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MOL: CREW PERFORMANCE ON DEMANDING WORK/REST SCHEDULES COMPOUNDED BY SLEEP DEPRIVATION

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FOREWORD

This report was prepared in the Biodynamics Branch under task No. 793003. The work was accomplished between January 1965 and April 1967. The paper was submitted for publication on 7 August 1967.

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This experiment was conducted as a specific response to work/rest questions posed by the medical group supporting the Manned Orbiting Laboratory program.

This report has been reviewed and is approved.

GEORGE E. SCHAFER
Colonel, USAF, MC
Commander

ABSTRACT

Thirteen subjects took part in a series of 12-day runs in an experiment on the effects of demanding work/rest schedules (4/2, 4/4, or 16/8 hours). On days 8, 9, and 10, subjects were deprived of sleep and worked continuously. No significant work/rest effects were seen until subjects were sleep-deprived. In general, subjects on the 16/8 schedule tolerated sleep deprivation better and recovered faster, as evidenced by psychomotor test scores and sleep reports.

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I. INTRODUCTION

Manned space flight to date provides a somewhat mixed picture on work/rest schedules. Clearly, those in-orbit tasks which relate to ground tracks and orbit times require relatively brief crew performance periods when compared to a conventional 8-hour work day. In the early planning for the Manned Orbiting Laboratory (MOL), specific attention was given to crew schedules which would provide relatively short periods of work and rest alternating around the clock. Questions were raised concerning the effect of such schedules on crew efficiency.

The most applicable research was conducted in the early 1960's under Air Force sponsorship. Alluisi et al. (1) obtained both performance and psychophysiologic data on subjects who were confined for 15 or 30 days and followed a 4/2 or 4/4 hours (work/rest) schedule around the clock. They reported that: (1) the 4/2 schedule was feasible, but it appeared to compromise the subjects' "performance reserves"; (2) motivational factors had a considerable impact on performance, but apparently were less critical in the 4/4 schedule; (3) there were significant diurnal variations in psychophysiologic measures, but these dropped to statistically nonsignificant levels by the 25th day; (4) performance measures gave mixed results relative to diurnal variations; and (5) high task loads appeared to be more sensitive to diurnal variation than medium or low task loads.

This work was followed by a study in which subjects were confined for 12 days and followed either the 4/4 or 4/2 schedule (2). On days 6 and 7, subjects were sleep-deprived and performed the psychomotor tasks continuously. The study showed that: (1) learning curves were obtained during the initial 5 days, but the rate of learning was less for subjects on the 4/2 schedule than for subjects on the 4/4 schedule; (2) both groups suffered performance decrement during sleep deprivation, but the decrement was greater on the 4/2 schedule than on the 4/4 schedule; (3) diurnal variations persisted throughout sleep deprivation; and (4) subjective alertness was degraded during sleep deprivation, partially recovered after the first postdeprivation sleep period, and fully recovered by the end of the first postdeprivation day, with performance measures confirming these changes grossly.

The study presented in this paper repeats the second study reported above, with some additions. The sleep deprivation period was extended to 3 days and a 16/8 schedule was added. These two steps were taken to look more closely at the compromise of "performance reserves," which we would prefer to call "physical reserves."

II. METHOD

Subjects were obtained from Lackland AFB, Tex., at the end of basic military training. They were selected from a group of volunteers after a detailed briefing and rough screening, which eliminated men with a poor medical, dental, or psychologic history, and low scores on the Airman's Classification Battery. They reported in groups of 4 subjects at 6-week intervals and remained 5 weeks. During the first week, they were given a comprehensive physical and psychologic examination. During the second week they received orientation and limited familiarization on the test cell and the psychomotor equipment and assisted in logistic preparations (picking out and storing food supplies, etc.). They participated in the experiment during weeks 3 and 4. They were given a physical examination immediately after the experimental run and spent the fifth week in administrative processing to return to Lackland AFB, go on convalescent leave, and transfer to a technical training school.

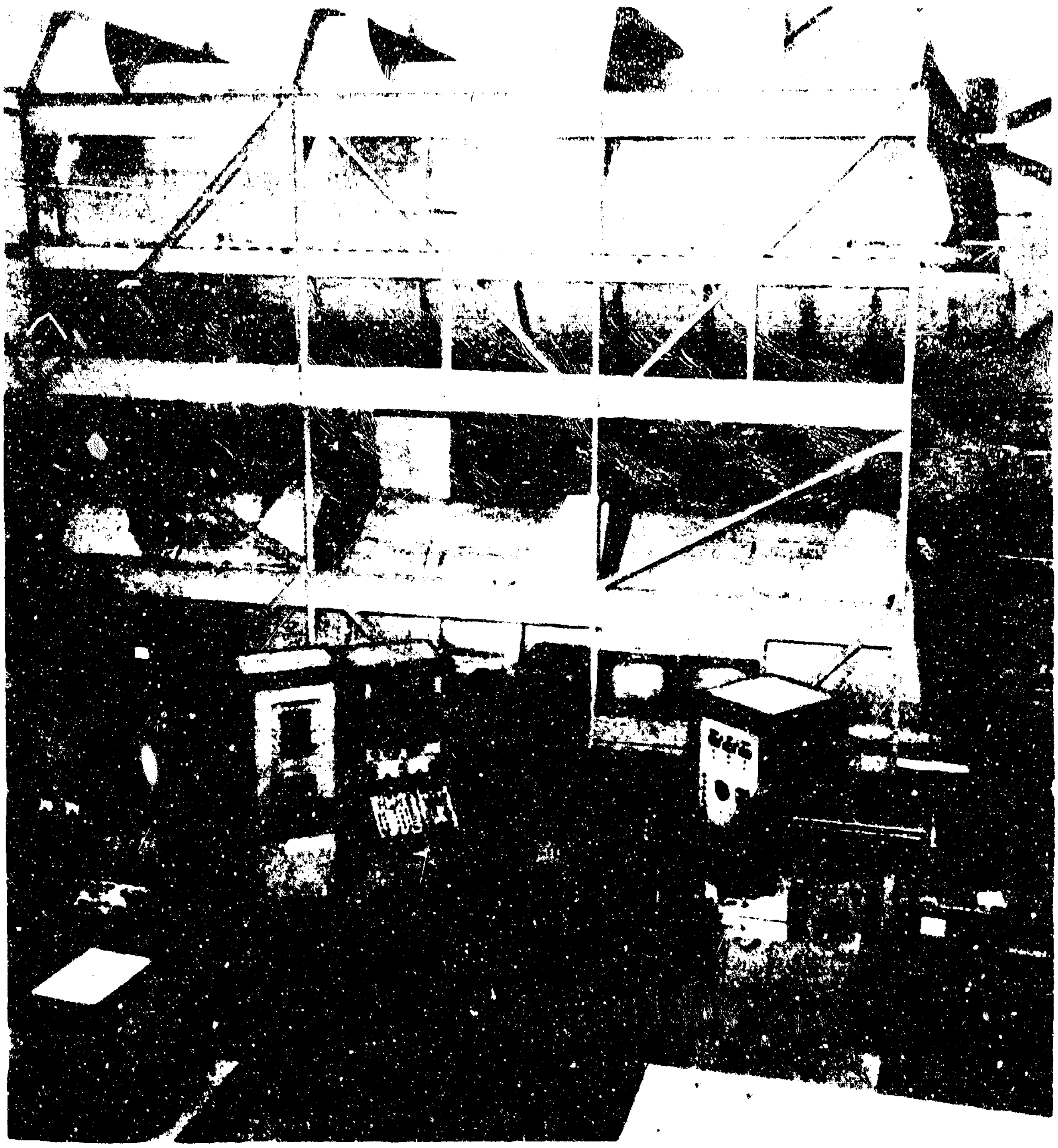


FIGURE 1

Exterior view of the test cell.

The test cell consists of two B-52 photo pods mounted one on top of the other; for this reason, it has been called the "double decker isolator." (See figure 1.) The interior equipment and bracketry have been removed to provide a usable volume of 750 cubic feet in each pod. The upstairs pod is the living area and contains a cot, card table and chair, stove, sink, commode, refrigerator, freezer, and storage shelves (fig. 2). The downstairs pod contains several pieces of psychomotor test equipment (fig. 3). Interior lighting is provided by four, 15-watt, wall-mounted fluorescent tubes in each pod. The interior walls are gray fabric, padded. Access to the top pod is through a vertical tunnel with a ladder. Each pod has a window-type air-conditioning unit at one end. There are no windows or portholes. Two closed-circuit television cameras downstairs and one upstairs are used to monitor the subject. An intercom provides two-way communication. The experimenter's station is adjacent to the test cell (fig. 4).

Each experimental run followed the same general schedule. Two subjects entered the test cell at 0730 on day 1 to prepare for the beginning of the run at 0800. Both were on the same work/rest schedule but with rest periods alternated as shown in figure 5, since only one man could sleep at a time. Subjects worked on the assigned schedule for 7 days. At the beginning of the work period closest to 0800 on day 8, subjects began sleep deprivation. After 68 to 72 hours of sleep deprivation, subjects returned to the assigned work/rest schedule; therefore, days 8, 9, and 10 required essentially continuous performance and no sleep. Days 11 and 12 were recovery days. Subjects came out of the test cell at 0800 on day 13. The other two airmen were kept on call to replace a subject who terminated, in order to salvage the data from the subject who continued.

The basic work block was 2 hours throughout the experiment. Subjects used the last

FIGURE 2

View of the interior of the upper pod (living area).

FIGURE 3

View of the interior of the lower pod (working area).

10 minutes of this work block to stretch, move to another piece of equipment, and take care of personal hygiene. Meals were eaten during the rest period. Frozen dinners, bread, milk, juices, coffee, and similar items were provided.

The test devices were as follows:

1. The *Complex Coordinator* (fig. 6) is a World War II device in which a subject matches a target light in the x-axis and another in the y-axis by moving an aircraft-type stick and rudder, holds the match for 0.5 second, and immediately receives a new problem. It is essentially a discontinuous tracking task. The subject's score is the number of problems solved in 1 hour 50 minutes.

2. The *Multidimensional Pursuit Test* (fig. 7) is a late World War II device consisting of a section of a simplified aircraft cockpit with four meters on a panel, and stick, rudder, and throttle controls. A cam-driven signal generator drives the meter needles off center in what appears to be a random manner. The subject operates the controls to center the needles. A timing circuit records on-target time when all four needles are centered simultaneously. A cycling circuit meters out 1-minute trials and 15 seconds of rest. The device is a four-element compensatory tracking task The subject's score is cumulative time on target in fifths of a second for 1 hour 50 minutes.

3. The *Neptune* (fig. 8) is a multitask device recently developed at the USAF School of Aerospace Medicine. Four of the subtasks in the battery were used:

a. Vigilance meters (3). Needles deflect right or left from a center-zero. Pushing the appropriate button returns the needle to center.

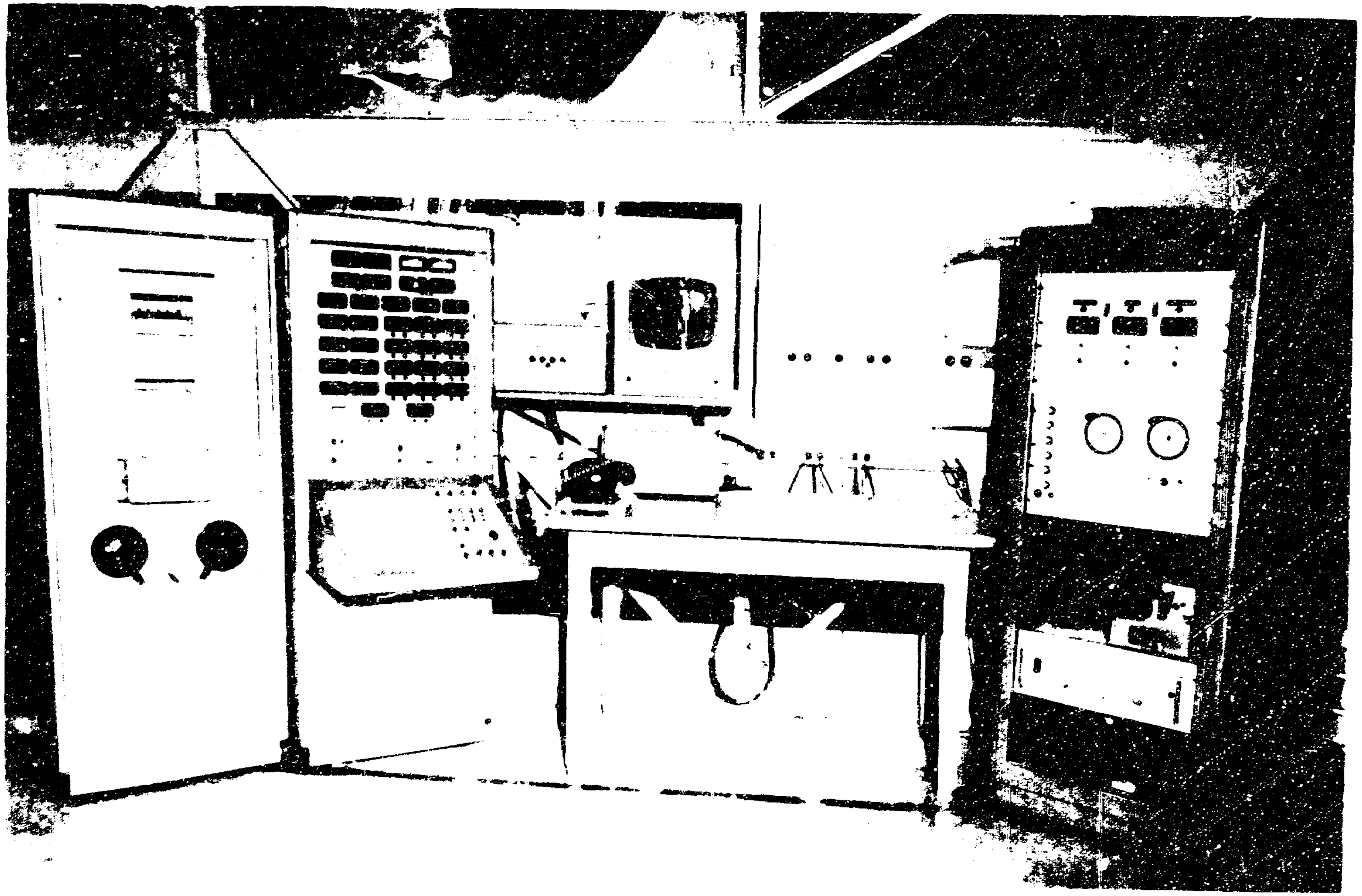


FIGURE 4

View of the experimenter's station.

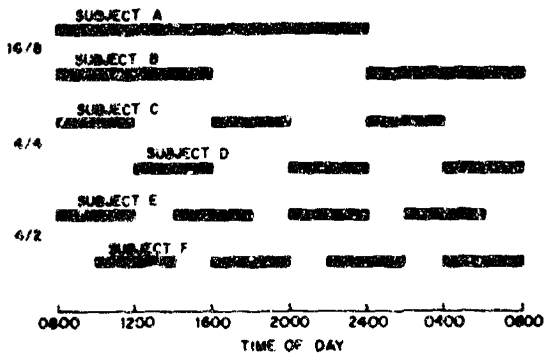


FIGURE 5

Graphic representation of 1 day of the three work/rest schedules.

Average response time in fifths of a second is the measure of performance. The needle deflections are programmed approximately 210 times in 1 hour 50 minutes.

b. Short-term memory. Flashes occur randomly on one of three parallel lights for 1 minute. The subject keeps count of the flashes on each light independently and reports these three values at the end of the minute by depressing three toggle switches the appropriate number of times. The subject's score is percentage error. Approximately 30 trials are programmed in 1 hour 50 minutes.

c. Arithmetic. The subject is presented four one-digit numbers on Nixie tubes arranged in a square. He adds these and then multiplies them diagonally to obtain two sums. The addition value is reported with push buttons, and the multiplication value is reported with a selector switch, the two responses being carried out simultaneously. The subject's score is average solution time. Approximately 35 problems are presented in 1 hour 50 minutes.

d. Tracking. A 30-c.p.m. sine wave signal is displayed on a center-zero meter. The subject rotates a potentiometer to cancel the sine wave and keep the meter needle centered. This is, therefore, a compensatory tracking task, in

FIGURE 6

The Complex Coordinator inside the test cell.

FIGURE 7

The Multidimensional Pursuit Test inside the test cell.

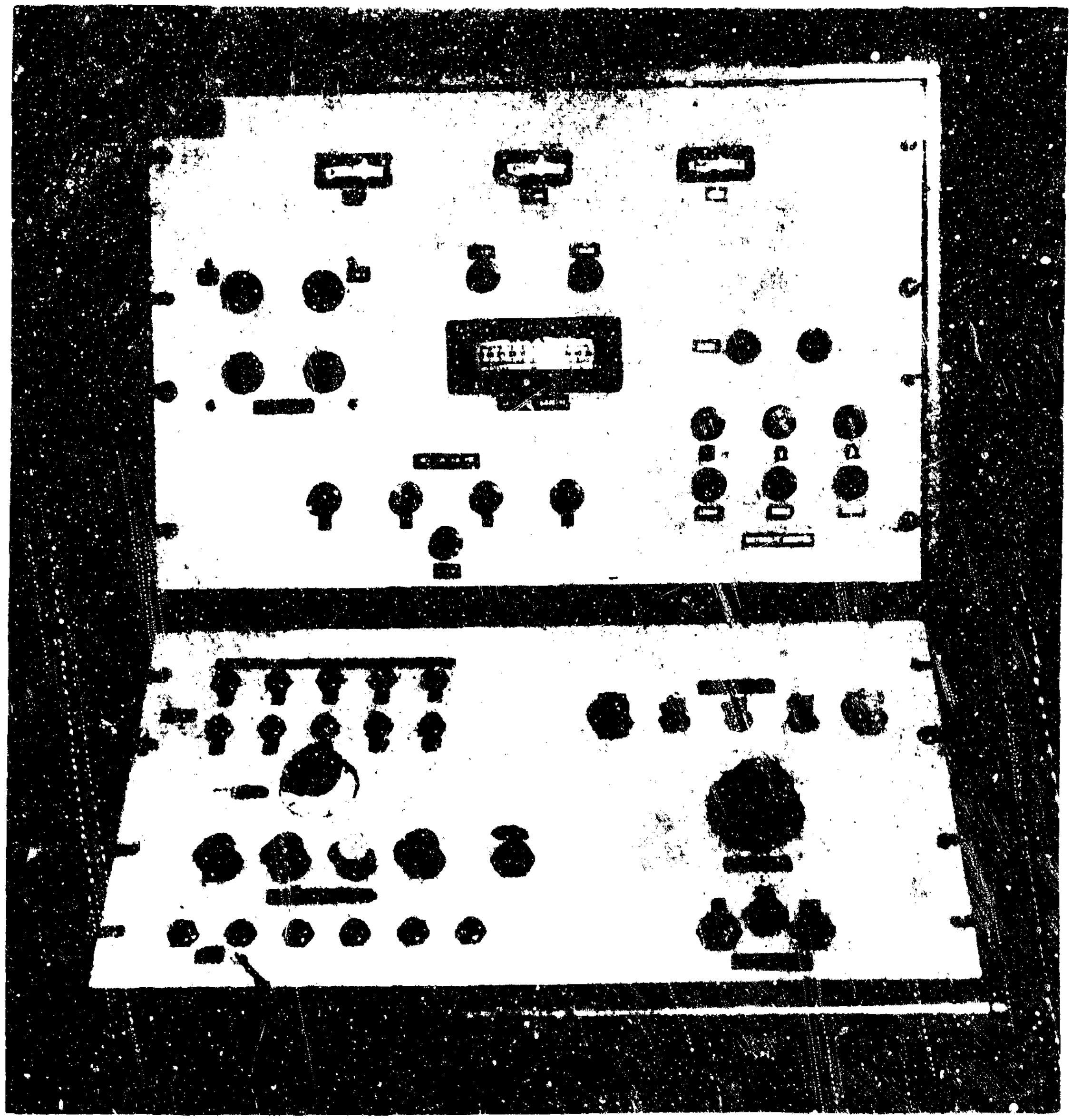


FIGURE 8
The Neptune subject's console inside the test cell.

which a subject sees only his error. The subject's score is time-on-target in fifths of a second. Each trial is 1 minute. Approximately 30 trials are programmed in 1 hour 50 minutes.

Neptune programming is done with a punched tape and reader, and counters record total events (signals) per task and cumulative response time or errors, as appropriate.

4. The *Multiple Reaction Time Task* (fig. 9) was developed at the USAF School of Aerospace Medicine. Three kinds of performance are required. In the simplest, one of three signal lights comes on and the subject

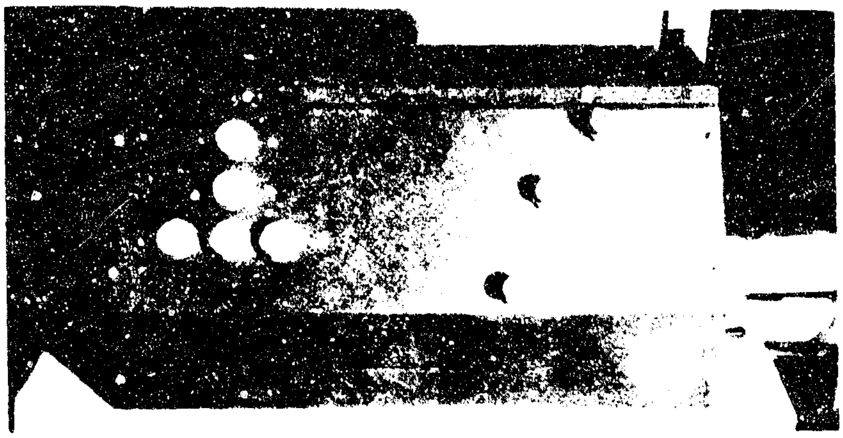


FIGURE 9

The Multiple Reaction Time device inside the test cell.

depresses the corresponding switch. This is called "level 1." For "level 2," two signal lights come on and the subject depresses the corresponding switches simultaneously. For "level 3," a signal light and a red or green light comes on. The subject uses the two-light information to select one of the two noncorresponding switches, and then depresses it. Scores for "level 4" are obtained by pooling response times obtained on the other three levels. The subject's scores are mean response times from 30 minutes of testing.

5. The *Complex Discrimination Reaction Time Test* (fig. 10) is a post-World War II task in which the subject is presented three lights in one of four arrays on the display panel, and decodes them to select the right switch in four similar arrays on the response panel. The subject's score is total number of problems solved in 30 minutes. This task was used as an alternate when malfunctions developed in other equipment. The scores were not analyzed because there was no pattern to the blocks of scores obtained (fig. 10).

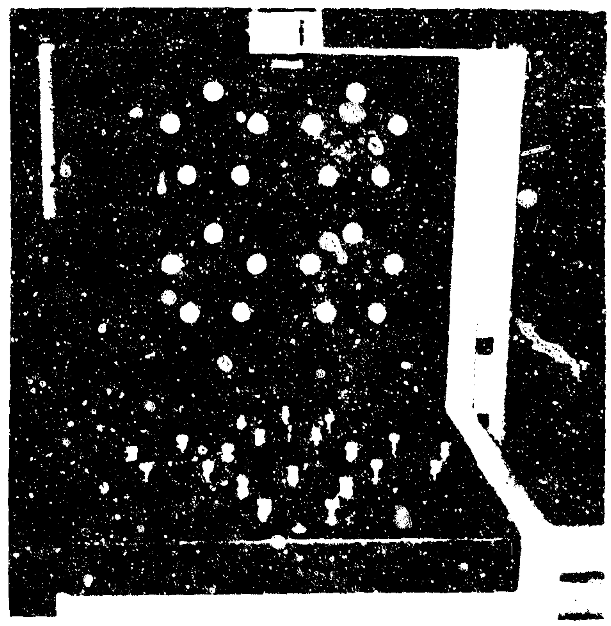


FIGURE 10

The Complex Discrimination Reaction Time Task inside the test cell.

Finally, subjects reported each morning on their sleep for the previous 24 hours, using a printed reporting form. Time asleep was reported in half-hour blocks on a time scale, and questions about sleep were answered on this form.

No physiologic or psychophysiologic data were obtained. Medical supervision was provided by the Psychiatry Branch. Runs could be terminated by the subjects at their request or by the supervising psychiatrist. The relationship between subjects and the staff was intentionally made impersonal and casual.

III. RESULTS

Ten runs were required to obtain a minimum of 4 subjects on each of the work/rest schedules. Table I summarizes these ten runs and presents the reasons for the terminations. Our own inexperience probably contributed as much to the first two terminations as did the feelings of the subjects.

Scores were pooled to obtain a daily mean on each task for each subject. Occasional missing scores were estimated; data were not analyzed for the Multidimensional Pursuit Test because there was an excessive number of missing scores. Analyses of variance (using the "repeated measurements" model) were performed on each task. The 12 days were divided into three segments: (1) days 1 through 7 (basic schedule effect); (2) days 8, 9, and 10 (impact of sleep deprivations); and (3) days 11 and 12 (recovery). The interaction of days x schedules provides the critical significance test. Table II summarizes probability levels for each task obtained from this interaction. Nine tables in appendix I present the analyses.

As table II indicates, only the Multiple Reaction Time Task yielded a significant interaction during the first 7 days. Inspection of the data indicated that subjects on the 16/8 schedule performed more poorly on day 1. During sleep deprivation, only the Complex Coordinator yielded a significant interaction. By day 10, subjects on the 16/8 schedule were performing better than subjects on the 4/4 schedule, and subjects on the 4/4 schedule were performing better than subjects on the 4/2 schedule. Four tasks (vigilance, arithmetic, tracking, and the Complex Coordinator) yielded significant interactions during the recovery period. In all four cases, subjects on the 16/8 schedule performed better than subjects on the other two schedules. Figures 11 through 19 present curves on each task, with daily means pooled across subjects for each work/rest schedule.

TABLE I

Summary of ten runs and reasons for terminating runs

	Run No.	Work/rest schedule	Terminations
Jan. 1965	1	4/2	Day 9—one subject had "strange feelings."
	2	4/4	Day 5—one subject had headaches, could not sleep.
	3	16/8	Day 9—one subject groggy, dizzy (other subject continued).
	4	4/2	Completed.
	5	4/4	Completed.
	6	16/8	Completed.
	7	4/2	Completed.
	8	4/4	Day 4—one subject nauseated, depressed.
			Day 6—other subject tired.
	9	4/4	Completed.
May 1966	10	16/8	Completed.

TABLE II

Summary of analyses of variance (days x schedules interaction only)

Tasks	Schedule (days 1 – 7)	Sleep deprivation (days 8 – 10)	Recovery (days 11 – 12)
Neptune			
Vigilance	NS	NS	$P < .01$ $C > \begin{cases} A \\ B \end{cases}$
Arithmetic	NS	NS	$P < .05$ $C > A > B$
Tracking	NS	NS	$P < .001$ $C > B > A$
Short-term memory	NS	NS	NS
Complex Coordinator	NS	$P < .005$ $C > B > A$	$P < .005$ $C > \begin{cases} B \\ A \end{cases}$
Multiple Reaction Time	$P < .05$* $\begin{rcases} B \\ A \end{rcases} > C$	NS	NS

A = 4/2 schedule.
B = 4/4 schedule.
C = 16/8 schedule.
*Subjects on the 15/8 schedule performed significantly poorer on day 1 only and on two of the four variations (levels) only.

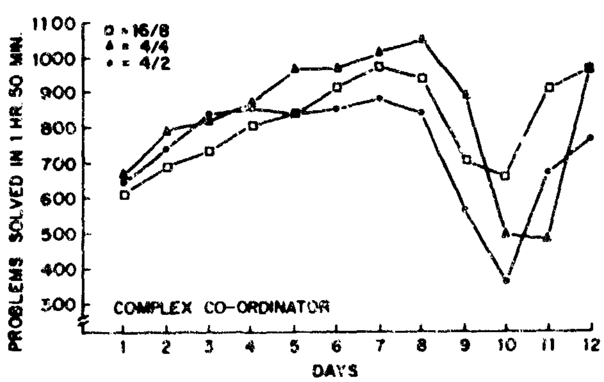


FIGURE 11

Daily means on the Complex Coordinator for each work/rest schedule, with subjects pooled.

An additional analysis of variance was performed on scores from the Complex Coordinator, the most stable of the tests used, to evaluate time-of-day (diurnal) effects. The day was divided into four segments: (1) 2400 to 0600 hours; (2) 0600 to 1200 hours; (3) 1200 to 1800 hours; and (4) 1800 to 2400 hours. Subjects were pooled to obtain a mean score for each segment of each day. Tables III and IV present this analysis. Time-of-day yielded an F-ratio short of significance, although the means for each segment of the day show a progression consistent with the concept of diurnal variation. For the reader who wants to consider diurnal effects in more detail, curves for each subject on the Complex Coordinator will be found in appendix II.

Sleep was the second area of interest in this study. Figure 20 shows the self-reporting form (SAM HQ Form 0-154) used to obtain information on sleep. Figures 21, 22, and 23 present curves for each subject on each of the three work/rest schedules. Subjects on the

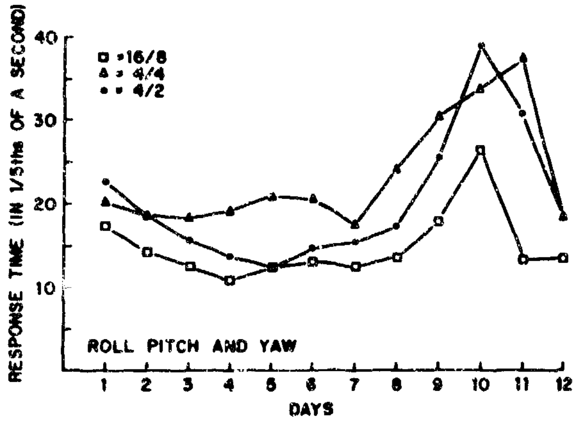


FIGURE 12

Daily means on the vigilance task (Neptune) for each work/rest schedule, with subjects pooled.

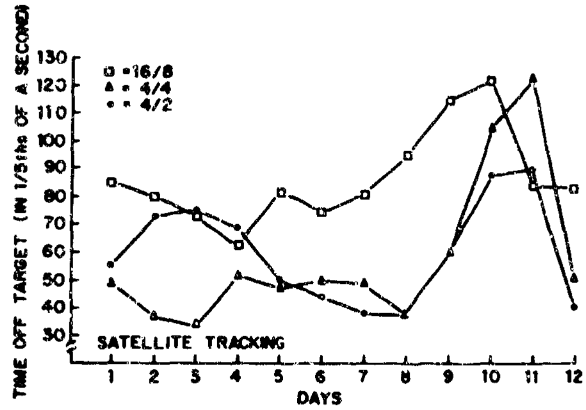


FIGURE 15

Daily means on the tracking task (Neptune) for each work/rest schedule, with subjects pooled.

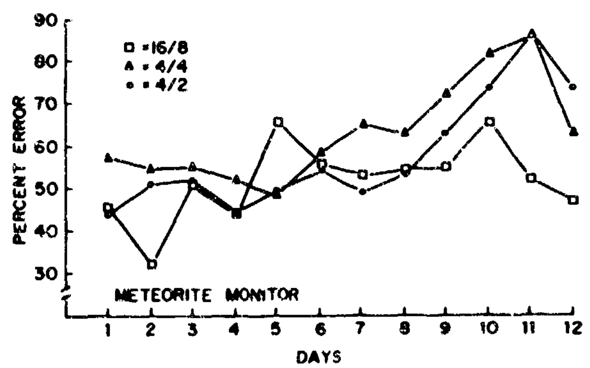


FIGURE 13

Daily means on the short-term memory task (Neptune) for each work/rest schedule, with subjects pooled.

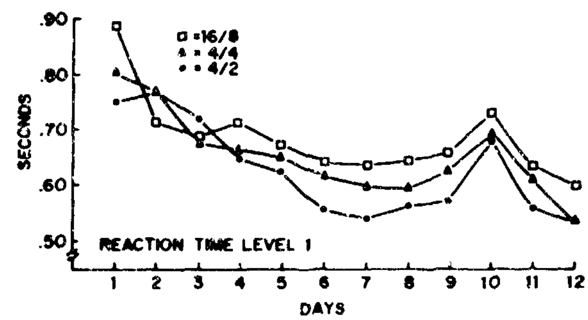


FIGURE 16

Daily means on the Multiple Reaction Time Task, level 1, for each work/rest schedule, with subjects pooled.

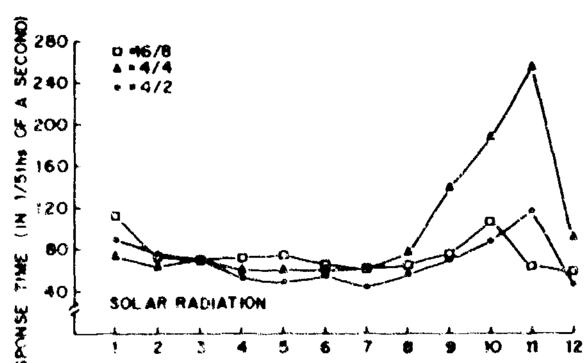


FIGURE 14

Daily means on the arithmetic task (Neptune) for each work/rest schedule, with subjects pooled.

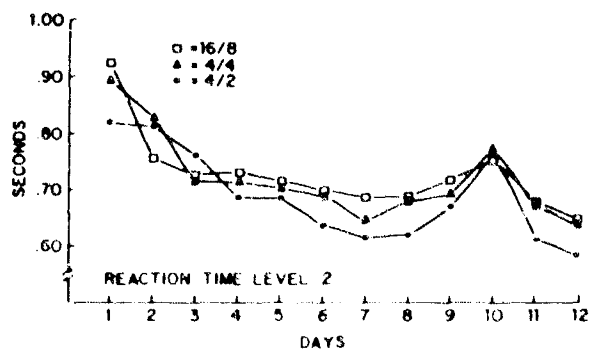


FIGURE 17

Daily means on the Multiple Reaction Time Task, level 2, for each work/rest schedule, with subjects pooled.

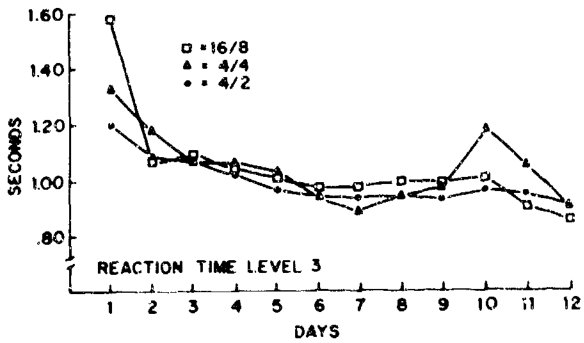


FIGURE 18

Daily means on the Multiple Reaction Time Task, level 3, for each work/rest schedule, with subjects pooled.

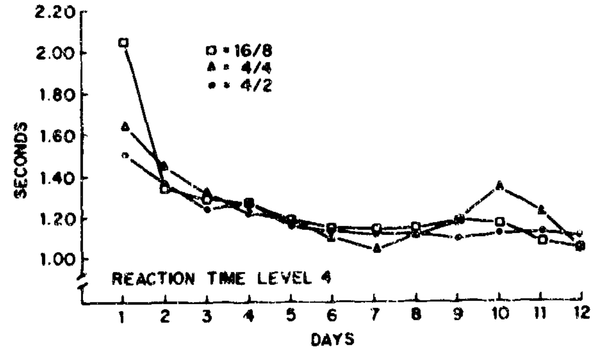


FIGURE 19

Daily means on the Multiple Reaction Time Task, level 4, for each work/rest schedule, with subjects pooled.

TABLE III

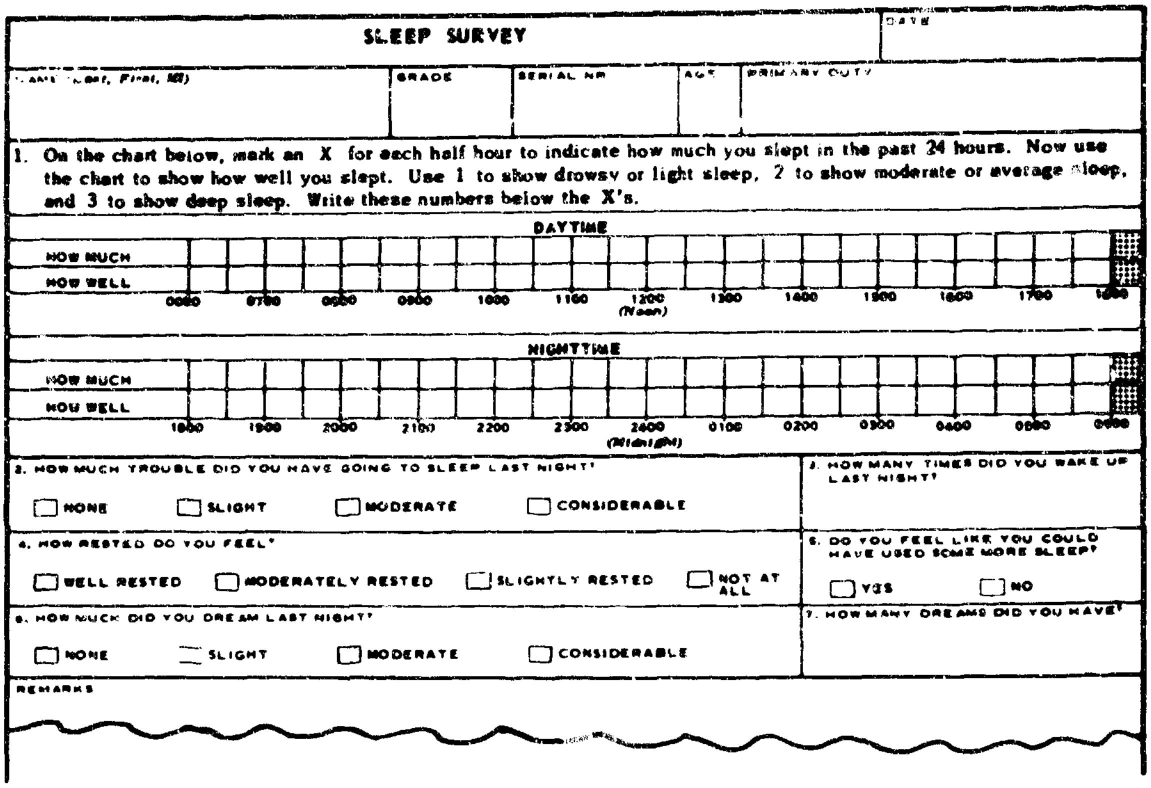
Analysis of variance on the Complex Coordinator, with days broken into four segments (all subjects pooled)

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Day	10	6162172.18	.61622	9.05	.001
Time	3	404681.61	.13489	1.98	NS
D x T	30	647247.05	2.1575	.32	NS
Error	283	19264711.51	6.8073		

TABLE IV

Mean scores on the Complex Coordinator, with days broken into four segments (all subjects pooled)

Day	Time 1 (2400-0600 hrs.)	Time 2 (0600-1200 hrs.)	Time 3 (1200-1800 hrs.)	Time 4 (1800-2400 hrs.)	Overall mean
2	654.0	687.2	728.3	800.0	717.4
3	631.7	746.0	817.1	874.8	767.4
4	785.5	832.0	852.0	883.8	838.3
5	804.0	846.6	902.8	852.5	851.5
6	926.7	[illegible]7.1	930.6	916.5	910.2
7	904.7	915.1	1009.8	949.3	944.7
8	942.7	777.4	877.1	888.9	871.5
9	693.8	644.0	670.7	647.8	664.1
10	466.4	436.2	435.4	486.6	456.1
11	441.0	586.2	782.9	775.7	646.4
12	825.0	787.2	934.3	839.3	846.5
Overall mean	734.1	738.6	812.8	810.5	774.0



SLEEP SURVEY

DATE

NAME (Last, First, MI) | GRADE | SERIAL NR | AGE | PRIMARY DUTY

1. On the chart below, mark an X for each half hour to indicate how much you slept in the past 24 hours. Now use the chart to show how well you slept. Use 1 to show drowsy or light sleep, 2 to show moderate or average sleep, and 3 to show deep sleep. Write these numbers below the X's.

DAYTIME

HOW MUCH

HOW WELL

0600 0700 0800 0900 1000 1100 1200 (Noon) 1300 1400 1500 1600 1700 1800

NIGHTTIME

HOW MUCH

HOW WELL

1800 1900 2000 2100 2200 2300 2400 (Midnight) 0100 0200 0300 0400 0500 0600

2. HOW MUCH TROUBLE DID YOU HAVE GOING TO SLEEP LAST NIGHT?

☐ NONE ☐ SLIGHT ☐ MODERATE ☐ CONSIDERABLE

3. HOW MANY TIMES DID YOU WAKE UP LAST NIGHT?

4. HOW RESTED DO YOU FEEL?

☐ WELL RESTED ☐ MODERATELY RESTED ☐ SLIGHTLY RESTED ☐ NOT AT ALL

5. DO YOU FEEL LIKE YOU COULD HAVE USED SOME MORE SLEEP?

☐ YES ☐ NO

6. HOW MUCH DID YOU DREAM LAST NIGHT?

☐ NONE ☐ SLIGHT ☐ MODERATE ☐ CONSIDERABLE

7. HOW MANY DREAMS DID YOU HAVE?

REMARKS

FIGURE 20

The self-reporting form used to obtain information on sleep.

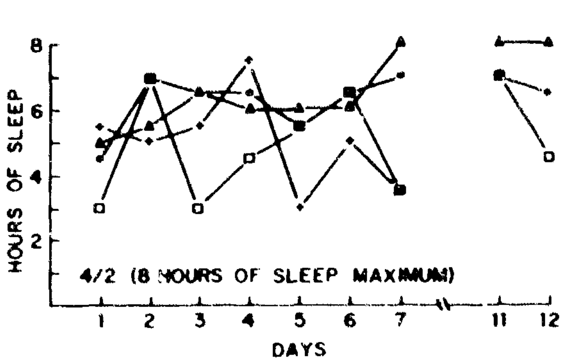


FIGURE 21

Total sleep per day for each subject on the 4/2 work/rest schedule.

16/8 schedule report the expected consistency across days and in comparison to each other. Subjects on the other two schedules report large differences across days and in comparison to each other.

Figure 24 shows average day-by-day responses to the question, "How much trouble did you have going to sleep?" There is a curve for each schedule. There are no obvious problems or differences.

Figure 25 shows average responses to the question, "How well rested do you feel?" Again there are no large differences, though the subjects on the 4/2 schedule seem to be having a little more difficulty than the others by day 3.

Figure 26 shows average responses to the question, "Do you feel you could have used more sleep?" Subjects on the 4/2 schedule always reported "yes" to this question. The subjects on the other two schedules showed large day-by-day differences.

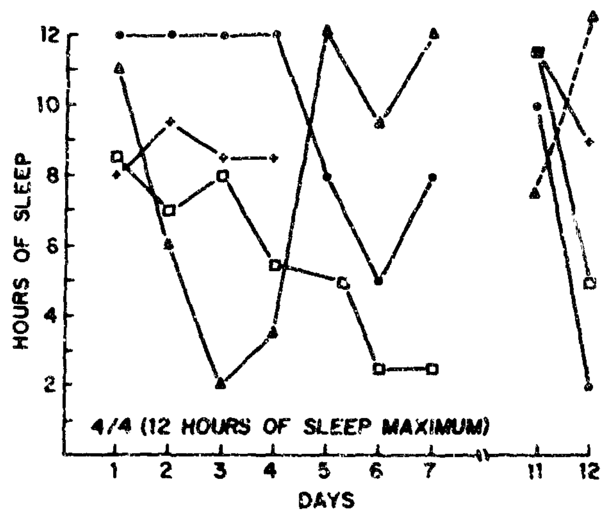


FIGURE 22

Total sleep per day for each subject on the 4/4 work/rest schedule.

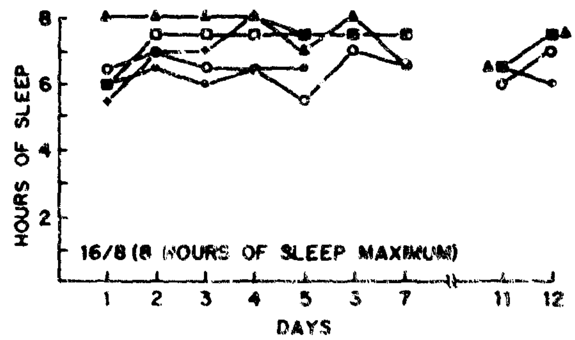


FIGURE 23

Total sleep per day for each subject on the 16/8 work/rest schedule.

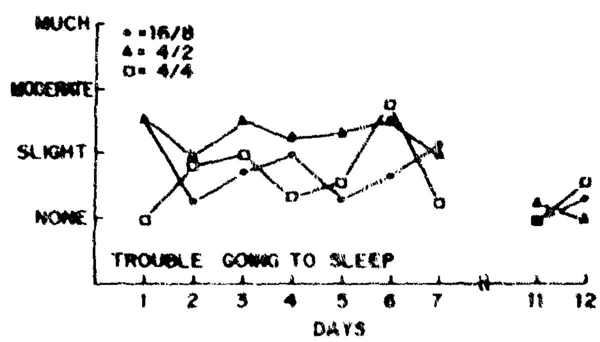


FIGURE 24

Average responses, day-by-day, to the question on trouble going to sleep.

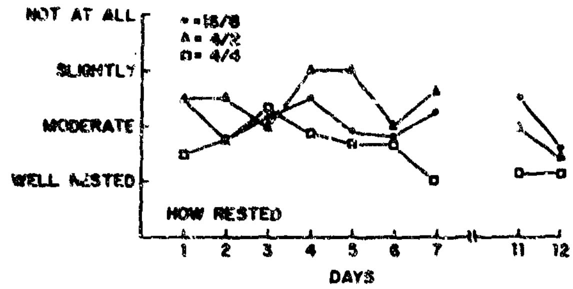


FIGURE 25

Average responses, day-by-day, to the question on how well rested the subjects felt following sleep.

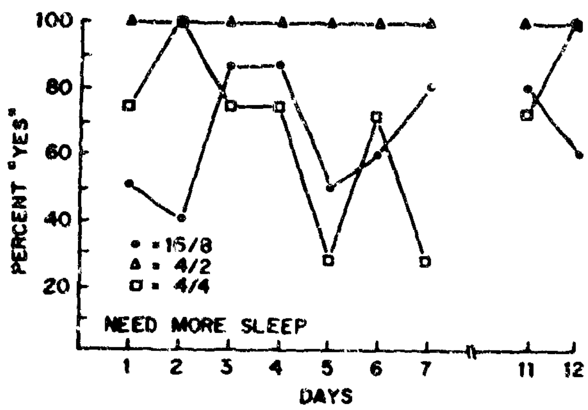


FIGURE 26

Average responses, day-by-day, to the question on the need for more sleep.

IV. DISCUSSION AND CONCLUSIONS

This study confirms the major finding of the earlier studies on demanding work/rest cycles. In general, subjects were able to perform at approximately the same level on all three schedules when the added stress of sleep deprivation was absent. During sleep deprivation they showed a differential decrement, with subjects on the 16/8 schedule showing the smallest psychomotor decrement and an even more substantial advantage during recovery from sleep deprivation.

The concept of "performance reserves" ("physical reserves," in our terminology) would lead to the prediction that subjects on a 16/8 schedule would function better during sleep deprivation, since 16/8 is the schedule closest to normal. In addition, these subjects could have 8 hours of uninterrupted sleep; it appears that interrupted sleep is in and of itself a stress, possibly because subjects do not get the usual amounts of each stage of sleep. In particular, subjects on the 4/4 and 4/2 schedules probably were deprived of some stage 1–REM. Dream deprivation has been reported to interfere with normal functioning; however, one must consider such findings cautiously because of inherent methodologic problems in most dream deprivation studies.

The study also confirms the earlier finding on diurnal cycle effects. Alluisi et al. (2) reported significant psychophysiologic cycling which was confirmed *only in a gross sense* by the psychomotor data. We, too, obtained only gross psychomotor cycling; it was not, in fact, large enough to be significant.

In addition, this study confirms the earlier finding that recovery from sleep deprivation proceeds rapidly. In general, our subjects showed substantial improvements by the end of the first day, even though they returned to a demanding schedule. It should be noted, however, that recovery was not as compl[illegible] on the 4/2 schedule.

Our sleep data permit some interesting inferences Subjects on the 16/8 schedule were consistent across days and in comparison to each other. The other two groups exper[illegible]nced large variations. Marked individual [illegible]fferences are generally considered to be a major characteristic of sleep. Our data suggest that individual differences in respect to sleep become pronounced only when abnormal sleep schedules are instituted. Tolerance for unusual sleep schedules may prove to be an important consideration in selecting crews for space flight.

Another interesting inference can be drawn from performance during the first 7 days. All three groups showed similar learning curves. None of the subjects on the 4/4 or 4/2 schedules went through a pre-experimental adaptation to the schedule. Adaptation to unusual duty cycles is considered highly desirable. It is generally assumed that a crewman will not function with normal efficiency until he has adapted to his new schedule; however, there were no signs of any interference in learning during the first few days. Perhaps some of the sleep problems might have been avoided with a pre-experimental adaptation period, but we obtained no evidence that *performance* suffered. Both the adaptation and sleep problems require further study.

This study has shown that: (1) all schedules showed learning curves; (2) there were no differences in performance as a function of work/rest schedules so long as schedules were the only experimental manipulation; (3) all schedules showed progressive decrement during sleep deprivation; (4) in general, subjects on the 16/8 schedule performed better during sleep deprivation; (5) all schedules showed rapid and substantial recovery from sleep deprivation; (6) the 16/8 schedule provided the best recovery; and (7) large individual differences were seen in subjects whose schedule required interrupted sleep. It seems clear that unusual work-rest schedules do not compromise concurrent performance. Instead, they deplete the physical reserves required to meet additional challenges.

REFERENCES

1. Alluisi, E. A., W. D. Chiles, T. J. Hall, and G. R. Hawkes. Human group performance during confinement. AMRL TDR 63-87, Nov. 1963.

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APPENDIX I

SEPARATE ANALYSES OF VARIANCE ON EACH TASK

TABLE IA

Analysis of variance of daily means on the Complex Coordinator

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	261086.59	13054.00	0.18	NS
Error A	11	8056294.80	732390.00		
Time	11	2710074.99	246370.00	36.48	< .001
Within 1	6	1033729.26	172290.00	28.59	< .001
Within 2	2	1106020.97	553010.00	77.19	< .001
Within 3	1	294899.09	294900.00	23.16	< .001
Period	2	275425.67	137710.00	24.86	< .001
Group x time	22	1034339.37	47015.00	6.96	< .001
Within 1	12	76982.83	6415.20	1.06	NS
Within 2	4	163477.36	40869.00	5.70	< .005
Within 3	2	261249.17	130620.00	10.26	< .005
Group x period	4	532630.01	133160.00	24.04	< .001
Error B	121	817205.85	6753.80		
Within 1	66	397661.48	6025.20		
Within 2	22	157613.14	7164.20		
Within 3	11	140059.89	12733.00		
Error P	22	121871.33	5539.60		

"Within 1" refers to days 1 through 7 (basic schedule effect)

"Within 2" refers to days 8, 9, and 10 (impact of sleep deprivations).

"Within 3" refers to days 11 and 12 (recovery).

TABLE IIA

Analysis of variance of daily means on the vigilance task (Neptune)

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	1957.03	978.51	0.77	NS
Error A	11	13977.59	1270.70		
Time	11	3974.95	361.36	10.75	
Within 1	6	319.26	53.21	3.58	< .01
Within 2	2	1108.11	554.06	10.36	< .001
Within 3	1	549.05	549.05	28.84	< .001
Period	2	1998.52	999.26	12.93	< .001
Group x time	22	1597.99	72.64	2.16	< .01
Within 1	12	191.01	15.91	1.07	NS
Within 2	4	477.44	119.36	2.23	NS
Within 3	2	487.15	243.58	12.79	< .01
Group x period	4	442.39	110.60	1.43	NS
Error B	121	4068.30	33.62		
Within 1	66	981.90	14.88		
Within 2	22	1176.40	53.47		
Within 3	11	209.41	19.04		
Error P	22	1700.59	77.30		

TABLE IIIA

Analysis of variance of daily means on the arithmetic task (Neptune)

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	23848.55	11924.00	0.67	NS
Error A	11	194713.65	17701.00		
Time	11	110195.84	10018.00	5.83	< .001
Within 1	6	10745.53	1790.90	11.28	< .001
Within 2	2	29043.59	14522.00	9.90	< .005
Within 3	1	33686.77	33687.00	11.19	< .01
Period	2	36719.96	18360.00	3.06	NS
Group x time	22	105840.13	4810.90	2.80	< .01
Within 1	12	3069.54	255.80	1.61	NS
Within 2	4	6974.97	1743.70	1.19	NS
Within 3	2	31600.41	15800.00	5.25	< .05
Group x period	4	64195.21	16049.00	2.68	NS
Error B	121	207842.19	1717.70		
Within 1	66	10481.59	158.81		
Within 2	22	32267.70	1466.70		
Within 3	11	33109.49	3010.00		
Error P	22	131985.41	5999.20		

TABLE IVA

Analysis of variance of daily means on the compensatory tracking task (Neptune)

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	29138.50	14569.00	0.40	NS
Error A	11	399214.09	36292.00		
Time	11	38562.36	3505.70	5.86	< .001
Within 1	6	1982.64	330.44	0.66	NS
Within 2	2	13432.93	6716.50	9.32	< .01
Within 3	1	9126.08	9126.10	71.12	< .001
Period	2	14020.71	7010.40	7.02	
Group x time	22	26678.90	1212.70	2.03	< .025
Within 1	12	7757.47	646.46	1.29	NS
Within 2	4	2243.18	560.79	0.78	NS
Within 3	2	6657.84	3328.90	25.94	< .001
Group x period	4	10020.42	2505.10	2.51	NS
Error B	121	72389.17	598.26		
Within 1	66	33165.39	502.51		
Within 2	22	15855.31	720.70		
Within 3	11	1411.59	128.33		
Error P	22	21956.88	998.04		

TABLE VA

Analysis of variance of daily means on the short-term memory task (Neptune)

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	3396.39	1698.20	0.27	NS
Error A	11	69411.93	6310.20		
Time	11	12189.06	1108.10	6.99	< .001
Within 1	6	2115.12	352.52	1.95	NS
Within 2	2	1893.70	946.85	14.58	< .001
Within 3	1	1123.32	1125.30	7.08	< .025
Period	2	7056.92	3528.50	19.01	< .001
Group x time	22	7514.25	341.56	2.15	< .025
Within 1	12	2904.06	242.00	1.34	NS
Within 2	4	178.65	44.66	0.69	NS
Within 3	2	421.16	210.58	1.33	NS
Group x period	4	4010.38	1002.60	5.40	< .005
Error B	121	19181.47	158.52		
Within 1	66	11923.06	180.67		
Within 2	22	1428.62	64.94		
Within 3	11	1744.55	158.60		
Error P	22	4084.35	185.65		

TABLE VIA

Analysis of variance of daily means on the simple reaction time task

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	1088.85	544.43	0.96	NS
Error A	9	5093.29	565.92		
Time	11	7267.47	660.68	22.30	< .005
Within 1	6	4447.91	741.32	29.81	< .001
Within 2	2	689.70	344.85	16.53	< .001
Within 3	1	98.58	98.58	2.72	NS
Period	2	2031.28	1015.60	20.58	< .001
Group x time	22	745.55	33.89	1.14	NS
Within 1	12	661.06	55.09	2.21	< .05
Within 2	4	24.59	6.15	0.29	NS
Within 3	2	24.40	12.20	0.34	NS
Group x period	4	35.49	8.87	0.18	NS
Error B	99	2933.37	29.63		
Within 1	54	1343.07	24.87		
Within 2	18	375.51	20.86		
Within 3	9	326.42	36.27		
Error P	18	888.37	49.35		

TABLE VIIA

Analysis of variance of daily means on the complex reaction time task

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	458.39	229.19	0.53	NS
Error A	9	3886.26	431.81		
Time	11	6649.29	601.48	18.88	< .001
Within 1	6	4427.65	737.94	35.44	< .001
Within 2	2	[illegible]93.60	293.80	8.57	< .01
Within 3	1	55.91	55.91	1.54	NS
Period	2	1572.13	786.06	12.92	< .001
Group x time	22	706.78	32.13	1.00	NS
Within 1	12	585.27	48.78	2.34	< .05
Within 2	4	75.63	18.91	0.55	NS
Within 3	2	1.59	.79	0.02	NS
Group x period	4	44.29	11.08	0.18	NS
Error B	99	3170.11	32.02		
Within 1	54	1124.55	20.83		
Within 2	18	623.49	34.64		
Within 3	9	326.56	36.28		
Error P	18	1095.51	60.86		

TABLE VIIIA

Analysis of variance of daily means on the two-step reaction time task

Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	861.26	430.63	0.22	NS
Error A	9	17952.42	1994.70		
Time	11	25038.80	2276.30	8.91	< .001
Within 1	6	18781.70	3130.30	8.63	< .001
Within 2	2	180.30	90.15	1.44	NS
Within 3	1	196.77	196.77	3.92	NS
Period	2	5880.03	2940.00	12.89	< .001
Group x time	22	4351.54	197.80	0.77	NS
Within 1	12	3149.40	262.45	0.72	NS
Within 2	4	435.00	108.75	1.73	NS
Within 3	2	85.81	42.90	0.85	NS
Group x period	4	681.33	170.33	0.75	NS
Error B	99	25282.19	255.38		
Within 1	54	19594.29	362.86		
Within 2	18	1129.29	62.74		
Within 3	9	452.17	50.24		
Error P	18	4106.44	228.14		

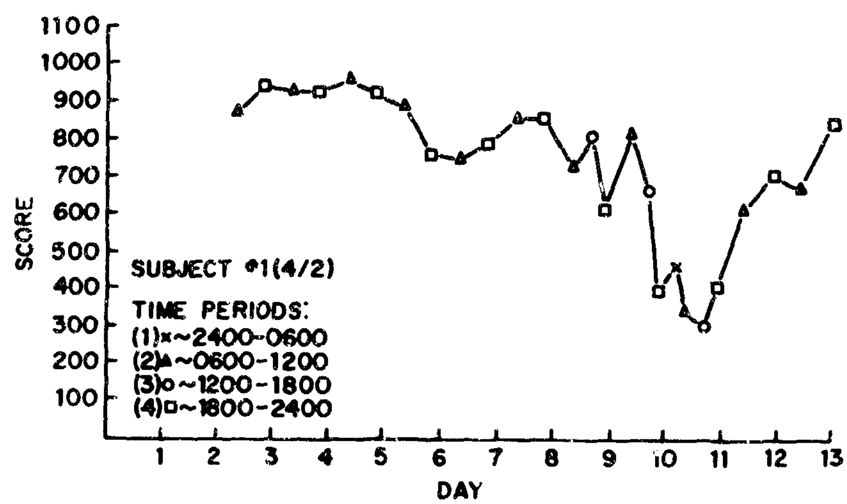
TABLE IXA

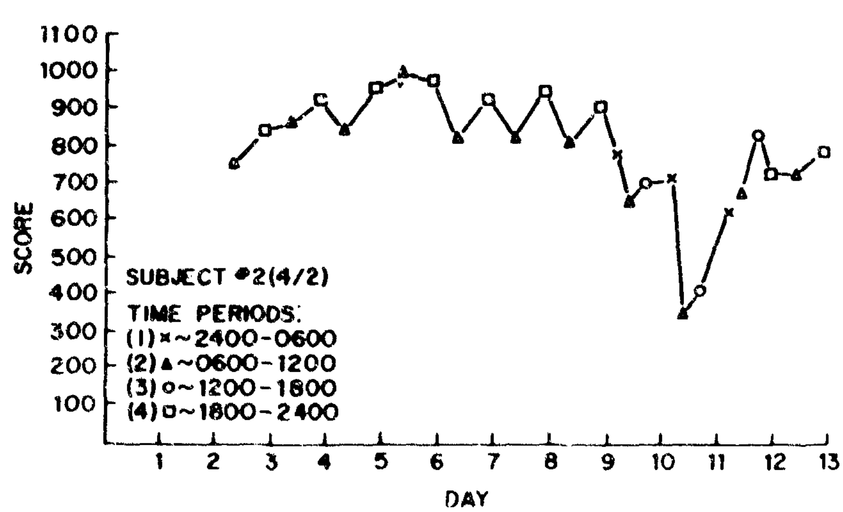
Analysis of variance of daily means on all forms of reaction time, combined

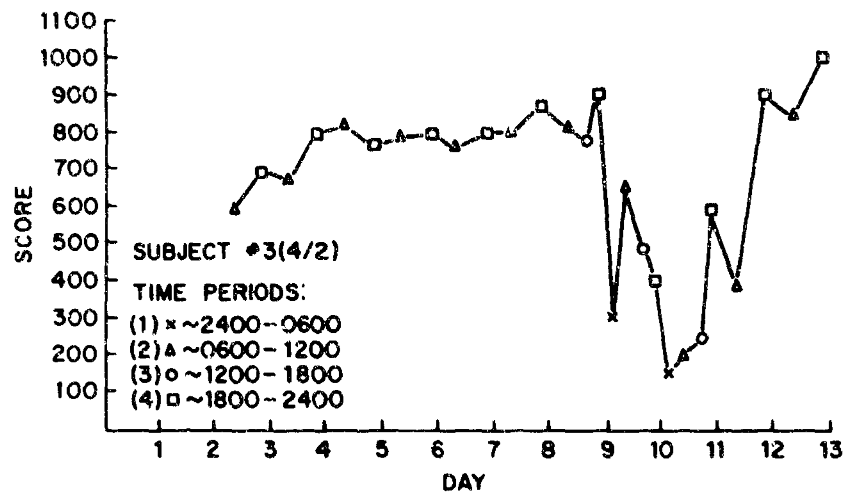
Source	d.f.	S.Sq.	M.Sq.	F-ratio	P
Group	2	759.31	379.65	0.22	NS
Error A	9	15370.32	1707.80		
Time	11	51797.36	4708.90	10.43	< .001
Within 1	6	39377.92	6563.00	10.00	< .001
Within 2	2	186.58	93.29	0.86	NS
Within 3	1	217.68	217.68	3.85	NS
Period	2	12015.68	6007.80	15.93	< .001
Group x time	22	8396.69	381.67	0.85	NS
Within 1	12	6497.11	541.43	0.82	NS
Within 2	4	483.81	120.95	1.12	NS
Within 3	2	186.42	93.21	1.65	NS
Group x period	4	1229.35	307.34	0.82	NS
Error B	99	44693.24	451.45		
Within 1	54	35451.14	656.50		
Within 2	18	1946.29	108.13		
Within 3	9	508.79	56.53		
Error P	18	6787.03	377.06		

APPENDIX II

INDIVIDUAL PERFORMANCE CURVES ON THE COMPLEX COORDINATOR FOR EACH SUBJECT DURING EACH TEST SESSION



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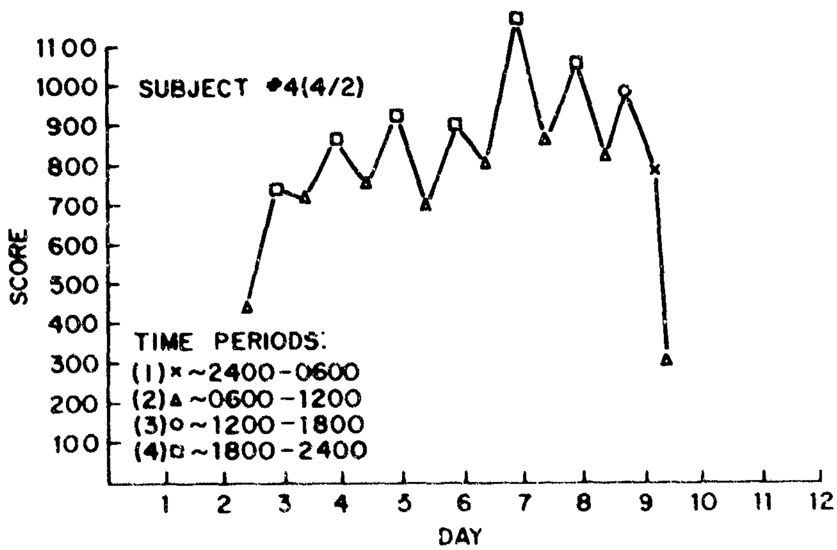
(3) o ~1200-1800
(4) □ ~1800-2400
SCORE
DAY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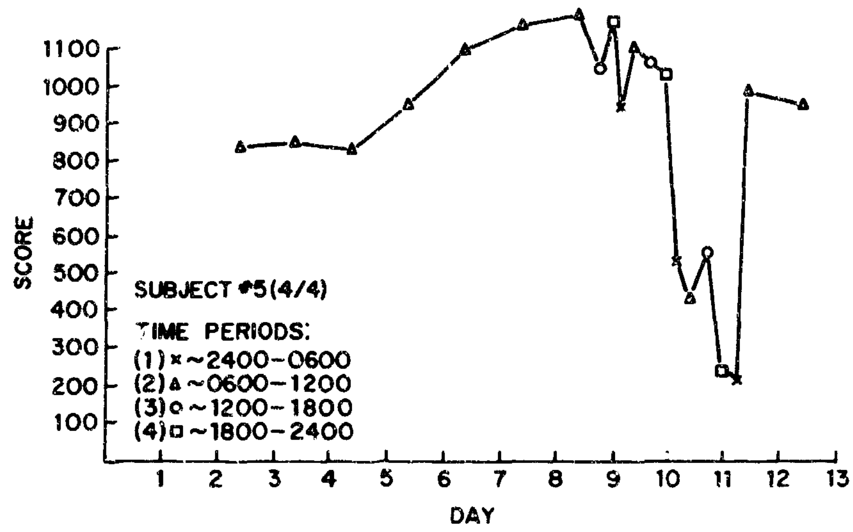
SCORE
DAY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(2) △ ~0600-1200
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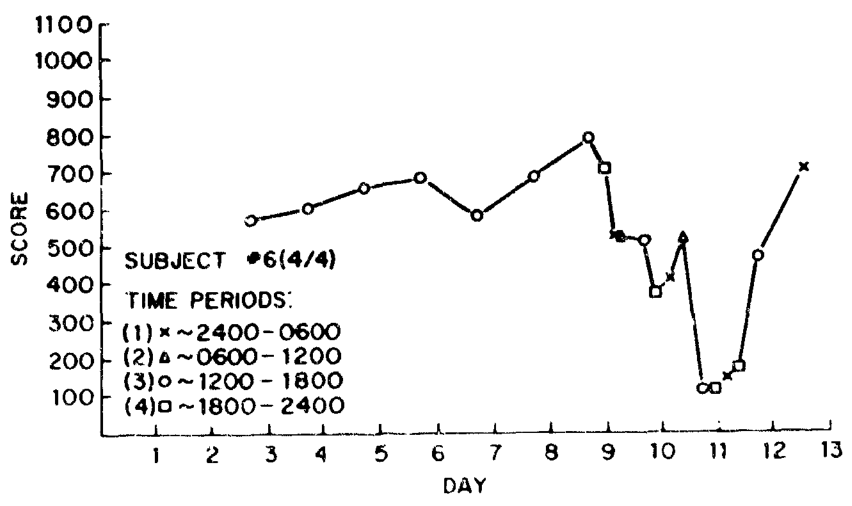
DAY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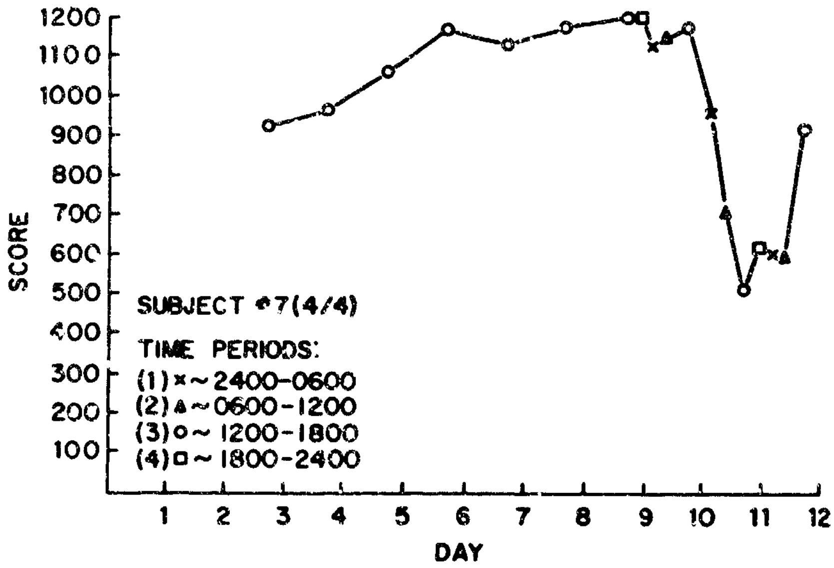
DAY


SCORE
DAY
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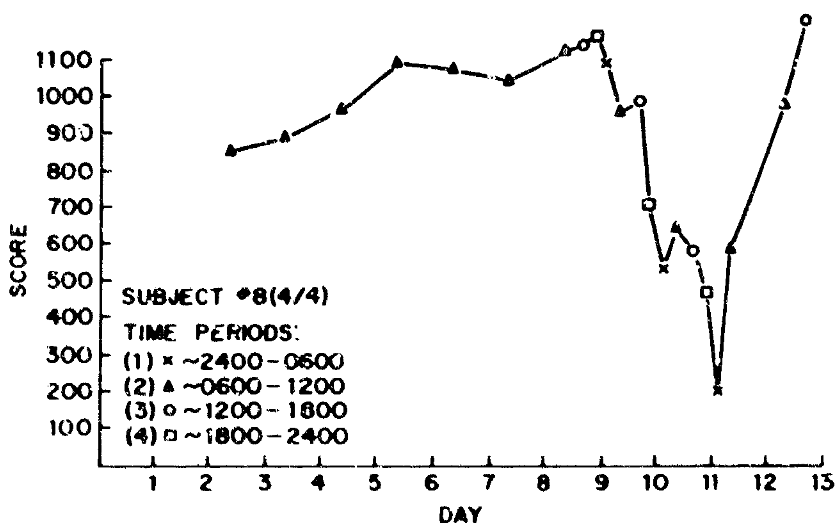
(3) o ~ 1200-1800
(4) □ ~ 1800-2400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DAY
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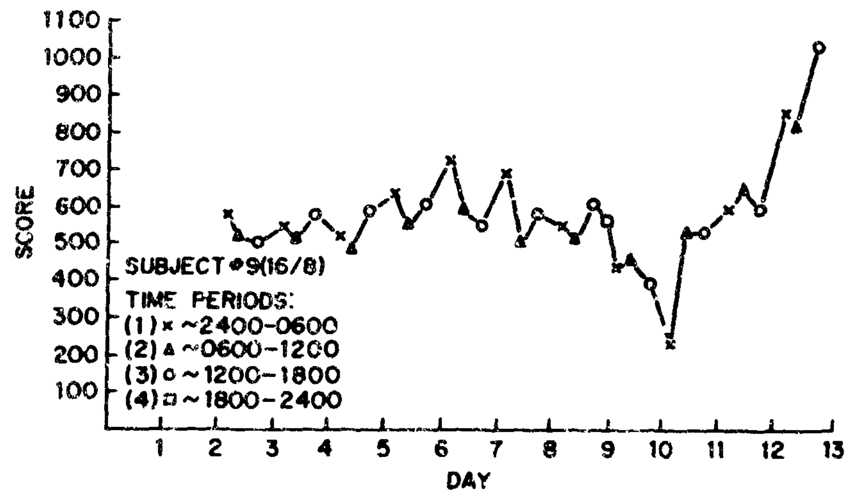
(4) □ ~1800-2400



SUBJECT #9(16/8)
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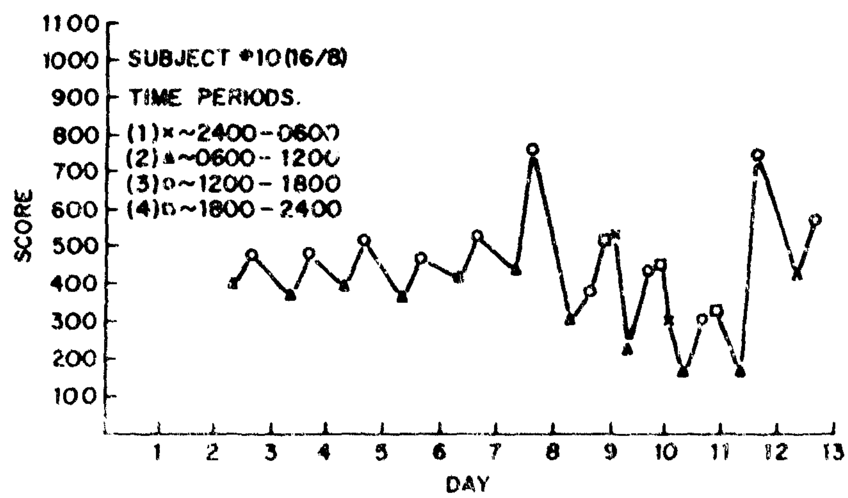
(2) ▲ ~0600-1200
(3) o ~1200-1800
(4) □ ~1800-2400
SCORE
DAY



SUBJECT #10(16/8)
TIME PERIODS.
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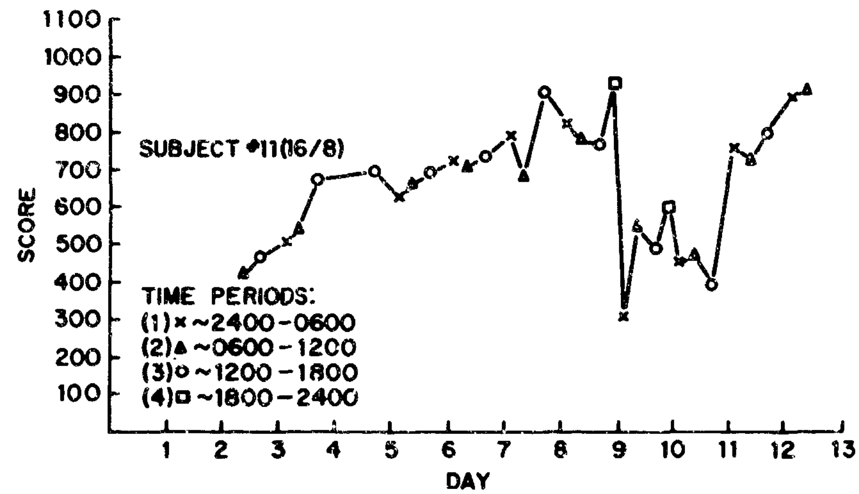
(3) o ~1200-1800
(4) □ ~1800-2400
SCORE
DAY



SUBJECT #11(16/8)
TIME PERIODS:
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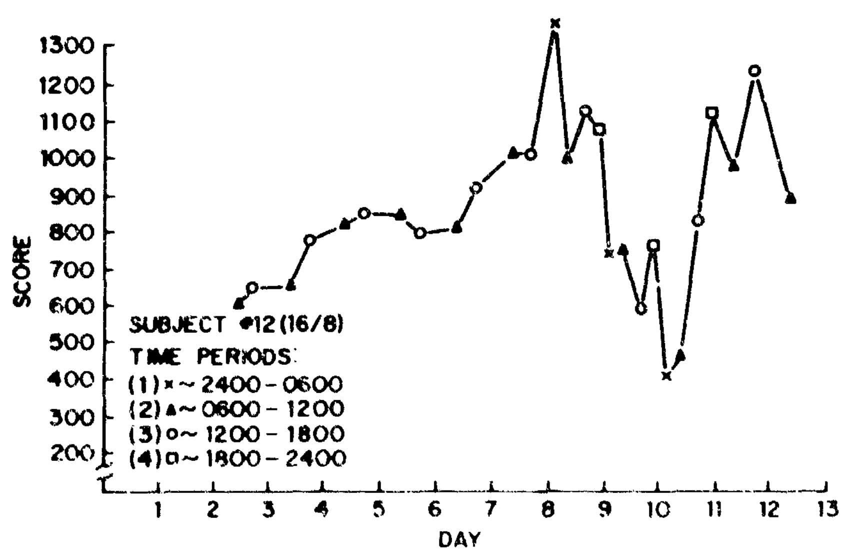
(3)○ ~1200-1800
(4)□ ~1800-2400
SCORE
DAY



SUBJECT #12 (16/8)
TIME PERIODS:
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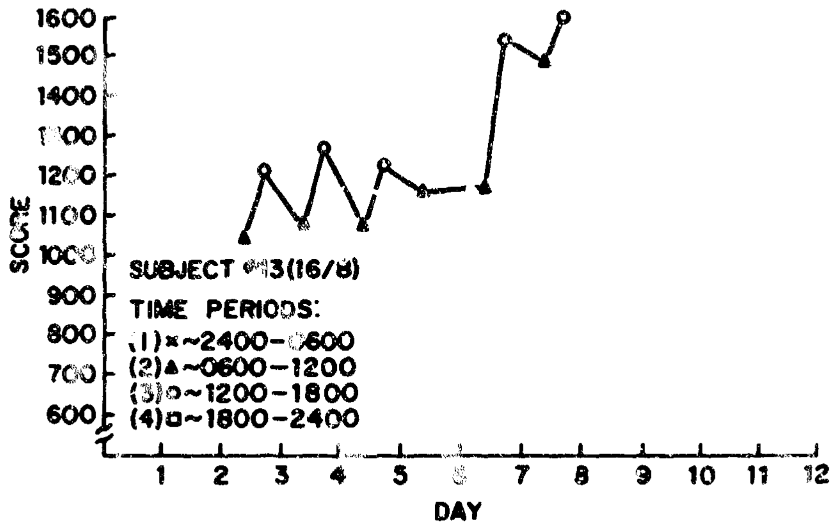
(2)▲ ~ 0600-1200
(3)○ ~ 1200-1800
(4)□ ~ 1800-2400
SCORE
DAY



1600
1500
1400
1300
1200
1100
1000
900
800
700
600
SCORE
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TIME PERIODS:
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(2)▲~0600-1200
(3)○~1200-1800
(4)□~1800-2400
1
2
3
4
5
6
7
8
9
10
11
12
DAY

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13. ABSTRACT

Thirteen subjects took part in a series of 12-day runs in an experiment on the effects of demanding work/rest schedules (4/2, 4/4, or 16/8 hours). On days 8, 9, and 10, subjects were deprived of sleep and worked continuously. No significant work/rest effects were seen until subjects were sleep-deprived. In general, subjects on the 16/8 schedule tolerated sleep deprivation better and recovered faster, as evidenced by psychomotor test scores and sleep reports.

DD FORM 1 JAN 64 1473

Unclassified
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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Psychology						
Work/rest schedules						
Sleep deprivation						
Psychomotor testing						

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