

Technical Report 69-8

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The Effects of Sleep Deprivation on Performance Over a 48-Hour Period

by

Eugene M. Drucker, L. Dennis Cannon, and
J. Roger Ware

HumRRO Division No. 2 (Armor)

May 1969

Prepared for:

Office, Chief of
Research and Development
Department of the Army

Contract DAHC 19-69-C-0018

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HUMAN RESOURCES RESEARCH OFFICE

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**HumRRO Division No. 2 (Armor)
Fort Knox, Kentucky
The George Washington University
HUMAN RESOURCES RESEARCH OFFICE**

**Technical Report 69-8
Work Unit ENDURE
Sub-Unit I**

The Human Resources Research Office is a nongovernmental agency of The George Washington University. HumRRO research for the Department of the Army is conducted under Contract DAHC 19-69-C-0018. HumRRO's mission for the Department of the Army is to conduct research in the fields of training, motivation, and leadership.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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FOREWORD

The research described in this report was performed by the Human Resources Research Office under Work Unit ENDURE, Tank Crew Performance During Periods of Extended Combat. The objective of ENDURE I was to conduct a laboratory experiment for the purpose of determining the endurance of troops under extended periods of activity. This report describes the results of the experiment and its implications for extended combat.

The research was conducted at HumRRO Division No. 2 (Armor) when Dr. Norman Willard was Director of Research. Dr. Donald F. Haggard is the present Director of Research. Dr. L.L. Ainsworth is the present Work Unit Leader; Dr. L. Dennis Cannon was Work Unit Leader when the research for ENDURE I was conducted.

Personnel of the U.S. Army Armor Human Research Unit provided military support for this effort. Those most directly involved were SP 4 Duane D. Bangs, SP 4 Anthony S. Biagiotti, SP 4 James L. Constantinides, SP 5 Thomas E. Epperson, SP 4 Dennis E. Mixon, and SP 4 Woodie C. Smith. LTC John A. Hutchins, Jr. is Chief of the Unit.

Before the research described in this report was planned, a Consulting Report, "Summary of Literature Review on Extended Operations," December 1964, was prepared for the U.S. Army Combat Developments Command Armor Agency, summarizing the psychological literature pertaining to performance over extended periods of time, and containing sections on such topics as sleep loss, temperature, prolonged performance, and stress.

HumRRO research for the Department of the Army is conducted under Contract DAHC 19-69-C-0018. Training, Motivation, Leadership Research is performed under Army Project 2J062107A712.

Meredith P. Crawford
Director
Human Resources Research Office

SUMMARY AND CONCLUSIONS

Problem

Military equipment capable of operating for 48 hours or longer is now being developed. When this equipment becomes available, military personnel will be able to participate in sustained combat for longer periods of time than has ever before been possible. While technological advances will enable this equipment to perform reliably over extended time periods, little is known about the effects of sustained combat on the personnel who will operate the equipment. If they are unable to maintain a satisfactory level of performance, then the new equipment will not be able to function at its maximum potential. New training programs will need to be developed, or changes in military doctrine will be necessary.

A review of the psychological literature and military records pertaining to prolonged performance was conducted at the request of the U.S. Army Combat Developments Command Armor Agency. The review yielded little information about men's ability to perform for 48 hours or longer, and the information that was available often contained contradictions.

In order to obtain more reliable information on sustained performance, a research program was developed to determine how performing for 48 hours without sleep would affect the efficiency of the work produced. Also studied were the effects of starting to perform in the morning compared to starting in the evening, and the effects of job rotation when it provides no additional rest time.

Approach

The subjects were 142 enlisted men trained in armor who were assigned to one of four experimental conditions. In three of these conditions, subjects worked for 48 hours with a 15-minute break after every 1½ hours of work and a one-hour meal break every six hours, but with no additional time provided for sleeping. Subjects in the fourth (control) condition performed according to the same schedule except during the night hours, when they were allowed to sleep.

Subjects were assigned to two-man teams. One member of each team tracked a continuously winding road on a driving simulator; the other member worked on a target detection task—attempting to detect brief, infrequent light signals presented on a large screen. In two of the four experimental conditions, the subjects remained at the same task throughout the experiment; in the other two conditions, they rotated jobs after each 1½-hour period. In three conditions, the experiment began in the evening; in the fourth, it began in the morning. By comparing the performance scores of subjects in different pairs of conditions, the effects of sleep deprivation, starting time, and job rotation on performance were determined.

Results

Subjects who worked for 48 hours without time allotted for sleep performed significantly worse on the driving task than the control subjects, who were allowed to sleep from 0200 to 0700 each night. The difference in the performances of the two groups on the target detection task approached statistical significance. In both analyses, the period from 0200 to 0700 was not included because no data were available from the control subjects, who were sleeping. It was during these hours, when the subjects in the experimental group would normally be asleep, that their major performance decrements occurred. The decrements were much larger during the second night than during the first night.

The analysis of the effects of starting time showed that this factor, per se, was not a significant one. Instead, the time of day during which work was performed was found to be critical. After working the same number of hours, whichever group was working during its normal waking hours performed better than the group that was working during its normal sleeping hours. Furthermore, this difference in performance became greater as time went on.

Decrements in performance over the 48-hour work period were not eliminated by allowing subjects to rotate jobs periodically.

Conclusions

(1) Under laboratory conditions large performance decrements occur when men perform a task for 48 hours without sleep.

(2) Decrements in performance occur primarily at night, especially during the second night of a 48-hour period.

(3) A 48-hour simulated combat exercise will be necessary to determine the extent to which the decrements found under laboratory conditions will occur in the field. The greater amount of activity in the field, as well as an increase in the motivation of the subjects, may reduce the magnitude of the performance decrements.

(4) If the decrements appearing in the field are too great to be tolerated, it may be necessary to reduce the intended duration of combat in order to avoid combat participation when the decrement is most likely to occur. If tactical considerations prohibit this reduction, the development of special conditioning or training programs to prepare military personnel for sustained combat might be explored.

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**The Effects of Sleep Deprivation on
Performance Over a
48-Hour Period**

INTRODUCTION

new military equipment that is capable of operating continuously for 48 hours, without resupply or maintenance, is currently being developed for the Army. This expanded equipment capability will place increased demands on the soldiers who will operate this equipment. The increased durability and capacities of these weapons and vehicles will allow them to be used in sustained combat operations for longer periods of time than has ever before been possible. In order to profit by these technological advances, the soldier of the future must be capable of sustained performance for these increased periods of time. If he is not, either military doctrine will have to be changed to allow for this lack of ability, or a conditioning or training program will have to be developed to increase the soldier's ability to sustain effective performance over long time periods.

In order to determine what information was available concerning the soldier's ability to sustain his performance for extended periods, an extensive search was made of both military records and the psychological literature. Of more than 1,300 reports and studies reviewed, 113 were summarized in a consulting report, but the available information was too inconclusive to formulate a solution to the military problem (1).

Although there were numerous reports describing sustained combat during World War II and Korea, the extent to which performance was maintained at a satisfactory level could not be determined. There is no doubt that soldiers often fought for longer than 48 hours, but there is no way of estimating accurately the level of efficiency at which this activity took place. In order to provide the reliable information needed as a basis for future military doctrine, the soldier's endurance would have to be assessed more precisely than was possible from these military records.

The psychological literature also had limitations. Relatively few studies were related to sustained performance, and fewer still were concerned with periods as long as 48 hours. Others measured performance only at the end of a specified time, and provided no information about performance levels at other time periods. Furthermore, in some of the studies a significant decrement in performance level over time was found, while in others there was no decrement. In one study, for example, the performance of pilots was found to decline throughout a flight when crews were airborne for 15 hours four times a week (2). In another, the performance of civilian aircrews on a problem-solving and a perceptual-motor task deteriorated upon their return from six-hour to 21-hour flights, compared to their performance before the flights (3). The performance of Army truck drivers on psychomotor tasks declined after they drove for periods up to nine hours, except for performance on the ninth hour itself (4). In contrast, no decrement was found in the performance of pilots between the first and last parts of flights that ranged from 10 to 17 hours (5), or in the performance of Army truck drivers on a monitoring task while driving heavy commercial trucks in nine-hour shifts (6).

Since neither military records nor the psychological literature provided adequate information about human endurance, particularly endurance in combat situations, further research was necessary to obtain the required data.

The present study was undertaken to obtain information on the performance of military personnel over a 48-hour work period. Since the main area of concern was the endurance of tank crew members, tankers were selected as subjects. They participated in three tasks in the laboratory, two of which were a simulated driving task and a target detection task that simulated tasks performed during armor combat operations. These two tasks make it possible to take measures of performance continuously over the 48 hours. With such measures, performance can be plotted over time and a precise estimate can be made of performance efficiency after the lapse of any given period of time. It is also possible to ascertain any trends in performance over the 48-hour period.

In addition, subjects were timed on their performance of a third task—disassembly and assembly of a machinegun—which was performed once every six hours to provide data on the performance of motor tasks that are both short in duration and infrequent in occurrence.

OBJECTIVES OF THE STUDY

The major objective was to investigate the effects of working for 48 hours, without provisions for sleep, on the efficiency with which work was performed. The approach required each subject either to work at one task, or to alternate between two tasks, for the entire 48 hours with only brief rest breaks. A control group performed the same task over a 48-hour period, but with provisions made for sleep. The object was to determine the effects of sleep deprivation on work efficiency by comparing the performance of the subjects who work continuously for 48 hours with the performance of the control group.

The person who works around the clock without sleep must contend not only with fatigue, but also with physiological changes that normally occur as part of the diurnal cycle and probably interfere with performance efficiency. To determine the extent to which the diurnal cycle influences performance, subjects performing without provisions for sleep were divided into two separate groups. The subjects in one group began the 48-hour work period in the morning, while those in the other group began in the evening. The object was to establish the effects of time of day on performance efficiency by comparing the performance level of the two groups after the same number of hours on the job.

One other variable investigated was the effect of job rotation on performance efficiency. In many military crews that must perform for extended periods of time, crew members rotate positions in order to allow each member either a turn on a less demanding task or a chance to rest. To provide information on the extent to which performance level is enhanced by job rotation, subjects in one group rotated positions after each 1 1/2-hour period. The object was to determine to what extent job rotation facilitates performance by comparing the performance of subjects who rotated positions on the two tasks with the performance of subjects who did not.

METHOD

EXPERIMENTAL DESIGN

The experimental design required four groups of subjects. Comparisons of the performances of certain pairs of groups made it possible to determine

the effects of sleep deprivation, starting time, and job rotation upon performance efficiency. The four experimental groups and the conditions under which each group was tested are listed in Table 1.

All groups except Group IV performed for a 48-hour period without sleep. To determine the effects of sleep deprivation on performance, Group IV served as a control group, and its performance was compared to that of Group I. Groups I and IV

were the only groups (a) that started the experiment in the evening, and (b) whose members did not rotate jobs. The experimental conditions under which Groups I and IV participated were identical except for the provisions made for sleep.

To determine the effects of starting time on performance efficiency, the performance of Group II was compared to that of Group III. The subjects in both of these groups rotated jobs after each 1 1/2-hour period and no sleeping provisions were made for either group. However, Group II began the experiment in the evening, while Group III began in the morning.

To determine the effects of job rotation on performance efficiency, the performance of Group II was compared to that of Group I. Subjects in both groups were deprived of sleep and both started in the evening. Subjects in Group II rotated jobs after each period, while subjects in Group I did not.

SUBJECTS

The participants in this study were 142 enlisted men who had been trained as tank crewmen and were stationed at Fort Knox, Kentucky. Some of them had just completed Advanced Individual Training, Armor, or Basic Unit Training, Armor; others had recently been assigned to a TOE unit. Their average age was 21 years, ranging from 18 to 36 years with a standard deviation of 2.5 years. Time in service averaged 14 months, the range being from 4 to 219 months; average education was 12 years, the range being from 8 to 16 years.

All subjects were tested for visual acuity and color blindness. Men with less than 20/30 corrected vision or with color-deficient vision were replaced by subjects who had normal vision.

It had been planned that 50 subjects would be used in each of the four experimental conditions. However, a breakdown of the equipment prevented completion of data collection. As a result, 42 subjects participated in Group I, 21 as drivers and 21 as monitors; 20 subjects participated in Group IV, 10 as drivers and 10 as monitors. Group II and Group III contained 40 subjects each, all acting as drivers and monitors in rotation.

The men were selected by their military units for four-day assignments at HumRRO Division No. 2. Ten subjects participated simultaneously during each week of the experiment, and for convenience all 10 were assigned to the same experimental condition.

Frequent equipment breakdowns caused repeated interruptions in the experimental schedule, which resulted in nonrandom assignments of subjects to experimental conditions and nonrandom scheduling of experimental conditions. However, effects on performance due to differences between subjects and to

Table 1
Experimental Conditions Under
Which the Groups Participated

Group	Sleep Deprivation	Starting Time	Job Rotation	N
I	Yes	Evening	No	42
II	Yes	Evening	Yes	40
III	Yes	Morning	Yes	40
IV	No	Evening	No	20

seasonal differences in temperature and humidity were judged to be minor compared to effects due to experimental conditions.

APPARATUS

Five sets of equipment, each consisting of a driving simulator and a target detection response indicator, were available, so five two-man crews could be tested simultaneously. The target detection display was located in such a way that it could be monitored by one member of each crew at the same time, while the other member of each crew performed the driving task (Figure 1).

Two-Man Crew in Position During the Experiment



One member of the crew performs the driving task on a simulator while the other monitors the target detection display. The target display consists of four scenes, only partially visible in the photograph.

Figure 1

Driving Simulator

The driving task was performed on a simulator consisting of two major component groups—a steering mechanism containing a light source, and a simulated winding road containing photoelectric cells sensitive to the light emitted from the source on the steering mechanism. The task required the subject to operate the steering mechanism in such a manner that the light was maintained on the simulated winding road, which served to screen the light from the photoelectric cells. If steering was improper, the light deviated from the road and activated the photoelectric cells.

The steering mechanism consisted of a tank steering wheel and a column connected to a rack and pinion gear. A box connected to the gear housed a light bulb and a lens that aimed the light at the road. Turning the steering wheel moved the light beam to the right or left, allowing the road to be tracked.

The simulated winding road was located in a box 4 $\frac{1}{2}$ feet from the steering wheel. The road was in actuality an elastic belt one inch wide (dyed black) that was constantly moving downward over a white surface at a steady speed of 27 feet per minute. While it moved downward, the road also moved horizontally across the white surface. It was this horizontal movement that the subjects were required to track. The horizontal movement, which covered a maximum distance of nine inches, was controlled by a selsyn motor connected to a stepper switch. This arrangement resulted in an infinitely random pattern of movement. Since the horizontal movement always began at the top of the display and worked its way downward as the road moved vertically, any changes in the horizontal movement of the road could be perceived before a response was required from the subject.

The white surface on which the road moved consisted of a series of white belts that moved downward along with the road. Behind these belts were two photoelectric cells five inches wide that together spanned the entire width of the display. The light beam was aimed at these photoelectric cells and was bright enough to activate the cells after passing through the white belts. However, the light was not bright enough to activate these cells after passing through the black belt which simulated the road. The task required the subjects to maintain the beam of light, $\frac{1}{2}$ inch high and $\frac{3}{16}$ inch wide, on the road to prevent the photocells from being activated.

When either photocell was activated, a clock would operate in the experimenter's control room, giving a measure of the time during which the subject was unsuccessful in tracking the road. Another clock would operate only when the subject was successfully tracking the road. Thus, there were measures of time both on the road and off. Occasionally, a driving simulator would require servicing, and the driver's performance would be interrupted. By having two clocks, the duration of such an interruption could easily be determined.

Target Detection Display and Response Indicator

A white plywood screen, 19 $\frac{1}{2}$ feet high and 16 feet wide, was located 23 feet from the subjects. Projected on this screen were four field scenes, one scene in each quadrant of the screen. Embedded randomly in each quadrant were 11 neon lamps, which were not visible unless illuminated. According to a pre-arranged random schedule and at irregular intervals, but at the rate of 15 signals per 1 $\frac{1}{2}$ -hour period, one of the neon lamps flashed on for 2 $\frac{1}{2}$ seconds. It was the task of the subjects to watch the screen in order to detect these flashes. The signal intervals were punched on a leader tape fed through a modified Gerbrands interval programmer, while a stepper switch determined which one of the 44 lamps would flash.

Each subject was allowed five seconds to respond from the onset of a signal. A response was made by pressing one of four response buttons located on a panel directly in front of the subject. The response buttons corresponded in position to the quadrants of the screen, and the subject was required to press the button that corresponded to the quadrant in which the signal occurred. Both these responses and the signal presentations were recorded on an Esterline-Angus operation recorder located in the experimenter's control room.

The purpose of dividing the screen into four quadrants, each with its own scene, was to force the subjects to scan the entire display. Preliminary investigations revealed that when a single scene was used, subjects tended to fixate in the center of the scene and to scan very little. This procedure resulted in a

great deal of eye fatigue, and often the subjects were physically unable to continue to perform the task. By using four scenes, one in each quadrant of the large screen, the subjects no longer fixated on one point. Although some subjects were still susceptible to eye fatigue, few became physically unable to continue the task.

The projected scenes were slides taken at Fort Knox. These were changed every six hours in order to reduce somewhat the boredom of looking at the same scene for long periods of time.

Machineguns

The subjects used M-73 machineguns in a task which required them to disassemble and reassemble the guns as quickly as possible. However, this task was not included in the data analysis, because the individual guns differed greatly in the ease with which they could be disassembled and reassembled. Time measures were obtained from each subject every six hours during the experiment, but these measures appeared to be more closely related to the particular weapons than to the subjects. Weapons in good condition were disassembled and reassembled quickly, while those in poor condition could not be disassembled and reassembled quickly regardless of the skill of the subject. Because of the frequency with which the weapons were used during the study, and because of a shortage of parts, it was impossible to maintain all the weapons in such condition that they could be handled readily.

PROCEDURE

Ten subjects reported to HumRRO Division No. 2 each Monday morning throughout the experiment. On arrival, each was tested for visual acuity and color vision. Men who failed to meet the minimum visual standards were replaced immediately. On Monday afternoons subjects were briefed by the Chief, U.S. Army Armor Human Research Unit, and by the Work Unit Leader on the nature of the study and its importance to the Army. After the briefing, subjects were given instructions on the disassembly and assembly of the M-73 machinegun. When all subjects appeared able to complete the task without assistance, they were taken to the laboratory, assigned randomly to two-man teams, and given job assignments. Each subject was instructed on the performance of his task(s) and was allowed to practice for 30 minutes. When the practice session was completed, subjects were returned to the HumRRO area and provided with quarters by the Armor Human Research Unit for the night preceding the experiment.

The subjects in Group III were awakened at 0600 hours the next morning. After breakfast they were taken to the laboratory, and the experiment began at 0800 hours. The subjects in Groups I, II, and IV were free until the evening. They were assigned no duties and were encouraged to rest during the day as much as possible. At 1900 hours, they were taken to the laboratory in order to be ready to begin the experiment at 2000 hours.

The 48-hour work schedule required the subjects to work for periods of 1 1/2 hours, which were followed by 15-minute rest breaks. Every third period was followed by a one-hour break. During the 15-minute breaks, subjects were allowed to leave the experimental booths. During the one-hour rest breaks, subjects first performed the machinegun task and then were served hot meals. After that they were allowed to rest or do whatever they wished, except for a

two-man team responsible for cleaning the trays and eating area. The two-man teams rotated cleaning duty assignments so that no pair of men served more than twice during the experiment.

The work schedule for the experiment is contained in Table 2. During the 48 hours, each subject in Groups I, II, and III worked a total of 24 periods or 36 hours, and rested for 16 15-minute periods and eight one-hour periods. Thus, each subject had 12 hours of rest (less the time spent on the machinegun task and cleaning details). Subjects in Group IV worked for 18 periods or 27 hours, and rested for 12 15-minute periods and eight one-hour periods. Each subject was also allowed 10 hours of sleeping time, resulting in a total of 21 hours for rest and sleep.

Each two-man team was assigned to one of five experimental booths. These booths were five feet by eight feet, with walls eight feet high. The top and rear

Table 2
Work Schedule for the Experimental Groups^a

Periods	Groups I, II, and IV ^b		Group III	
	Hours	Day	Hours	Day
1	2000-2130	Tuesday	0800-0930	Tuesday
2	2145-2315	Tuesday	0945-1115	Tuesday
3	2330-0100	Tuesday	1130-1300	Tuesday
Break	0100-0200	Wednesday	1300-1400	Tuesday
4	0200-0330	Wednesday	1400-1530	Tuesday
5	0345-0515	Wednesday	1545-1715	Tuesday
6	0530-0700	Wednesday	1730-1900	Tuesday
Break	0700-0800	Wednesday	1900-2000	Tuesday
7	0800-0930	Wednesday	2000-2130	Tuesday
8	0945-1115	Wednesday	2145-2315	Tuesday
9	1130-1300	Wednesday	2330-0100	Tuesday
Break	1300-1400	Wednesday	0100-0200	Wednesday
10	1400-1530	Wednesday	0200-0330	Wednesday
11	1545-1715	Wednesday	0345-0515	Wednesday
12	1730-1900	Wednesday	0530-0700	Wednesday
Break	1900-2000	Wednesday	0700-0800	Wednesday
13	2000-2130	Wednesday	0800-0930	Wednesday
14	2145-2315	Wednesday	0945-1115	Wednesday
15	2330-0100	Wednesday	1130-1300	Wednesday
Break	0100-0200	Thursday	1300-1400	Wednesday
16	0200-0330	Thursday	1400-1530	Wednesday
17	0345-0515	Thursday	1545-1715	Wednesday
18	0530-0700	Thursday	1730-1900	Wednesday
Break	0700-0800	Thursday	1900-2000	Wednesday
19	0800-0930	Thursday	2000-2130	Wednesday
20	0945-1115	Thursday	2145-2315	Wednesday
21	1130-1300	Thursday	2330-0100	Wednesday
Break	1300-1400	Thursday	0100-0200	Thursday
22	1400-1530	Thursday	0200-0330	Thursday
23	1545-1715	Thursday	0345-0515	Thursday
24	1730-1900	Thursday	0530-0700	Thursday
Break	1900-2000	Thursday	0700-0800	Thursday

^aShaded areas indicate the nighttime portions of the schedule

^bGroup IV was allowed to sleep during Periods 4, 5, 6, 16, 17, and 18.

of the booths were open, while the front wall of each booth was only 2 1/2 feet high in order to allow the subject who performed the target detection task to see the screen. The monitor's target detection response indicator was connected to the front wall. The driver sat next to the monitor, but faced in the opposite direction. A schematic diagram of the booths and the location of the equipment is shown in Figure 2.

Schematic Diagram of the Experimental Situation

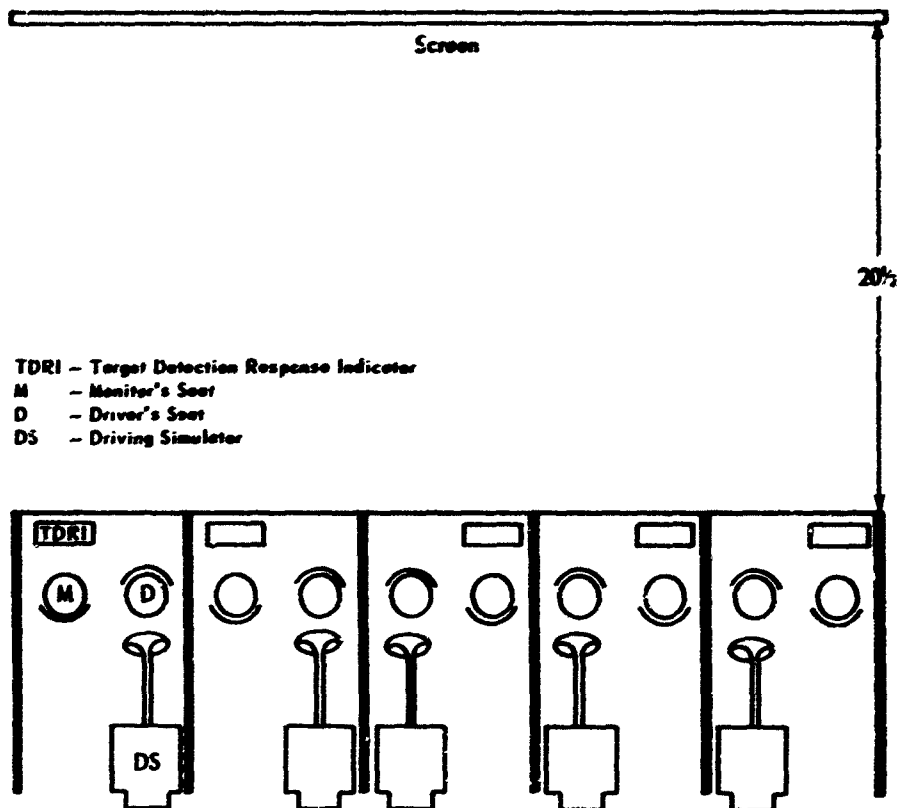


Figure 2

As an incentive to maintain a high level of performance, and as a means of alleviating the boredom involved in performing the same task(s), subjects were allowed to listen to a radio broadcast while they performed their jobs. Although it served as an incentive, the radio also created an interdependency between the two members of each team. The radio would remain on only when the monitor detected a signal. When a signal was missed, the radio was disconnected, and was not connected again until the monitor detected his next signal. This interdependent relationship between the monitor and his partner was judged to be comparable to that existing in combat situations where the welfare of the entire crew is dependent on the performance of each crew member. While the consequences of missing a target are far less severe in the laboratory than in combat, in both situations the crew members who are not conducting the watch must depend on the efficiency of those who are.

Each booth contained two sets of earphones over which the radio broadcasts could be heard. The radio was tuned to a local popular music station unless the subjects requested another station. During the evening when the local stations

were not broadcasting, tape recordings of daytime programs were played. Several tapes were prepared so that the subjects did not listen to the same programs repeatedly.

As an added incentive to remain awake for the duration of the experiment, each subject was informed during the briefings that he would be recommended for a weekend pass on completing his participation in the study. The recommendation would be made only when his performance was judged satisfactory. This incentive proved extremely attractive to many subjects, since they rarely if ever received such a pass. Also, it was announced during the briefing that each participant would be given a certificate of appreciation for his participation in the experiment. This certificate could be placed in the permanent military file of any subject who wished it placed there. Finally, it was announced that a letter of commendation would be sent to the military commander of any subject who did an outstanding job in the experiment, but that a letter of disapprobation would be sent to the military commander of any subject who was uncooperative and did an exceptionally poor job.

In order to facilitate communication between the experimenters and the subjects, an intercom system was installed between the experimental control room and each of the five booths. The experimenter used the intercom system primarily to inform the subjects when to begin working at the start of each period. The subjects' primary use of the intercom was to request permission to leave the booth to use the latrine.

The beginning of each period was announced over the intercom system. The experimenter indicated the rest breaks and the one-hour breaks to the subjects by turning off the driving simulators. Two minutes before the end of each break, a buzzer was sounded to alert subjects to return to the booths and prepare to resume the experiment. Every 30 seconds thereafter, the time remaining was announced over the intercom system. A final announcement was made five seconds before resuming the test.

In order to provide feedback to the subjects about their performance, scores were posted on the wall during each break. During the first day of each subject's participation in the study, interest in the scores was great. Competition for high scores was very common between the drivers and between the monitors, but it faded during the second day when most subjects became increasingly tired.

Strict discipline was not maintained during the experiment. The subjects were allowed to talk to their partners and to dress in any manner they wished. Although they were encouraged to stay awake, no effort was made to force them to do so. Subjects who fell asleep were awakened during the next break; the experimenter made certain that all subjects were awake at the beginning of a new period. Coffee was made available at all times, and aspirin was provided for any subject who requested it. When a subject complained of severe headache or illness, he was encouraged to continue with the experiment; if he insisted that he could not, he was allowed to rest on a cot located in the rear of the laboratory. Only rarely did a subject leave for this reason. More typically, a subject who developed severe eyestrain or headache would fall asleep on the job.

The subjects in Group IV were allowed to sleep after completing the machine-gun task begun at 0100, and they were awakened at 0700. Military cots were provided for sleeping.

RESULTS

The mean driving scores and the standard deviations for each of the four experimental groups are presented in Table 3, and the means are shown graphically in Figure 3. These scores indicate the mean amount of time, in minutes, during which the drivers successfully tracked the road during each 90-minute period. The maximum possible score was 90; the minimum score was approximately 25 because the random movement of the road would cause the road to block the light beam on occasion even if the driver made no attempt to track the road.

The mean driving scores of Groups I, II, and III showed marked fluctuations over the 24 periods, while Group IV maintained a high level of performance throughout the 18 periods during which it performed. The mean scores for Group IV ranged from a high of 89.8 to a low of 87.1. On the other hand, the scores for Group I ranged from a high of 86.8 to a low of 35.0; those for Group II ranged from a high of 87.8 to a low of 45.3; those for Group III ranged from a high of 86.8 to a low of 28.1. Thus, the highest mean scores attained by the three groups that performed without provision for sleep approximated the lowest score attained by the group that was allowed provision for sleep.

Table 3
Mean Driving Scores and Standard Deviations for the Experimental Groups^a
(Minutes)

Period	Group I		Group II		Group III		Group IV	
	Mean ^b	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1	86.8	2.9	87.7	3.3	84.0	8.2	88.5	1.8
2	86.0	7.6	87.7	2.0	86.8	2.7	89.2	1.0
3	85.6	11.5	87.8	5.2	86.3	2.8	88.9	1.2
4	82.8	10.6	84.6	10.0	86.2	5.3		
5	79.2	15.9	84.8	10.9	83.7	7.2		
6	70.0	20.2	78.7	16.4	85.8	3.9		
7	76.2	21.8	80.2	18.3	85.2	7.0	89.8	0.3
8	80.8	16.2	78.9	15.7	85.3	5.0	89.7	0.5
9	75.9	17.8	81.4	16.2	82.8	7.0	89.4	0.8
10	74.5	22.4	81.8	9.8	77.6	18.2	87.1	5.1
11	74.8	21.5	85.8	7.7	75.1	14.0	88.8	1.8
12	74.5	23.0	82.3	9.9	62.5	25.1	89.2	1.1
13	75.4	18.3	71.6	30.3	73.6	21.7	89.1	0.7
14	67.0	24.7	68.9	27.8	79.0	16.1	88.8	1.4
15	48.7	27.1	61.5	34.1	77.4	17.8	88.7	1.8
16	35.0	29.9	49.8	36.0	71.5	18.7		
17	40.1	30.1	50.7	35.5	73.4	12.6		
18	37.7	30.0	45.3	30.6	77.3	14.7		
19	56.7	28.9	68.0	27.6	79.5	17.6	88.0	3.7
20	67.7	25.1	64.7	26.8	66.9	27.2	88.5	2.7
21	76.6	18.3	81.5	16.3	40.3	28.0	87.5	3.6
22	76.4	18.2	51.0	34.0	38.4	27.2	88.0	3.8
23	67.0	24.4	84.2	11.5	28.1	27.8	88.2	1.8
24	72.0	20.8	71.0	25.4	35.9	32.0	88.4	1.2
Mean	69.5		73.8		71.8		88.6	

^aShaded areas indicate the nighttime portions of the schedule.

^bMaximum possible score, 90; minimum 25.

**Mean Driving Scores Obtained in Each Period
Over 48 Hours by the Four Groups**

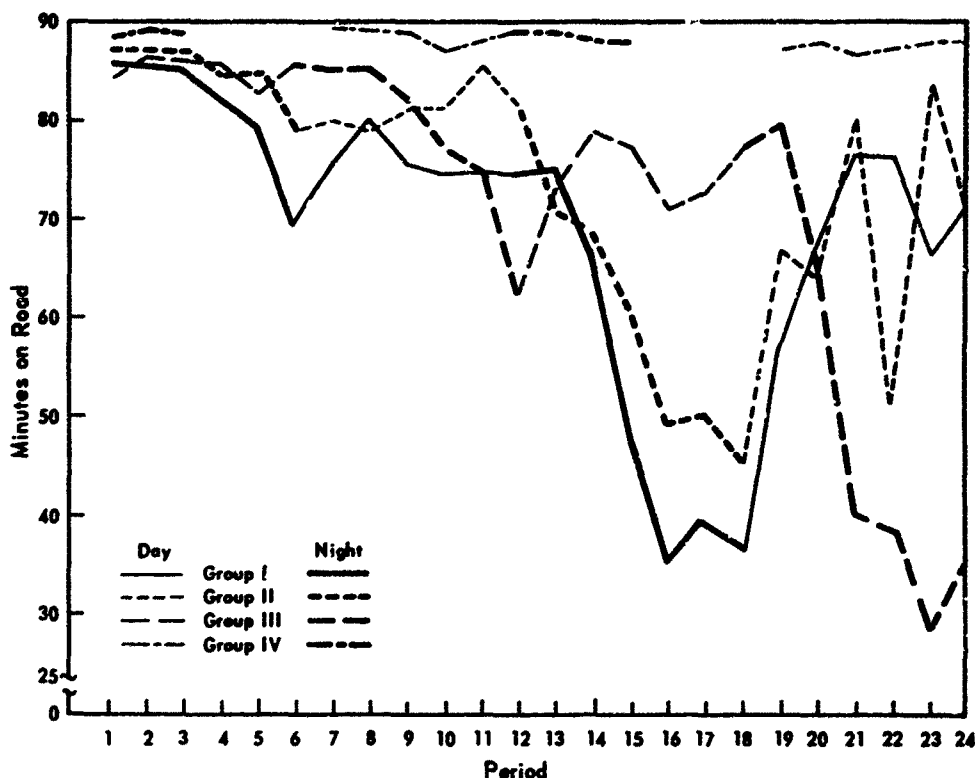


Figure 3

Groups I, II, and III showed deterioration in performance during the first night of the study. For Groups I and II, both of which began the experiment in the evening, maximum deterioration occurred during Period 6, or from 0530 to 0700 hours. For Group III, which began the experiment in the morning, maximum deterioration occurred during Period 12, also from 0530 to 0700 hours. In all three groups, performance declined throughout the first night, reaching its lowest point during either Period 6 or Period 12.

Performance recovered somewhat during the day after the first night, but deteriorated again during the second night, when deterioration became much more marked than it was during the first night. Groups I and II made their lowest scores during Periods 16 through 18, which occurred from 0200 to 0700 hours. Group III made its lowest scores during Periods 21 through 24, which occurred from 2330 to 0700 hours.

A second recovery appeared for Groups I and II during the day after the second night. Group II showed an additional drop during Period 22, from 1400 to 1530 hours, but performance again rose thereafter.

The standard deviations of the scores during each of the 24 periods also showed marked fluctuations. They ranged from 2.9 to 30.1 for Group I, and from 2.0 to 36.0 for Group II. For Group III, the range was from 2.7 to 32.0. The standard deviations for Group IV were much smaller than those for the other three groups, ranging from 0.3 to 5.1.

The magnitude of the standard deviations in Groups I, II, and III increased during the night, and observations indicated that subjects differed in ability

to stay awake. While some subjects were able to remain awake and continue to perform the tasks, most were unable to do so.

The mean target detection scores and their standard deviations are presented in Table 4, and the means are shown graphically in Figure 4. The maximum score attainable during a period was 15. As in the driving scores, there were marked fluctuations in the means over the 24 periods. Group IV did not maintain the level of performance throughout the target detection task that they did for the driving task. Instead, during those periods in which Group IV performed, the detection scores overlapped those attained by the other groups.

Table 4
Mean Target Detection Scores and Standard Deviations
for the Experimental Groups

Period	Group I		Group II		Group III		Group IV	
	Mean ^a	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1	11.3	2.5	10.5	2.4	9.8	2.6	11.4	1.7
2	11.5	2.6	9.0	3.2	10.2	3.2	10.6	2.2
3	10.2	2.5	11.4	2.3	10.1	2.6	9.7	2.7
4	10.2	2.5	10.3	2.3	9.6	3.0		
5	10.2	2.5	9.5	2.5	10.2	2.2		
6	10.2	2.5	8.5	2.7	10.1	2.1		
7	8.8	4.5	9.2	3.9	11.3	2.5	9.9	3.2
8	10.2	2.4	9.4	3.5	12.6	1.5	10.5	2.3
9	8.9	3.5	11.4	2.8	11.0	2.4	12.2	2.0
10	10.1	4.6	9.4	4.4	7.5	4.9	11.0	2.7
11	10.4	4.0	11.0	2.7	8.2	4.6	8.7	2.5
12	11.1	3.3	10.6	2.5	6.4	4.6	10.4	2.6
13	10.4	2.5	7.8	2.6	6.6	4.0	12.0	2.9
14	8.3	2.6	9.0	4.4	8.0	3.9	10.2	3.8
15	1.4	4.4	4.6	4.4	7.2	3.9	10.7	3.1
16	8.3	0.9	3.8	5.2	8.8	4.1		
17	1.5	2.1	3.3	5.2	8.4	3.4		
18	1.6	3.1	7.7	4.6	9.8	2.8		
19	6.2	4.4	4.4	3.0	10.4	3.6	10.1	3.1
20	7.0	3.7	9.2	4.9	6.9	4.0	10.9	2.2
21	10.6	3.6	10.2	2.5	5.2	5.1	10.1	2.2
22	11.0	3.4	10.7	2.5	4.6	4.1	11.7	3.1
23	11.1	2.2	11.0	3.0	3.2	4.5	12.3	1.7
24	10.6	3.1	12.6	2.1	4.4	4.7	10.6	2.8
Mean	8.4		8.8		8.4		10.7	

^aMaximum possible score, 15.

The trend toward performance deterioration during the night appeared in this task, as in the driving task. Groups I and III showed gradual declines in performance during the night, the greatest deterioration occurring between 0530 and 0700 hours during the first night, and between 0200 and 0700 hours during the second night. Group II exhibited its poorest performance in Periods 4 through 6 during the first night of the experiment, or from 0200 through 0700 hours, and in Periods 15 through 17 during the second night, or from 2330 to 0515 hours.

**Mean Target Detection Scores Obtained in Each Period
Over 48 Hours by the Four Groups**

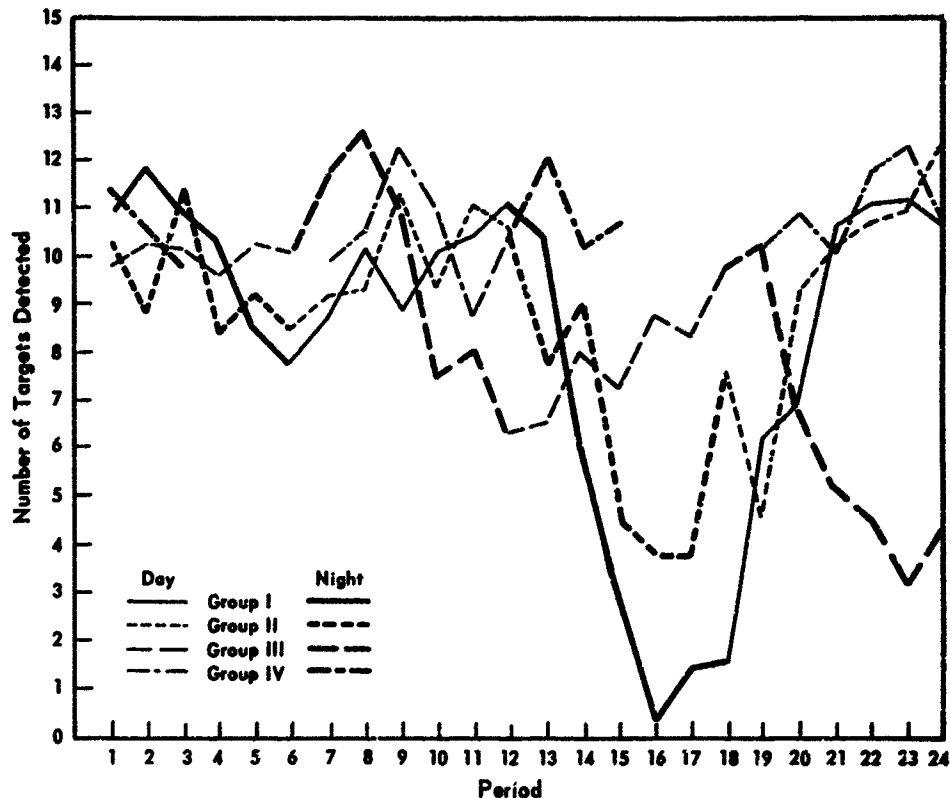


Figure 4

The standard deviations of the target detection scores, like those of the driving scores, showed great differences between periods. They ranged from 0.9 to 4.6 for Group I and from 2.1 to 5.2 for Group II. For Group III, the range was from 1.5 to 5.1; for Group IV it was from 1.7 to 3.8.

The marked heterogeneity of the standard deviations between experimental periods, and therefore of the variances also, violates one of the assumptions required for the use of analysis of variance. However, since heterogeneity was inevitable because of inherent differences between subjects in their ability to withstand the effects of sleep deprivation, analyses of variance were performed regardless. The probability values obtained under these circumstances are therefore not exact, but are approximations of the true probability values.¹

SLEEP DEPRIVATION

In order to determine the effects of sleep deprivation on the performance of the driving task, an analysis of variance was performed to compare Group I with Group IV. Only those periods in which both groups were working were included

¹The analysis of variance is a robust statistical procedure, and even major violations of underlying assumptions have small effects on the validity of the results. Some investigators conventionally assign probability levels to *F* ratios that are one step higher than tables indicate to compensate for violating the assumption. In this report, probability levels are taken directly from standard tables; *F* ratios and associated degrees of freedom are indicated so that other investigators may reinterpret the findings if they wish.

in the analysis; the data obtained from the subjects in Group I during Periods 4, 5, 6, 16, 17, and 18 were omitted. The mean driving score for Group I was 73.5, compared to 88.6 for Group IV. Significant effects were obtained for sleep deprivation, $F=25.49$, $df=1/29$, $p<.01$; and for periods, $F=5.65$, $df=17/493$, $p<.01$. There was also a significant interaction between sleep deprivation and periods, $F=2.56$, $df=17/493$, $p<.01$.

The significant effect for sleep deprivation suggests that the subjects who worked without sleep over the 48-hour period performed significantly worse than those who were allowed to sleep during their normal sleeping hours. The importance of this conclusion becomes enhanced when it is further considered that the periods in which Group I performed the poorest were omitted from the analysis.

The fluctuations in performance over periods by Group I, as well as the overall decline of the group in driving efficiency, is reflected in the significant effects for periods as well as in the significant interaction between periods and sleep deprivation. Again, these results were obtained in spite of the fact that the portion of the data in which the performance of Group I was worst was omitted.

On the target detection task, Group I detected a mean of 9.4 targets per period when the data from Periods 4, 5, 6, 16, 17, and 18 were omitted, compared to a mean of 10.7 targets detected by Group IV. While the difference between the two groups was not statistically significant, $F=4.02$, $df=1/29$, $p>.05$, a difference this large would occur by chance less than 10% of the time when there is no difference between the two groups. As on the driving task, fluctuations in performance were reflected by a significant effect for periods, $F=10.44$, $df=17/493$, $p<.01$, and by a significant interaction between periods and sleep deprivation, $F=4.91$, $df=17/493$, $p<.01$.

STARTING TIME

In order to compare the effects of starting the experiment in the evening with the effects of starting in the morning, an analysis of variance was performed to compare Group II (which started in the evening) with Group III (which started in the morning). Since subjects in both groups rotated jobs after each period, it was necessary to combine the data from each two consecutive periods in order to perform the analysis, in effect reducing the number of periods from 24 to 12. These new periods will be designated as Periods 1', 2', 3', through 12'. A summary of starting and terminating times for Periods 1' through 12' is shown in Table 5.

The means and standard deviations for Groups II and III on the driving task for each of the 12 periods are shown in Table 6. The overall mean for Group II is 73.8, and that for Group III is 71.8. The difference between the two groups was not statistically significant, $F=0.85$, $df=1/78$. The effect for periods, however, was significant, $F=33.30$, $df=11/858$, $p<.01$, as was the interaction between starting time and periods, $F=22.58$, $df=11/858$, $p<.01$.

The mean driving scores for the two groups over each of the 12 periods is shown graphically in Figure 5, which shows that the two groups alternated across periods in their performance efficiencies. During Period 3', the subjects in Group III maintained the light beam on the road about three minutes longer than those in Group II. Period 3' occurred in the late afternoon for Group III, but in the early morning for Group II. Twelve hours later, during Period 6', the performance of Group II surpassed that of Group III by about 15 minutes. This time Group II was performing in the late afternoon and Group III in the early

Table 5
Work Schedule for Combined Periods Used
in the Analysis of Starting Time Data^a

Periods	Group II		Group III	
	Hours	Day	Hours	Day
1'	2000-2130	Tuesday	0800-0930	Tuesday
	2145-2315	Tuesday	0945-1115	Tuesday
2'	2330-0100	Tuesday	1130-1300	Tuesday
	0200-0330	Wednesday	1400-1530	Tuesday
3'	0345-0515	Wednesday	1545-1715	Tuesday
	0530-0700	Wednesday	1730-1900	Tuesday
4'	0800-0930	Wednesday	2000-2130	Tuesday
	0945-1115	Wednesday	2145-2315	Tuesday
5'	1130-1300	Wednesday	2330-0100	Tuesday
	1400-1530	Wednesday	0200-0330	Wednesday
6'	1545-1715	Wednesday	0345-0515	Wednesday
	1730-1900	Wednesday	0530-0700	Wednesday
7'	2000-2130	Wednesday	0800-0930	Wednesday
	2145-2315	Wednesday	0945-1115	Wednesday
8'	2330-0100	Wednesday	1130-1300	Wednesday
	0200-0330	Thursday	1400-1530	Wednesday
9'	0345-0515	Thursday	1545-1715	Wednesday
	0530-0700	Thursday	1730-1900	Wednesday
10'	0800-0930	Thursday	2000-2130	Wednesday
	0945-1115	Thursday	2145-2315	Wednesday
11'	1130-1300	Thursday	2330-0100	Wednesday
	1400-1530	Thursday	0200-0330	Thursday
12'	1545-1715	Thursday	0345-0515	Thursday
	1730-1900	Thursday	0530-0700	Thursday

^aShaded areas indicate the nighttime portions of the schedule

Table 6
Mean Driving Scores and Standard Deviations
for Groups II and III in Starting Time Comparison
(Minutes)

Period	Group II		Group III	
	Mean	Standard Deviation	Mean	Standard Deviation
1'	87.7	2.6	85.5	6.3
2'	86.2	8.0	86.2	4.2
3'	81.8	14.1	84.8	5.8
4'	79.6	16.9	85.2	6.0
5'	81.6	13.2	80.2	13.9
6'	84.1	8.9	68.8	21.0
7'	70.2	28.8	76.2	19.0
8'	55.7	35.1	74.6	18.2
9'	48.0	32.8	75.3	13.8
10'	66.4	26.9	73.2	23.7
11'	66.7	30.3	39.4	27.6
12'	77.5	20.7	32.0	30.2
Mean	73.8		71.8	

Mean Driving Scores Obtained in Each Combined Period Over 48 Hours
by Groups II and III in Starting Time Comparison

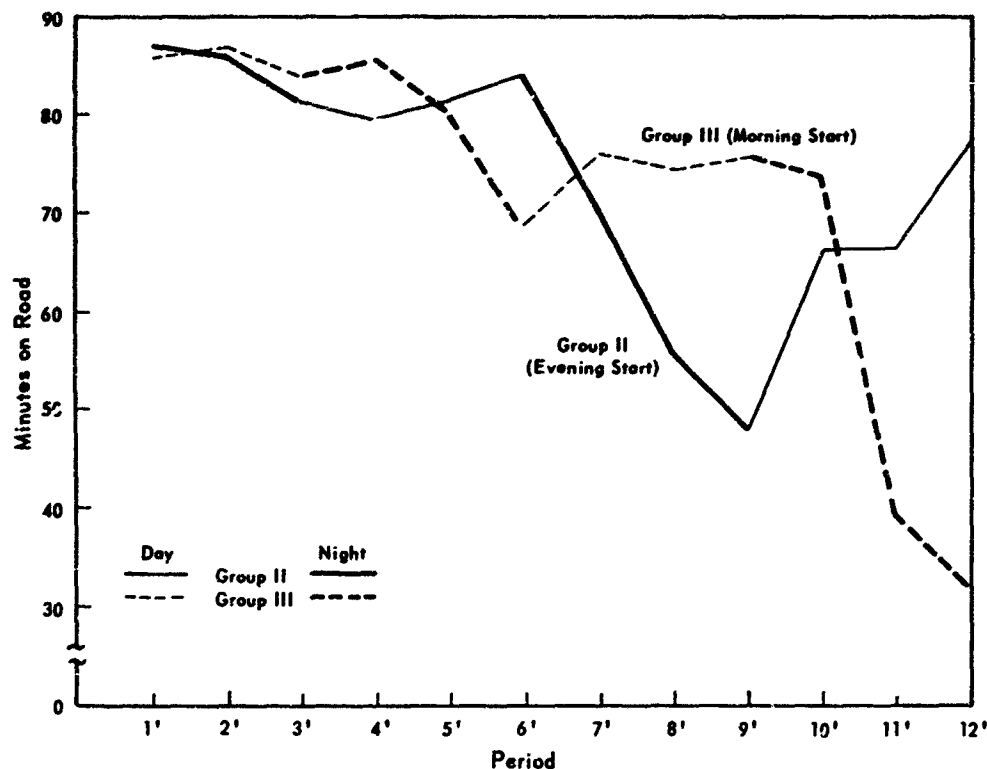


Figure 5

morning. Twelve hours later, during Period 9', the time was again identical to that of Period 3'. As before, Group III was superior to Group II, this time by approximately 27 minutes. Finally, after another 12 hours, during Period 12', Group II performance was again superior to Group III performance, and the difference between the two groups had grown to more than 45 minutes.

These data suggest that, after the same number of hours of sleep deprivation, whichever group is performing during its normal waking hours will be superior to the group that is performing during its normal sleeping hours. Also the difference between the two groups will increase as sleep deprivation is prolonged.

The means and standard deviations for Groups II and III on the target detection task are listed in Table 7. The overall mean was 8.8 for Group II and 8.4 for Group III. The difference between the performances of the two groups on this task was not statistically significant, $F = 0.98$, $df = 1/78$. The effect for periods, however, was significant, $F = 14.96$, $df = 11/858$, $p < .01$; also, the interaction between starting time and periods was significant, $F = 26.55$, $df = 11/858$, $p < .01$.

The mean target detection scores for the two groups are shown graphically in Figure 6. As in driving, the two groups alternated in their performance efficiencies. During Period 3', Group III was superior to Group II, detecting an average of 1.3 more targets per subject. During Period 6', the subjects in Group II detected an average of 3.6 targets more than the subjects in Group III. During Period 9', Group III once again detected more targets than did Group II,

Table 7
Mean Target Detection Scores and
Standard Deviations for Groups II and
III in Starting Time Comparison^a

Period	Group II		Group III	
	Mean	Standard Deviation	Mean	Standard Deviation
1'	9.6	2.9	10.0	2.9
2'	9.9	3.2	9.8	2.8
3'	8.8	4.2	10.2	2.1
4'	9.3	3.7	12.2	2.1
5'	10.4	3.8	9.2	4.2
6'	10.8	2.6	7.2	4.6
7'	8.4	3.6	7.3	4.0
8'	4.2	4.8	8.0	4.0
9'	5.8	5.2	9.1	3.1
10'	6.8	4.7	8.6	4.2
11'	10.4	2.5	4.9	4.6
12'	11.8	2.7	3.8	4.6
Mean	8.8		8.4	

^aShaded areas indicate the nighttime portions of the schedule.

Mean Target Detection Scores Obtained in Each Combined Period
Over 48 Hours by Groups II and III in Starting Time Comparison

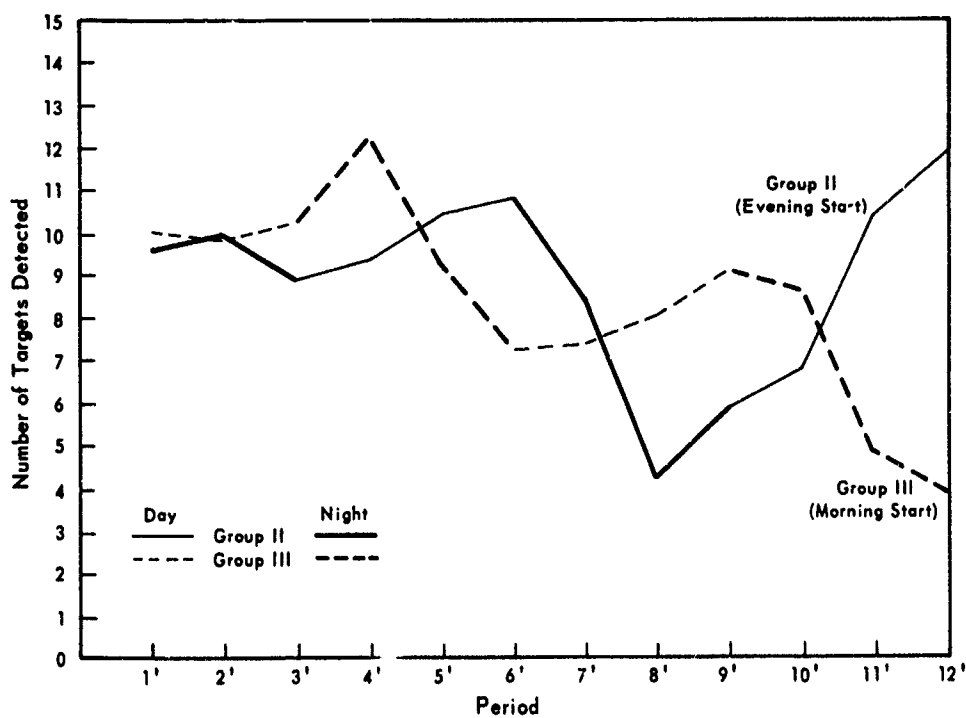


Figure 6

although the difference between the performance of the two groups decreased to 3.4. Finally, during Period 12', the subjects in Group II detected an average of 8.0 more targets than the subjects in Group III.

The data obtained from the target detection task support those obtained from the driving task. After working the same number of hours without sleep, whichever group is working during the day or during its normal waking hours will be superior in performance to the group that is working at night or during its normal sleeping hours.

JOB ROTATION

To determine the effects of job rotation on performance efficiency, the performance of Group II, whose members rotated jobs after each 1 1/2 hour period, was compared to the performance of Group I, whose members did not rotate jobs. In the analysis for starting time, where both groups rotated positions, each adjacent two periods were combined so that each subject would have one score on each task during each period. This procedure could not be used in the analysis for job rotation. If adjacent periods were combined, each subject in Group I would have two scores on a task, but each subject in Group II would have only one score. For this reason, separate analyses of variance were performed for even-numbered periods and for odd-numbered periods. Although team scores could have been derived, the analyses were performed on data obtained from individual subjects so that all analyses performed in the study would be consistent.

The mean driving scores are shown graphically in Figure 7 for odd-numbered periods and in Figure 8 for even-numbered periods. During all the odd-numbered periods except Period 13, the subjects in Group II, who rotated jobs after each period, obtained higher driving scores than subjects in Group I, who did not rotate jobs. The analysis of variance resulted in a significant effect for rotation, $F=5.72$, $df=1/39$, $p<.05$. The effect for periods was also significant, as expected, $F=17.28$, $df=11/429$, $p<.01$; while the interaction between rotation and periods was not significant, $F=0.91$, $df=11/429$.

During most of the even-numbered periods except Period 8, the subjects in Group II, who rotated positions, obtained higher driving scores than the subjects in Group I. However, during Periods 20, 22, and 24, subjects in Group I obtained higher scores than subjects in Group II. This difference appeared in the analysis as a significant interaction between periods and rotation, $F=2.50$, $df=11/429$, $p<.01$. The effect for rotation was not significant, $F=0.25$, $df=1/39$, and the effect for periods was significant, $F=21.51$, $df=11/429$, $p<.01$.

The mean target detection scores are shown graphically in Figure 9 for odd-numbered periods and in Figure 10 for even-numbered periods. The analyses of variance showed no significant effects for rotation either during the odd-numbered periods, $F=0.16$, $df=1/39$; or during the even-numbered periods, $F=1.90$, $df=11/429$. The effects for periods were significant for both the odd periods, $F=39.85$, $df=11/429$, $p<.01$; and the even periods, $F=31.33$, $df=11/429$, $p<.01$. The interaction between rotation and periods was significant for both odd periods, $F=2.56$, $df=11/429$, $p<.01$; and even periods, $F=6.57$, $df=11/429$, $p<.01$.

DISCUSSION

The results of the study indicate that performance cannot be sustained at a high level of efficiency over a 48-hour period of sleep deprivation, at least not

**Mean Driving Scores Obtained Over 48 Hours in Odd-Numbered Periods
by Groups I and II in Job Rotation Comparison**

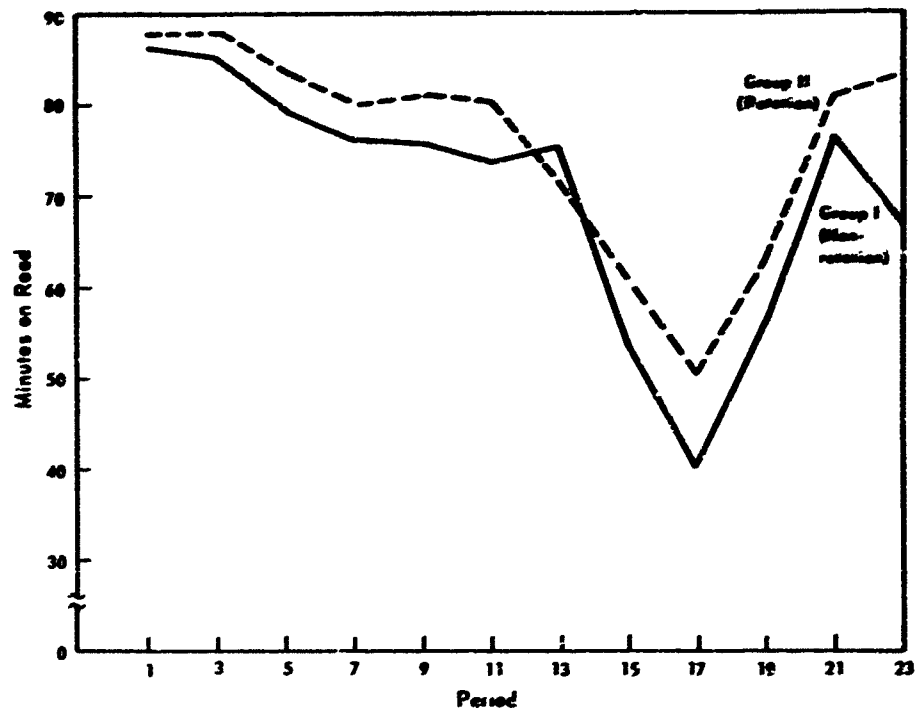


Figure 7

**Mean Driving Scores Obtained Over 48 Hours in Even-Numbered Periods
by Groups I and II in Job Rotation Comparison**

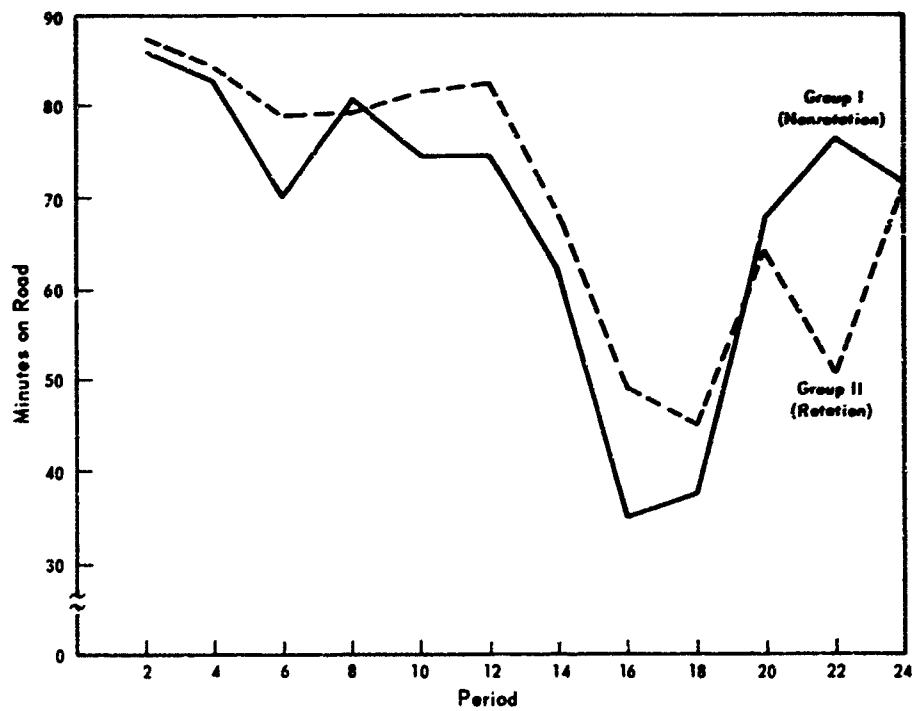


Figure 8

**Mean Target Detection Scores Obtained Over 48 Hours
in Odd-Numbered Periods by Groups I and II in Job Rotation Comparison**

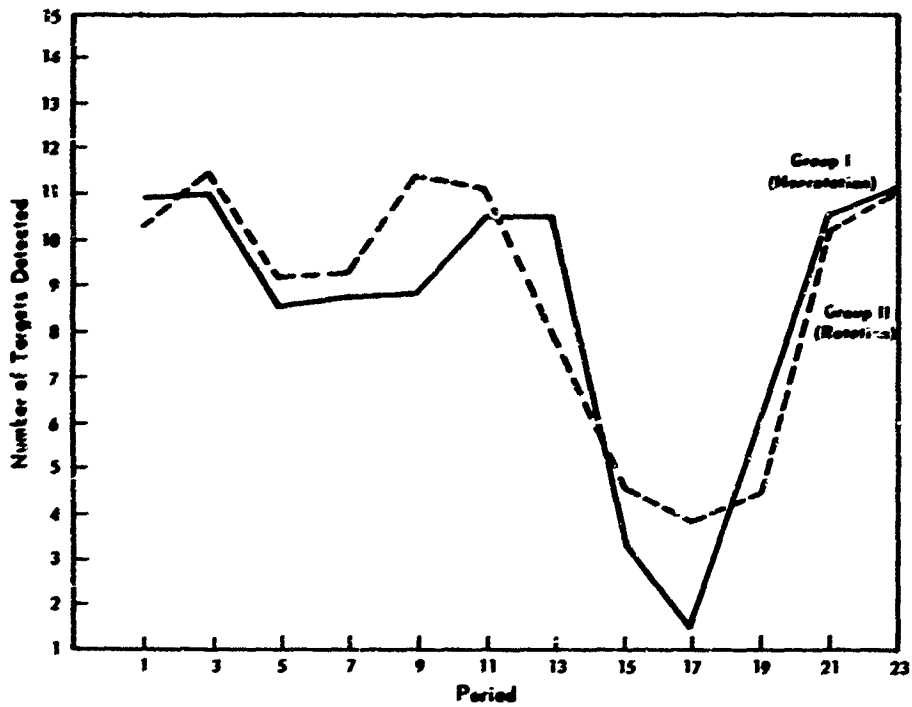


Figure 9

**Mean Target Detection Scores Obtained Over 48 Hours in
Even-Numbered Periods by Groups I and II in Job Rotation Comparison**

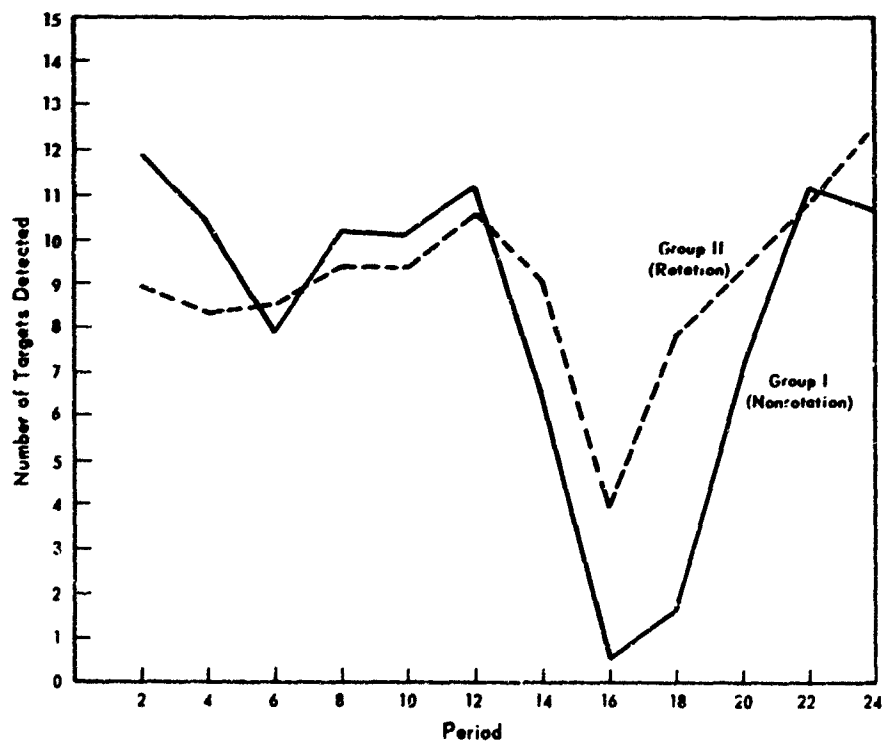


Figure 10

under the conditions that prevailed during the experiment. In all three groups whose members were required to work without provision for sleep, performance deteriorated markedly. The statistical analysis that compared the performance of Group I with that of Group IV showed driving performance to be worse for subjects who were scheduled to work without sleep. Although the statistical analysis of the target detection data did not yield a significant difference between the two groups, there was a strong trend towards a difference that approached significance. Furthermore, the data used in the statistical analysis did not include the performance measures obtained from Group I between 0200 and 0700 hours (when the group performed at its lowest levels), since it was during these hours that the subjects in Group IV were sleeping.

The difference between the performance levels of Groups I and IV can also be shown by comparing their lowest scores. On the target detection task, the lowest mean score for Group IV during any period was 8.7 targets. The lowest score obtained by Group I was 0.5 target, that is, an average of less than one target per subject. Furthermore, in nine of the periods in which it participated, Group I averaged fewer detections than the 8.7 targets detected by Group IV during its worst period. On the driving task, at no time during the entire experiment did the subjects in Group I attain an average driving score that surpassed the lowest average obtained by Group IV. Moreover, during the second night of the experiment, the subjects in all three groups deprived of sleep performed so poorly that their mean scores approached the lowest score possible on the driving simulator. In spite of the fact that scores below 25 minutes could not be received, Group I recorded a mean score of 35.0 minutes during its period of poorest performance, while Groups II and III attained scores of 45.3 and 28.1 during their poorest periods. On the other hand, the lowest score attained by Group IV on the driving task was 87.1 minutes.

It therefore appears that there is relatively little gain in total productivity as a result of working for 48 hours without sleep, compared to working a shorter period with time off for sleep. Performance during the second night of the experiment was so poor that the subjects in Groups I, II, and III might as well have been allowed to leave the experimental situation to sleep. Apparently they were unable to stay awake during this time in spite of being awakened at the end of each period and at the beginning of the following period. Had they been allowed to sleep during the two evenings, it can be assumed that their performance during the other hours would have been approximately equal to that of the subjects in Group IV.

The sharp differences in performance level that occurred between day and night hours suggests that it is somewhat misleading to speak of the relationship between sleep deprivation and performance. After the same number of hours of sleep deprivation, performance may be at a relatively high level, or at a relatively low level, depending upon the time of day in question.

For example, after 33 1/2 hours of sleep deprivation the subjects in Group II attained a mean driving score of 45.3 minutes, and those in Group III attained a mean score of 77.3 minutes. However, after 39 1/2 hours of sleep deprivation, the relative performance levels of the two groups were reversed. Group II attained a mean score of 81.5 minutes and Group III a mean score of 40.3 minutes. The difference is due to the time of day at which the two groups were working. After 33 1/2 hours, the work period for Group II began at 0530 and ended at 1700 hours, while the work period for Group III began at 1730 and ended at 1900 hours. Six hours later, after 39 1/2 hours of sleep deprivation, the work period for Group II began at 1130 and ended at 1300 hours and the work period for Group III

began at 2330 and ended at 0100 hours. Performance in both cases was better for whichever group was working during its normal waking hours, and worse for whichever group was working during its normal sleeping hours.

The relationship between sleep deprivation and time of day in determining the level of performance efficiency is supported by the analyses. On each of the two analyses pertaining to the effects of sleep deprivation, there was a significant interaction between sleep deprivation and periods. There was also a significant interaction between starting time and periods on the two analyses pertaining to the effects of starting time. The importance of time of day in affecting performance is further emphasized by the fact that in every one of the analyses of variance, there was a significant effect for periods.

The large standard deviations that were obtained in the experiment—especially during the evening, although they were by no means limited to these hours—are also noteworthy. The magnitude of these standard deviations, and the degree to which they fluctuated over time, suggest that the effects of sleep deprivation vary markedly from person to person. Apparently some subjects are more susceptible to the negative effects of sleep deprivation than are others. Since the standard deviations were comparatively small during the first few periods of the experiment and increased markedly thereafter, it appears that subjects were homogeneous in their abilities to perform the tasks at the beginning of the experiment. With increasing amounts of sleep deprivation, performance became more erratic, until differences were very great between subjects in performance level.

Whether these individual differences in susceptibility to sleep deprivation were due primarily to differences in ability to withstand fatigue or to differences in motivation could not be determined from the data. It is probable that both factors contributed to subject performance. Some subjects may have been too nearly exhausted physically to continue to perform efficiently; others may have lost their motivation to perform well during periods of stress created by sleep deprivation. In either case, the performance levels of some subjects declined more than others, and the variances of the scores increased.

Concerning the increased durability of future military equipment, the results of this study suggest that the equipment may be more durable than the men who will operate it. Performance decrement, especially during the night, was plainly evident in the laboratory. The subjects who participated in the experiment without provision for sleep could not maintain a reasonable level of performance throughout the 48-hour period.

Not only would the deterioration of human performance reduce the potential effectiveness of the new equipment; also, the variability in human performance that appeared with sleep deprivation would probably interfere with team operations, since each member would be operating at a different proportion of his maximum potential. On a task in which more than one crew member must make a contribution if the task is to be completed successfully, marked deterioration in the contribution of one crew member may cause the entire crew to be totally ineffective. The successful attempts made by the more effectively performing crew members would be negated by the less effective crew members, and the task would either remain incomplete or be poorly performed.

Also limiting the combat efficiency of the new military equipment would be the marked deterioration of performance that was found to occur in the laboratory during the second night of the experiment. Should subsequent data obtained in the field support the validity of this finding, it would be expected that performance during the second night of sustained combat would be much less effective than combat during either daytime hours or the first night.

Assuming that a combat engagement was to begin in the morning, the effects of fatigue could be reduced by limiting the engagement to 36 to 40 hours. In this manner, the final night would be eliminated, avoiding that portion of a 48-hour period when performance is at its worst. Assuming that the engagement was to begin during the evening instead of the morning, the maximum decrement would occur before 36 hours elapsed. Halting the engagement before this decrement is due would limit the duration of engagement too severely to provide a satisfactory alternative. In either case, perhaps crews could be conditioned to work more efficiently for 48 hours. Job rotation, although it might be expected to solve the problem, does not appear to substantially reduce the decrement when there is merely a change in jobs without a gain in total rest time.

Before these results can be applied to actual combat, the findings should be validated in a simulated combat situation. Since the amount of noise and vibration would be greater in the field than in the laboratory, and since the element of personal danger and the variety of tasks to be performed would be greater in the field, it is unlikely that decrements in simulated combat will be as large as those obtained in the laboratory. All these factors that are present in the field should arouse the subjects to a much greater degree than they were aroused in the laboratory. In addition, many of the tasks in simulated combat (as opposed to laboratory conditions) are short, rather than long, in duration. Research has shown that under prolonged sleep deprivation, performance decrements are greater for tasks of long duration than for tasks of short duration (1).

Even though performance decrements may not be as large in the field as they were in the laboratory, they are certain to occur. When they do, they will probably occur at night. Also, great individual differences in susceptibility to the effects of sleep deprivation are likely. It will remain the function of a simulated combat exercise to determine the extent to which findings from the laboratory will generalize to the field. The important question is not whether there will be a performance decrement in the field, but whether the decrement will be small enough to be tolerated. And while there may be differences between the effects of sleep deprivation on performance in simulated and actual combat, simulation will yield the best estimate of its effects outside of actual combat.

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13. ABSTRACT An experiment was conducted to determine, for extended periods of work, the effects of (a) working for 48 hours without sleep on the efficiency of the work done, (b) starting work periods at night compared with starting in the morning, and (c) rotating jobs. Two-man teams performed a driving task and a target detection task; a control group performed the same tasks, but with provisions for sleep. Results indicate that performance deteriorates over a 48-hour period of work without sleep, and that deterioration occurs primarily at night, or during the subjects' normal sleeping hours. Job rotation to introduce another activity did not prevent performance decrements. (←		

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