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Ames Research Center
Moffett Field, California

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INTRODUCTION

Minimum weight is essential for space vehicles. Weight is approximately proportional to volume; therefore, it is essential to know the minimum volume consistent with getting the job done. One of several methods proposed to reduce the booster requirements, hence the development time, for the lunar mission (1),[1] is to reduce the launch weight by using only a two-man crew and a small capsule. This report describes a 7-day habitability study designed as a first look at continuous human performance of this type in a small work space.

A number of confinement studies in space cabin simulators of various types have been conducted at the U. S. Naval Air Materiel Center and the Air Force School of Aviation Medicine and Aerospace Medical Laboratory, as well as various industrial concerns. These projects provided useful background information and test techniques for the present study but, so far as is known, little of the previous effort has been directed specifically at the problem of minimum size. The pertinence of the available data to the present problem depends on the size and type of work space, the tasks, and the type of subject. A partial bibliography of such studies and other pertinent data are presented at the end of this report.

The present study considered just the stresses produced by the restricted work space and the 2-man 7-day work schedule. No attempt was made to provide a completely closed ecological system or to simulate unusual environmental conditions or atmospheres. The psychological factors of sensory deprivation and isolation were present to some degree, but their effects were not emphasized. The present test subjects were sufficiently experienced and motivated to be reasonably equivalent to the astronaut group in this regard. One subject was an NASA research test pilot, the other a physiologist with extensive experience in conducting Arctic survival experiments.

This paper describes the test program and summarizes the preliminary results.

EQUIPMENT AND TEST PROCEDURE

Subjects

The first subject, Mr. Glen W. Stinnett, is an NASA research test pilot with 6 years of experience and approximately 3,000 hours of flight time. Prior to

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[1]Numbers in parentheses refer to references at end of paper.

joining NASA, he was a naval aviator for 5 years. He holds a B.S. degree in Aeronautical Engineering. He is 33 years old, is 6 feet 2 inches tall, and weighs 155 pounds.

The second subject, Dr. Terence A. Rogers, is assistant professor of physiology at Stanford University. He holds a Ph.D. in physiology and is experienced in conducting Arctic survival experiments of approximately the same time duration as the present test (2). He is 38 years old, is 5 feet 9 inches tall, and weighs 176 pounds. He had previously collaborated in the NASA studies of the effects of acceleration on pilot performance and physiology reported in references (3) and (4).

Capsule

Physical layout.- The capsule was a conical shell with a smooth inner surface of plywood and an outer covering of soundproofing material. The cone had an angle of 60° and a removable quasi-spherical base as specified on the dimensioned drawing, Fig. 1. The cone was supported so that the center line was horizontal.

The internal furnishings included two chairs, an instrument panel, food and supply cabinets, a wash-water system, a pass-out box, and a removable toilet seat. Figs. 2 and 3 show the interior. As can be seen in Fig. 2, the two chairs were hinged so that one occupant at a time could form a completely horizontal cot. The simple seat design was compatible with the use of a crew restraint system similar to that described in reference (5). In practice the subjects used the right-hand seat as the bed and the left-hand seat as the control station. There was sufficient room between the seats at their backs to permit one subject to stand and exercise.

It is difficult to define the internal volume unequivocally for comparison with other studies and facilities because of differing conventions with regard to equipment facilities and so-called unusable odd-shaped volumes. The total internal volume of the empty shell was 149.5 cubic feet. The volume available to the subjects in the furnished capsule, deduced by subtracting volumes of the instrument panel, underfloors, cabinets, and seats, was 123 cubic feet or 61.5 cubic feet per man.

The capsule was located on the floor of a large aircraft hangar. The noise level, due to the surrounding activity, was reduced to perceptible but nonirritating levels by the use of sound proofing around the capsule.

Instrumentation.- These subsystems consisted of the instrument panel, controls, and communications. Fig. 3 is a photograph of the instrument panel. A 14-inch television screen was used to display most of the task information. A pencil-type side-arm controller was located on the right arm of the left-hand seat. A standard intercommunications system was installed with the option of either cabin speaker or head sets for the subjects. There was no provision for monitoring the subjects' conversation, except when they desired to transmit and used the hand microphone. A television monitor camera equipped with a wide-angle lense was mounted to photograph the subjects as typified by Fig. 4. A lense cap was supplied to afford privacy when desired.

Life support system.- The subsystems consisted of provisions for food and water, air circulation, and waste removal. The subjects' food consisted of selected items from Air Force In-Flight Rations No. 10. The only liquid the subjects were allowed to consume was distilled water and they were allowed to consume this at will, with the quantity being recorded. The subjects were placed on the diet for 4 days prior to confinement and remained on the diet 3 days after confinement.

Waste products were removed through the pass-out box. The subjects urinated directly into labeled containers which were then frozen and stored for analysis as described in a subsequent section on the medical monitoring task. The feces were removed in waterproofed paper bags, weighed, and disposed of. Small samples were kept for analysis.

The cabin atmosphere consisted of outside sea-level hangar air, passed through a commercial room air-conditioning unit for temperature control as regulated by the subjects. The humidity was measured and recorded, but the variations from 31 percent were negligible from the viewpoint of working conditions, so no control was necessary. No special filtering or odor removal equipment was used.

The subjects were permitted electric razors and normal personal hygiene equipment. They made considerable use of commercial premoistened disposable wash towels. One change of clothing was made during the experiment.

External Equipment

Command station.- The test director was located just outside the capsule. His equipment, Fig. 5, included an intercommunications station, a television monitor screen showing the inside of the capsule, and a kinescope recorder to record sight and sound as desired. The equipment used to generate most of the tasks was set up along with the television camera used to transmit the displays to the TV screen on the capsule instrument panel. Two additional monitor screens were used as shown on the right in Fig. 5. One showed the picture to the test director only (used when setting up the task) and one was an exact duplicate of the display in the capsule.

Medical monitor station.- The medical monitor was located in a separate office overlooking the test site. He was provided with an oscilloscope continuously displaying the ECG of both subjects. He could talk to the test director privately if desired. A tape recorder was installed at this station in order to make a permanent record in real time of the medical information, the conversations, and the tasks as desired. Fig. 6 is a photograph of this station.

Tasks

The eight tasks which were combined to make up the test schedule were selected to represent the work load during a 7-day lunar mission. There were three categories: engineering tasks which included various monitoring and control problems; psychological tasks with the dual function of monitoring the well-being of the subjects as well as being of independent research value; and medical tasks, again, with a dual function of monitoring and research. The amount of research background information available in the literature for each task was also a consideration in its selection. The tasks are described in the Results and Discussion section of this paper.

Test Procedure and Work Schedule

The two test subjects entered the capsule at noon on March 30, 1962, and remained 7 days. In the absence of a firm preference in the literature for any other approach, the traditional 4-hour-on, 4-hour-off work schedule was selected. The work schedule synthesized from the list of available tasks could not be kept completely symmetrical because the navigation problem was running in real time, and the work load varied with the stage of the mission. A typical complete schedule for one day of six 4-hour shifts is presented in table I. The tasks were administered by the test director with a specialist in each task monitoring or participating as required. Exercise and other activities of the subjects will be described in the results and discussion.

Radio and television contact was maintained with the subjects throughout the test in a form representing normal good communications on a lunar mission. The only appreciable artifacts with regard to isolation were occasional extraneous noises and the use of the pass-out box to remove urine samples and waste, and supply task materials. However, it is emphasized that the subjects were consciously investigating their ability to perform the work described in table I for 7 days in the amount of space available rather than pretending to be on a lunar flight.

RESULTS AND DISCUSSION

The first part of the discussion will consider each task as an individual experiment, including background, experimental design, and preliminary results. In some cases, analyses that are not yet completed are described in order to clarify the objectives of the task. Definitive analyses of each task are being considered for separate publication.

Tracking Task[2]

The tracking task used to assess psychomotor performance was essentially one previously used in research on fixed- and moving-base simulators (6), the NADC Johnsville centrifuge (7), and in flight at 1g and near 0g. The procedure includes provisions for determining the pilot transfer function (8). Pursuit tracking was used in one-dimensional control of the pitching axis of an airplane. The subject was required to use a side-arm pencil controller to make a tracking index follow a target marker in a TV screen display (see Fig. 7).

The dynamic motion between the controller and the tracking index was developed on an analog computer to simulate the short-period dynamics of a typical airplane. Both good dynamics and poor dynamics were used to study the deterioration of tracking ability under the stress of the confined situation. Actually the good dynamics were tracked first; then, at a time unknown to the subject, poor aerodynamics were introduced by simulating a failure of the damper of the airplane. Although the subjects did not know the exact time the damper would fail, obviously, as the experiment progressed over the 7 days, they were quite aware that it was going to fail at some time during the run and the element of surprise was largely lost. They still had the difficult task of adapting as rapidly as possible to the change in dynamics.

Two target motion drives were used. The conventional one was the sum of six sine waves, giving a motion which appeared to be random but was still uniform enough to allow easy analysis. Also, as an experimental task which might have advantages in data reduction, the sum of six square waves was used. Each of these was used in runs of 8-minute duration to provide adequate record length for the data analysis. Prior to each presentation of a tracking task the subject was given 2 minutes of random step inputs which he tracked with a stick motion in order to obtain response time.

The input, the output, and the controller motion were recorded on analog tape. These data will be analyzed on a digital computer to give the cross-spectral density of the input to the controller and the controller to the output. From these data an estimation of the pilot's transfer function can be obtained. As a check on the system, the transfer function of the simulated airplane dynamics can be computed and compared with that actually used. In addition to this method of analysis, the pilot efficiency for each tracking task can be computed.

Fig. 8 is a summary of the response time measurements over the period of the study. There are no significant decrements or trends.

Fig. 9 is a summary of the pilot performance index, $100[\Sigma(\text{input}^2 - \text{error}^2)/\Sigma\ \text{input}^2]$, at selected intervals through the period of the study. It should be noted that subject S as a test pilot had extensive experience with similar tracking problems and is quite proficient; subject R was naive to the task and is not a pilot. Therefore, the observed differences in proficiency and learning were expected. In neither case was there a consistent decrement in performance as the period of confinement increased. There are individual instances of poor

[2]Designed by Mr. Norman M. McFadden

performance in single runs; however, correlation with the log book has shown that they are attributable to sleepiness as indicated. Although quantitative data are not yet available, inspection of the records indicates that there were no significant differences in ability to cope with the pitch damper failure except for the anticipated learning effects.

The human pilot transfer functions are being extracted from the tracking records using the power spectral techniques of (8). Fig. 10 is presented as a sample of the data obtained and shows the transfer function of the pilot subject S in early and late stages of the test. There are a few small differences in the subject's amplitude ratio, but little change in the phase angle, indicating only minor changes in the pilot's response over the period of the confinement.

Navigation Task[3]

As noted previously, this task was based on a proposed emergency manual midcourse guidance system in which the astronauts photograph the earth's disc and its star background and calculate their trajectory using measurements from the photographs and simplified mathematical techniques. The method was developed by Mr. C. Dewey Havill of the Ames Research Center. It was used as a task not only for studying the feasibility of the method but because it was felt to be a test of intellectual reasoning and mathematical facility that would be more interesting and stimulating to the subjects than standard test batteries.

The subjects became familiar with the various procedures beforehand, but had no time to become adept at performing them. A digital computer program employing four-body equations was used, external to the capsule, to compute the vehicle's actual trajectory from an assumed set of initial conditions. Based on these computations an accurate optical apparatus was set up to produce photographic negatives of elliptic earth images with two simulated stars in the background. These accurate photographs were passed in to the subjects and substituted for polaroid pictures taken by them of an inaccurate simulated display outside the capsule window. The subjects were also supplied tables of the angular separation of the stars from which they could compute the magnification factor of the photographs. They then performed the navigation measurements and made the calculations indicated on the sample data work sheet, Fig. 11.

The orbital corrections computed by the subjects were then applied to the actual trajectory on the external digital computer, a new set of photographs was made, and the entire process was repeated. Approximately six midcourse corrections per one-way flight were computed (8 or 9 would be desired on an actual flight), and the process took about 45 minutes out of each 4-hour work period. In addition, a 1-day photographic task was devised to represent the problem of determining the trajectory while in orbit about the moon and used at the appropriate time.

The qualitative results of this test will be summarized. Two complete one-way flights were performed during the study, one in the first 3-day period

[3]Designed by Messrs. C. Dewey Havill and Richard F. Weick

and one in the last 3 days. The most interesting result was the number and effect of mistakes in arithmetic. Measurement errors resulted in relatively small trajectory errors which were cancelled by subsequent course corrections. Arithmetic mistakes, however, can result in trajectory errors which are greater by orders of magnitude. During the first course computation, it became apparent that there was not sufficient time allowed to permit the subjects to check their work, and a number of arithmetical errors were made giving ridiculous answers. It was obvious that the navigation procedure was useless until some means of eliminating mistakes could be devised. Methods to accomplish this might include having the two pilots check each other independently, a simple mechanical or nomograph computing scheme, or the prior training of the pilots to give them previous knowledge of approximate values at various points in the computations.

Since it was not feasible during this confinement study to alter the procedure to use these techniques and since a knowledge of the guidance procedure accuracy without arithmetic mistakes was desired, the following procedure was used in the second course computation. All errors in measurement were retained in the calculations, but wherever arithmetic mistakes occurred they were corrected before proceeding with the orbital computations. Using this method, the subjects reduced an initial 500-mile error in perigee radius to an acceptable final error of 5.7 miles using only six midcourse corrections.

In summary, the subjects' ability to make the required photographic measurements remained satisfactory throughout the confinement period. Their performance of the mathematical computations was not satisfactory, but this was not dependent on the period of confinement and, in retrospect, appears to be due to improper design of the computing procedure and preparation of the subjects.

Mission Status Monitoring Task[4]

Fig. 12 is an example of the slides shown to the subjects to represent a proposed instrument to display mission-status information in the form of a bar chart. Four such slides were shown in each shift at times typified by table I. The response-time data were obtained by timing the subjects' verbal response with a stopwatch since the more sophisticated apparatus desired was not available by the start of the test program. Scrutiny of the data and test procedure has shown that the verbal-response method permitted the subjects' latitude to start a response before they had actually located the malfunction. The subjects' alertness apparently did not deteriorate since their techniques to "beat the system" continually improved throughout the test period.

[4]Designed by Mr. Thomas M. Edwards

Vigilance Task[5]

Continual monitoring and checking of vehicle control systems is a crucial part of the piloting operation. It is a task generally assigned to the man in the system rather than to a mechanized monitor and becomes particularly important in emergency situations where corrective action must be taken. However, in any long-term period of watching, the human operator is known to be susceptible to fatigue, boredom, and other factors which contribute to reducing his attentiveness. A number of previous studies document the deterioration that occurs in the detection of nonnormal or crucial information signals as observing time increases.

In most of the previous investigations, observing time periods were relatively short and the number of successive days the behavior was tested was fewer than in the current study. In this study, monitoring or vigilance behavior was sampled for 10 minutes twice during the subjects' 4-hour active duty phase.

The apparatus was constructed to represent the attitude control system of the capsule and was located on the instrument panel directly in front of the subject (see Fig. 3). He received discrete-type signals, either a red or green light from four pairs of lights arranged in a diamond-shaped configuration representing the four attitude positions. The green light represented a system check and went on each time in all four positions. The red light, which occurred at only one position and at irregular intervals, signaled an out-of-tolerance attitude condition and required correction.

Unfortunately the data recording apparatus for this particular task malfunctioned sufficiently often to make the statistical analyses of the results difficult. A cursory examination indicates that subject R's performance remained sensibly constant through the test period while subject S showed a uniform improvement. Further comment is not possible until a more complete data analysis is available.

Rate Estimation Task[6]

In a series of studies carried out by Held and White (9) through (11), velocity estimations were found to fluctuate according to immediately preceding visual experience. The authors concluded that the process of estimating speed was not necessarily stable and invariant, but was a modifiable phenomenon, dependent, in part, upon recent inputs from the environment.

The accurate estimation of velocities constitutes part of many of the tasks an operator of a spacecraft will have to perform: maneuvering the vehicle relative to external reference points, estimating the rates at which his instrument dials change, and so forth. Therefore, it is of interest to attempt to obtain some empirical data on changes in the perception of velocity during a prolonged state of confinement and relative immobility.

[5]Designed by Dr. Richard Bellville and Miss Julaine Beasley
[6]Designed by Miss Julaine Beasley

The confined state constitutes a relatively stable and unchanging environment and provides an unusual visual experience. The only velocities the crew members experience are those of self-produced movements and those involved in a limited number of perceptual tasks. Given this reduction in visual input, where the man involved has fewer opportunities to confirm his velocity estimation than he does during his normal daily visual experience, one might expect a resulting shift in adaptation level and a tendency to overestimate apparent velocity. It was this possibility which was investigated in this experiment.

Velocity judgments were made using three different speeds of rotation of a hand on a circular face. The hand swept clockwise at either 1, 2, or 4 rpm. The display was constructed so that the moving hand was visible only during its rotation over 90° of the face (see Fig. 13). The subject was asked to estimate by pressing a switch when the hand would reach a line that was a variable distance from the point at which it was last visible. The test line could be made to vary from 36° to 240° away from the disappearance point of the hand. The apparatus was set up outside the capsule and relayed by TV monitor to the screen inside the capsule.

In analyzing the data, the deviation of operator's response from the point of coincidence of the clockhand and switch was used as the error score. A positive error score indicated a late response, and a negative error score indicated an early response, relative to switch position.

Main results, Fig. 14, showed that subject S generally maintained a small positive error throughout the days of confinement. Exceptions occurred on days 4 and 5 in which his mean error became negative. Subject R, however, showed a more systematic change in error score. As days of confinement progressed, mean error increased in the negative direction, gradually shifting from an error of $+4^{\circ}$ on day 1 to -10° by day 7.

The data do not appear to show any significant diurnal trends for either subject. There were no noticeable changes in either size or direction of error with respect to the position of switches for subject R. Subject S, however, yielded positive mean errors for the first three switches and increasing negative errors for the farthest three switches.

These results seem to show that a general decrement in accuracy of velocity perception does occur as a result of confinement. The order of magnitude, and direction, of the decrement tentatively appears to be somewhat dependent on the training and background of the subject. In this experiment, the more practiced operator (S) did not show a decremental effect as strong as the relatively unpracticed subject (R).

Pattern Discrimination Task[7]

The present study was an adaptation of several studies reported in (12) and (13). Patterns were developed by an appropriately programmed digital computer using a "random-walk" technique. Each pattern consisted of an array of 3, 4, 5, 6, or 7 dots. Several thousand patterns were produced and the subject responded to more than 5,000 patterns over the course of the 7 days.

Computer-produced punched tapes, with holes corresponding to the desired patterns, were of a length sufficient to provide patterns for a 25-minute session (75 pattern pairs). These were read by a tape reader, and activated the appropriate lamps within a 6x6 matrix of lamps. A vidicon viewed the matrix and presented the patterns on the subjects' screen. Lens and iris settings were chosen which rendered the lamp patterns as white-appearing dots on a uniformly gray field. The unactivated lamps were not visible.

The stimulus-response relationships were as follows:

1. Presentation of standard pattern, 0.2 second
2. Blank, 3 seconds
3. Presentation of the comparison pattern, 0.2 second
4. Blank - response period, 6 seconds

Each comparison pattern was rotated 180° from the orientation of the standard pattern. The order of presentation of the various pattern sizes was randomly determined as was the choice of a "same" or "different" comparison pattern. A "different" pattern was one in which one of the dots in the comparison pattern was displaced from its position in the standard pattern. The subject indicated "same" or "different" by pushing the appropriate one of two buttons.

The task was presented once at the beginning and once at the end of each 4-hour shift.

Fig. 15 presents the subjects' error scores, day by day, for the 7 days of confinement. Performance improved until about the third day. In the figure, the dashed line originates at the level at which the subjects performed on pre-study trials. No data are plotted for the first day because the scoring apparatus was not reliable until the second day.

The performance of subject S was better on sessions at the end of shifts than it was on sessions at the beginning for the first half of the study (Fig. 16(a)). This trend did not continue through the second half of the study.

The performance of subject R was worse on sessions at the end of shifts than it was on sessions at the beginning (Fig. 16(b)). These differences were apparent over the extent of the study.

[7] Designed by Mr. Robert Randle and Dr. Mark Patton

Figure 17 shows the mean error score by day and shift - afternoon at the left, night at the center, and morning at the right for each day.

The task was deemed lacking in inherent interest, and no knowledge of performance was provided the subjects; therefore, motivation was judged to be low. The decrements reported above may well have been attributable to boredom rather than a real decrease in discriminative ability. Though boredom will probably be a part of the astronauts psychological enviroment, there should be an abundance of counterbalancing elements. This study is thought to represent a worst case on the scale of the stress of boredom, and extrapolations to the real world may be made in an optimistic direction.

Cancellation Task[8]

The cancellation task assessed the subjects' ability to perform a routine information processing task, locating designated items of information within a larger array of such items. It was thought that such a task would be more likely to show decrements of performance under the conditions of the experiment than other tasks which were inherently more highly motivating.

The task occupied a 24-minute session once during each 4-hour duty period. A test booklet consisted of 10 sheets of paper, each containing an array of 800 typed capital letters. These were arranged in 16 double-spaced rows of 50 letters each. The sheets contained varying numbers (24, 12 or 6) of different letters, each letter repeated many times on a given sheet. The letters appearing on a given sheet were chosen by a random procedure, while the sequence in which they occurred was determined haphazardly, resulting in each chosen letter occurring approximately equally often on a given sheet. The subject was required to locate a certain letter, or letters (designated at the top of the sheet), and to draw a vertical line through such a letter when it appeared. He was instructed to continue immediately to the next page each time a page was completed, and thus to continue through the booklet during the time allowed. Variation in the number of letters to be located and the number of different letters in the array permitted variation of the level of task complexity within each experimental session. Both the speed of the subject's performance and the number of errors made were scored.

Both subjects, Fig. 18(a), showed a rather consistent day-to-day rise in speed of task performance over the 7-day confinement experience. The only marked exception to this was a decrease in speed evidenced by subject S on day 6. The two worked equally rapidly for the first 3 days. During the last 4 days subject S worked consistently more rapidly than subject R.

Subject R generally made fewer errors than S (Fig. 18(b)). Subject R's error score is relatively stable from day to day, with only one deviant day (day 5), when his number of errors was extremely low. Subject S showed a day-to-day cyclical effect, with a large number of errors on days 1, 2, 4, and 6, and a relatively small number on days 3, 5, and 7.

[8]Designed by Dr. Mark Patton

Both subjects showed decrements in performance related to task complexity. The requirement to search for more letters within the array slowed performance and increased errors. Subject R's speed did not vary with time of day, but his error rate did. His best shift was that beginning at 12 p.m. (all times refer to beginning of the shift), his next best was the 4 p.m. shift, and his worst was the 8 a.m. shift. Subject S's speed of performance was sensitive to time of day, his best-to-worst order of shifts being 8 p.m., 12 a.m. and 4 a.m. Subject S's error rates for 8 p.m. and 12 a.m. shifts were the same, but his error rate was distinctly higher on the 4 a.m. shift. In his case there was an interactive effect on the error rate between time of day and task difficulty. Error rate on the simplest task did not vary by shift, but the combination of nonpreferred (4 a.m.) shift and difficult task led to an increase in error. This is probably due to subject S's difficulty in staying awake on his 4 a.m. shift.

Physiological Research Task[9]

As part of this task the subjects were required to perform a number of functions representative of the self-monitoring on an actual flight. They took each others pulse rate and blood pressure at stated intervals, collected and labeled urine and feces samples, drew blood samples, used pneumotachographs at intervals, and kept complete procedural logs. The physiological studies were devoted to three overlapping purposes, namely:

(a) Estimating the food, water, and oxygen requirements of crew members under these conditions.

(b) Determining physiological correlates of changing psychomotor and cognitive functions.

(c) Monitoring the subjects' over-all physiological status from the point of view of their health and safety.

Since a primary purpose of the experiment was to provide immediately useful data, the physiological studies were limited to those which could be implemented by techniques already available at the Ames Research Center. A large number of relatively routine chemical determinations were carried out under contract by the clinical laboratory of the El Camino Hospital.

The experimental procedures and results are described under the following headings:

A. Work-rest schedule
B. Food and water intake
C. Respiration
D. Energy cost
E. Nitrogen turnover
F. Fluid and electrolyte balance

[9]Designed by Drs. H. A. Smedal, T. A. Rogers, and Donald R. Young, and Mr. Gene Lyman

G. Urinary catecholamines, 17-ketosteroids and OH-steroids
H. Cardiovascular

A. Work-rest schedule.- There are two points of physiological interest. Both subjects agreed to undertake a schedule of exercises at the beginning of each off-duty period. The exercises were designed to minimize the muscular atrophy and the likelihood of phlebothrombosis which could otherwise result from forced inactivity. In general, the exericse periods were enjoyable and neither subject felt inclined to let them slide as the confinement period progressed. Subject R, however, abandoned push-ups because he could not do them without incurring infuriating minor injuries. The resulting atrophy of his upper arms was subjectively most striking at the end of the week, suggesting the desirability of developing exercise regimens which can be followed even in prolonged periods of weightlessness.

Also the sleep log, table II, shows that subject R averaged 5.75 hours of sleep per day compared with 4.5 hours per day for subject S. It will be noted that the order of watches was very much to subject S's disadvantage. He was off duty in the watches 0800-1200, and 1600-2000, which are both times at which one is ordinarily alert and in which sleep is more difficult. At the same time, he was always on duty at the grisly time of 0400-0800, and this was the watch in which he had the most trouble staying awake.

B. Food and water intake.-

1. Diet:

An important part of the investigation was the determination of body fluid and electrolyte changes induced by the confinement (see F below). Therefore, the intake of food and water was standardized as much as possible so that variations in excretion could be attributed to changes in a near-steady state, without the necessity of making allowances for variations in intake.

Almost any nutritionally complete diet could have been selected, and diets made up entirely of dehydrated foods have been designed and prepared for use in space vehicles. For the present experiment (in which water was not recycled), it was considered that Air Force In-Flight Rations No. 10 were suitable. Their chief advantages related to the extensive information on their composition already acquired by one of the investigators in the course of other work. The rations may be briefly described as resembling the familiar C-rations. Each subject selected his own menu, table III, yielding about 2,000 kilocalories and consumed these same items every day for 14 days.

2. Water intake:

The total water consumption of each subject is shown in table IV. To begin with, each subject drank 1,200 ml of water (in addition to the food water), so that R's total water intake was 70 ml greater than S's. After 24 hours in the capsule, R felt that this was not enough, and after some extra intake as shown, he settled down with 1,400 ml/day. Subject R's greater water loss is discussed in section F below. From this experiment then, it appears that under comparable conditions of temperature and humidity, the minimum water requirement with dehydrated food is 2-2.5 liters/man/day.

C. Respiration.- The expired air volume and oxygen consumption of each subject were measured at intervals using the Wolff Integrating Motor Pneumotachograph (IMP). Briefly, after one or more hours of use, the instrument yields the total expired air volume and a representative sample of expired air for gas analysis. With the total volume known, the oxygen and carbon dioxide content permit calculation of the oxygen consumption and carbon dioxide production. In this experiment only the oxygen analysis was carried out since the diet was such that the carbon dioxide production could be reliably predicted from the oxygen consumption.

The instruments performed satisfactorily insofar as the expired air volume measurements were concerned, but one of the instruments used on subject S had a defective sampling pump. Furthermore, there were difficulties with the oxygen analysis and several determinations were clearly aberrant. In other instances, however, the mean expired air oxygen content was the 17 percent ordinarily expected. This value was used in all the runs, giving the data shown in table V.

The actual oxygen consumption was certainly higher than that calculated, since the IMP's were not worn during the brief exercise periods. The values obtained represent the "steady states" of work or rest. On this basis it can be predicted that 500 liters of oxygen per day per man will meet the requirements (about 700 gm). The carbon dioxide production would be about 90 percent of the oxygen consumption, namely 450 liters, but this weighs 885 grams.

D. Energy cost.- This is calculated directly from the oxygen consumption data and is also listed in table V. The results show that the dietary estimate of 2,000 kilocalories per day is realistic. They also show that the dissipation of this much heat must be considered in the design of the vehicle.

The surface areas of the subjects are 1.95 M^2 (S) and 2.0 M^2 (R). Therefore the calculated caloric expenditures are just above the normal basal rate (irreducible minimum) of 38 kilocalories/hr/M^2. This confirms the common-sense prediction that for this kind of physical activity the energy cost is insignificantly more than that for the simple maintenance of body functions.

It should be noted, however, that the subjects were in an essentially thermoneutral environment and, with the same clothing, lower ambient temperature would increase the caloric expenditure (and oxygen requirement) substantially.

E. Nitrogen turnover.- At the time of writing this paper, the urinary nitrogen data are not available. Nitrogen is a characteristic constituent of protein, and a comparison of the nitrogen intake with that excreted will indicate the protein balance of the subject. A negative balance indicates extra breakdown of body protein for use as fuel.

F. Fluid and electrolyte balance.- All urine was collected over 4-hour periods from the beginning of the prior-control period to the end of the follow-up period - a total of 2 weeks. The subjects were able to urinate once every 4 hours, thereby avoiding the necessity of storing urine within the capsule. The volume of each urine sample was measured and recorded. It was recognized that the 4-hour urine samples would probably yield valuable information on diurnal variation in the subjects, but because there were a total of 168 such samples, it was agreed that preliminary analyses of a "survey" nature could be profitably undertaken on 24-hour pooled samples. Accordingly, a fixed percentage of each 4-hour urine sample was taken and these aliquots pooled to give a representative 24-hour urine sample. As indicated below, certain analyses are now being carried out on the 4-hour samples but these data are not yet available.

The urine analyses were carried out under contract by the Clinical Laboratory of the El Camino Hospital. The determinations included: specific gravity, pH, sodium, potassium, calcium, phosphorus, creatinine, epinephrine, nor-epinephrine, 17-ketosteroids, and 17-OH-steroids. The methods used are all well known and, with the possible exception of the last four items, are routine in all hospital laboratories.

Major blood samples were drawn four times, once during the prior-control period, once just before entering the capsule, once on emergence, and once on the last day of the follow-up period. The blood analyses (which were also undertaken by the El Camino Hospital laboratory) included determinations of sodium, potassium, calcium, chloride, total CO_2, hemoglobin, total protein, albumen, globulin, glucose, erythrocyte count and a differential white cell count.

During confinement, the subjects drew blood samples in capillary tubes from finger punctures. These samples were centrifuged to measure the hematocrit; then the supernatant plasma was removed for the optical determination of specific gravity.

1. Water balance:

The water balance of the subjects is shown in table IV. If the body weight is unchanged, the difference between urine volume and the total water intake is that lost as sweat and as "insensible perspiration." This latter archaic term refers to water loss by evaporation through the skin and through pulmonary surfaces. The body weight changes during confinement amounted to about 0.5 kg for R and 1.0 kg for S, and even if these changes were due entirely to changes in hydration, they would still account for less than 1 liter of water. Therefore, since the subjects scrupulously avoided overt sweating, most of the difference between urine volume and water intake can be attributed to evaporative losses. Subject R's losses in this respect (10.91 liters for the 7 days) are almost twice those of S (6.56 L), and this is consistent with R's markedly smaller urine volume. (The fluid intakes of the subjects were approximately the same.)

This difference between the subjects is to be expected from their different body types. Heat is lost from the body by radiation, conduction, and evaporation of water. The subcutaneous fat layers enjoyed by R have considerable insulative value, causing relatively smaller conductive loss. Since the caloric turnover (and therefore the total heat loss) was essentially the same in each subject (see D), it follows that R's evaporative losses must be greater. At 30° C, the latent heat of evaporation of water is 580 kilocalories/kg. Therefore the mean daily heat loss by this route was 904 kilocalories (or 45 percent of the total) for R and 534 kilocalories (27 percent of total) for S.

2. Extracellular fluid volume:

One of the hazards encountered in prolonged bed-rest is a diminution in blood volume. One of the planned advantages of the monotonous diet was that during the 4 day prior-control period, the subjects would reach a near-steady state of sodium excretion, and then any fluctuations in urinary sodium excretion would be indirectly suggestive of changes in extracellular fluid volume. The sodium excretion of the subjects is shown in table VI and in Figs. 19 and 20. During confinement, S showed a net loss of 113 mEq of sodium, which was not reflected in a change in hematocrit. The sodium loss and concomitant extracellular fluid loss probably accounts for part of S's body weight decline during confinement, while his small caloric deficit (see D) accounts for the remainder. R's negative sodium balance was similar, with -105 mEq for the 7 days.

It is interesting to note that the sodium deficit in both subjects is largely accounted for by an increased sodium excretion for two or three days in the middle of the confinement period (see Figs. 19 and 20).

3. Other electrolytes:

The excretion of potassium is also shown in Figs. 19 and 20. It was larger during the prior-control period because the diet was inadequate for that level of activity (especially for R); the breakdown of tissues to supply the extra calories releases cellular potassium which is then excreted. Generally, about 100 mEq of potassium are associated with each kilogram (wet weight) of tissue. S was in flight positive potassium balance for the last five days of confinement, for which there appears no ready explanation.

S's excretion of calcium during confinement was substantially in excess of intake (see Fig. 21). R's dietary intake of calcium was larger than the excretion throughout, but the absorbability of dietary calcium is by no means complete and is subject to change by numerous factors. The sudden extra excretion of calcium by R on the last day of confinement is possibly significant. Urine phosphorus excretion is shown in Fig. 22. The increased excretion during confinement is to be expected from the calcium data.

A loss of skeletal calcium during bed rest or even during immobilization of a single limb, is well recognized by orthopedic surgeons. It is agreed that under good dietary conditions the mineralization of bone is increased when the bone is subjected to frequent physical stresses and is reciprocally diminished when the skeleton bears no weight. This is not unexpected on teleological grounds but the physiological mechanism is obscure. We feel that the calcium mobilization during confinement may prove to be a hazard in space flights of long duration, not so much from the demineralization of the skeleton *per se*, but because the consequently high concentration of urinary calcium salts may lead to the formation of renal and bladder calculi. On this basis, therefore, a case can be made for maintaining a larger than minimum water intake (so that the urine will be more dilute). If the space vehicle is equipped for recovery of urine water, a more rapid turnover of water should not present a serious weight and space problem.

G. Catecholamine and ketosteroid excretion.- The urinary excretion of these hormones (or catabolic end products) is shown in Fig. 23. It will be noted that R's excretion of all these compounds is high during the prior-control period. This was a time of considerable anxiety from several causes, including the intense activity associated with the final arrangements for the experiment, apprehension about personal performance during the experiment, and some unrelated personal problems. Although S was probably under less intrinsic stress at this time, the main difference is certainly attributable to the fact that R is a much more anxious individual than S.

As described elsewhere in this paper, the psychological testing of the subjects included their completing a "mood" questionnaire every 12 hours during confinement. The over-all mood changes are highly correlated with the catecholamine excretion data obtained so far. Some emotional factors showed a distinctly cyclic rhythm, and, accordingly, the catecholamine content of the 4-hour urine samples is now being measured for comparison with the psychometric data.

H. Cardiovascular.- The subjects wore lateral chest electrodes throughout the confinement period, permitting almost continuous tape recording of their ECG traces. Real-time paper records for short periods at intervals throughout the experiment are being recovered from the tape. In addition, a computer analysis is being made to recover the mean heart rate at hourly intervals.

At each change of watch, the subjects took their blood pressures which were recorded and presented in Fig. 24. The only cardiovascular manifestation was that R's heart rate and blood pressure declined steadily throughout the experiment. This is entirely consistent with the urinary catecholamine excretion and the psychometric data. It is no exaggeration to state that R was in better shape emotionally and physiologically at the end of the confinement than at the beginning, and probably in better shape than he had been for years. In some ways, the records show an almost classic example of the value of enforced bed rest for an anxious, overworked man. This is significant in that it is the reverse of the more obvious expectations of the consequences to the "stress" of close confinement of this kind.

The cardiovascular data on S are unremarkable.

1. Neurological:

Routine neurological examinations with electroencephalograms were carried out on each subject before and after the confinement. The findings were unremarkable in all examinations.

The most important summary result of the biological investigation is that the confinement of two men in 123 cubic feet for 1 week is completely tolerable. The physiological deterioration was of the same kind as that to be expected from a week's confinement to bed, but less extensive. The only remotely sinister manifestation was the excretion of calcium in excess of intake. Since this could favor the formation of kidney stones, it is suggested that water intake should be in excess of the 2-2.5 liters/man/day we found to be the comfortable minimum.

It is conceivable that even under zero-G conditions, a suitable exercise regimen could minimize demineralization of the skeleton as well as prevent muscular atrophy. This would appear to be an appropriate area for research in connection with future confinement studies.

Subjective Opinions of Subjects

In view of the possible repetition of this type of test or the use of similar techniques for training, the subjects were given an engineering-oriented de-briefing questionnaire. This was completely separate from a professional psychological examination given before and after the test program which will be considered for separate publication. Some selected questions and replies pertinent to the use of such techniques for training follow:

1. Q. Did you feel the experiment was realistic?

   a. Were you always conscious of being in the hangar, or did it sometimes seem as if you were really in space?

   b. What do you think might have decreased your consciousness of being in the hangar?

Ans. Stinnett.- As a habitability study, the confinement seemed realistic; as a space flight simulation it did not. Only one task (navigation) remotely resembled a flight mission task.

Rogers.- The experiment was not realistic. I had no doubt about my being in the hangar all the time. I did lose track of where the monitors might be actually located, but I never felt I was in space. I suppose the experiment would be slightly more realistic with more difficult and more formal communication, but even then the increase in realism would hardly merit the change. I cannot see how sophisticated people can ever persuade themselves that a simulator is the real thing.

2. Q. Which tasks seemed particularly easy?

   a. Which particularly hard?

   b. Which did you enjoy doing?

   c. Which did you dislike doing?

Ans. Stinnett.- Considering only the following: (a) rate estimation, (b) vigilance, (c) pattern recognition, (d) tracking, (e) navigation, (f) cancellation

Easiest:	rate estimation
Hardest:	cancellation task required the most intense effort
Enjoyable:	navigation
Unpleasant:	At first the cancellation caused eye discomfort; later this disappeared and pattern recognition became the most unpleasant task due to its boring nature and long duration.

Ans. Rogers.- The easiest task was reading the system status slides. I regard these as puerile. The hardest task, in terms of hardest to put up with, was the pattern recognition. The hardest in terms of cognitive difficult was the navigation task. I would put the tasks in the following descending order of difficulty:

Navigation
Vigilance (It was short.)
Cancellation
Tracking
Rate estimation
Pattern recognition

3. Q. What task was the most realistic in relation to a lunar mission?

Ans. Stinnett.- See question 1.

Rogers.- Navigation.

4. Q. Do you think you could have continued the task for another 7 days?

a. If not, why not?

b. How much longer?

Ans. Stinnett.- My situation was quite tolerable and could be endured indefinitely in my opinion - just how long, I am not prepared to guess. Reaching conclusions by extrapolation is not appropriate in a case of this nature.

Rogers.- I think I could have continued for another 7 days, but I think my performance was beginning to fall off. I could have gone another 7 days without voluntarily letting my performance deteriorate.

5. Q. What day or shift was most difficult?

Ans. Stinnett.- Generally, most difficult shift was from 4 a.m. to 8 a.m. because of drowsiness to the point of dozing. Specifically, the most difficult shift was my third duty cycle due to eye discomfort and drowsiness both.

Rogers.- The midnight to 4 a.m. shift of the first day.

6. Q. How long did it take to establish your routines?

   a. Work?

   b. Sleep?

Ans. Stinnett.- A fairly regular routine developed within the first two days for all but the 4 a.m. - 8 a.m. period. Alertness on this shift continued to fluctuate throughout the confinement period.

Rogers.- My routine was well in hand by the second day, both for work and sleep.

7. Q. Was the 4-hour-on - 4-hour-off schedule acceptable?

   a. If not, do you have any recommendations as to shift length?

Ans. Stinnett.- Schedule was satisfactory except that drowsiness occurred as mentioned above on the 4 a.m. - 8 a.m. shift.

Rogers.- I think that for a 2-man crew, the 4-on - 4-off routine is acceptable and cannot be improved upon.[10]

8. Q. What gave you the most satisfaction?

   a. Completing performance tasks?

   b. Eating?

   c. Sleeping?

   d. Other - specify.

Ans. Stinnett.- The single most satisfying factor seemed to be the realization that the program was going smoothly. This caused a gradual loosening-up or relaxation toward the end of the first day and a feeling of general satisfaction continued from then on. Toward the end, completion of task performance was rather satisfying because I felt performance was improving and was pleased by this.

Rogers.- The most satisfactory sensation was at the completion of the spell of pattern recognition that terminated each work shift. I derived

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[10] It should be noted in considering these two answers that with the symmetrical 2-man, 4-hour shifts used herein the same individual (Stinnett) always got the undesirable 4 a.m. to 8 a.m. duty period. It appears that the basic 4-on - 4-off shift is quite acceptable but should be lengthened slightly or some other provision made for rotating the undesirable shift over the seven days.

no satisfaction from eating (except supper (8 p.m.) on third or fourth day). Ordinarily it varied from a chore to a bore. Sleeping was fine, but I find it hard to rate this as a satisfaction.

9. Q. Could the effective capsule volume be reduced without performance decrement?

Ans. Stinnett.- Volume could be reduced in certain areas if: (a) exercise equipment were installed and (b) special equipment for toilet duties were provided and (c) enough space be allowed for subjects to stretch, bend, double up, etc.

Rogers.- I believe the capsule volume could be markedly reduced for a lunar mission without decreasing performance. I have many thoughts about this which I would like to develop at leisure and at length.

10. Q. Could you operate in the sitting-lying position without the standing between the seats for this length of time?

Ans. Stinnett.- See question 9. Yes, in a zero-g field - no, in a one-g field.

Rogers.- See above. In a one-g field, probably not; in a zero-g field the question has no meaning.

CONCLUDING REMARKS

It is apparent from the preceding material that no phenomena were encountered under the restricted conditions of this experiment that would preclude using a capsule with a usable volume of about 60 cubic feet per man for a 7-day mission approximating the work load described in table I. Both subjects sustained expected levels of performance throughout the test. At the conclusion both subjects were in condition to continue the test and both subjects proposed further consideration of capsules of even smaller volume than the one used here, strongly suggesting that the minimum feasible size was not reached in the present test. Pending a more detailed scrutiny of the data, the two most serious problems within the scope of the experiment were an indication of increasing loss in skeletal calcium and the difficulty of one subject in remaining awake on the 0400-0800 shift at the existing level of motivation.

Since the use of similar devices and procedures might be considered to train astronauts of the same level of sophistication as the present subjects, it is pertinent to summarize their attitude toward the tasks. The nondevelopmental tasks and procedures intended chiefly to enhance the realism of a mock lunar mission, such as the mission status monitoring, were not highly regarded. On the other hand, the task most closely connected to the lunar mission but which contained a large amount of developmental research on the task itself, the mid-course navigation problem, was well appreciated and highly rated. The "test-battery" types of task (vigilance, pattern-recognition and cancellation) were recognizably boring but successful because they had a research background in the literature which could be used to demonstrate their significance and value to the subjects.

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REFERENCES

1. Eggers, A. J., Jr., Wong, T. J., Hornby, H., and Wyss, J. A.: Some General Considerations of Manned Lunar Return Missions. ARS Lunar Missions Conference, Cleveland, Ohio, July 17-19, 1962.

2. Rogers, T. A., and Setliff, J.: Caloric Cost and Fluid Balance in a Simulated Arctic Survival Situation. Fed. Proc. 21, 224-c, 1962.

3. Rogers, T. A., and Smedal, H. A.: The Ventilatory Advantage of Backward Transverse Acceleration. Aerospace Medicine, vol. 32, Aug. 1961, pp. 737-730.

4. Smedal, H. A., Rogers, T. A., Duane, T. D., Holden, G. R., and Smith, J. R., Jr.: Effects of Acceleration in Certain Physiological Quantities Which Limit the Pilot's Tolerance and Performance. Paper presented at Aerospace Medical Assn. meeting, Atlantic City, New Jersey, April 10-13, 1962.

5. Vykukal, H. C., Gallant, R. P., and Stinnett, G. W.: Description and Performance of an Interchangeable, Mobile Pilot-Restraint System Designed for Use in High Sustained Acceleration Force Fields. Aerospace Medicine, vol. 33, Mar. 1962, pp. 279-328.

6. Sadoff, M.: The Effects of Longitudinal Control-System Dynamics on Pilot Opinion and Response Characteristics as Determined From Flight Tests and From Ground Simulator Studies. NASA MEMO 10-1-58A, 1958.

7. Sadoff, M., McFadden, N. M., and Heinle, D. R.: A Study of Longitudinal Control Problems at Low and Negative Damping and Stability With Emphasis on Effects of Motion Cues. NASA TN D-348, 1961.

8. McRuer, D. T., and Krendel, E. S.: Dynamic Response of Human Operators. WADC Tech. Rep. 56-524, Oct. 1957.

9. Held, R.: Exposure-History as a Factor in Maintaining Stability of Perception and Coordination. J. Nervous and Mental Disorders, 132, Jan. 1961, pp. 26-32.

10. Held, R., and White, B.: Sensory Deprivation and Visual Speed: An Analysis. Science, vol. 130, Oct. 2, 1959, pp. 860-861.

11. White, B.: The Role of Visual Experience in Velocity Perception. Ph.D. Thesis, Brandeis University.

12. French, R. S.: The Discrimination of Dot Patterns as a Function of Number and Average Separation of Dots. J. Experimental Psychology, Vol. 46, No. 1, July 1953, pp. 1-9.

13. French, R. S.: Identification of Dot Patterns From Memory as a Function of Complexity. J. Experimental Psychology, vol. 47, no. 1, 1954, pp. 22-26.

BIBLIOGRAPHY OF CONFINEMENT STUDIES

General

Czeh, R. S.: Isolation, Confinement, and Vigilance: A Review of the Literature. Human Factors Rep. 60-1, General Elect. Co., Philadelphia, Pa., Jan. 15, 1960.

Environmental Requirements of Sealed Cabins for Space and Orbital Flights - A Second Study. Part 1: Rationale and Habitability Aspects of Confinement Study, NAMC-ACEL-413, 8 Dec. 1959. Part 3: Performance and Habitability Aspects of Extended Confinement. NAMC-ACEL-385, 26 Sept. 1958.

Leiderman, P. H., and Stern, R.: Selected Bibliography of Sensory Deprivation and Related Subjects. ASD Tech. Rep. 61-259, July 1961.

Lectures in Aerospace Medicine, 11-15 Jan. 1960. S.A.M.

Lectures in Aerospace Medicine, 16-20 Jan. 1961. S.A.M.

Lectures in Aerospace Medicine, 8-12 Jan. 1962. S.A.M.

Adams, O. S.: Aircrew Fatigue Problems During Extended Endurance Flight, Phase I: Planning. WADC Tech. Rep. 57-510, May 1958.

Arai, T.: Mental Fatigue. Teachers College Contr. Educ., 1912, No. 54.

Jackson, K. F.: Aircrew Fatigue in Long Range Maritime Reconnaissance: Pilot Performance. Air Ministry Flying Personnel Research Committee Rep. 907.2, Aug. 1956.

Celentano, J. T., Copping, D. G., Falbaum, H. F., and Martin, B. G.: Biomedical Aspects of a Seven-Day Space Cabin Study. North American Aviation, IAS Summer Meeting, June 19-22, 1962.

Physiology

Lectures in Aerospace Medicine (Sealed Cabin Experimentation) 16-20 Jan. 1961. S.A.M.

Gerathewohl, S. J., Downs, S. W., Jr., Champlin, G. A., and Wilbarger, E. S., Jr.: Bio-Telemetry in the Nose Cones of U. S. Army Jupiter Missile. IRE Trans., April-July 1960.

Feeding

Physiological and Psychological Considerations for Manned Space Flight With Bibliography. CVA Rep. E9R-12349.

Environmental Control

Physiological and Psychological Considerations for Manned Space Flight. CVA Rep. E9R-12349.

Lectures in Aerospace Medicine. 11-15 Jan. 1960, School of Aviation Medicine.

Steinkamp, G. R., Hawkins, W. R., Hauty, G. T., Burwell, R. R., and Ward, S. E.: Human Experimentation in the Space Cabin Simulator: Development of Life Support Systems and Results of Initial Seven Day Flights. School of Aviation Medicine Rep. 59-101, Aug. 1959.

Taylor, A. A., Lt Col USAF, Finkelstein, B., and Hayes, R. E.: Food for Space Travel. ARDC TR 60-8, July 1960.

Keating, D. A.: Design Parameters for the Engineering of Closed Respiratory Systems. WADC TR 59-766, Dec. 1960.

Closed Circuit Respiration/Ventilation System. WADD TR 60-33, Jan. 1960.

Des Jardins, J., Zeff, J. D., and Bambenek, P. A.: Waste Collection Unit for a Space Vehicle. WADD TR 60-290, May 1960.

Redden, R. J.: Urine Collection and Disposal Device for Pressure Suit. ASD TR 61-329, Aug. 1961.

Collection Unit for Wastes During Space Travel. ASD TR 61-314, July 1961.

Manhigh III, USAF Manned Balloon Flight Into the Stratosphere. AFMDC TR 60-16, April 1961.

Display

Burns, N. M., and Gifford, E. C.: Human Engineering Investigation of Aircraft Cockpit Displays. NAMC-ACEL-424, 29 Jan. 1960.

Physiological and Psychological Considerations for Manned Space Flight (Crew Space Color and Lighting). CVA Rep. E9R-12349.

Work-Rest Cycle

Adams, O. S., and Chiles, W. D.: Human Performance as a Function of the Work-Rest Cycle. WADD TR 60-248, March 1960.

Adams, O. S., and Chiles, W. D.: Human Performance as a Function of the Work-Rest Ratio During Prolonged Confinement. USAF ASD TR 61-720, Nov. 1961.

Physiological and Psychological Considerations for Manned Space Flight - CVA Rep. E9R-12349 (Work-Rest Cycle) (Isolation, p. 126).

Hauty, G. T.: Modifiability of Day-Night Cycling. ARS 13th Annual Meeting, New York, N. Y., Nov. 1958.

Lectures in Aerospace Medicine (Psychophysiological Problems in Manned Space Vehicles - George T. Hauty) 11-15 Jan. 1960.

Lectures in Aerospace Medicine (Experimental Approach to the Psychophysiological Problem of Manned Space Flight - Bryce O. Hartman) 16-20 Jan. 1961.

Kleitman, N.: Sleep and Wakefulness. Univ. of Chicago Press, 1939.

Ray, J. T., Martin, O. E., Jr., and Alluisi, E. A.: Human Performance as a Function of the Work-Rest Cycle. NAS, NRCP-882, 1961.

Adams, O. S., and Chiles, W. D.: Prolonged Human Performance as a Function of the Work-Rest Cycle. ORD 273, May 1961, Lockheed Aircraft Corp., Marietta, Ga.

Psychology

Hagen, D. H.: Crew Interaction During a 30-Day Simulated Space Flight - Preliminary Study. S.A.M. 61-66, June 1961.

Ormiston, D. W.: A Methodological Study of Confinement. Behavioral Sciences Lab., Aerospace Med. Lab., WADD TR 61-258, March 1961.

Vivid Hallucinations Plague Test Subjects. Aviation Week, Feb. 1, 1960.

Physiological and Psychological Considerations for Manned Space Flight. CVA Rep. E9R-12349.

Wexler, D., Mendelson, J., Leiderman, P. H., and Soloman, P.: Sensory Deprivation. A Technique for Studying the Psychiatric Aspects of Stress. AMA Arch. Neur. Psychiat., 79, 225-233, 1958.

Lectures in Aerospace Medicine (Psychophysiological Problems of Manned Space Vehicles - G. T. Hauty) 11-15 Jan. 1960, S.A.M.

Lectures in Aerospace Medicine (Experimental Approach to the Psychophysiological Problem of Manned Space Flight - Bryce O. Hartman) 16-20 Jan. 1961.

Gerathewohl, S. J.: Work Proficiency in Space Cabin Simulator. Aerospace Medicine, vol. 20, pp. 722-735, Oct. 1959.

Bevan, W., and Patton, R. M.: Fatigue, Stress, Bodily Change, and Behavior. A Selected Bibliography, ORD 108, Lockheed Aircraft Co., Marietta, Georgia.

Adams, O. S., Levine, R. B., and Chiles, W. D.: Research to Investigate Factors Affecting Multiple-Task Psychomotor Performance. WADC Tech. Rep. 59-120, March 1959.

Huxtable, Z. L., White, M. H., and McCarton, M. A.: A Re-Performance and Re-Interpretation of the Arai Experiment in Mental Fatigue With Three Subjects. Psychol. Monog., 1946, 59, No. 5 (shole No. 275).

Kleitman, N.: The Sleep-Wakefulness Cycle of Submarine Personnel. In Panel on Psychology and Physiology, A survey Report on Human Factors in Undersea Warfare, Washington, D. C. National Res. Council Comm. on Undersea Warfare, 1949, 329-341.

McGill University Study 1954

Bexton, W. H., Heron, W., and Scott, T. H.: Effects of Decreased Variation in Sensory Environment. Canad. J. Psychol. 8: 70-76, June 1954.

Scott, T. H.: Intellectual Effects of Perceptual Isolation. Doctoral Thesis, McGill Univ., Aug. 1955.

Heron, W., Doane, B. K., and Scott, T. H.: Visual Disturbances After Prolonged Perceptual Isolation. Canad. J. Psychol. 10: 13-18, March 1956.

Sleep Deprivation

Morris, G. O., Williams, H. L., and Lubin, A.: Misperception and Disorientation During Sleep Deprivation. AMA Arch. Neurol. Psychiat.

Vernon, J. A.: Pain Threshs and Time Orientation in Sensory Deprivation. Paper read at symposium entitled, "Experimental Foundations of Clinical Psychology," under chairmanship of J. Bachrach, U. of Va., April 1959.

Tyler, D. B., Goodman, J., and Rothman, T.: The Effect of Experimental Insomnia on the Rate of Potential Changes in the Brain. Amer. J. Physiol., 1947, 149, 185-193.

Bjerner, B.: Alpha Depression and Lowered Pulse Rate During Delayed Actions in a Serial Reaction Test. Acta Physiol. Scandinavica, 1949, 19, Suppl. 65.

Armington, J. D., and Metnicle, L. L.: EEG and Sleep Deprivation. J. Appl. Physiol., 1959, 14, 247-250.

Isolation and Space Flight

Ogle, D. C.: Man in Space Vehicle. U. S. Armed Forces M. J. 8: 1561-1570, Nov. 1957.

Walters, R. H., and Henning, B.: Isolation, Confinement and Related Stress Situations. Aerospace Medicine, 32, No. 5, May 1961, 431.

Kraft, J. A.: Measurement of Stress and Fatigue in Flight Crews During Confinement. Aerospace Medicine, 30, June 1959, 424.

Levy, E. Z., Ruff, G. E., and Thaler, V. H.: Studies in Human Isolation. J.A.M.A. 169: 236-239, Jan. 17, 1959.

Ruff, G. E., Levy, E. Z., and Thaler, V. H.: Studies in Isolation and Confinement. Aerospace Med., 30: 599-604, Aug. 1959.

Michael, D. N.: How to Keep Space Crews Content. Missiles and Rockets, 3: 110-114, April 1948.

Dempsey, C. A., Van Wart, I. D., Duddy, J. H., and Hockenberry, J.: Long Term Human Confinement in Space Equivalent Vehicles. Trans. Am. Astronautical Soc. (1956), pp. 89-93, 1957.

Weybrew, B. B., Parker, J. W.: Bibliography of Sensory Deprivation, Isolation and Confinement. U. S. Armed Forces M. J., 2, Aug. 1960, 903.

Isolation

Studies in Human Isolation I. Perceptual Findings. Freedman, S. J., and Greenblatt, Armed Forces Med. J., Nov. 1960, No. 11, p. 1330.

Held, R., and White, B. L.: Sensory Deprivation and Visual Speed: An Analysis. Science 130: 861-862, Oct. 2, 1959.

Miscellaneous

Holt, R. R., and Goldberger, L.: Personological Correlates of Reactions to Perceptual Isolation. WADC Tech. Rep. 59-735, Nov. 1959.

Walters, R. H., and Karal, Pearl: Social Deprivation and Verbal Behavior. J. Personality, 28: 89, 1960.

Walters, R. H., Marshall, W. E., and Shooter, J. R.: Anxiety, Isolation, and Susceptibility to Social Influence. J. Personality, 28: 518, 1960.

Walters, R. H., and Quinn, M. J.: The Effects of Social and Sensory Deprivation on Autokinetic Judgments. J. Personality, 28: 210, 1960.

Lilly, J. C.: Mental Effects of Physical Restraint and of Reduction of Ordinary Levels of Physical Stimuli on Intact, Healthy Persons. Psychiat. Res. Rep. (No. 5), June 1956, pp. 1-9.

Vernon, J., and Hoffman, J.: Effect of Sensory Deprivation on Learning Rate in Human Beings. Science, 123: 1074-1075, June 15, 1956.

Azima, H., and Cramer-Azima, F. J.: Effects of Decrease in Sensory Variability on Body Scheme. Canad. Psychiat. A. J. 1: 59-72, April 1956.

Azima, H., and Cramer-Azima, F. J.: Studies on Perceptual Isolation. Dis. Nerv. System (Monograph Supplement), 18, No. 8: 1-7, Aug. 1957.

Vernon J., et al.: Progress report VII: Sensory Deprivation. Princeton Univ., June 1957. Unpublished manuscript.

Held, R., and White, B. L.: Sensory Deprivation and Visual Speed: An Analysis. Science, 130: 861-862, Oct. 2, 1959.

Bossom, J., and Held, R.: Shifts in Egocentric Localization Following Prolonged Displacement of Retinal Image. Paper read before Am. Psychol. Assn., New York, N. Y., Sept. 1957.

Held, R., and Hein, A. V.: Adaptation of Disarranged Hand-Eye Coordination Contingent Upon Re-afferent Stimulation. Percept. and Motor Skills, 8: 87-90, June 1958.

An Investigation of Some Factors Affecting Multiple-Task Performance. Ord 149, April 1958. Human Factors Res. Dept., Military Operations Res. Engr. Div., Lockheed Aircraft Corp., Marietta, Georgia.

Aircrew Stress and Fatigue Problems During Extended Endurance Flight. Phase I: Planning. ORD 122, Aug. 1957. Human Engineering Dept., Military Operations Res. Engr. Div., Lockheed Aircraft Corp., Marietta, Georgia.

TABLE I.- HABITABILITY INVESTIGATION WORK SCHEDULE

Monday, April 2, 1962
Shift No. 19
Stinnett on Duty

12:00 M.	Medical monitoring
12:15	Rate estimation
12:35	Vigilance
12:45	Pattern recognition
1:10 P.M.	Mission status
1:15	Navigation
2:10	Rest
2:25	Tracking
2:45	Cancellation test
3:15	Vigilance
3:25	Pattern recognition
3:50	Rest, shift

Shift No. 20
Rogers on Duty

4:00 P.M.	Medical monitoring
4:15	Rate estimation
4:35	Vigilance
4:45	Pattern recognition
5:10	Mission status
5:15	Navigation
6:10	Rest
6:25	Tracking
6:45	Cancellation test
7:15	Vigilance
7:25	Pattern recognition
7:50	Rest, shift

Shift No. 21
Stinnett on Duty

8:00 P.M.	Medical monitoring
8:15	Rate estimation
8:35	Vigilance
8:45	Pattern recognition
9:10	Mission status
9:15	Navigation
10:10	Rest
10:25	Tracking
10:45	Cancellation test
11:15	Vigilance
11:25	Pattern recognition
11:50	Rest, shift

Tuesday, April 4, 1962
Shift No. 22
Rogers on Duty

12:00 P.M.	Medical monitoring
12:15	Rate estimation
12:35	Vigilance
12:45	Pattern recognition
1:10 A.M.	Mission status
1:15	Navigation
2:10	Rest
2:25	Tracking
2:45	Cancellation test
3:15	Vigilance
3:25	Pattern recognition
3:50	Rest, shift

Shift No. 23
Stinnett on Duty

4:00 A.M.	Medical monitoring
4:15	Rate estimation
4:35	Vigilance
4:45	Pattern recognition
5:10	Mission status
5:15	Navigation
6:10	Rest
6:25	Tracking
6:45	Cancellation test
7:15	Vigilance
7:25	Pattern recognition
7:50	Rest, shift

Shift No. 24
Rogers on Duty

8:00 A.M.	Medical monitoring
8:15	Rate estimation
8:35	Vigilance
8:45	Pattern recognition
9:10	Mission status
9:15	Navigation
10:10	Rest
10:25	Tracking
10:45	Cancellation test
11:15	Vigilance
11:25	Pattern recognition
11:50	Rest, shift

TABLE II.- SLEEP LOG

Day	Watch	Rogers	24 hour total	Stinnett	24 hour total
3/30	1200	0		W	
	1600	W		0	
	2000	2.0		W	
3/31	0000	W		3.0	
	0400	3.2		W	
	0800	W		1.0	
	1200	2.5	7.7	W	4.0
	1600	W		1.0	
	2000	2.0		W	
4/1	0000	W		2.5	
	0400	3.3		W	
	0800	W		1.2	
	1200	1.5	6.8	W	4.7
	1600	W		1.0	
	2000	1.5		W	
4/2	0000	W		3.0	
	0400	3.3		W	
	0800	W		1.0	
	1200	1.0	5.8	W	5.0
	1600	W		1.3	
	2000	1.5		W	
4/3	0000	W		3.0	
	0400	3.5		W	
	0800	W		1.3	
	1200	0	5.0	W	5.6
	1600	W		1.0	
	2000	1.5		W	
4/4	0000	W		1.5	
	0400	2.7		W	
	0800	W		1.0	
	1200	2.0	6.2	W	3.5
	1600	W		0.2	
	2000	0		W	
4/5	0000	W		2.0	
	0400	3.2		W	
	0800	W		1.0	
	1200	2.2	5.4	W	3.2
	1600	W		1.0	
	2000	0		W	
4/6	0000	W		2.5	
	0400	3.3	3.3	W	
	0800	W		2.0	
		40.2		31.5	

Av per day 5.75 Av per day 4.5

Av per watch 1.91 Av per watch 1.50

TABLE III.- MENUS

Rogers Item	Rogers Kilocalories	Stinnett Item	Stinnett Kilocalories
Crackers	219	Crackers	219
Peaches	133	Peaches	133
Fruit cocktail	129	Pears	129
Apricots	146	Apricots	146
Beef	281	Spiced beef	329
Chicken and noodles	231	Ham and eggs	334
Turkey loaf	282	Tuna	168
Fruit cake	550	Fruit cake	550
Total	1971		2008

TABLE IV.- WATER BALANCE

Days Confined	Water drunk	Free water in food	Metabolic water	Total water	Urine Volume	Fecal water	Insensible and sweat loss
Stinnett							
1	1200	677	245	2122	838	---	1284
2	1200	677	245	2122	780	---	1342
3	1200	677	245	2122	1298	---	824
4	1200	677	245	2122	1178	7	937
5	1200	677	245	2122	1212	18	892
6	1200	677	245	2122	1401	416	305
7	1200	677	245	2122	1096	161	865
	8400	4739	1715	14854	7803	602	6449
			Mean	2122			Mean 921 ml/day
Rogers							
1	1200	747	242	2189	704	155	1330
2	1400	747	242	2389	632	203	1554
3	1700	747	242	2689	661	167	1861
4	1400	747	242	2389	687	82	1620
5	1400	747	242	2389	708	141	1540
6	1400	747	242	2389	660	253	1476
7	1400	747	242	2389	751	109	1529
	9900	5229	1694	16823	4803	1110	10910
			Mean	2403			Mean 1559 ml/day

Heat loss by evaporation: S. 534 kilocalories/day
R. 904 kilocalories/day

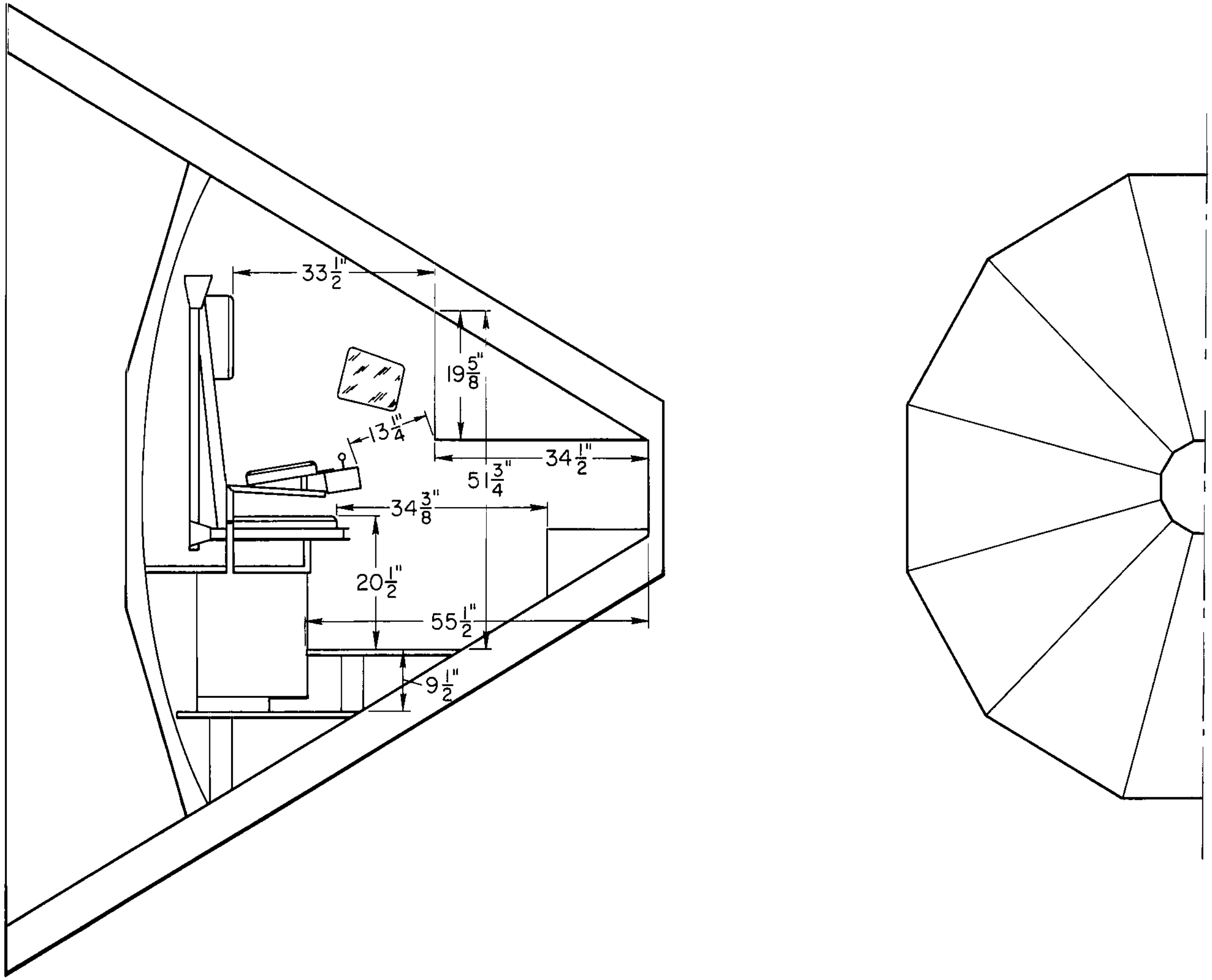
TABLE V.- ENERGY COST

	Rogers	Stinnett
Mean oxygen consumption		
Work	299 ml/min	215 ml/min
Rest	271 ml/min	287 ml/min*
Mean energy expenditure		
Work	87.0 kilocalories/hr	62.7 kilocalories/hr
Rest	78.9 kilocalories/hr	83.5 kilocalories/hr
Total energy	1991 kilocalories/day	1754.4 kilocalories/day
Total oxygen for week	2873 liters	2531 liters

*This subject consumed more oxygen at rest than at work because he pursued a vigorous exercise program (pushups, running in place, arm and leg movements) during his rest periods, and the tasks were primarily sedentary. Both subjects used the same type of exercise but subject Stinnett was much more active.

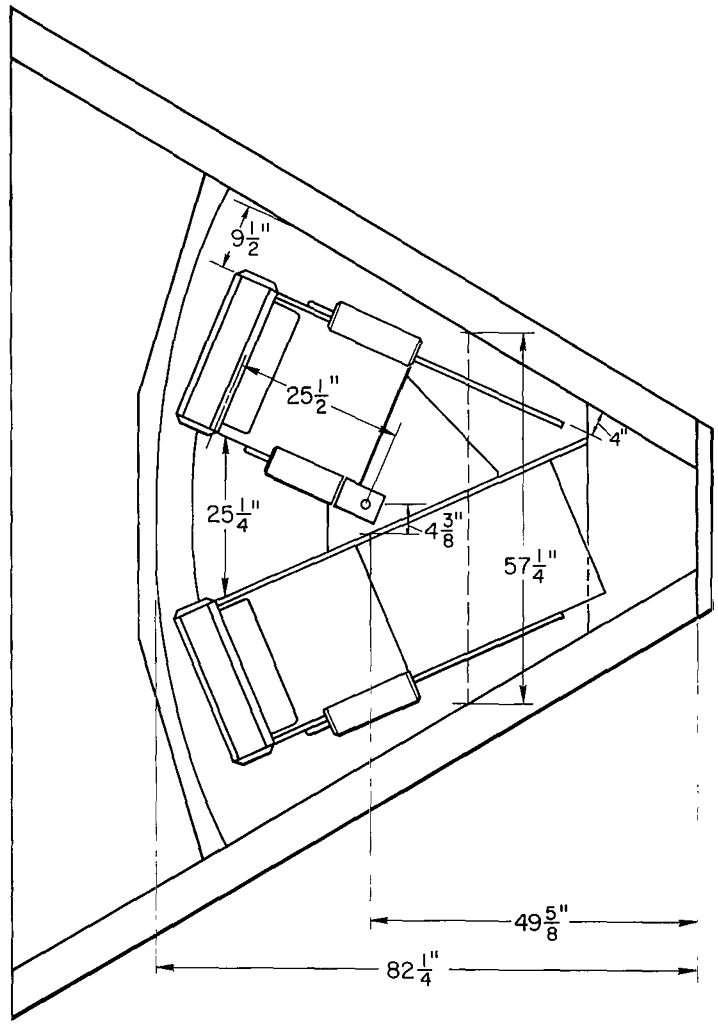
TABLE VI.- SODIUM BALANCE

	Days Confined	Urine	Intake	Balance
Stinnett	1	117	123	
	2	101	123	
	3	152	123	
	4	164	123	
	5	159	123	
	6	142	123	
	7	139	123	
Total		974	861	-113
Rogers	1	142	131	
	2	134	131	
	3	159	131	
	4	175	131	
	5	132	131	
	6	129	131	
	7	151	131	
Total		1022	917	-105



(a) Side elevation.

Fig. 1.- Engineering drawings of capsule.



(b) Plan view.

Fig. 1.- Concluded.

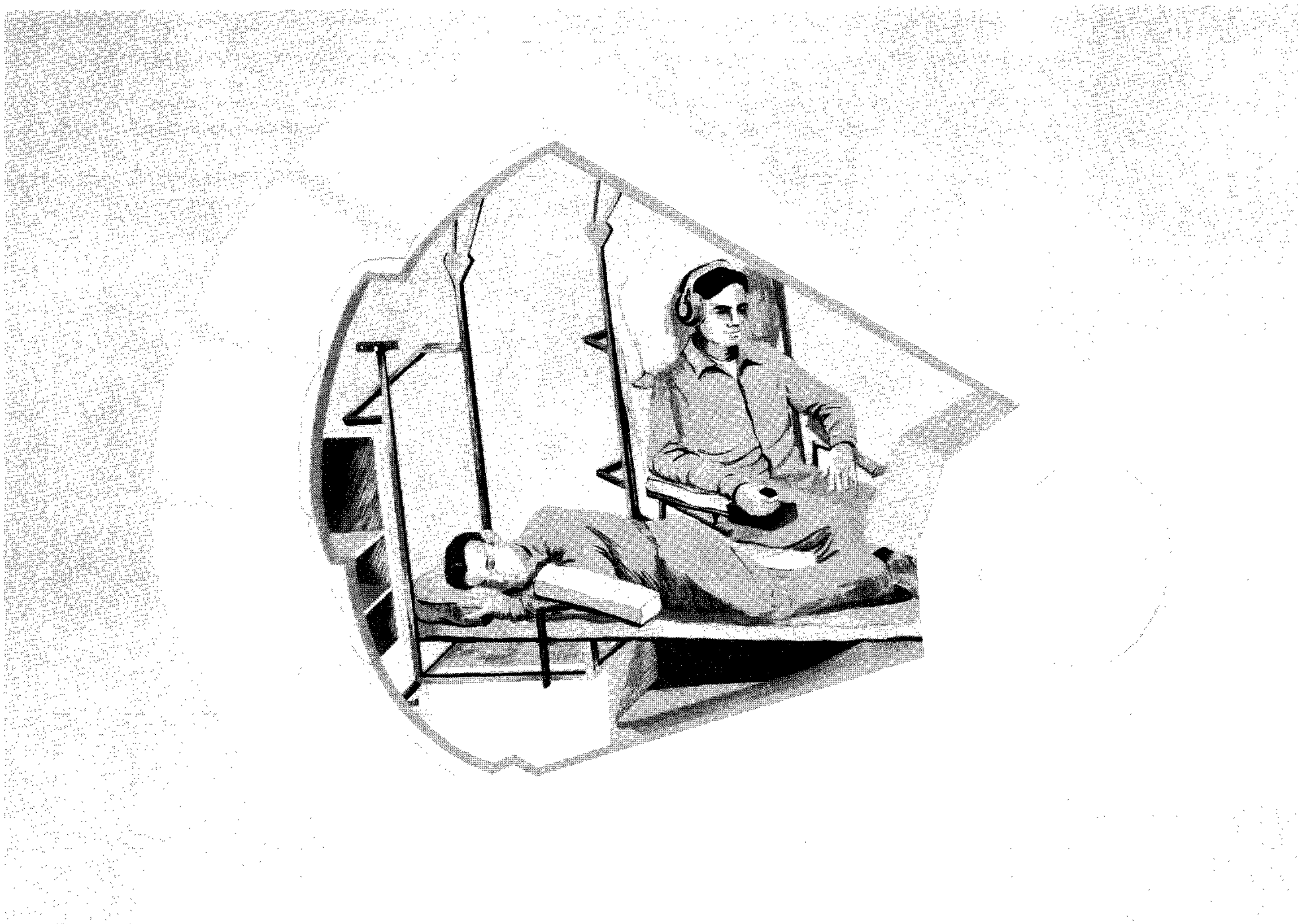


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Fig. 2.- Artist's rendering of capsule interior.

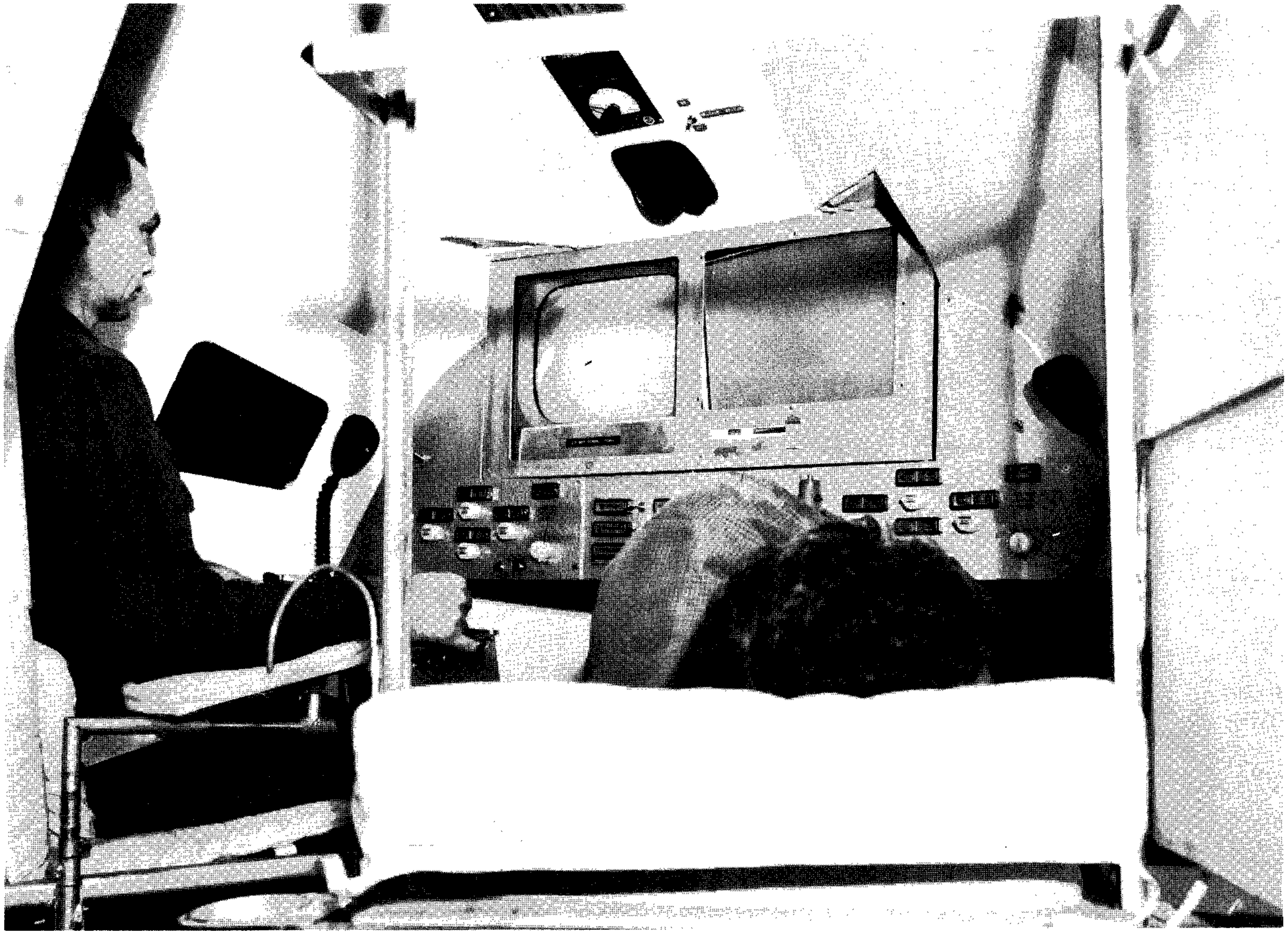

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Fig. 3.- Capsule interior and instrument panel.

Fig. 4.- Typical view of subjects on television monitor.

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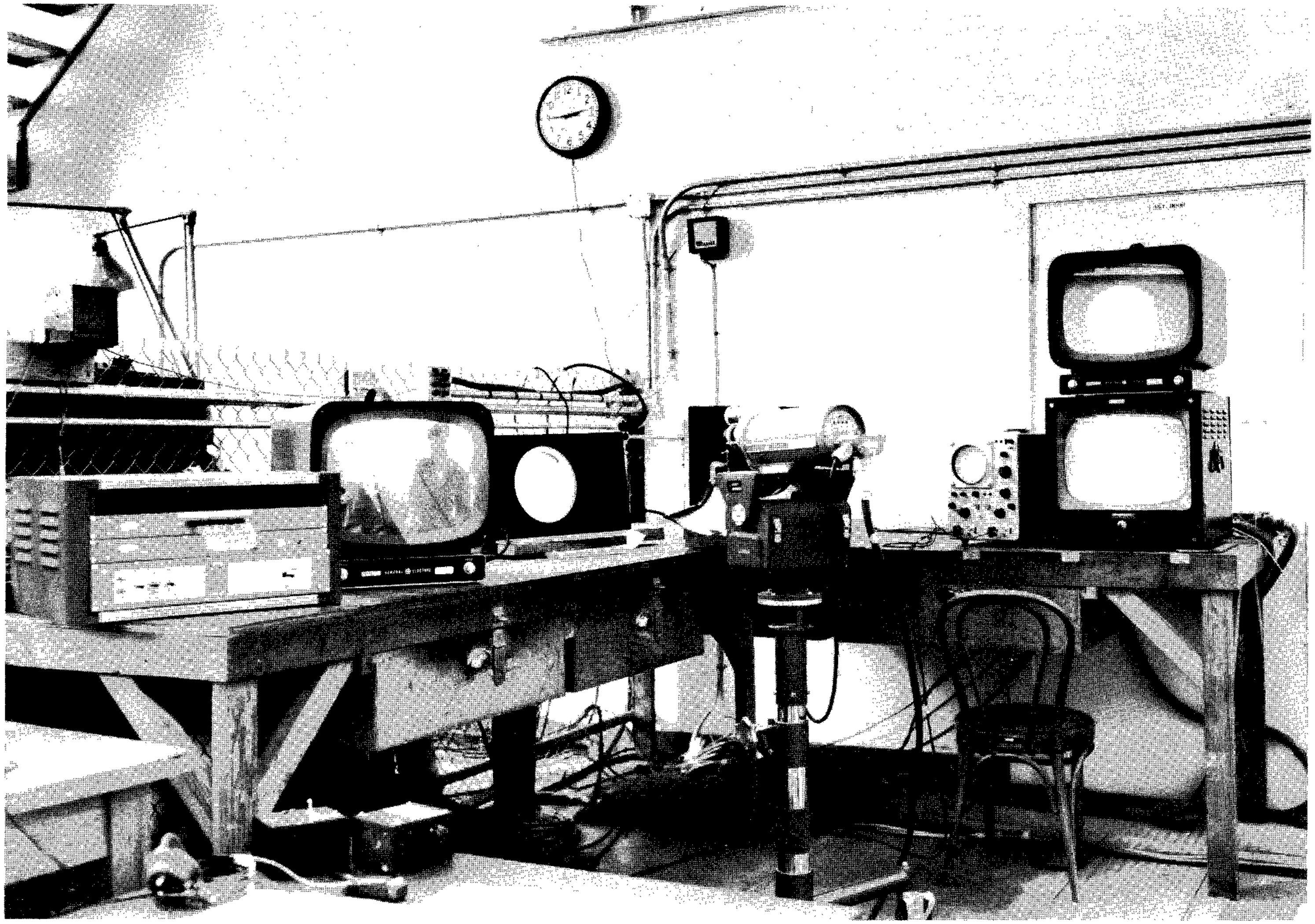

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Fig. 5.- Equipment at tests director's station.

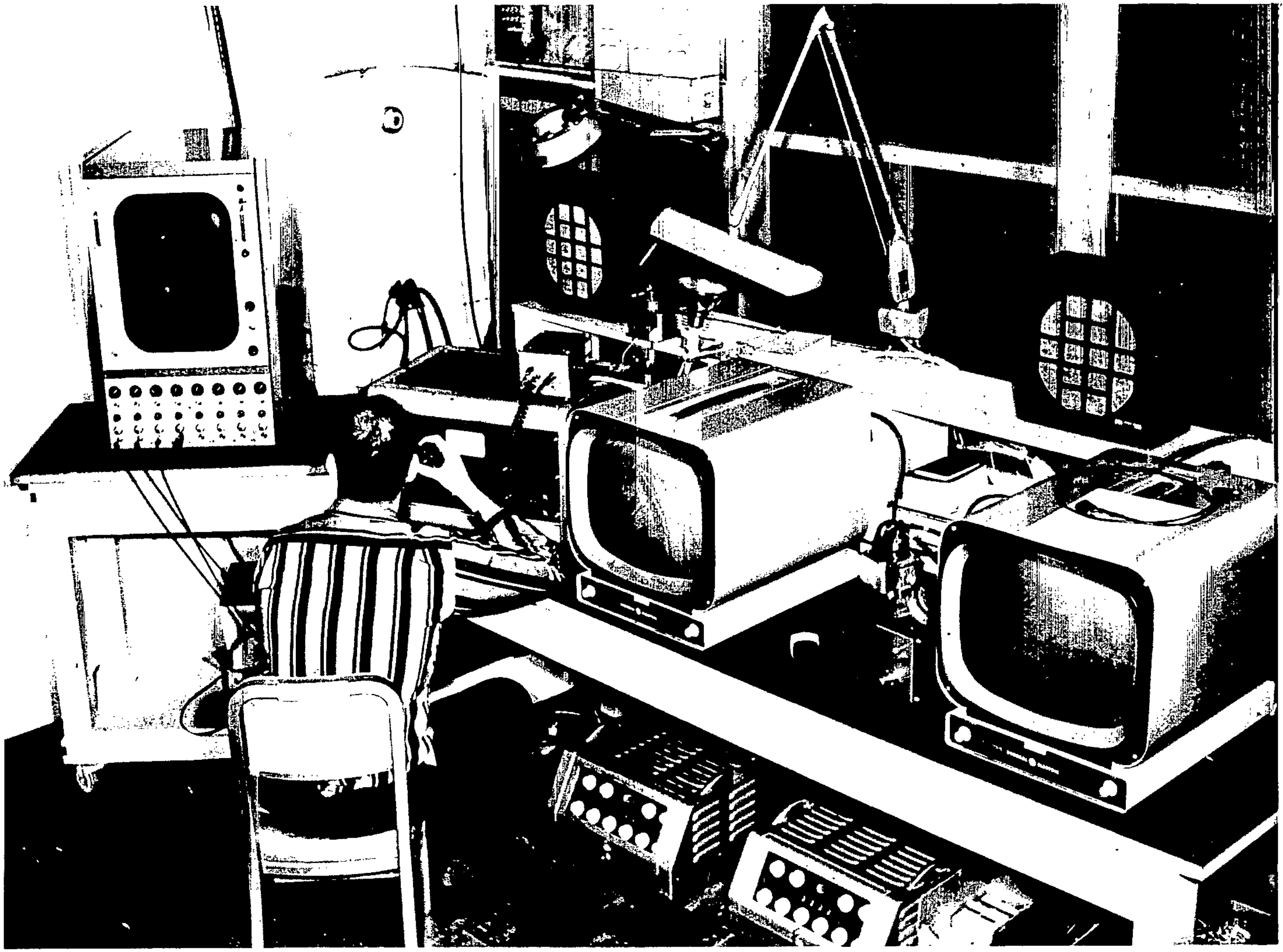

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Fig. 6.- Medical monitor's station.

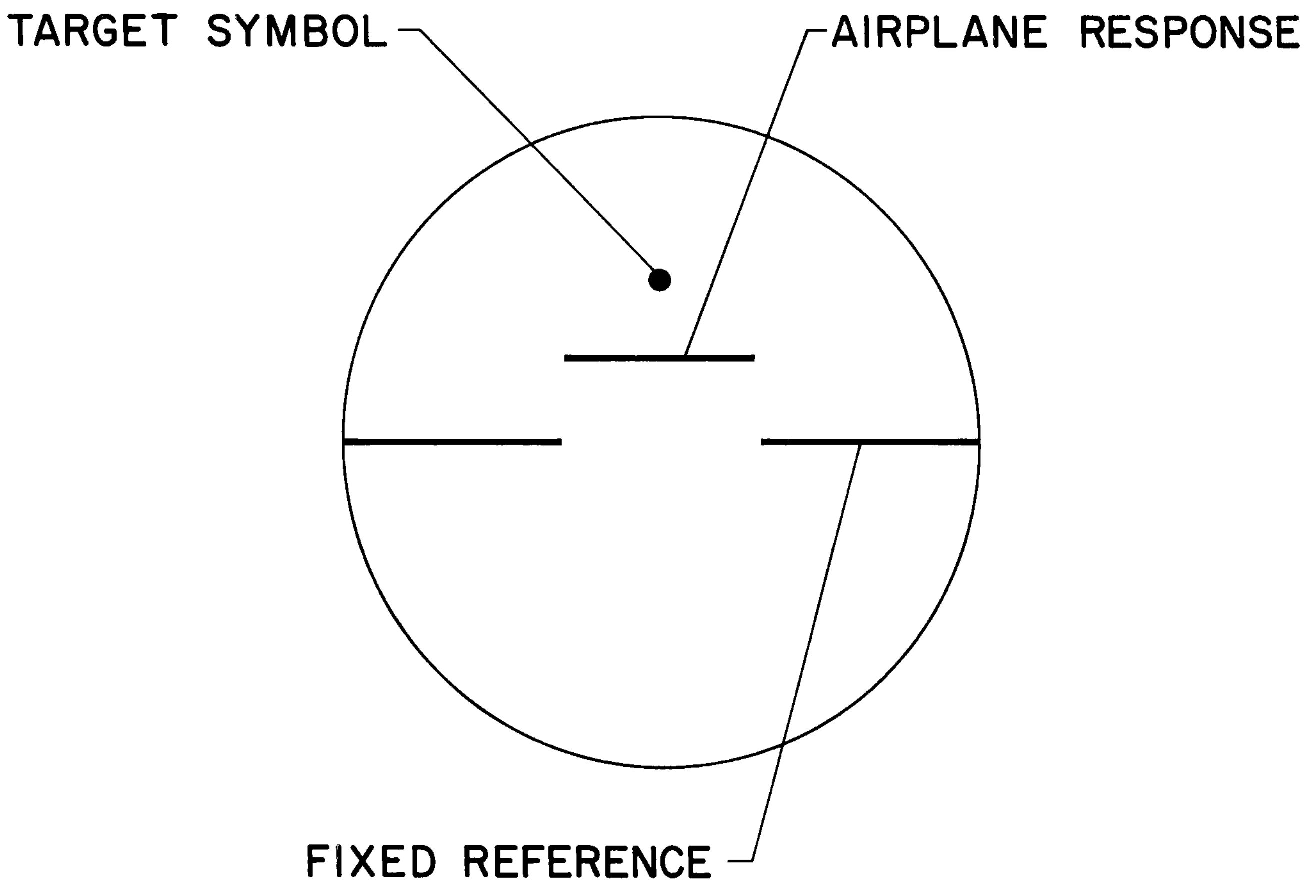

Fig. 7.- Television tracking problem display.

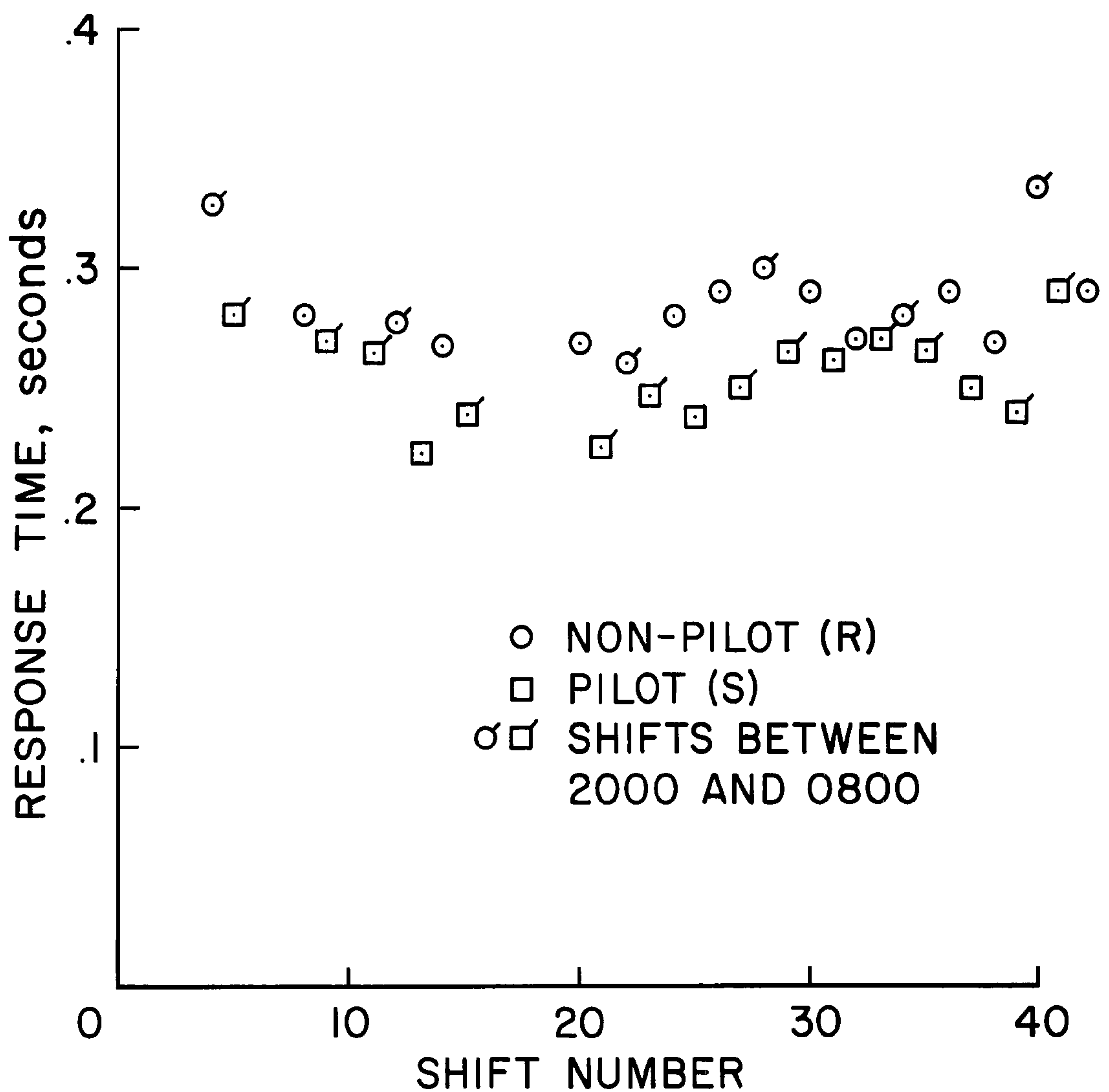

Fig. 8.- Response time as a function of shift number, tracking task.

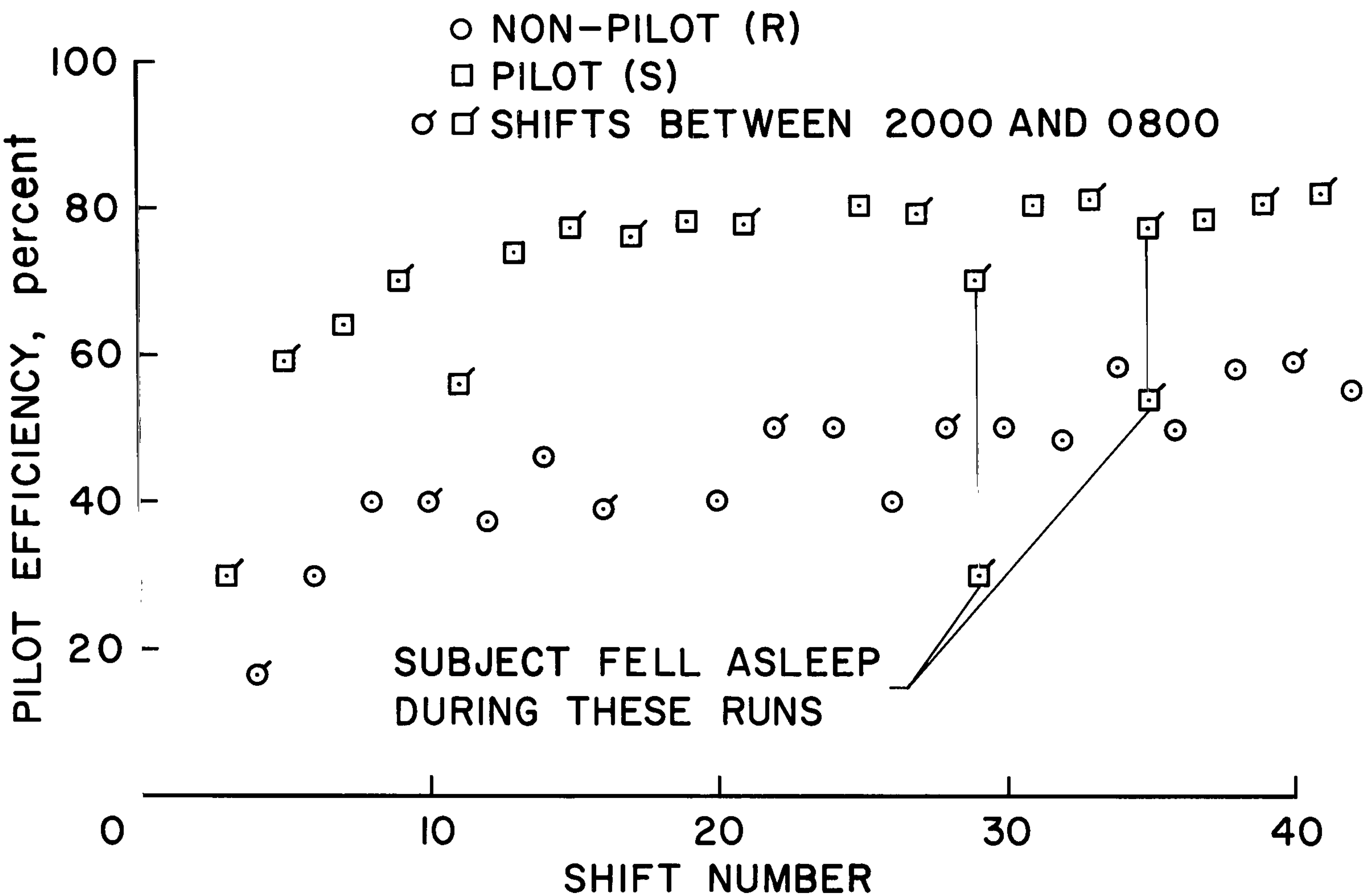

Fig. 9.- Pilot tracking efficiency as a function of shift number.

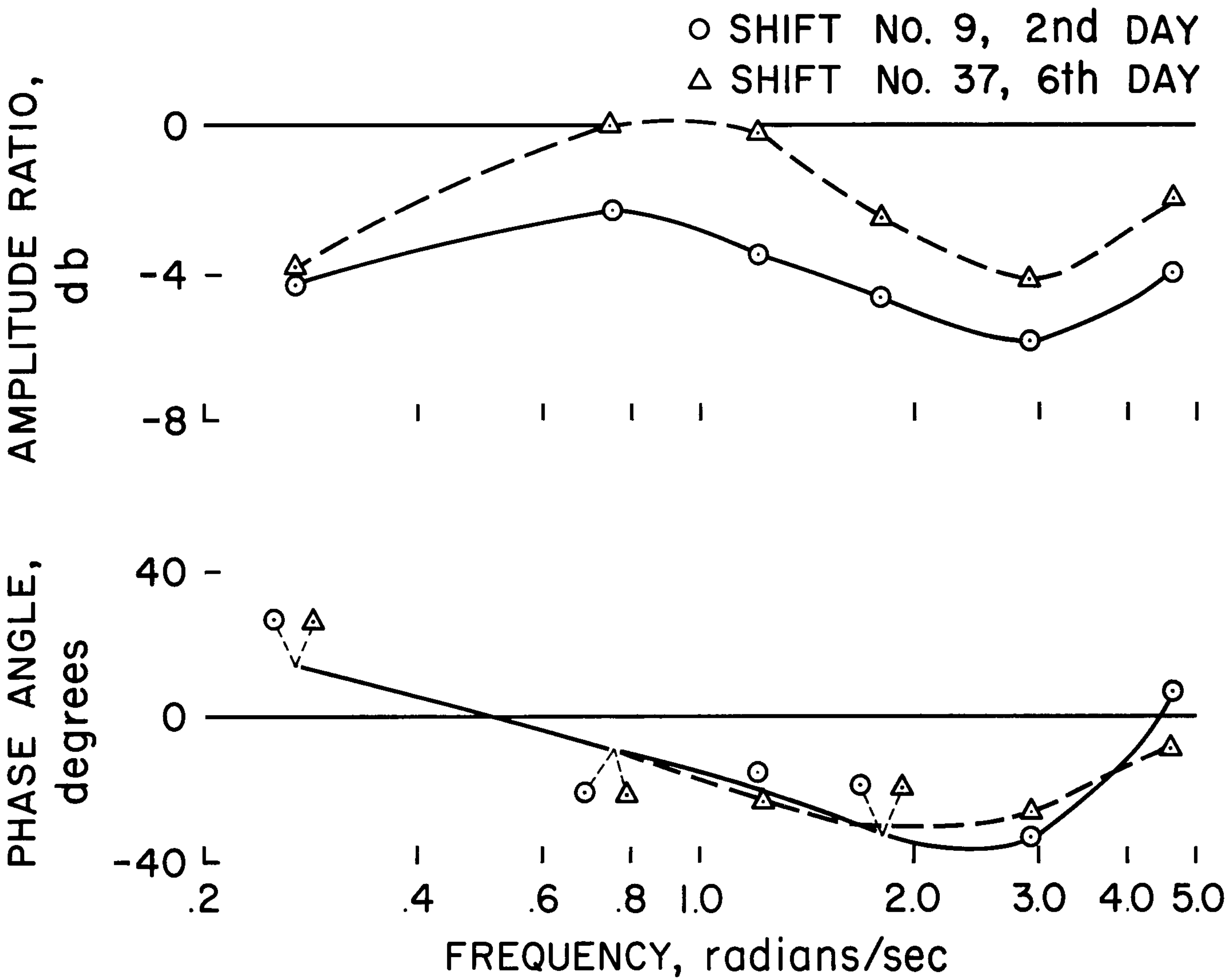

Fig. 10.- Pilot frequency response during tracking task.

$Re = 0.20981 \times 10^{8}$ $Rm = 1.2350 \times 10^{9}$ $\mu = 1.40773 \times 10^{16}$

MEASUREMENTS		GIVEN			
d'		α		$K = \alpha/d'$	
d_1		$\psi_1/2 = Kd_1/2.0$		$\sin(\psi_1/2)$	
d_2		$\psi_2/2 = Kd_2/2.0$		$\sin(\psi_2/2)$	
d_3				$\Delta\theta = Kd_3$	

$R_1 = Re/\sin(\psi_1/2)$	$\pm$		t_2	$-$	
$R_2 = Re/\sin(\psi_2/2)$			t_1		
$R_1 + R_2$			$\Delta t = t_2 - t_1$		
$R_1 - R_2$					

$R_3 = \frac{R_1 + R_2}{2.0}$		$\dot{\theta}_3 = \Delta\theta/\Delta t$		$\dot{R}_3 = \frac{R_1 - R_2}{\Delta t}$		
				$\dot{R}_3^2$	$+$	
R_3^2		$\dot{\theta}_3^2$		$V_t^2 = R_3^2\,\dot{\theta}_3^2$		
				$V_3^2 = \dot{R}_3^2 + V_t^2$		

$2.0/R_3$	$-$	
V_3^2/μ		
$2.0/R_3 - V_3^2/\mu$		

a

$a = 1.0/(2.0/R_3 - V_3^2/\mu)$	

R_3/a		$1.0 - R_3/a$		$(1.0 - R_3/a)^2$	$+$	
$R_3^2\,\dot{R}_3^2$		μa		$R_3^2\,\dot{R}_3^2/\mu a$		
				e^2		

e

e	

$1.0 - e$			$-$	$.20986 \times 10^{8}$
		$Rp = a(1.0 - e)$		
		ΔRp		

CURVE

R_3/R_m		$(\Delta V/\Delta Rp)$		$\Delta V = (\Delta V/\Delta Rp)\Delta Rp$	

Fig. 11.- Pilot work sheet for manual midcourse navigation task.

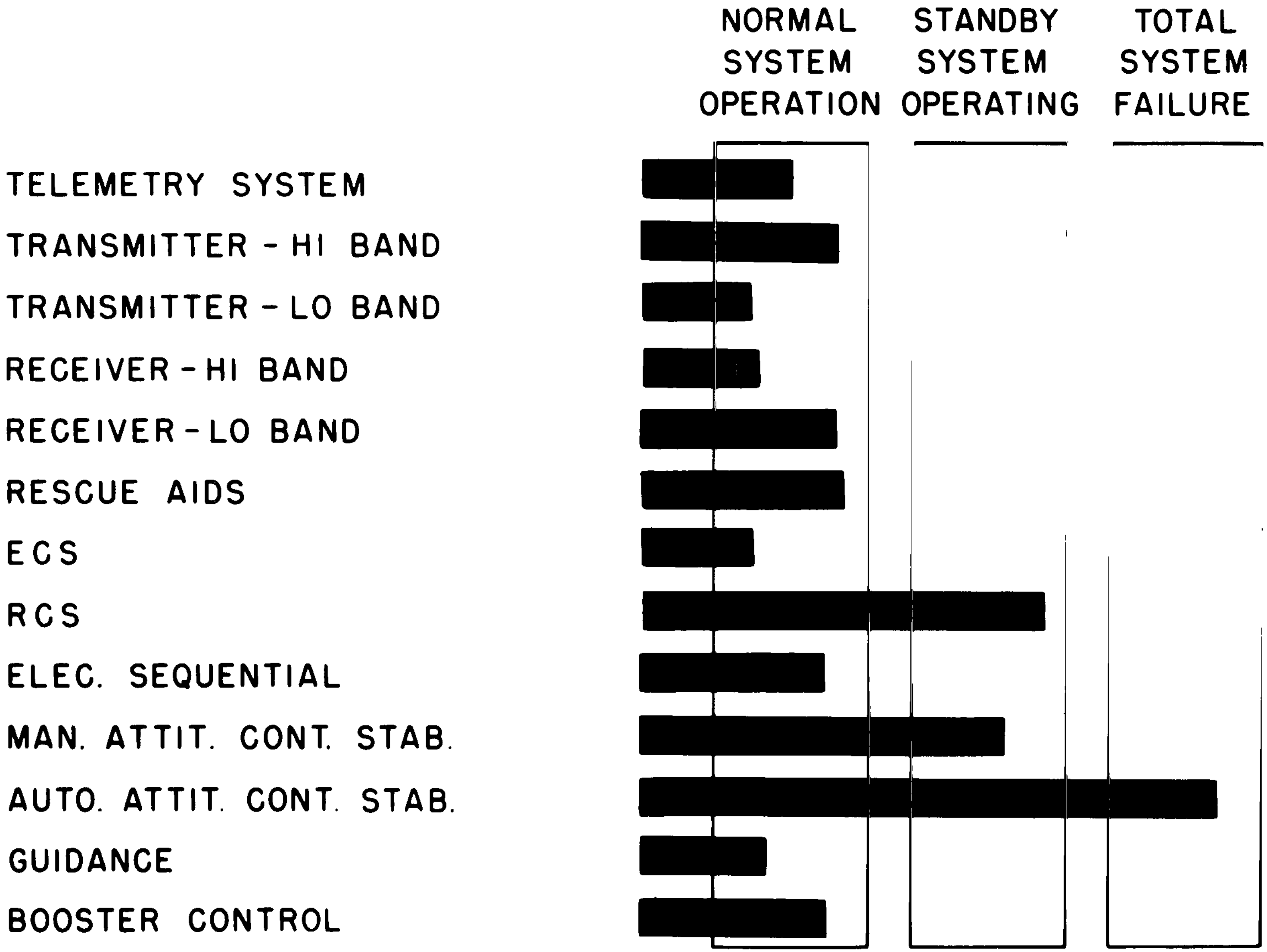

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Fig. 12.- Sample of slides used to represent a mission status monitor display.

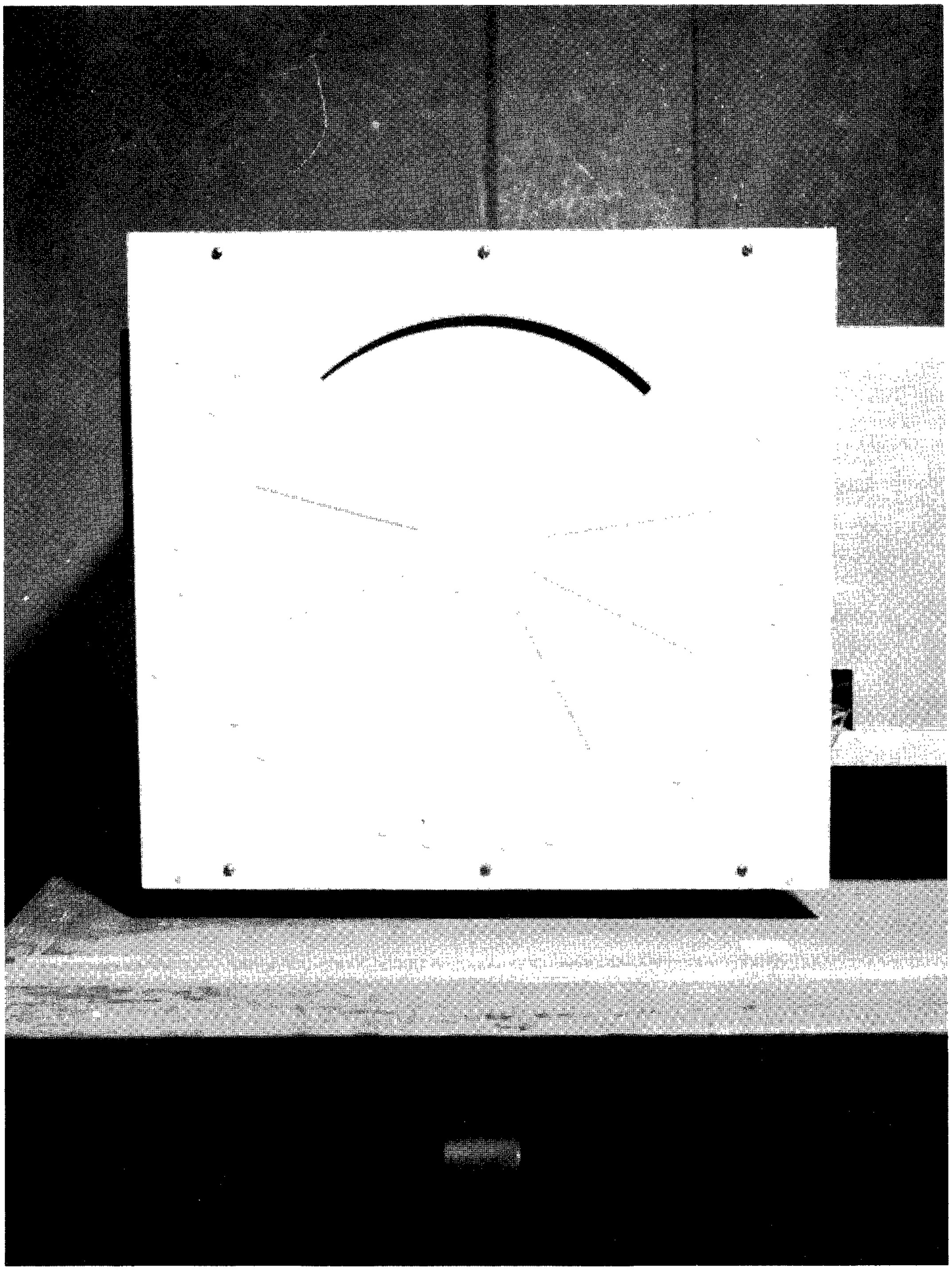

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Fig. 13.- Visual display for rate estimation task.

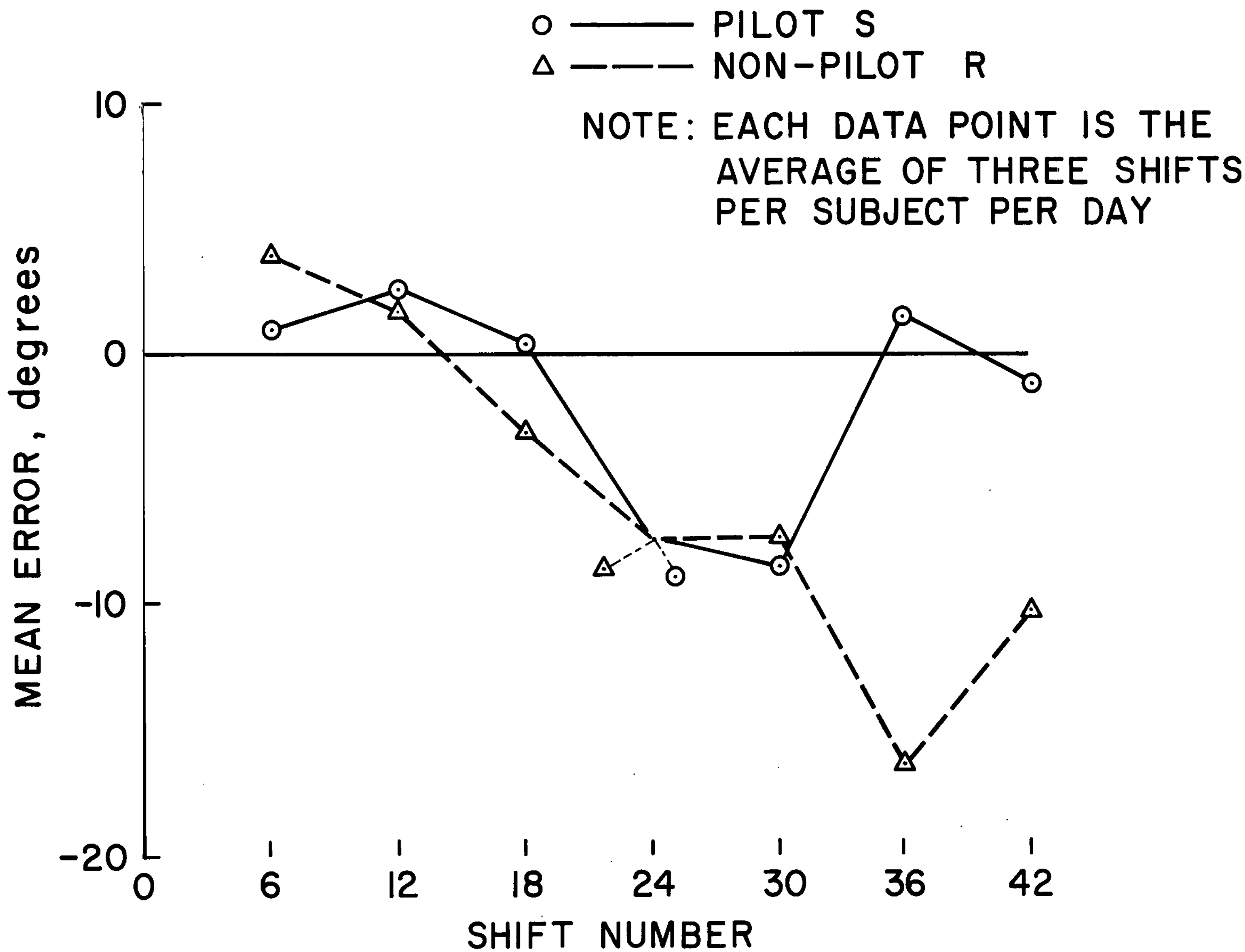


Fig. 14.- Mean error scores for the rate estimation task.

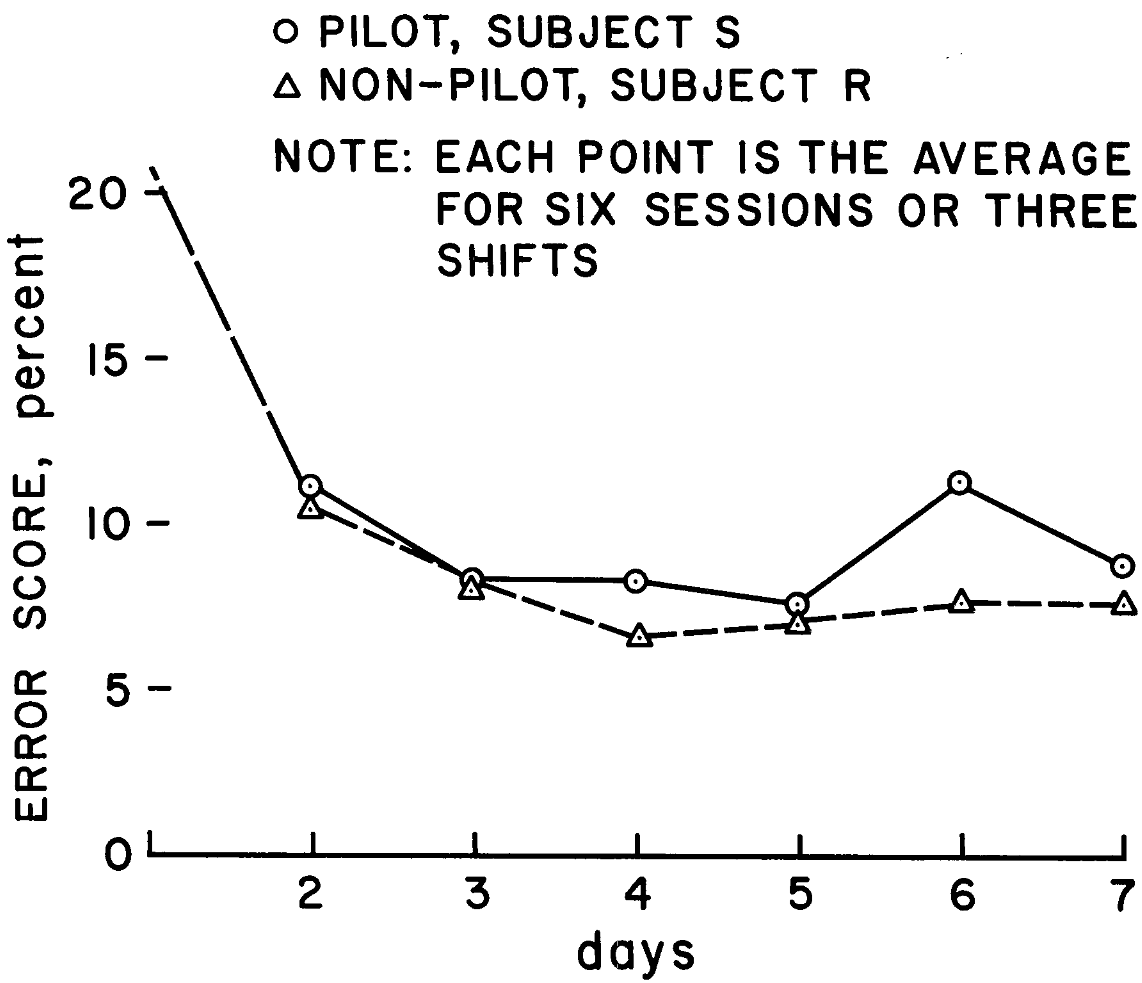
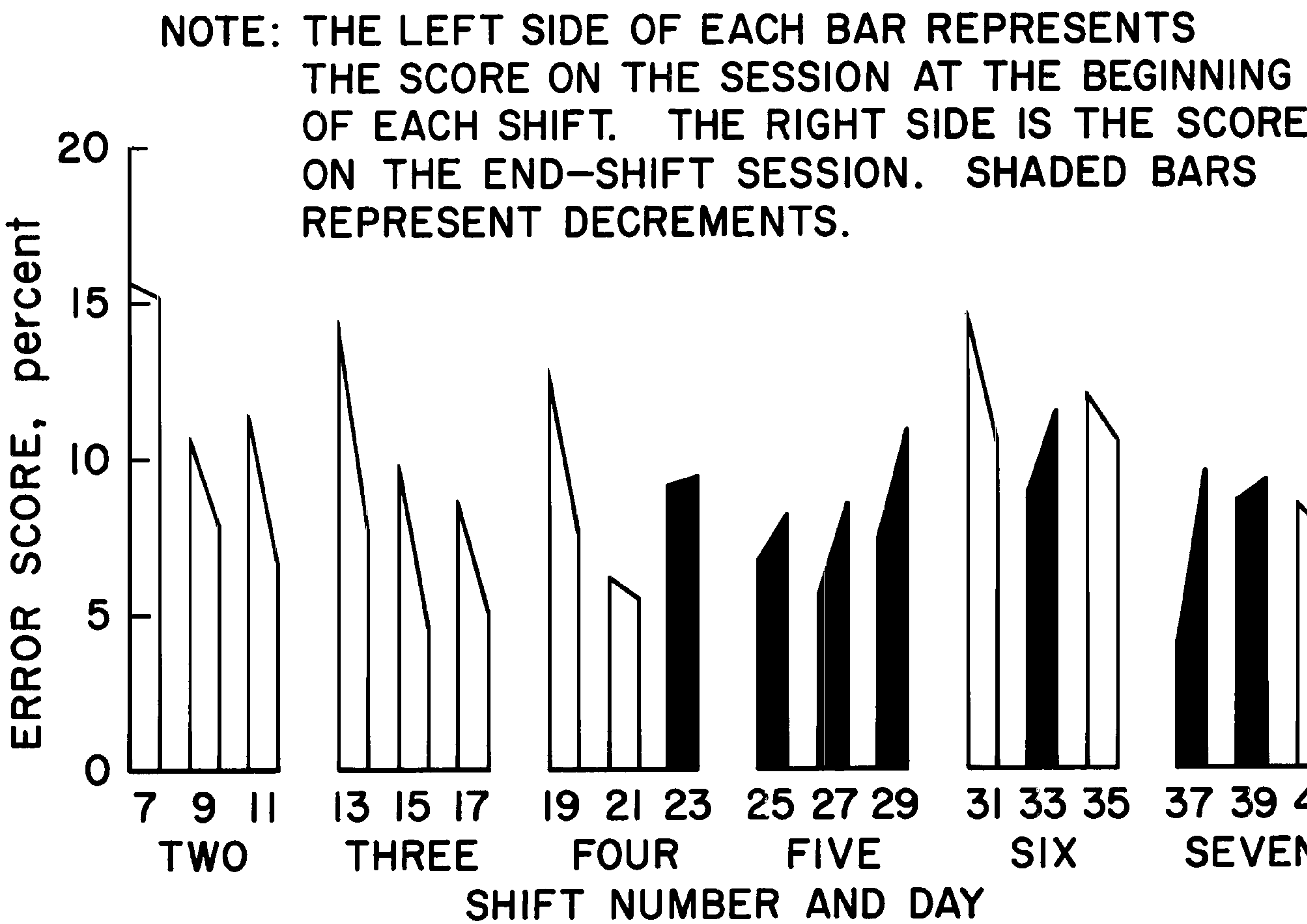
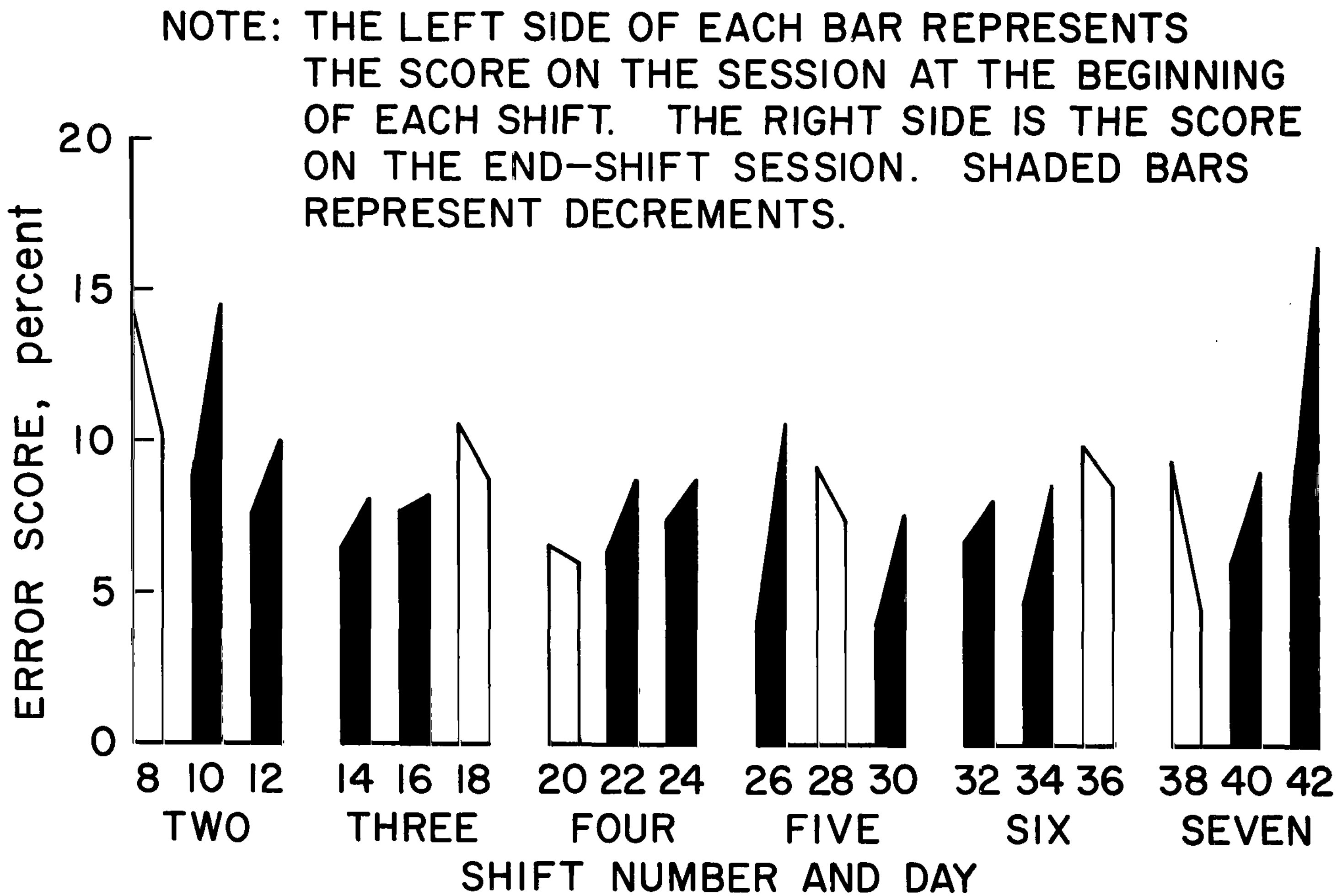


Fig. 15.- Daily error scores for the pattern recognition task.



(a) Pilot, subject S.

Fig. 16.- Begin-end shift score differences for the pattern recognition task.



(b) Non-pilot, subject R.

Fig. 16.- Concluded.

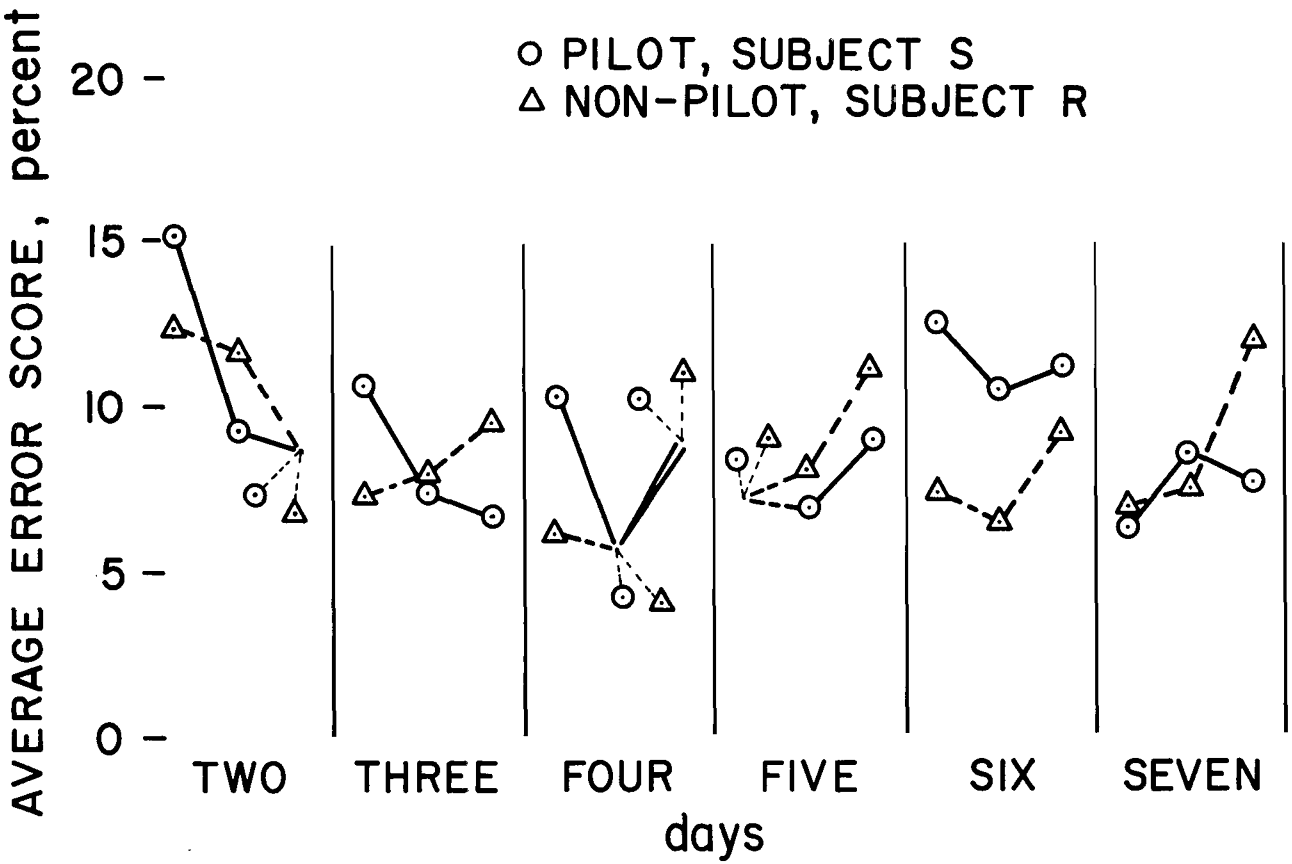
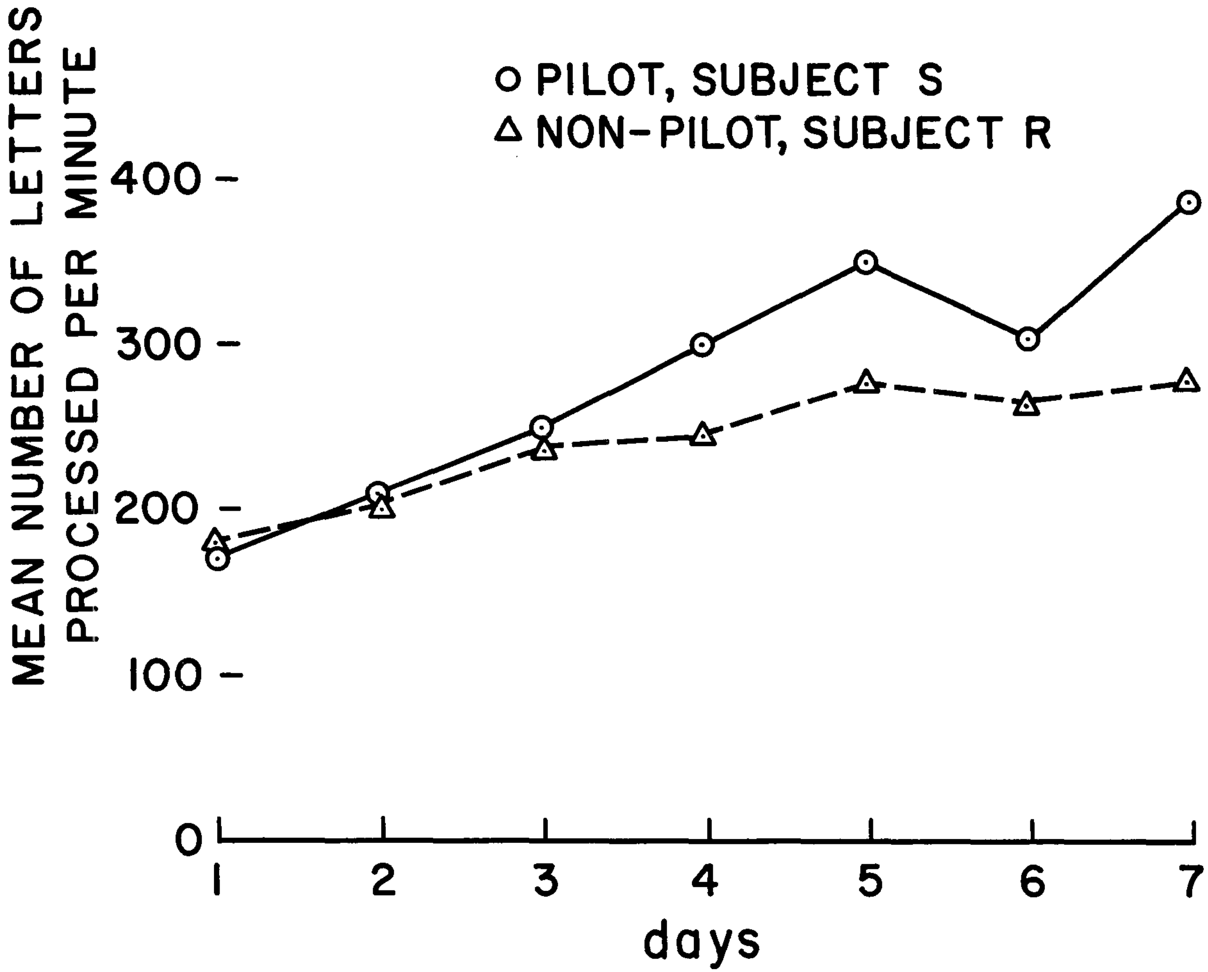
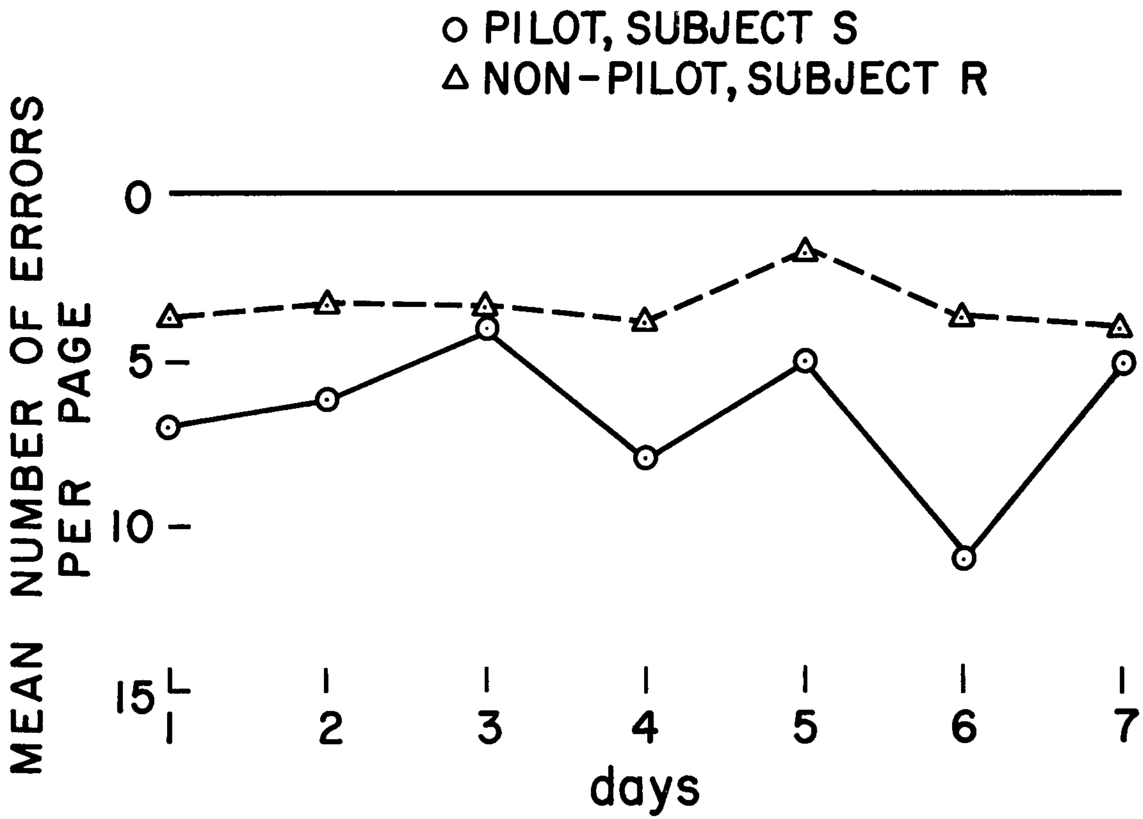


Fig. 17.- Error scores averaged by shift (two sessions) for each subject, pattern recognition task.



(a) Speed of performance.

Fig. 18.- Results from the cancellation task averaged by working day.



(b) Accuracy of performance.

Fig. 18.- Concluded.

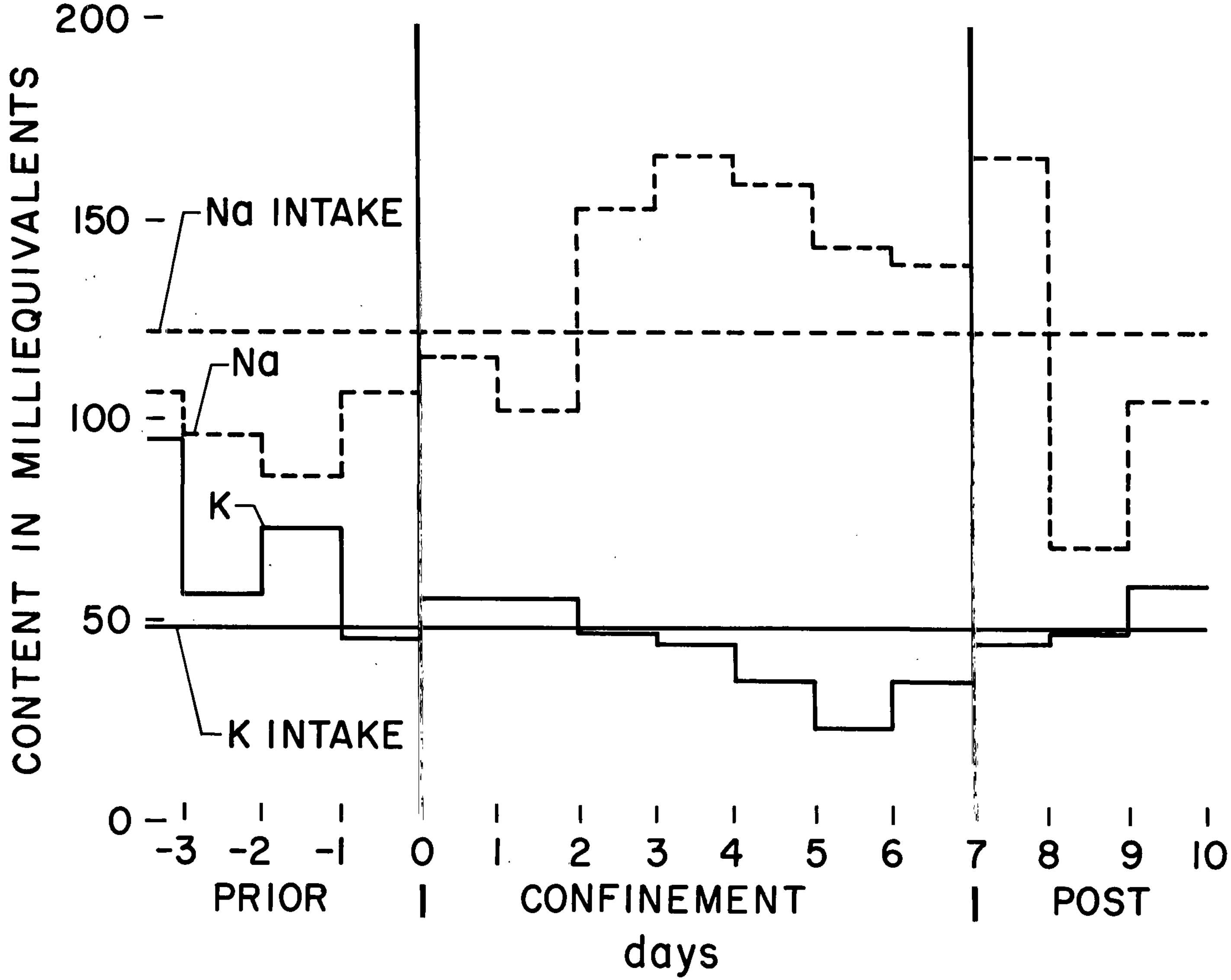


Fig. 19.- Urine sodium and potassium for pilot, subject S.

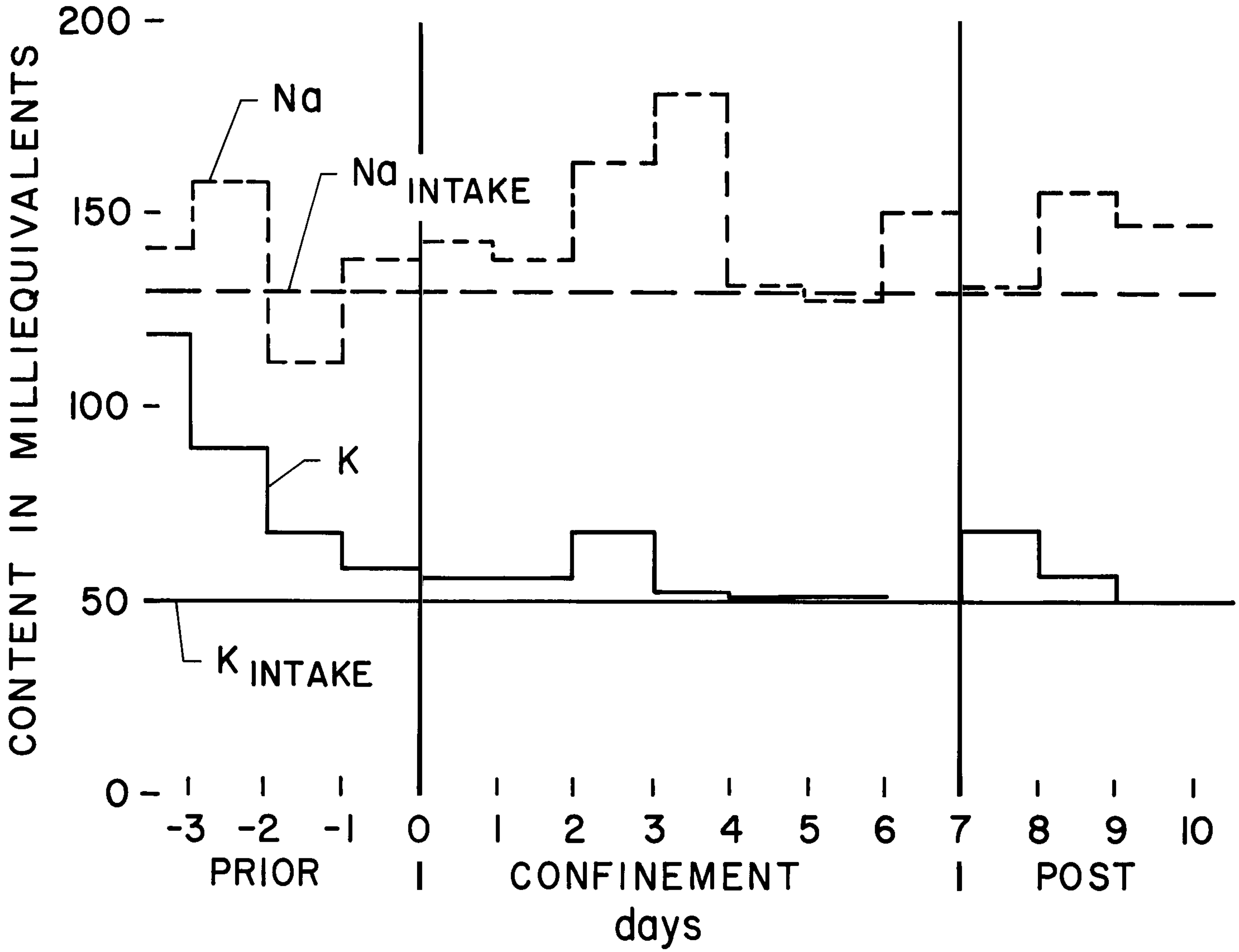


Fig. 20.- Urine sodium and potassium for non-pilot, subject R.

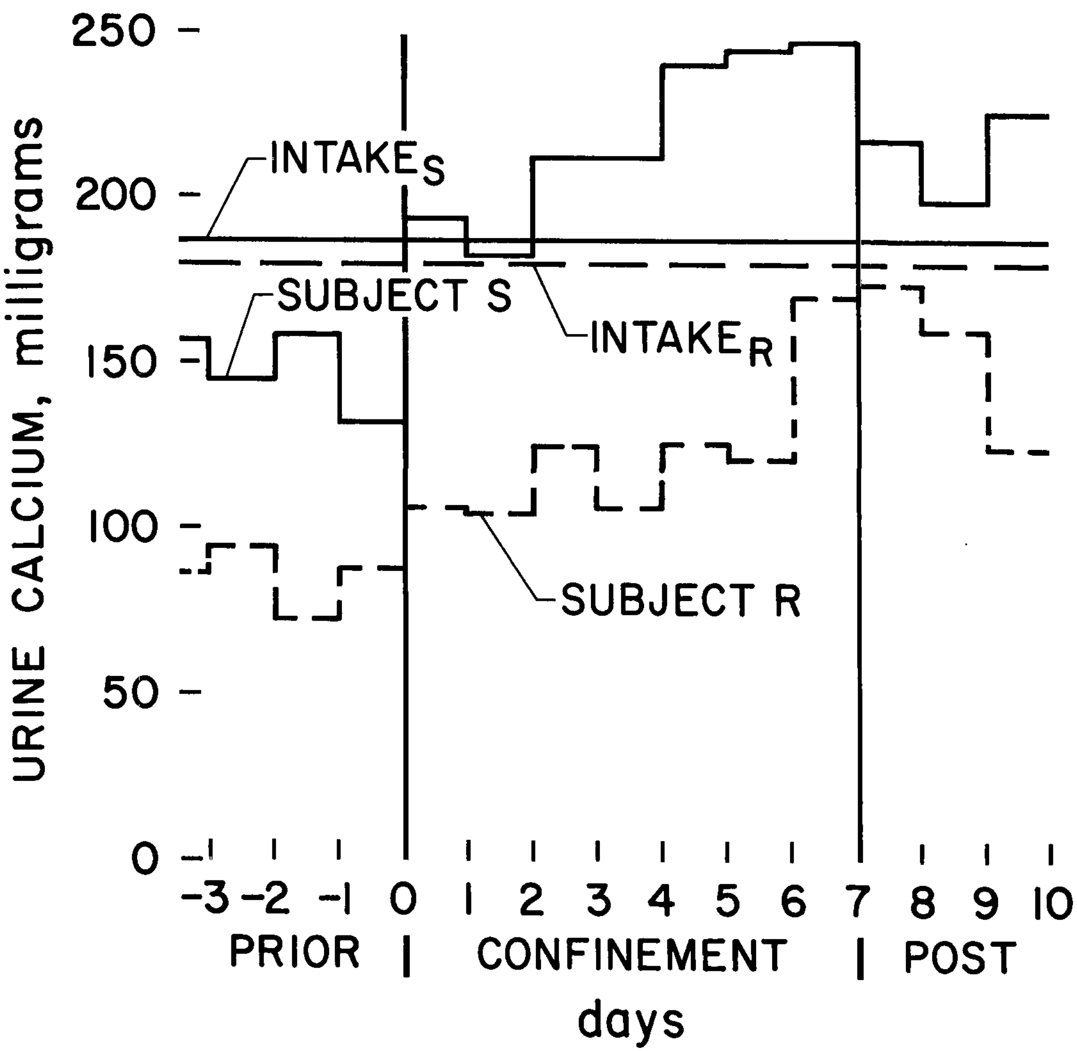


Fig. 21.- Urine calcium for both subjects.

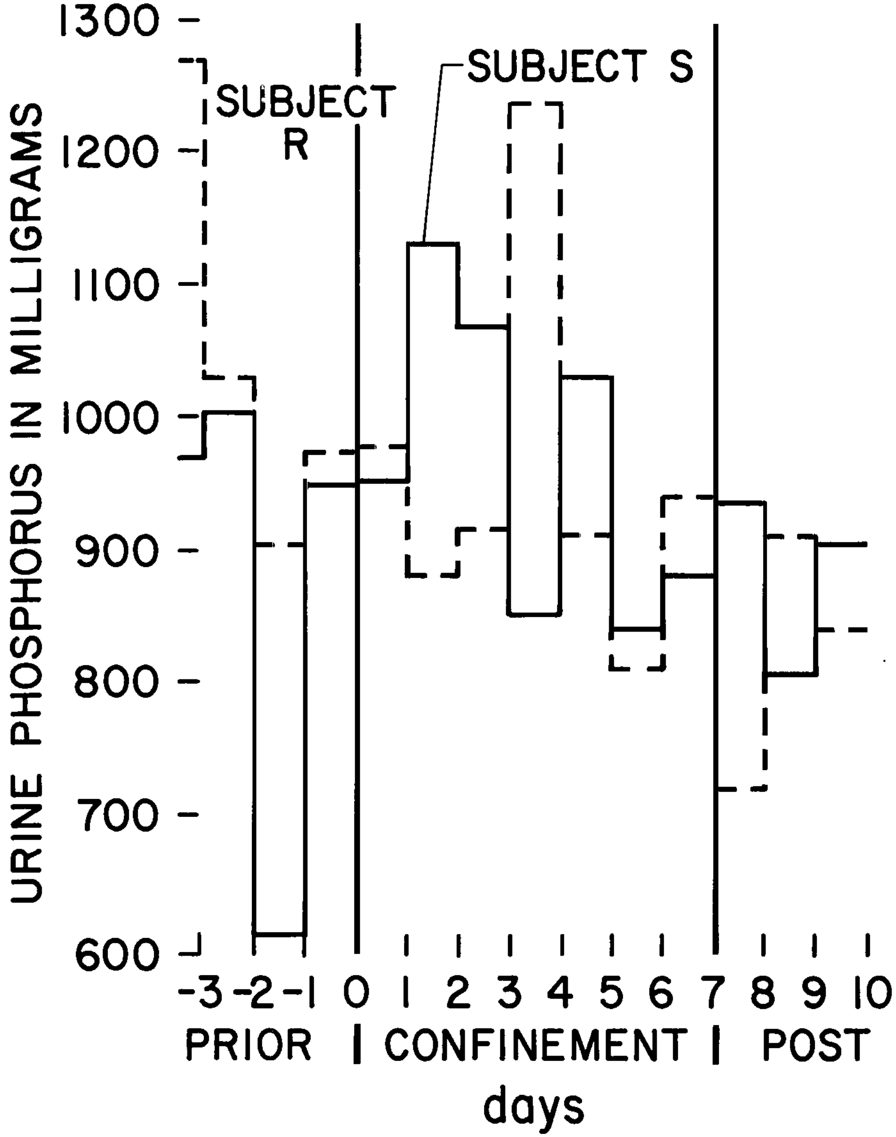


Fig. 22.- Urine phosphorus for both subjects.

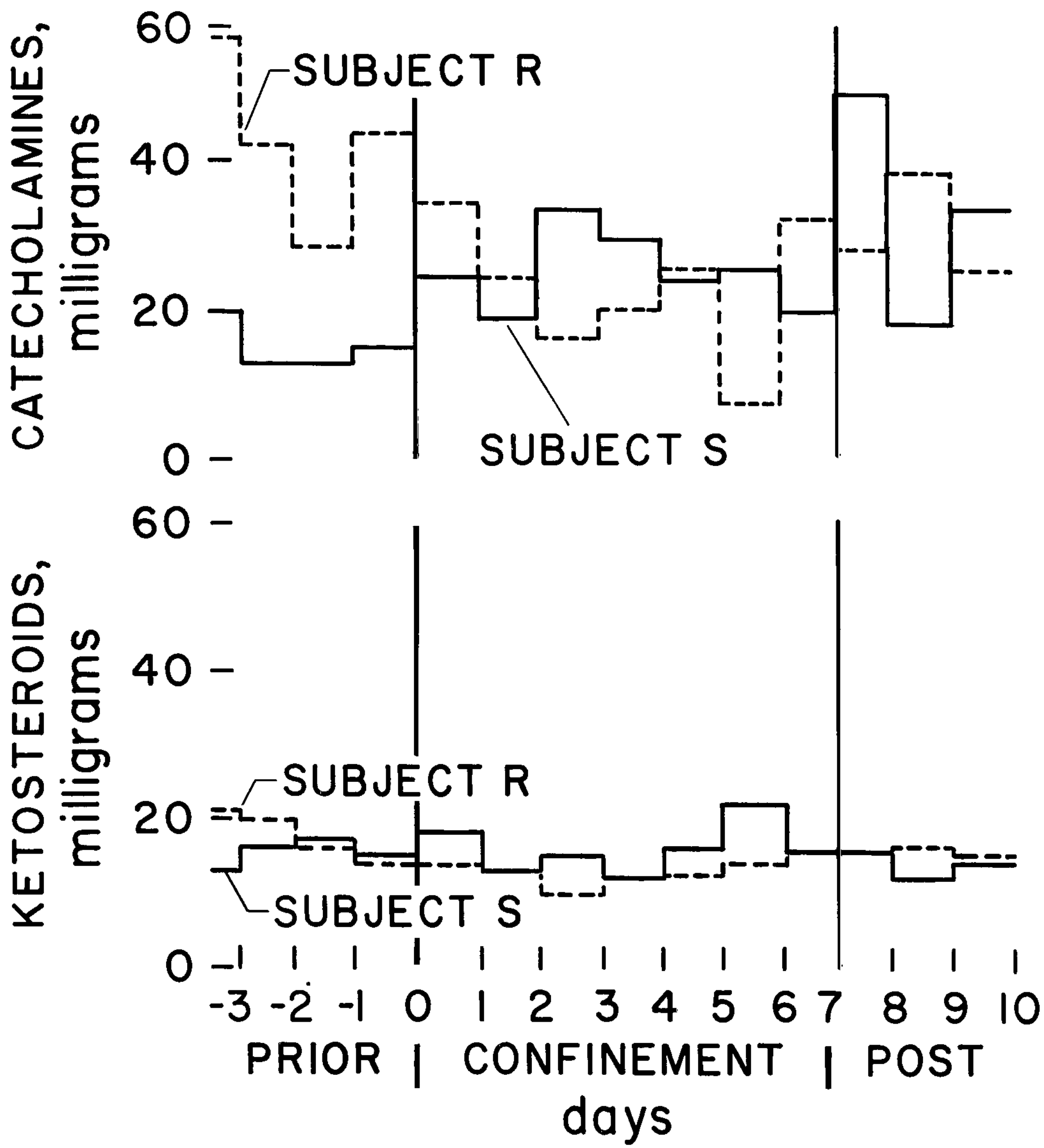
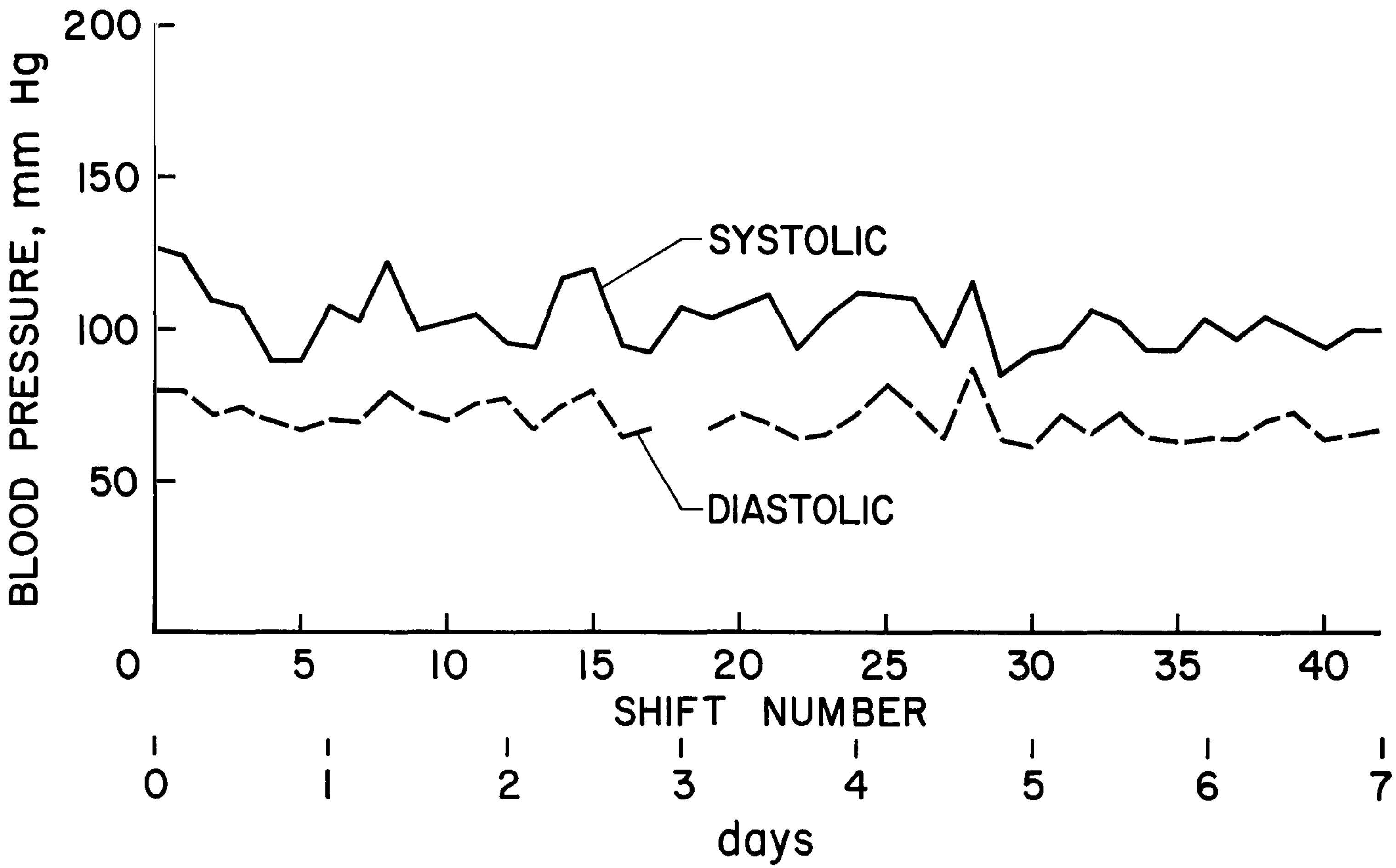
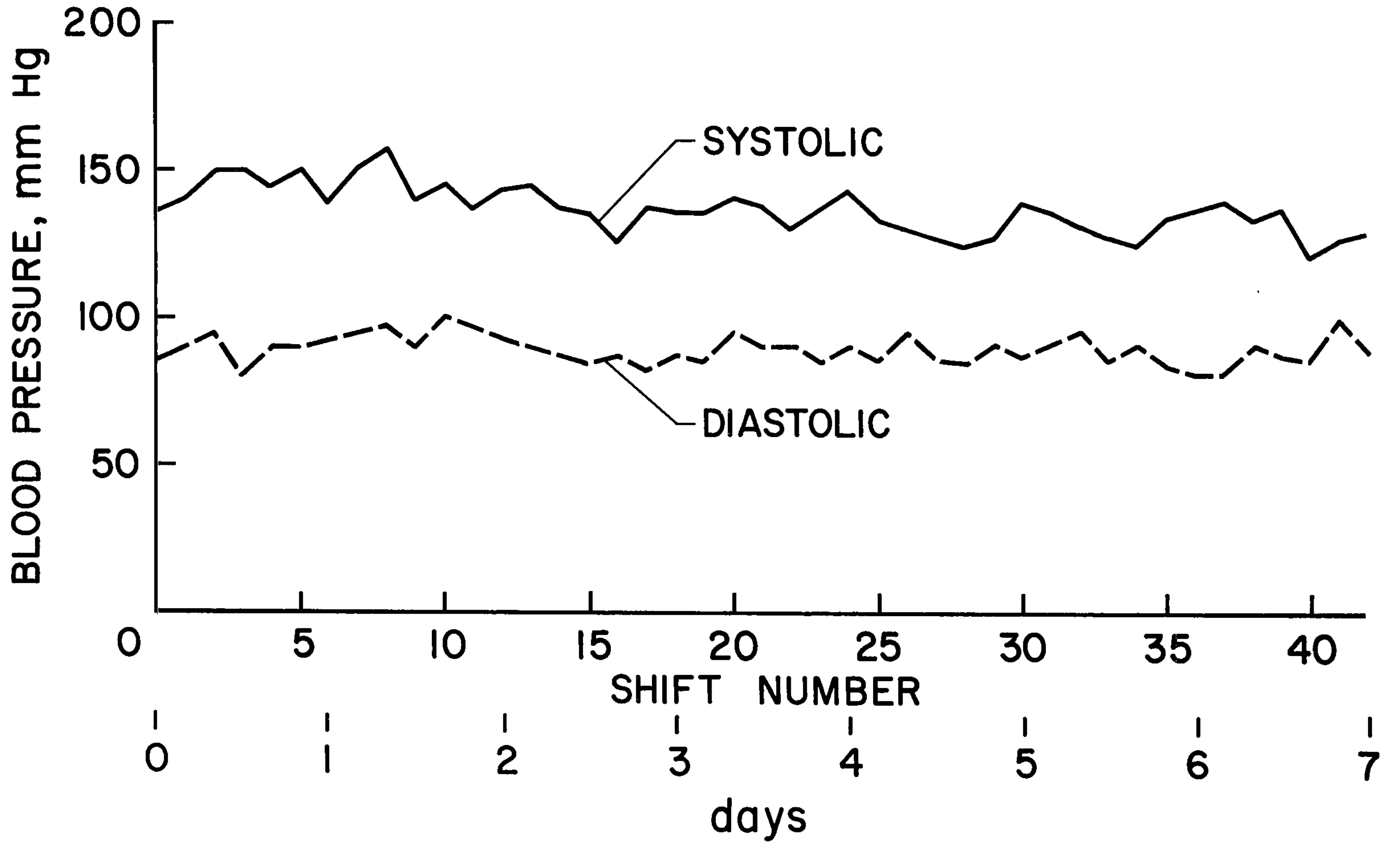


Fig. 23.- Urine catecholamines and ketosteroids for both subjects.



(a) Pilot, subject S.

Fig. 24.- Blood pressure at each change of shift.



(b) Non-pilot, subject R.

Fig. 24.- Concluded.

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