroom for a nap test. Subjects were asked to lie down on their beds and remove their shoes. On each test they were given the instruction, "Now close your eyes, relax, and try to fall asleep". The technician then turned off the light, closed the door, and returned to the technician control room to monitor the subject's EEG, EOG, and EMG on the polygraph machine.

Technicians were trained to recognize the moment of onset of sleep. The first 30 seconds of Stage 1 sleep was marked on the paper record (see glossary definition of lights out to sleep onset (LO/SO)). To be certain of sleep onset, observation continued until the first 30-second period of Stage 2 sleep appeared, or until 20 minutes had elapsed. At this moment, the technician signaled the subject via intercom with the neutral statement, "The nap test is now over". The technician returned to the subject's bedroom and turned on the lights.

Because Stage 1 typically lasted less than 2 minutes, the subjects accumulated at most only a few minutes of the lightest stages of sleep in the course of bi-hourly MSLTs during their simulated work shifts.

At no time during the study were subjects given details about the test procedures (i.e., that they were to be awakened at the earliest stages of sleep). They were not permitted to take clocks or watches into the test, so they had no direct knowledge of the duration of each test until they returned to the simulation laboratory control room to resume duties.

Stanford Sleepiness Scale (SSS)

The following is a more complete description of the Stanford Sleepiness Scale:

Subjects were asked to record the scale value of the statement which best described their state of sleepiness from the following list of statements: (1) Feeling active and vital; alert; wide awake. (2) Functioning at a high level, but not at peak; able to concentrate. (3) Relaxed; awake; not at full alertness; responsive. (4) A little foggy; not at peak; let down. (5) Fogginess; beginning to lose interest in remaining awake; slowed down. (6) Sleepiness; prefer to be lying down; fighting sleep; woozy. (7) Almost in reverie; sleep onset soon; lost struggle to remain awake. This scale was developed by having research subjects classify hundreds of descriptive terms (Hoddes et al., 1973).

Scale for Global Vigor and Affect (GVA)

The scale for Global Vigor and Affect involved presenting subjects with a question, followed by a 100 mm line scale, labeled at either end with descriptions of opposite extremes of degrees of feeling (very little, very much). The subject's task was to draw a vertical hatch mark on the line based on how he felt at the moment. The questions asked on this GVA Scale (in order of presentation) were: (1) How alert do you feel?; (2) How sad do you feel?; (3) How tense do you feel?; (4) How much of an effort is it to do anything?; (5) How happy do you feel?; (6) How weary do you feel?; (7) How calm do you feel?; (8) How sleepy do you feel?. The items were always presented in this order, and were arranged to avoid problems of adjacent opposites (e.g. "alert" is not immediately followed by "sleepy").

Technicians measured the distance (mm) from the left end of the line to the subject's hatch mark. These values were then entered into computer files for statistical analysis and for computation of values for Global Vigor (GV) and Global Affect (GA) according to the following formula:

Global Vigor = [(alert) + 300 - (sleepy) - (effort) - (weary)] divided by 4

Global Affect = [(happy) + (calm) + 200 - (sad) - (tense)] divided by 4

Performance Assessment Battery
Walter Reed Army Research Institute

The following gives a more detailed description of the cognitive performance battery taken by subjects each hour during their simulated work shifts.

Logical Reasoning

This test was an exercise in transformational grammar adapted from Baddeley (1968). The subject was presented with a two letter string (either "AB" or "BA") along with a logical statement describing the order of the letters within the string (e.g., "B follows A," or "A is not preceded by B"). The subject's task was to press the "S" key if the logical statement was true or the "D" key if it was false (these keys were chosen over "T" and "F" keys because they are adjacent to one another on a conventional keyboard).

Two-Column Addition

This was a subject-paced arithmetic task. The subject was presented with a column of five 2-digit numbers in the center of the screen. The subject's task was to determine the 3-digit sum without using aids for the carry operation, and then to enter the sum from the numeric key pad as quickly as possible. The column of digits disappeared with the first key entry.

Four-Choice Serial Reaction Time

In this standard test developed by Wilkinson and Houghton (1975), the subject was presented with an array of four boxes arranged in a square on a black background. The subject was told that each box corresponds to one of four adjacent keys (4,5,1, and 2; also in a square pattern) on the numeric key pad. A red lighted background appeared in one box at a time, and the subject pressed the key on the key pad which corresponded to the position of the lighted box. The lighted background then moved to another box until a predetermined number of trials were completed.

Interval Production

This was a self-paced task, where the subject was asked to estimate sixty 1-second intervals. The subject was instructed to place his fingers on the "m" through "?" keys if he was right handed or the "z" through "v" keys if he was left handed. A red circle (clock face) and green radial arm (clock hand) appeared on the screen. The hand rotated clockwise 1/60 of the circumference of the circle each time the "M" or "V" key was pushed. The subject's task was to estimate 1-second intervals as nearly as possible. The time between key strokes was measured as one trial and this process was repeated for 60 trials.

Serial Add/Subtract

This was a machine-paced mental arithmetic task requiring sustained attention. The subject was instructed to place his fingers on the 4,5,6, and 0 keys of the numeric key pad. The subject first was presented with a single digit, then another single digit and then a plus or minus sign, all in the same screen location. The subject's task was to enter the least significant digit of the addition or subtraction result. (e.g. 8, 6, + equals 14, so the subject enters 4). If the result was a negative number, his task was to add 10 to it and enter the positive single digit remainder (e.g., 3, 9, - equals -6, so the subject enters 4).

Manikin

The Manikin Test was a visual/spatial perceptual task in which the subject was required to determine in which hand a stylized man (manikin) holds an object. The manikin appeared on the screen holding a solid red circle in one hand and a solid green square in the other. A border around the manikin indicated which target to identify (i.e. a red circular border indicated the solid red circle as the target; a green square border indicated the solid green square as the target). The subject's task was first to identify the shape of the outline, find the target, decide whether the target was held in the left or right hand of the manikin, and press a key to signify either left or right. The task was made more difficult by varying the position of the manikin, which appeared upside down or right-side-up, and facing either front or back.

Stroop

In this standard test (Stroop, 1935), the subject was presented with a word that was either red, green, or blue. The subject's task was to press the "1" key if the word was red, the "2" key if the word was green, or the "3" key if the word was blue. Neutral trials were those in which the word presented had nothing to do with color (e.g., the word "HOUSE" appeared in green, and the correct response was "2"). Incongruent trials were those in which a word describing color appeared, but the actual color of the word as it was presented on the CRT screen was different from the meaning of the word (e.g. "BLUE" appeared on the screen in red color; the appropriate response was "1", the incorrect response was "3").

In classical studies using the Stroop test, the incongruent condition produces an *interference effect*, meaning that the subject has difficulty suppressing the reading of the word in order to attend only to the color of the stimulus. This interference can appear in two forms, either as an increase in response latency, or as a reduction in accuracy.

	TIME	SUBJECT A	SUBJECT B
11 pm	23:00-23:15	PANEL	BACKUP
	23:15-23:30	BACKUP	PANEL
	23:30-23:45	PERF. #1	PANEL
	23:45-00:00	PANEL	PERF. #1
12 am	00:00-00:15	PANEL	BACKUP
	00:15-00:30	BACKUP	PANEL
	00:30-00:45	PERF. #2	PANEL
	00:45-01:00	PANEL	PERF. #2
1 am	01:00-01:15	MSLT 1	PANEL
	01:15-01:30	(same)	MSLT 1
	01:30-01:45	PERF. #3	(same)
	01:45-02:00	PANEL	PERF. #3
2 am	02:00-02:15	PANEL	BACKUP
	02:15-02:30	BACKUP	PANEL
	02:30-02:45	PERF. #4	PANEL
	02:45-03:00	PANEL	PERF. #4
3 am	03:00-03:15	MSLT 2	PANEL
	03:15-03:30	(same)	MSLT 2
	03:30-03:45	PERF. #5	(same)
	03:45-04:00	PANEL	PERF. #5
4 am	04:00-04:15	PANEL	BACKUP
	04:15-04:30	BACKUP	PANEL
	04:30-04:45	PERF. #6	PANEL
	04:45-05:00	PANEL	PERF. #6
5 am	05:00-05:15	MSLT 3	PANEL
	05:15-05:30	(same)	MSLT 3
	05:30-05:45	PERF. #7	(same)
	05:45-06:00	PANEL	PERF. #7
6 am	06:00-06:15	PANEL	BACKUP
	06:15-06:30	BACKUP	PANEL
	06:30-06:45	PERF. #8	PANEL
	06:45-07:00	PANEL	PERF. #8
7 am	07:00-07:20	MSLT 4	PANEL
	07:20-07:40		MSLT 4
	08:00	SLEEP	SLEEP

Table A This table shows a sample daily duty schedule given to subjects at the beginning of each simulated work shift. This example is for an 8-hr night shift. Subjects worked in pairs during this study. The order of the simulated work assignments, performance tests, and MSLT tests was varied by alternating subject designations (Subject A/Subject B) each experimental day. PANEL indicates operation of the Foxboro simulator, PERF indicates the hourly Walter Reed Performance Assessment Battery, MSLT indicates the bi-hourly Multiple Sleep Latency Test, and BACKUP indicates time for completing subjective rating scales and an opportunity to move freely about the simulated control room.

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC. Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-6046

2. TITLE AND SUBTITLE

Alertness, Performance, and Off-Duty Sleep on 8-Hour and 12-Hour Night Shifts in a Simulated Continuous Operations Control Room Setting

3. DATE REPORT PUBLISHED

MONTH	YEAR
April	1995

4. FIN OR GRANT NUMBER

L2630

5. AUTHOR(S)

T. L. Baker

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION – NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Institute for Circadian Physiology
677 Beacon Street
Boston, MA 02192

9. SPONSORING ORGANIZATION – NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This study of simulated 8-hr and 12-hr work shifts compares alertness, speed, and accuracy of subjects assigned to the two shift conditions. Twenty male subjects, ages 20 to 45, were randomly assigned to either an 8-hour or 12-hr shift protocol, working in teams of two in a process control simulator. In addition to the simulator monitoring task, subjects completed a 15-minute performance assessment battery and a vigor and affect scale hourly. Throughout the simulated work shift, alertness was monitored by recording electroencephalogram (EEG), electrooculogram (EOG) and electromyogram (EMG) data. At 2-hour intervals, subjects' sleepiness-alertness level was assessed via standardized nap tests. During off-shift hours, subjects lived in attached, self-contained apartments. Subjects were restricted to bed for an 8-hour sleep period in total darkness one hour after work shifts; EEG, EOG, AND EMG recordings were continued during sleep. During days off between blocks of shifts, subjects left the facility, but kept detailed logs of sleep-wake activities. No significant differences were found between subjects on 8-hr and 12-hr night shifts in performance on the simulator task, in length or quality of daytime sleep, or in physiological or subjective sleepiness-alertness on shift. Except for one subtest in the performance test battery, subjects on 12-hr shifts were slower, but more accurate, than those on 8-hr shifts. Several measures showed better alertness, mood, and off-duty sleep on evening shifts than on night shifts.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Alertness; Performance; Sleep; Twelve-Hour (12-Hour) Shifts; Eight-Hour (8-Hour) Shifts; Shiftwork; Fatigue; Shift Schedules; Circadian Rhythms

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE